POWDER TESTING CENTER MODEL PTC-04DM

An automated, computer controlled, Desktop Modular Testing Center

USER'S MANUAL V-42

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Thank you for purchasing the **POWDER TESTING CENTER MODEL PTC-04DM**. We appreciate any comments and suggestions that you may have. Please contact us at:

***KZK* Powder Tech Corp.**
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e-mail: info@kzkptc.com

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Safety Precautions

Please read and follow the safety precautions listed below. They are intended for your safety and the safe operation of the **PTC**.

* **NEVER** operate the PTC in a hazardous or combustible environment. PTC's switches generate electrical arcs that may initiate combustion of gases in the area.
* **NEVER** touch exposed hot die surfaces
* **NEVER** operate the PTC with the die door open or allow ANY objects to fall inside the unit.
* **NEVER** blow air towards the PTC. Always use vacuum cleaner to clean.
* **DO NOT** use liquid solvents or cleaners on the PTC.
* **ALWAYS** use an approved eye protection when the PTC is in operation.
* **NEVER** attempt to operate the PTC if you suspect a malfunction. Do not attempt to repair or readjust the unit on your own. The high forces within the PTC can cause extremely hazardous conditions if the control and safety features do not work properly.

EC Declaration of Conformity

KZK POWDER TECH CORP.
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Tomorrow's Technology – TODAY!

EC Declaration of Conformity

Manufacturer:

KZK Powder Tech Corp.
3501 Lord Baltimore Way
Monkton, MD 21111, U.S.A.

Herewith declares that:

Product description:	Powder Testing Instrument
Product Name:	Powder Testing Center
Model Number:	PTC-04DM

is in conformity with provisions of the Directive 2006/95/EC.

Year in which CE marking first affixed: 2016

Issued by:	KZK Powder Tech Corp.
Date:	January 4, 2016
Place:	Monkton, U.S.A.
Signature:	Dr. Karol Korczak General Manager

KZK POWDER TECH CORP.
3501 Lord Baltimore Way
Monkton, MD 21111 USA
www.kzkptc.com

1. PTC OVERVIEW BROCHURE

POWDER TESTING CENTER

MODEL PTC-04DM

PRESSING MODES: SET DENSITY or PRESSURE

CAPACITY:
3,210 MPa (225 TSI)

DIE TEMPERATURE:
UP TO 300°C (570°F)

AVERAGE TEST TIME: 10 MINUTES

- COMPACTIBILITY
- DIE WALL FRICTION
- COHESIVENESS
- Green Strengths
- Green Expansions
- Bulk Density
- Tap Density
- Angle of Repose
- Compaction Curves
- Ejection Characteristics
- Crushing Characteristics

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TEST UNIT BASIC SETUP

The PTC consists of three modules: the **testing module** (main front part), the **power module** (back and bottom) and the **bulk powder tester** module (attached to the right column). It interfaces with a driving computer through a USB port. A separate **HEPA vacuum cleaner** unit is usually placed below the bulk powder tester.

The PTC must be connected to a dedicated USB port in a driving computer. The computer, preferably a laptop, is placed on the left side of the PTC. A separate USB hub with 3 or 4 USB ports is attached to the back of the PTC. The hub is used to connect all other devices.

An **electronic micrometer**, mounted on the front of the unit in a micrometer's base, is used for measuring green compact expansions after compaction. It connects to and is powered by the USB hub.

An **electronic scale (mass balance)** is placed on the right of the PTC. It connects to the USB hub. It's power supply can be plugged in an outlet on the back of the PTC.

The **bulk powder tester ("BPT")** can be attached to a column of the testing module (as shown) or mounted on a dedicated stand. It connects to the USB hub. A separate power supply, for the tapping motor, can be plugged in an outlet on the back of the PTC.

The MAXIMUM PRESSING FORCE is 10 metric tons.

EQUIPMENT OPTIONS

POWDER TESTING CENTER MODEL PTC-04DM
- basic unit: test and power modules
- attached bulk powder tester module
- external vacuum cleaner with HEPA filter
- internal microcomputer controller, USB interface
- driving & general compacting/sintering program
- direct micrometer and scale reading software
- user manual in pdf version
- one year limited warranty

Standard (Cold) Test Die Set
- tungsten carbide insert in stainless steel body
- tungsten carbide or steel punches
- may be heated up to 70^{0}C

Cold/Hot Universal Die Set
- interchangeable die cylinders
- ceramic heat insulators
- 300^{0}C maximum test temperature

Die Band Heater & Temperature Sensor
- for use with standard cold dies for up to 70^{0}C
- for use with hot dies for up to 300^{0}C

Electronic Micrometer
- range 0-25 mm/0-1", with SPC and USB adapter

Scale (Mass Balance)
- 0.001 gram readability, with USB adapter

Computer
- laptop with MS Windows 10 Pro
- access to printer

TECHNICAL SPECIFICATIONS

POWER:	
AC Voltage:	100-240 VAC, 50/60 Hz
Max. Power:	650 Watts (approximately)
PTC TEST UNIT:	compaction, green expansions and axial/radial crushing tests
Control:	internal computer board with USB interface, laptop PC
Testing Module:	pressing & control unit, mounted on the Power Module
Power Module:	power unit with stepper motor
Maximum Load:	98.1 kN (22,000 lbf)
Die Temperature:	up to 300^{0}C (570^{0}F)
Pressing Speed:	0.5-1.5 mm/s user selectable
Size W/H/D:	180/584/279 mm (7.1/23/11 inches)
Weight:	23 kg (50 lbs) approximately
Test Compact:	cylindrical pellet 2-16 mm (0.08-0.63 in) long
BPT:	**Bulk Powder Tester**
Control:	internal computer powered by USB
Mounting:	attached to PTC or separate base
Angle of Repose:	inclinometer gravity sensor
Tapping:	selectable, independently powered
Lab Air:	air humidity and temperature sensor
SOFTWARE:	MS Windows compatible for testing and data processing, Manual (pdf)

COLD PRESSING TEST DIE SET

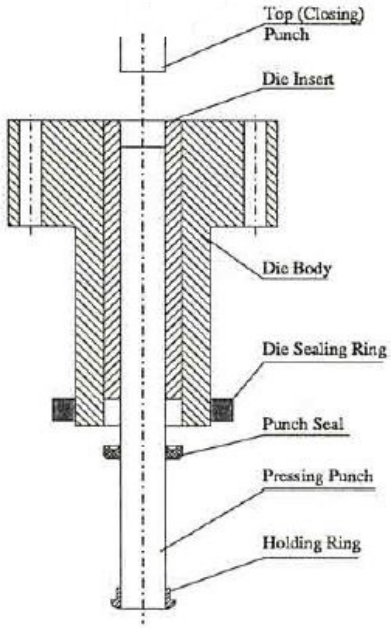
Test dies should be made compatible (die material and surface finish) with working production dies to ensure identical pressing conditions. For compaction friction optimization, one can use test dies made of different materials and various die surface finishes.

Test dies can be made as one piece, with inserts, or with surface coating. The die diameter is selected to have most compaction tests performed within 10-60 % of the maximum pressure (see table below).

The recommended die diameters are from 6.25 mm (0.250 in) to 19.05 mm (0.750 in). The standard compaction length of the test die is 80 mm (3.150 in). The standard pressing punch length is 132.08 mm (5.200 in). These standard sizes will ensure that the pressing punch will always be in contact with the die.

The cold pressing die may be used in a **warm pressing at up to 70^{0}C (160^{0}F)** when used with a standard band heater. Exceeding the temperature limit can overheat the testing unit (cold dies have no thermal insulation). For a test die made of a steel body with a tungsten carbide insert, overheating would push the insert out during a test.

Test Die installation in the PTC takes around 2 minutes.



COLD/HOT PRESSING TEST DIE SET

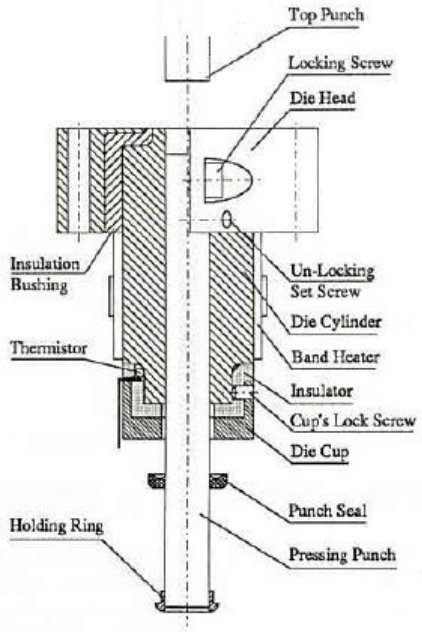
The cold/hot test die consist of a **universal mounting head** and an interchangeable **die cylinder** where a compaction takes place. Any suitable die material may be used (tool steel, steel with tungsten carbide or ceramic inserts, solid tungsten carbide, ...) with corresponding temperature limit for hot pressing. The die cylinder is surrounded with **ceramic heat shields** to limit heat transfer to the testing unit.

Tests may be conducted continuously at various temperatures up to 300^{0}C (570^{0}F). There are **three user selectable testing options**:

- **no heating**: pressing at room temperature
- **cold powder**: heating the die first, adding cold powder, pressing
- **hot powder**: adding powder, heating the die with powder, pressing.

The die cylinder is heated with a **band heater** (up to 600 W) powered and controlled by the test unit. A temperature sensor provides a continuous temperature readings. **The heating cycle is automatic**. The heating time depends on the testing temperature and the power of the band heater.

Maximum Testing Temperature: up to 300°C (570°F)



STANDARD DIES

Testing should be conducted within the recommended pressure range with the max. limit left for pressing overshots.

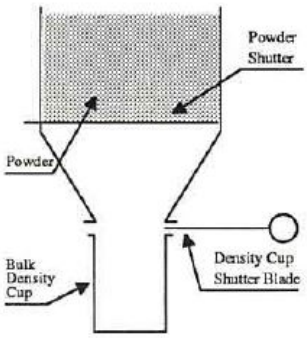
Standard Die Diameter:	Max. Pressing Pressure:	Recommended Pressure Range:
19.05 mm (0.750”)	343 MPa (25 TSI)	34 – 225 MPa (2 – 17 TSI)
12.70 mm (0.500”)	765 MPa (56 TSI)	76 – 500 MPa (5 – 37 TSI)
9.525 mm (0.375”)	1295 MPa (94 TSI)	130 – 845 MPa (9 – 62 TSI)
6.35 mm (0.250”)	3090 MPa (225 TSI)	309 - 2010 MPa (22 – 146 TSI)

OVERVIEW	SUB-TEST #1: PROPERTIES OF THE BULK POWDER

REQUIRED PARAMETERS FOR TESTING

- Powder Name
- Powder Batch (optional)
- Pressing Mode: max pressure or fixed density
- Desired Pressure or Density
- Theoretical Density of the powder mixture
- Desired Compact Size for mass of die filling powder
- Pressure Hold Up time
- Heating Arrangement and Die Temperature

The **SUB-TEST # 1** is conducted with the **Bulk Powder Tester** ("**BPT**"). The **BPT is an independent testing unit** attached to the PTC or mounted on a free standing base.

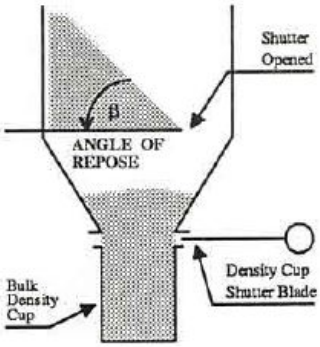


STEP 1: FILLING THE TESTER WITH LOOSE POWDER

The **POWDER TESTER** is detachable from its base for a convenient assembly, filling and cleaning. It is mounted on its base attached to the front of the BPT. The powder mix should fill approximately 75% of the tester.

Required amount of powder mix: approximately 20 cm³.

STEP 2: ANGLE OF REPOSE β OF THE POWDER

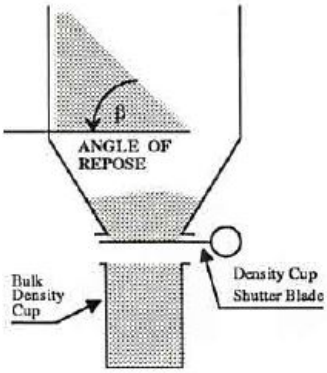


After the **Powder Shutter** is pulled out approximately 10 mm, the powder flows into the **Bulk Density Cup**. The powder left on the shutter forms the **Angle of Repose β**. It represents the actual ***ability*** of the powder to fill uniformly the cavity of a die. Preference is to have β in the 40° or less range.

The **Angle of Repose** could be measured in several ways and is quite independent from any particular measuring method. The angle is read directly by an inclinometer sensor attached to a dial positioned parallel to the powder surface by an operator.

ADVANTAGE: RELIABLE and REPEATABLE for almost all powders.

STEP 3: BULK (APPARENT) DENSITY ρ_b OF THE POWDER



The **Bulk Density ρ_b** (also known as **Apparent Density)** is the density of a loose powder under the given tested conditions. The method implemented here uses a Bulk Density Cup with a precision measured volume.

The cup is overfilled with powder flowing along the inclined surface. The powder in the cup is separated from the overflow with a thin shutter blade to prevent any accidental and undesirable densification of the powder in the cup. Such extra powder densifications are quite common with other commonly used methods.

ADVANTAGE: ACCURATE, REPEATABLE, and RELIABLE measurements.

STEP 4: TAP DENSITY ρ_{tp} OF THE POWDER

The **Tap Density** is the density of a loose powder subjected to a number of prescribed taps. The number of taps is user selectable. For this test, the Bulk Density Cup with the powder is mounted back into the Powder Tester. The tapping motor taps the entire Powder Tester assembly. When done, the Density Cup with tapped powder is removed and weighed.

OVERVIEW	SUB-TEST #2: COMPACTION & EJECTION

POWDER COMPACTING PROCESS is described by 2 distinct phenomena:

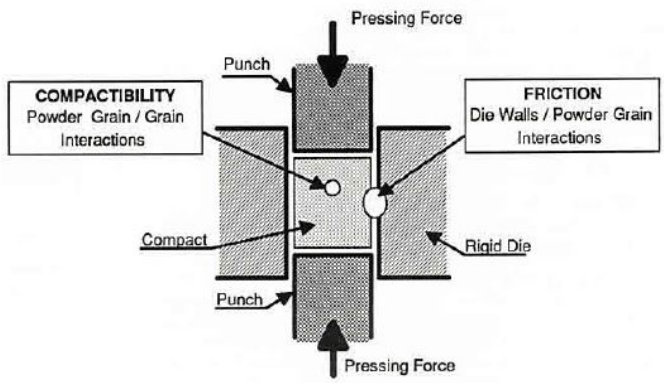
COMPACTIBILITY:

the **ability of a powder to densify** under pressure. For a given material, it is influenced primarily by particle sizes, shapes, and size distribution.

An increase in the **compactibility coefficient α** results in higher green compact density at a given compacting pressure.

DIE WALL FRICTION:

friction interactions between powder grains and the die walls. It is defined as **slide coefficient η** and varies from 0 (infinity friction) to 1 (no friction). It should always be as high as possible.



STEP 1: COMPACTION

The powder mixture is put into the die (cold or heated to a set temperature) and compacted to a desired pressure or density. If needed, the compact may be held in the die under pressure for a specified period of time to allow transformations within the green compact (polymerization, chemical reactions) to finalize.

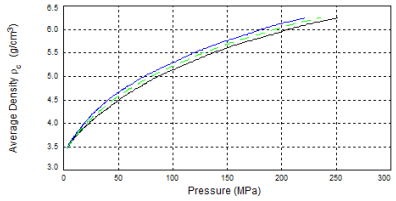


Figure 1. Test compaction pressure: pressing, net, closing. (T152)
In a rigid die, the net (isostatic) cross-section occurs where h=H/2

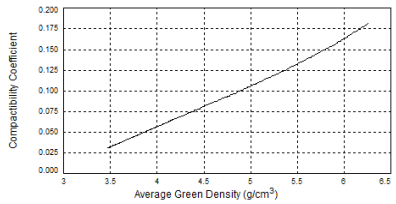


Figure 2. Compactibility Coefficient variations with green density. (T152)

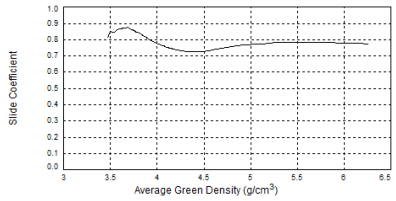


Figure 3. Slide Coefficient variations with green density. (T152)

STEP 2: COMPACT EJECTION

The compact is ejected from the test die by the pressing punch. The **ejection pressure** (punch force per cross section area) and the travel distance during ejection are measured and plotted as the **compact ejection characteristic**.

In the standard configuration, the compact has to travel approximately 5 mm (0.2 in) to the surface of the die. On the plot below, "0" indicates the position of the face of the compact in the die under full load. When the load is released, before ejection, the compact expands within the die in the axial direction as seen on the plot.

The ejection characteristic is the base for calculating:

- **stripping pressure** - peak initial ejection force over compact's friction area (in contact with die)
- **average ejection pressure** - ejection pressure averaged over initial 5 mm of travel
- **ejection (start) pressure overshot** - the ratio of the maximum initial and the average ejection pressure
- **total ejection energy**
- **unit ejection energy** - the ejection energy per unit of the compact's friction surface and per unit of the ejection length

NOTE: The ejection data is **geometry dependent**.

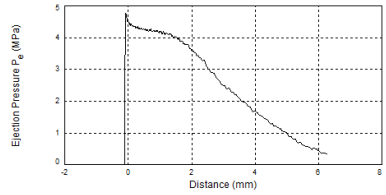


Figure 4. The test compact ejection characteristic. (T152)
The ejection pressure is measured on the ejecting punch.

OVERVIEW — SUB-TEST #3: GREEN COMPACT EXPANSIONS

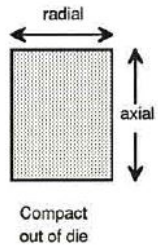
GREEN COMPACT EXPANSIONS

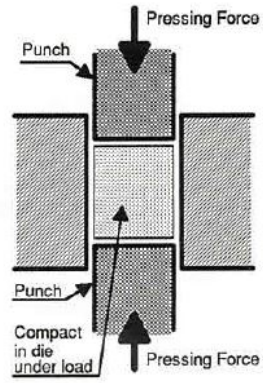
The **compact height** and **diameter** are measured, after ejection from the die, with a micrometer. These values will depend on the time lapsed after ejection (compacts keep expanding for a short time).

The **expansion coefficients**, calculated as a ratio of dimensions in a free compact and in the same compact in die under full load, are:

- **RADIAL** - the ratio of radial dimensions
- **AXIAL** - the ratio of axial dimensions

NOTE: The **expansion coefficients are important in tool design**. The axial expansion is typically greater than the radial expansion.



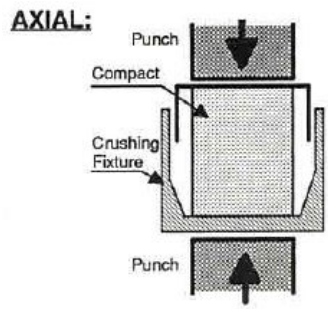


OVERVIEW — SUB-TEST #4: GREEN COMPACT CRUSHING TESTS

AXIAL CRUSHING TEST

The **green compact**, placed in a fixture, **is crushed in axial direction** by the main punches. A rapid readout of the force and compact height change provides data for the **axial crushing characteristic** (below). The maximum crushing pressure - **AXIAL GREEN STRENGHT** - represents a measure of the green strength that holds the compact together during ejection from a die.

A **COHESIVENESS** of a green compact represents the resistance of the compact to cracking and lamination during ejection from a die. It is calculated as a ratio of a green strength and a maximum friction during ejection.

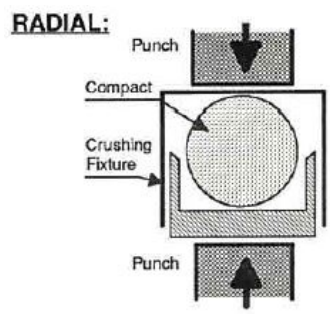


RADIAL CRUSHING TEST

The **green compact** is **crushed along its diameter**. Crushing force and distance data are used to calculate the **radial crushing characteristic** (crushing force over instantaneous crushing contact area) and the **diametral crushing characteristic** (crushing force over half of the cylindrical compact area).

The maximum values in both characteristics are the:

- **RADIAL GREEN STRENGTH**
- **DIAMETRAL GREEN STRENGTH**.



GREEN COMPACT CRUSHING CHARACTERISTICS

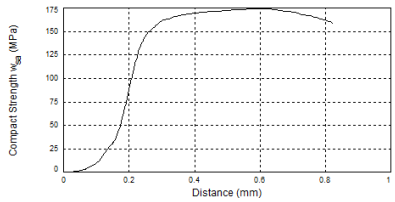


Figure 5. The green test compact axial crushing characteristic. (T152)

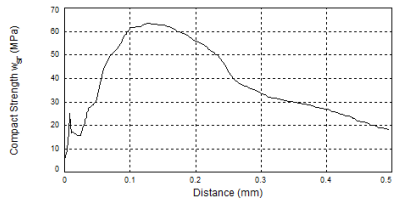


Figure 6. The green test compact radial crushing characteristic. (T152)

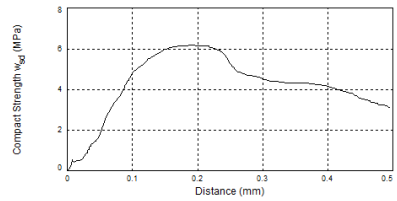


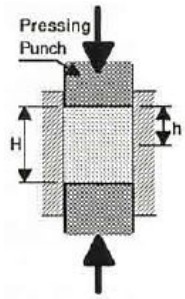
Figure 61. The green test compact diametral crushing characteristic. (T152)

OVERVIEW	RIGID DIE AND ISOSTATIC PRESSING

The **test results allow calculations of properties variations within the test compact**. More importantly, with the help of a **Ga** parameter (compact geometry non-dimensional number), local variations in any compact can be determined. For practical reasons, determination of a local green compact density is critical. It allows direct calculations of the local shrinkage and the shape of the end product.

The graphical presentations of test results provide bases for:

- **designing compaction and sintering processes**
- **determining optimal pressure during compaction**
- **calculating die dimensions.**



DIE WALL FRICTION AND ISOSTATIC COMPACTION

The slope of the curves in the local properties graphs (below) depends on the slide coefficient (die wall friction). The higher the slide coefficient (lower friction), the lower the slope. The **cross section at h/H=0.5** is not affected by wall friction and represents **ISOSTATIC pressing conditions**. There, the local density is equal to the average density of the compact and the pressure (called **net pressure**) is equal to **ISOSTATIC pressure** for that density.

With no die wall friction, during compaction (plot on the right) the pressing and closing pressure would merge and be equal to the net (isostatic) pressure.

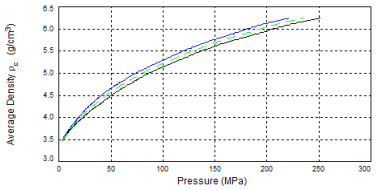


Figure 1. Test compaction pressure: pressing, net, closing. (T152)
In a rigid die, the net (isostatic) cross-section occurs where h=H/2

The **local pressure, density** and **shrinkage** are shown below at **fixed average** compact **densities** listed below each graph. With **NO FRICTION**, all **graph lines would be HORIZONTAL** !

ONE-SIDED PRESSING

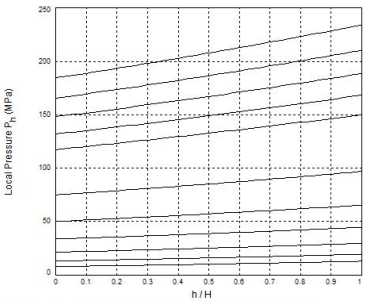


Figure 7. Local pressure distribution in a one-sided pressing. (T3.02)
Valid only for compacts with Ga = 0.0 and ρ = 5.8 at the nominal length H.
The solid lines represent average densities, the dashed lines are compaction curves.
Lines (g/cm³): 4.40 4.60 4.80 5.00 5.20 5.40 5.60 5.65 5.70 5.75 5.80

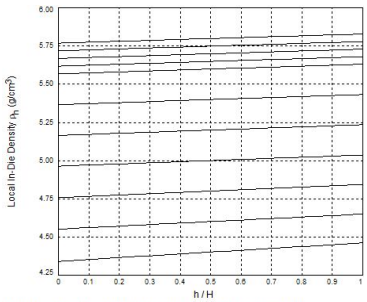


Figure 8. Local density distribution in a one-sided pressing. (T3.02)
Valid only for compacts with Ga = 0.0 and ρ = 5.8 at the nominal length H.
The solid lines represent average densities, the dashed lines are compaction curves.
Lines (g/cm³): 4.40 4.60 4.80 5.00 5.20 5.40 5.60 5.65 5.70 5.75 5.80

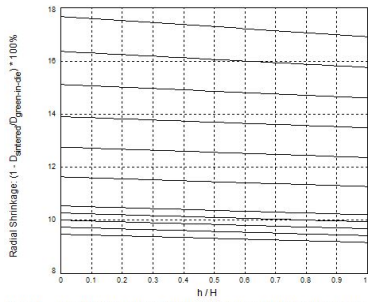


Figure 9. Local Radial Shrinkage during sintering (one-sided pressing). (T3.02)
Valid only when: Ga = 0.0 at the in-die average ρ = 5.8, er = 0.0 , ea = 0.0 .
The solid lines represent local shrinkage at listed below average in-die densities.
Line values from top to bottom (g/cm³): 4.40 4.60 4.80 5.00 5.20 5.40 5.60 5.65 5.70 5.75

DOUBLE-SIDED PRESSING

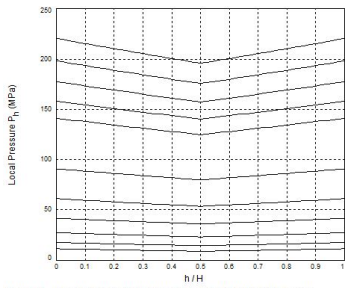


Figure 11. Local pressure distribution in a double-sided pressing. (T3.02)
Valid only for compacts with Ga = 0.0 and ρ = 5.8 at the nominal length H.
The solid lines represent average densities, the dashed lines are compaction curves.
Lines (g/cm³): 4.40 4.60 4.80 5.00 5.20 5.40 5.60 5.65 5.70 5.75 5.80

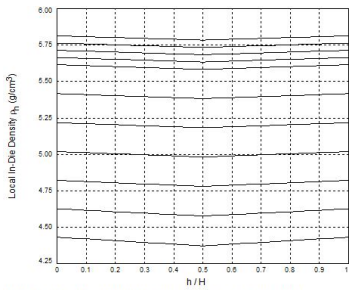


Figure 12. Local density distribution in a double-sided pressing. (T3.02)
Valid only for compacts with Ga = 0.0 and ρ = 5.8 at the nominal length H.
The solid lines represent average densities, the dashed lines are compaction curves.
Lines (g/cm³): 4.40 4.60 4.80 5.00 5.20 5.40 5.60 5.65 5.70 5.75 5.80

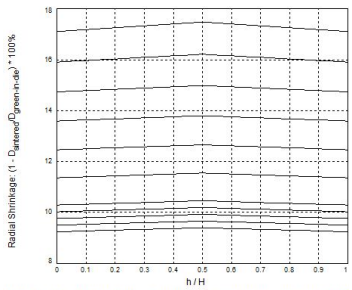


Figure 13. Local Radial Shrinkage during sintering (double-sided pressing). (T3.0
Valid only when: Ga = 0.0 at the in-die average ρ = 5.8, er = 0.0 , ea = 0.0 .
The solid lines represent local shrinkage at listed below average in-die densities.
Line values from top to bottom (g/cm³): 4.40 4.60 4.80 5.00 5.20 5.40 5.60 5.65 5.70 5.75

OVERVIEW	TESTED PARAMETERS AND APPLICATIONS

The **Powder Testing Center** provides basic information necessary in designing and controlling a dry powder compaction process. The testing capability covers a wide range of powders: metallic, ceramic, refractories, nuclear (fuel rods), pharmaceutical, abrasives, explosives, chemicals and others. The testing process is **computer controlled** and **automated**. A typical test takes less than **10 minutes** allowing testing for direct quality control on production lines.

The test results are geometry independent, applicable to rigid-die and isostatic pressing.

TESTING MODES

- **FIXED PUNCH PRESSURE** - pressing to a desired maximum pressing pressure
- **FIXED COMPACT DENSITY/LENGTH** - pressing to a desired in-die average compact density or length
- **FIXED ISOSTATIC PRESSURE** - pressing to a desired isostatic/net pressure

The pressing position and pressure are controlled by precision gauges. A motor brake stops the compaction at a desired point. **The final pressure may be held up for a selected time period before release.**

TYPICAL APPLICATIONS

POWDER QUALITY CONTROL:

- **direct (in-line) quality control** of powder after mixing and before pressing. If tested parameters are out of predetermined limits, the powder should be remixed or rejected
- control of a lubricant content in a powder mixture
- control of a binder content in a powder mixture

PROCESS DEVELOPMENT & OPTIMIZATION:

- determination of an optimum average green density of a compact for new powders
- determination of an optimum lubricant and binder content
- determination of an optimum die material to minimize friction
- determination of control limits on variations for quality control
- determination of temperature effects on compaction parameters

RESEARCH AND DEVELOPMENT:

- new powders and mixtures
- temperature effects on pressing (warm and hot)
- new die materials to minimize wall friction
- new die surface coatings to minimize wall friction
- new binders, lubricants and direct die lubrication methods

TESTED PARAMETERS

POWDER MIXTURE PROPERTIES:

- ✓ **angle of repose** (flowability) - the ability of the powder to fill uniformly a cavity of a die
- ✓ **bulk (apparent) density** of a loose powder
- ✓ **tap density** - the density of a loose powder subjected to prescribed tappings
- ✓ testing environment **humidity** and **temperature**

COMPACTION & GREEN COMPACT PROPERTIES:

- ✓ **compactibility coefficient** - the ability of a powder to densify under a given pressure
- ✓ **slide coefficient** - the measure of frictional interactions at die walls during compaction
- ✓ **stripping pressure** - the ratio of the maximum initial ejection force and the compact's friction area
- ✓ **average ejection pressure** for the test compact
- ✓ **ejection start pressure overshot** - the ratio of the maximum initial ejection pressure and the average ejection pressure
- ✓ **total ejection energy** for the test compact
- ✓ **radial** and **axial** green **expansion coefficients**
- ✓ **cohesiveness of a compact** - crack and lamination resistance
- ✓ **green** test compact **axial strength** during axial crushing
- ✓ **green** test compact **radial strength** during diametral crushing

GENERAL CHARACTERISTICS (GRAPHS):

- ✓ test compaction pressure: pressing, net (isostatic), closing
- ✓ isostatic pressing characteristic
- ✓ compactibility coefficient variations with green density
- ✓ slide coefficient variations with green density
- ✓ ejection characteristic for the test compact
- ✓ axial crushing characteristic for the test compact
- ✓ radial crushing characteristic for the test compact
- ✓ diametral crushing characteristic for the test compact
- ✓ local pressure distribution in a compact
- ✓ local density distribution in a compact
- ✓ local shrinkage perpendicular to pressing direction
- ✓ local shrinkage parallel to pressing direction

Contact us for more information or to request a testing demonstration.

KZK* Powder Tech Corp. ---------- www.kzkptc.com ---------- info@kzkptc.com >>> *In Business Since 1987

1.1 INTRODUCTION

All computer programs supplied for the driving of the **Powder Testing Center** (the "**PTC**") may be installed on other computers for analysis and processing of Test Data Files (the "TDF"). There is no limit or restriction on the installations of the software *provided the computers belong to the purchaser* of the PTC or the user was granted a permission from the KZK Powder Tech Corp.

The purchaser of the testing center is licensed to manufacture test dies and related components exclusively for internal use associated with that specific testing center.

1.1.1 About Program Version

The program is compatible with Microsoft Windows and with international settings. It should correctly interpret local numbering conventions, date formats and the like. It provides the capability for generating customized outputs with local definitions for test parameters and local language. The relevant parameter definitions are assembled in *Text Tables* and the user may create any number of different definitions and languages. All symbols and figures may be modified to fit specific needs, requirements and conventions.

Please forward any comments, suggestions and any problems to the **KZK Powder Tech Corp.** (e-mail: info@kzkptc.com). The development process will incorporate all constructive suggestions and corrections of any conflicts or errors. All suggestions are highly appreciated and will lead to a more productive experience with the instrument.

1.1.2 The Testing Method

The PTC provides the basic information necessary in design and controlling of a dry powder compaction process in a rigid die. The tests are also used for quality control of powders not destined for compaction. The testing center capability covers a wide range of powders: metallic, ceramic, refractories, nuclear, pharmaceutical, abrasives, explosives, chemical and others. The tests performed have been selected to create a single testing station for powder evaluation. The testing process is computer controlled and automated. It typically takes less than 15 minutes (for unheated dies) which allows testing for direct quality control on production lines.

The test pressing arrangement is a one-sided pressing to a desired density or pressure with the length of the compact within 2 to 16 mm. During compaction all required measurements are taken at numerous punch positions and, for the corresponding actual intermediate average compact densities, the compacting parameters are calculated and stored in a permanent test data file. Those parameters show actual compaction conditions at any density, up to the actual final test density, allowing printing of a complete test data output with plots for any desired compact density in that range. However, for high accuracy, the test should be conducted for a final compact density equal to or close to the desired one.

The testing can be conducted in one of the following modes:

- pressing to a **fixed pressure** (maximum pressing punch pressure)
- pressing to a **fixed** compact **density/length** (in-die under load)
- pressing to a **fixed net** (isostatic) **pressure** (maximum net pressure)

The test series consists of three groups of tests:

- bulk powder properties tests: bulk density, tap density, flowability (angle of repose)
- powder compacting & ejecting properties tests (cold or heated dies): compactibility coefficient, slide coefficient, ejection pressure and energy
- green compact properties tests: green expansion coefficients, cohesiveness of the compact, crushing properties, green strength.

The test results are printed and presented as general graphs that show the following (standard graphs):

- test compaction pressure: pressing, net (isostatic compaction characteristic), closing
- compactibility coefficient variations with green density
- slide coefficient variations with green density
- ejection characteristic for the test compact
- crushing characteristics (axial and radial) for the test green compact
- local pressure distribution in arbitrary compacts
- local density distribution in arbitrary compacts

- local shrinkage perpendicular to pressing direction (optional)
- local shrinkage parallel to pressing direction (optional).

The testing method is based on a technology that represents many years of research and development. The most important advantage of this technique is that the test results are general (for all compact shapes and sizes) and applicable to any rigid die pressing configuration (one-sided, double sided symmetrical and non-symmetrical) as well as to isostatic pressing. The method separates the basic processes that describe the behavior of a powder during densification in a rigid die: the resistance of the powder to outside pressure (compactibility of a powder) and the friction between powder particles and the die walls (frictional interactions). That separation leads to an introduction of two fundamental parameters that describe the compaction process: the compactibility coefficient and the slide coefficient. The two coefficients are mostly geometry independent and, in many cases, only slightly depend on the green compact density.

The testing center results are used in various applications. The main areas are:

- powder quality control: direct in-line quality control of powders, control of lubricant/binder content in mixtures
- process development and optimization: determination of optimum average green density of a compact, determination of optimum additive (lubricants, binders) content in a powder mixture, determination of control limits on powder parameter variations for quality control
- research and development of new powders, powder mixtures, die materials and others.

The main areas of applications include powder producers, parts manufacturers (rigid die and isostatic), research and development labs, and others. The testing center is also used in quality control of powders that are not destined for compaction.

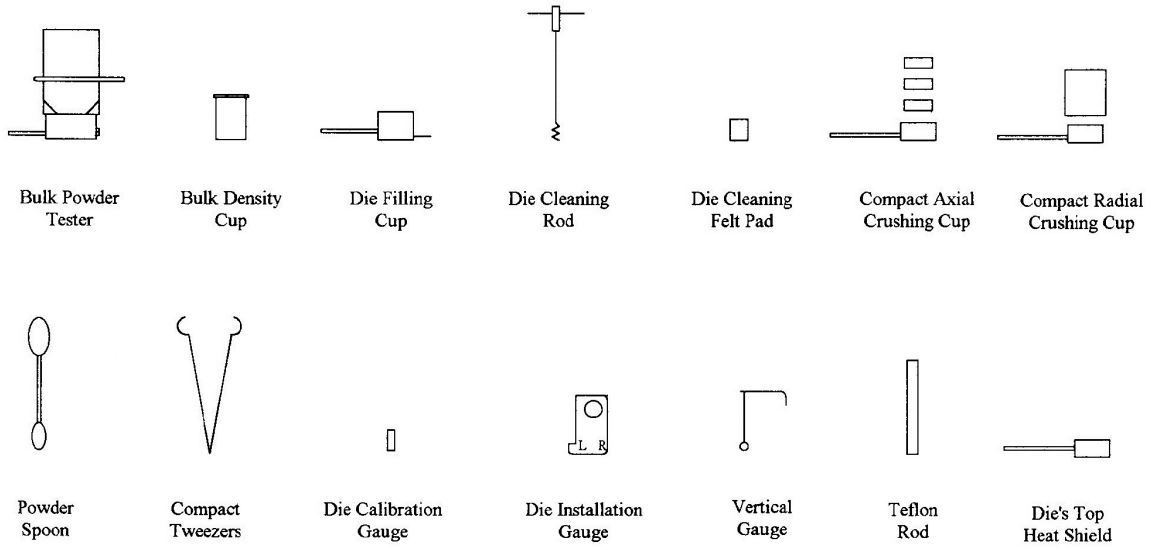
The related sections provide definitions and theoretical background for the testing approach.

2. EQUIPMENT OVERVIEW

2.1 Standard Equipment

You should receive the main **TEST UNIT: Testing Module**, **Power Module**, **Bulk Powder Tester Module** and the following **standard accessories** (see figures below):

- Vacuum Cleaner
- User's Manual (pdf version) & Driving Software
- Power Cables (US customers only, all others must provide 2 standard computer power cables)
- USB Control Cables
- Bulk Powder Tester
- Bulk Density Cup
- Die Filling Cup
- Die Filling Vibrator
- Die Cleaning Rod
- Die Cleaning Felt Pads (10)
- Compact Axial Crushing Cup & Cover Set
- Compact Radial Crushing Cup & Cover
- Powder Spoon
- Compact Tweezers
- Die Calibration Gauge Set
- Die Installation Gauge
- Punch Mounting Spacer
- Teflon Rod
- Die's Top Heat Shield
- Hex Ball-Point 4 mm Driver, Hex Ball-Point L-Key Set (metric), 10 mm Wrench, Phillips Screwdriver.



2.2 The Powder Testing Center

The PTC includes two independent units: the **Powder Compaction Unit** and the **Bulk Powder Tester**. The standard testing always starts with the bulk properties tests followed by compaction properties tests.

The **Powder Compaction Unit** ("**PCU**") consists of two modules that are packed separately for shipping. When packed separately, each module is very rigid and can be shipped in any position as a regular small package. When assembled, the unit can only be transported in a vertical position.

The PCU should be placed on a firm desk. There is a slight vibration generated by the PCU while in operation. The rubber legs form a vibration absorbing layer between the PCU and the desk. Place the vacuum cleaner next to the PCU on the right side with the exhaust window pointing away from the PCU. The **Bulk Powder Tester** ("**BPT**") unit is mounted on a bracket attached to the right side of the PCU. If the BPT is attached to a separate stand, it should be placed in front of the vacuum cleaner. In a standard setup, a micrometer mount is attached to the front of the PCU. Alternatively, it may be attached to one of the columns of a BPT stand.

On the front of the PCU are located the following:

- the **Main Power On/Off** rocker switch at the bottom left corner
- the emergency **STOP** pushbutton switch on the top left side of the Name Plate.

The back of the PCU houses the following:

- the **main USB port** for a control cable
- the **die heater** outlet
- the **main power receptacle** (accepts standard computer power cable) with the **main fuse**
- two standard USA-type power outlets

Plug in the power cable into the receptacle on the back panel and connect it with available power source. The **PCU accepts a universal voltage 100-240 VAC**. However, a **die heater voltage must be the same as the power source voltage**. THE POWER SOCKET MUST BE GROUNDED and POLARIZED. The back panel has two power outlets to plug in power supplies used for optional scale and for the separate USB Hub or BPT.

Connect the USB control cable to the PCU and **directly to a dedicated port** in the computer. A separate USB Hub is used for connecting the BPT, an optional micrometer and scale (mass balance). The USB Hub should have a separate power

supply to prevent overloading of the internal computer power source. The power supplied by the USB connection drives the BPT's internal computer, its light and, in older versions, the tapping motor. All newer BPT modules use a dedicated 6 VDC power supplies for the tapping motor.

The separate **Vacuum Cleaner** must be connected to a power source outlet. On the back side, next to the power receptacle, is the outlet for a **die filling vibrator**. The standard **Die Filling Vibrator** accepts universal power supply in the range of 100-240 VAC.

2.2.1. The Powder Compaction Unit

The Powder Compaction Unit is shipped as two separate module: the **Testing Module** and the **Power Module**. The power module is the base of the testing center. The contact area between the two modules is covered to keep dust out.

To assemble the testing unit, please follow the steps below:

a) Remove the protective cover on the base of the **Power Module** and mount it to the front side of the module

b) The key slot in the sprocket (the bottom of the base) must be aligned with the mark lines (parallel to the side of the module). If needed, connect the power to the unit, turn the power switch on and press the "Motor ON" button on the front wall until the desired position is reached. Afterwards, turn the power off and disconnect the power cable from the module.

c) The key at the bottom of the **Testing Module** must be parallel to the short side of the module. If not, turn it accordingly.

d) **The contact area in the sprocket and at the bottom of the testing module must be completely clean - vacuum it if necessary**.

e) Carefully place the testing module on the base of the power module. If needed, gently twist the testing module (a small misalignment should self correct).

f) When in place, twist the testing module clockwise until it touches a stop screw (bottom left side in the back). The front of the testing module should be parallel with the front of the power module. If not, twist it accordingly.

g) Use the 2 mounting screws on each sides of the power module (at the bottom) to secure the modules together. Use the 10 mm wrench to tighten the screws, do not use excessive force.

h) On the top back of the testing module, connect the modules with the control ribbon cable.

i) Plug in the heating cable into the power module and attach the cables cover to the testing module. Make sure not to damage the cables.

j) Attach the other cable cover to the top of the power module.

Notes: To separate the modules, follow the steps above in a reverse order. Do not allow any objects to fall inside the power module. Keep the modules clean and dust free.

2.2.2. The Bulk Powder Tester Module.

The BPT module is shipped fully assembled and ready for testing. The module's control and light is powered by the USB connection. In older models, the tapping motor was powered by the USB as well with power requirement of around 0.3 A at 5 V. All new models have a separate 6 VDC power supply for the tapping motor. In a standard arrangement, the unit is plugged into a USB Hub with independent power supply to ease power drain from a computer (particularly important when connected to a laptop).

The BPT module is mounted to a bracket attached to the side (right or left) of the PTC testing module. The module can also be mounted on an independent stand and operated with or without the main testing module. The testing assembly on the stand can be moved up/down on the columns to a desired height.

In a standard arrangement, a micrometer holding arm is attached to front of the testing module. Alternatively, it can be mounted to one of the BPT's columns. The position of the micrometer is adjustable.

2.3 Required and Optional Accessories

A Test Die Set must be mounted on the PTC and calibrated before testing. The Test Die Set may be ordered from the factory or it may be manufactured by the user. Since the test results are influenced by the die material, a proper material for the die must be used. In many cases one keeps on hand several test dies with different die materials.

The testing accuracy and repeatability depend greatly on the accuracy with which the specified mass of a powder sample is obtained. An accurate external scale is required. The program interfaces with scales equipped with a computer adapter for a direct scale reading.

An electronic micrometer is needed during testing. The micrometer is necessary to determine green compact expansion coefficients. The program allows direct reading of micrometer measurements if the micrometer has a SPC capability and is connected directly to the computer.

The die heating option provides a controlled power outlet for a die heater (600 VA max.) and a connector for a thermistor temperature sensor. The die heating cycle is controlled by the program.

2.4 Computer and Printer Specifications.

All functions of the PTC are initiated by a dedicated computer running Microsoft Windows. The program uses the default printer specified by the computer.

3. SOFTWARE INSTALLATION AND REQUIREMENTS

The program is based on two independent displays: the **Table Data Display** window and the **Tests** window. The Table Data Display window displays the test data files and allows general data processing and printing. The Tests window is used exclusively for testing and manual operation of the instrument. It is accessible only on the computer connected with the testing unit.

The main program is installed in one step for a general use. Access to the Tests window requires installation of a USB driver for the PTC's internal computer. The testing part of the program can only be run with an active PTC unit connected through a USB port. **ATTENTION**: The software must be installed before the PTC is connected.

To operate, the program requires the main control file: PTC#####.CON (the ##### is the Serial Number of the testing center found on the back of the unit). The control file is stored in the PTC's internal memory and is copied to the main driving computer automatically when the program establishes communication with the PTC. The control file contains all calibrations and system constants for the testing center. It also keeps current counter of the last test number necessary for proper test numbering and test data file identification.

Original installation and UPGRADE of the driving program require installation of all components and libraries of the program which are provided on a CD as well as available for downloading at www.kzkptc.com (the Service section). Follow these steps to install the program:

- turn the computer ON
- create an application directory for the PTC: c:/PTC04DM
- insert the Installation CD or download the installation programs
- open the PTC Installation folder and run the program Setup.exe
- install the program in c:/PTC04DM
- follow the Setup instructions.

The Setup program adds the PTC04DM entry to the list of Programs in the Window's Start menu. It is advisable to create a shortcut to the program and place the PTC04DM icon directly on the Desktop screen.

When running the PTC04DM program the first time, the program asks for the PTC Administrator Name and Administrator Password. Do NOT forget that password, it protects access to all major parts of the program such as main control data and settings for individual users of the PTC. Initially, the program is installed for a default PTC (Serial Number 1) with data processing and viewing capabilities only. That is the option for all computers not directly connected to the PTC. The main Table Data Display window should appear after the program is initialized. The user must select a reference directory with the Test Data Files (the previous run directory is listed by default) or, for initial installation, to select/create directory for the test data files.

UPDATES and corrected versions of the driving program involve only the main program PTC04DM.EXE. That file must be copied directly to the main driving directory for the PTC to replace the old one (always remember to rename the original files first to preserve them as a backup before overwriting them with new files). Installation of the program on a new computer always requires the full installation to load all libraries but updates require only the new PTC04DM.EXE program which may be transferred between computers or over a network.

The initial installation does not activate the Tests window which requires additional driver installation steps. That option should be activated only on a computer connected to the testing center. It will not work on any other computer. To activate the Tests window, follow the steps below:

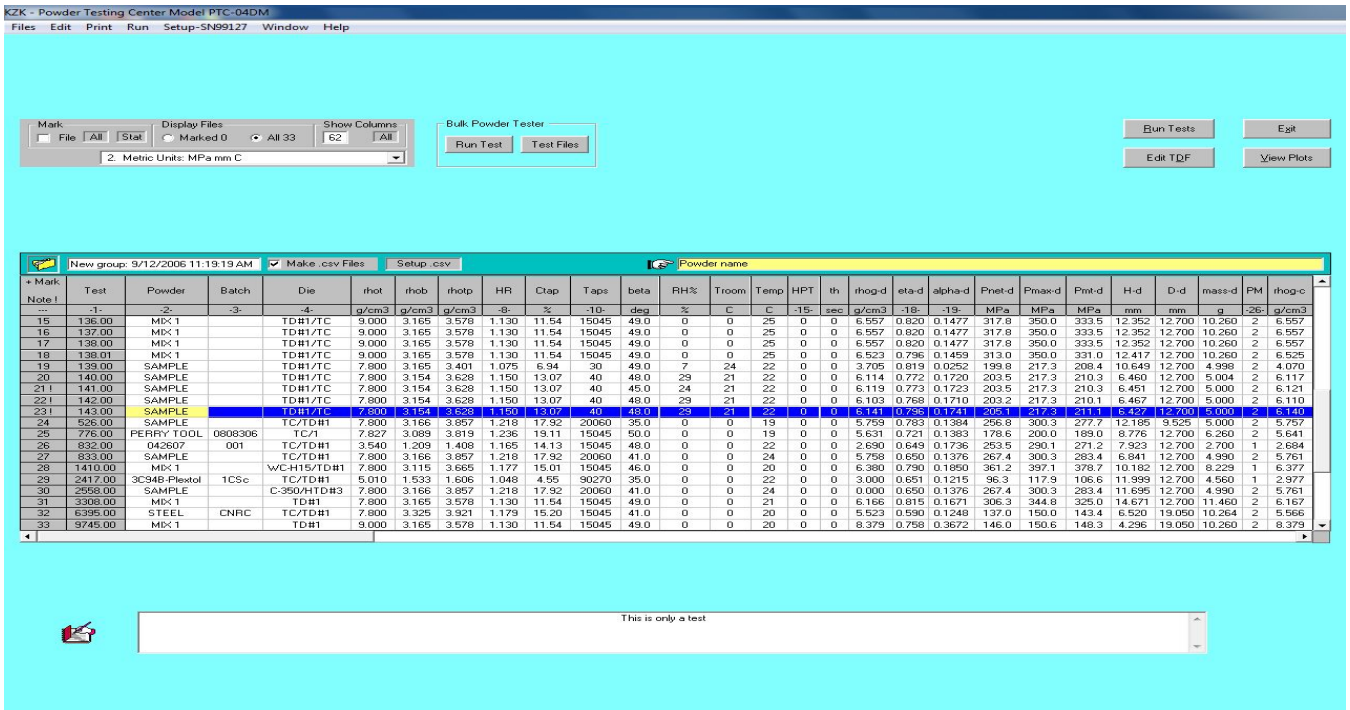
- open the PTC04DM Drivers folder and select the driver version based on the operating system version
- follow the specific instructions as outlined in the InstallationNotes file
- install micrometer USB driver
- connect the PTC's USB control cable to the computer
- run the PTC04DM program
- select the option Setup-SN## / Load Driver
- turn ON the testing center
- click the Run Tests button (the Tests window should appear)
- follow the initialization instructions
- operate the PTC.

When done with the software installation, store the installation disks in a safe place.

II. TEST DATA PROCESSING

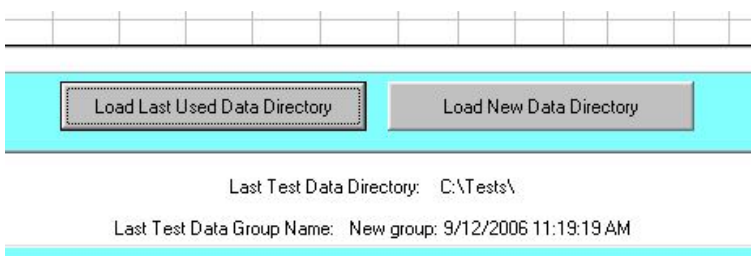
4. MAIN TABLE DISPLAY WINDOW

This is the main window for file and data processing and all related programs are initiated from here.



+ Mark Note !	Test	Powder	Batch	Die	rhot	rhob	rhotp	HR	Ctap	Taps	beta	RH%	Troom	Temp	HPT	th	rhog-d	eta-d	alpha-d	Pnet-d	Pmax-d	Pmt-d	H-d	D-d	mass-d	PM	rhog-c
---	-1-	-2-	-3-	-4-	g/cm3	g/cm3	g/cm3	-8-	%	-10-	deg	%	C	C	-15-	sec	g/cm3	-18-	-19-	MPa	MPa	MPa	mm	mm	g	-26-	g/cm3
15	136.00	MIX 1		TD#1/TC	9.000	3.165	3.578	1.130	11.54	15045	49.0	0	0	25	0	0	6.557	0.820	0.1477	317.8	350.0	333.5	12.352	12.700	10.260	2	6.557
16	137.00	MIX 1		TD#1/TC	9.000	3.165	3.578	1.130	11.54	15045	49.0	0	0	25	0	0	6.557	0.820	0.1477	317.8	350.0	333.5	12.352	12.700	10.260	2	6.557
17	138.00	MIX 1		TD#1/TC	9.000	3.165	3.578	1.130	11.54	15045	49.0	0	0	25	0	0	6.557	0.820	0.1477	317.8	350.0	333.5	12.352	12.700	10.260	2	6.557
18	138.01	MIX 1		TD#1/TC	9.000	3.165	3.578	1.130	11.54	15045	49.0	0	0	25	0	0	6.523	0.796	0.1459	313.0	350.0	331.0	12.417	12.700	10.260	2	6.525
19	139.00	SAMPLE		TD#1/TC	7.800	3.165	3.401	1.075	6.94	30	49.0	7	24	22	0	0	3.705	0.819	0.0252	199.8	217.3	208.4	10.649	12.700	4.998	2	4.070
20	140.00	SAMPLE		TD#1/TC	7.800	3.154	3.628	1.150	13.07	40	48.0	29	21	22	0	0	6.114	0.772	0.1720	203.5	217.3	210.3	6.460	12.700	5.004	2	6.117
21 !	141.00	SAMPLE		TD#1/TC	7.800	3.154	3.628	1.150	13.07	40	45.0	24	21	22	0	0	6.119	0.773	0.1723	203.5	217.3	210.3	6.451	12.700	5.000	2	6.121
22 !	142.00	SAMPLE		TD#1/TC	7.800	3.154	3.628	1.150	13.07	40	48.0	29	21	22	0	0	6.103	0.768	0.1710	203.2	217.3	210.1	6.467	12.700	5.000	2	6.110
23 !	143.00	SAMPLE		TD#1/TC	7.800	3.154	3.628	1.150	13.07	40	48.0	29	21	22	0	0	6.141	0.785	0.1741	205.1	217.3	211.1	6.427	12.700	5.000	2	6.140
24	526.00	SAMPLE		TC/TD#1	7.800	3.166	3.857	1.218	17.92	20060	35.0	0	0	19	0	0	5.759	0.783	0.1384	256.8	300.3	277.7	12.185	9.525	5.000	2	5.757
25	776.00	PERRY TOOL	0808306	TC/1	7.827	3.089	3.819	1.236	19.11	15045	50.0	0	0	19	0	0	5.631	0.721	0.1383	178.6	200.0	189.0	8.776	12.700	6.260	2	5.641
26	832.00	042607	001	TC/TD#1	3.540	1.209	1.408	1.165	14.13	15045	48.0	0	0	22	0	0	2.690	0.649	0.1736	253.5	290.1	271.2	7.923	12.700	2.700	1	2.684
27	833.00	SAMPLE		TC/TD#1	7.800	3.166	3.857	1.218	17.92	20060	41.0	0	0	24	0	0	5.758	0.650	0.1376	267.4	300.3	283.4	6.841	12.700	4.990	2	5.761
28	1410.00	MIX 1		WC-H15/TD#1	7.800	3.115	3.665	1.177	15.01	15045	46.0	0	0	20	0	0	6.380	0.790	0.1850	361.2	397.1	378.7	10.182	12.700	8.229	1	6.377
29	2417.00	3C94B-Plextol	1CSc	TC/TD#1	5.010	1.533	1.606	1.048	4.55	90270	35.0	0	0	22	0	0	3.000	0.651	0.1215	96.3	117.9	106.6	11.999	12.700	4.560	1	2.977
30	2558.00	SAMPLE		C-350/HTD#3	7.800	3.166	3.857	1.218	17.92	20060	41.0	0	0	24	0	0	0.000	0.650	0.1376	267.4	300.3	283.4	11.695	12.700	4.990	2	5.761
31	3308.00	MIX 1		TD#1	7.800	3.165	3.578	1.130	11.54	15045	49.0	0	0	21	0	0	6.166	0.815	0.1671	306.3	344.8	325.0	14.671	12.700	11.460	2	6.167
32	6395.00	STEEL	CNRC	TC/TD#1	7.800	3.325	3.921	1.179	15.20	15045	41.0	0	0	20	0	0	5.523	0.590	0.1248	137.0	150.0	143.4	6.520	19.050	10.264	2	5.566
33	9745.00	MIX 1		TD#1	9.000	3.165	3.578	1.130	11.54	15045	49.0	0	0	20	0	0	8.379	0.758	0.3672	146.0	150.6	148.3	4.296	19.050	10.260	2	8.379

When the program is started, it offers a choice to select a new test data directory or start with the last accessed test data directory:



It assembles all **Test Data Files** ("**TDF**") from that directory, sorts them by their test number and loads them into the Main Table. Only files from one directory at a time are displayed.

The **TDF** is a standard ASCII file with a distinctive name, **A00123.00F**, identified by a unique 5 digit test number (including leading zeros) and by 2 digit extension for any versions of the same test. Each directory with TDF files is considered a file Group. The user can specify a descriptive name for each group which is stored in that directory in a file named A00000.00F. That file also stores the number of the last created or accessed file in that Group. The program always searches directories for the TDF files and sorts them according to their test number before displaying them.

The program provides the option of creating test data files in the .csv (**comma separated values**) format **compatible with spreadsheets**. Those files are created for currently selected units and stored in a unit-specific folder in the test data directory. The program can create the following files (details in 5.7):

- **A00123_00_units.csv** - standard output Test Data File (for each A00123.00F test file) with General Test Data and Plots for compaction, ejection, axial and radial crushing

- **Table_units.csv** - table data file identical to the Screen Table Display
- **All_units.csv** - a combined plots file for user selected test plot parameters from all tests.

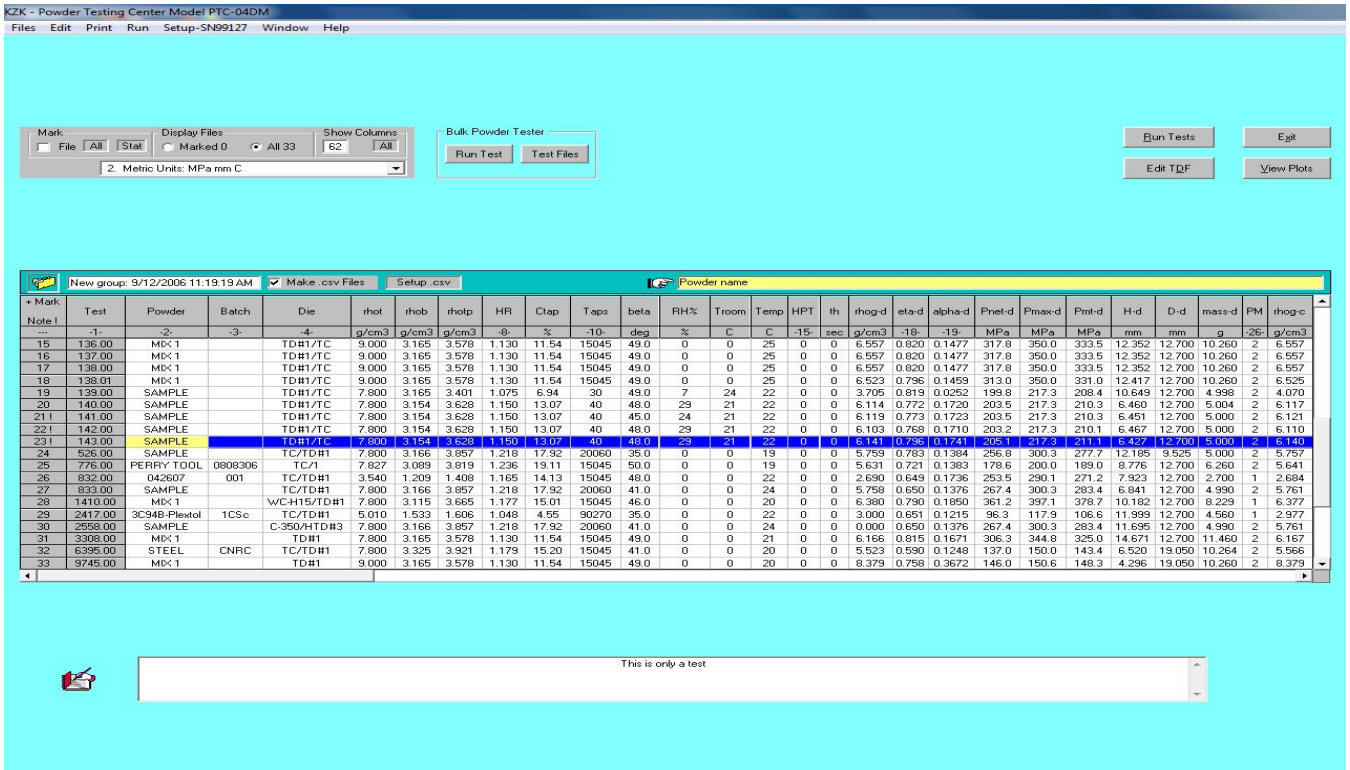
Here, "units" refers to the currently selected units (MPa_mm_gpercm3, PSI_in_gpercm3, ...). The details of the data arrangement in the csv files are shown in the **Setup.csv** screen option. Checking the **Make .csv File** box will automatically generate the individual csv files for new test data files or for any test data file that does not have a corresponding csv file.

The Main Table Display window also provides a direct access to the Bulk Powder Tester options:

- select the **Run Test** option to run bulk powder tests with the Bulk Powder Tester (BPT Testing)
- select **Test Files** option to view the bulk powder test data from tests run previously (BPT Files).

4.1 Data Table

The **Data Table** ("**Table**") is the central feature of the window.



+ Mark Note !	Test	Powder	Batch	Die	rhot	rhob	rhotp	HR	Ctap	Taps	beta	RH%	Troom	Temp	HPT	th	rhog-d	eta-d	alpha-d	Pnet-d	Pmax-d	Pmt-d	H-d	D-d	mass-d	PM	rhog-c
---	-1-	-2-	-3-	-4-	g/cm3	g/cm3	g/cm3	-8-	%	-10-	deg	%	C	C	-15-	sec	g/cm3	-18-	-19-	MPa	MPa	MPa	mm	mm	g	-26-	g/cm3
15	136.00	MIX 1		TD#1/TC	9.000	3.165	3.578	1.130	11.54	15045	49.0	0	0	25	0	0	6.557	0.820	0.1477	317.8	350.0	333.5	12.352	12.700	10.260	2	6.557
16	137.00	MIX 1		TD#1/TC	9.000	3.165	3.578	1.130	11.54	15045	49.0	0	0	25	0	0	6.557	0.820	0.1477	317.8	350.0	333.5	12.352	12.700	10.260	2	6.557
17	138.00	MIX 1		TD#1/TC	9.000	3.165	3.578	1.130	11.54	15045	49.0	0	0	25	0	0	6.557	0.820	0.1477	317.8	350.0	333.5	12.352	12.700	10.260	2	6.557
18	138.01	MIX 1		TD#1/TC	9.000	3.165	3.578	1.130	11.54	15045	49.0	0	0	25	0	0	6.523	0.796	0.1459	313.0	350.0	331.0	12.417	12.700	10.260	2	6.525
19	139.00	SAMPLE		TD#1/TC	7.800	3.165	3.401	1.075	6.94	30	49.0	7	24	22	0	0	3.705	0.819	0.0252	193.8	217.3	208.4	10.649	12.700	4.998	2	4.070
20	140.00	SAMPLE		TD#1/TC	7.800	3.154	3.628	1.150	13.07	40	48.0	29	21	22	0	0	6.114	0.772	0.1720	203.5	217.3	210.3	6.460	12.700	5.004	2	6.117
21 !	141.00	SAMPLE		TD#1/TC	7.800	3.154	3.628	1.150	13.07	40	45.0	24	21	22	0	0	6.119	0.773	0.1723	203.5	217.3	210.3	6.451	12.700	5.000	2	6.121
22 !	142.00	SAMPLE		TD#1/TC	7.800	3.154	3.628	1.150	13.07	40	48.0	29	21	22	0	0	6.103	0.768	0.1710	203.2	217.3	210.1	6.467	12.700	5.000	2	6.110
23 !	143.00	SAMPLE		TD#1/TC	7.800	3.154	3.628	1.150	13.07	40	48.0	29	21	22	0	0	6.141	0.796	0.1741	205.1	217.3	211.1	6.427	12.700	5.000	2	6.140
24	526.00	SAMPLE		TC/TD#1	7.800	3.166	3.857	1.218	17.92	20060	35.0	0	0	19	0	0	5.759	0.783	0.1384	256.8	300.3	277.7	12.185	9.525	5.000	2	5.757
25	776.00	PERRY TOOL	0808306	TC/1	7.827	3.089	3.819	1.236	19.11	15045	50.0	0	0	19	0	0	5.631	0.721	0.1383	178.6	200.0	189.0	8.776	12.700	6.260	2	5.641
26	832.00	042607	001	TC/TD#1	3.540	1.209	1.408	1.165	14.13	15045	48.0	0	0	22	0	0	2.690	0.649	0.1736	253.5	290.1	271.2	7.923	12.700	2.700	1	2.684
27	833.00	SAMPLE		TC/TD#1	7.800	3.166	3.857	1.218	17.92	20060	41.0	0	0	24	0	0	5.758	0.650	0.1376	267.4	300.3	283.4	6.841	12.700	4.990	2	5.761
28	1410.00	MIX 1		WC-H15/TD#1	7.800	3.115	3.665	1.177	15.01	15045	46.0	0	0	20	0	0	6.380	0.790	0.1850	361.2	397.1	378.7	10.182	12.700	8.229	1	6.377
29	2417.00	3C94B-Plextol	1CSc	TC/TD#1	5.010	1.533	1.606	1.048	4.55	90270	35.0	0	0	22	0	0	3.000	0.651	0.1215	96.3	117.9	106.6	11.999	12.700	4.560	1	2.977
30	2558.00	SAMPLE		C-350/HTD#3	7.800	3.166	3.857	1.218	17.92	20060	41.0	0	0	24	0	0	0.000	0.650	0.1376	267.4	300.3	283.4	11.695	12.700	4.990	2	5.761
31	3308.00	MIX 1		TD#1	7.800	3.165	3.578	1.130	11.54	15045	49.0	0	0	21	0	0	6.166	0.815	0.1671	306.3	344.8	325.0	14.671	12.700	11.460	2	6.167
32	6395.00	STEEL	CNRC	TC/TD#1	7.800	3.325	3.921	1.179	15.20	15045	41.0	0	0	20	0	0	5.523	0.590	0.1248	137.0	150.0	143.4	6.520	19.050	10.264	2	5.566
33	9745.00	MIX 1		TD#1	9.000	3.165	3.578	1.130	11.54	15045	49.0	0	0	20	0	0	8.379	0.758	0.3672	146.0	150.6	148.3	4.296	19.050	10.260	2	8.379

The first column, in addition to numbering the rows, displays symbols indicating presence of **Test Notes** (**!**) in TDF files and **marking** (+). The second column lists the test number for the displayed file. These two columns are fixed and always displayed. All other columns are arranged in a desired order by the user who also specifies the number of columns to be displayed in the table.

Common Table operations:

- to find the Name of any entry, click that column and the name is displayed
- to move to the last (first) column, use the Home (End) key
- to move to the First (Last) file in the list, press Ctrl+Home (+End) keys
- to change the unit for any column, use Edit Unit in the Edit option (see details in Section 4.3.4)
- to change the column arrangement in the table, select one in the Table Setup list
- to edit the desired parameters in a file, double click any entry in that file or use the Edit TDF button
- to edit or add a note for a selected file, enter the changes in the Note window
- to change the File Group name, edit it
- to copy a selected file from the table to a buffer, use Copy TDF in the Edit menu
- to remove a selected file from the table (to a buffer), use Cut TDF in the Edit menu
- to paste a file from a buffer to the table, use Paste TDF in the Edit menu
- to Mark or unMark a selected file, press the M key or click on the Mark File check box
- to Mark or unMark all files, click on the Mark All check box
- to display statistical values (min, max,...) for marked files (3 or more), click the Stat button
- to create .csv (spreadsheet compatible) test files, mark the "Make .csv Files" and select the "Setup .csv"

4.1.1 Table Setup List

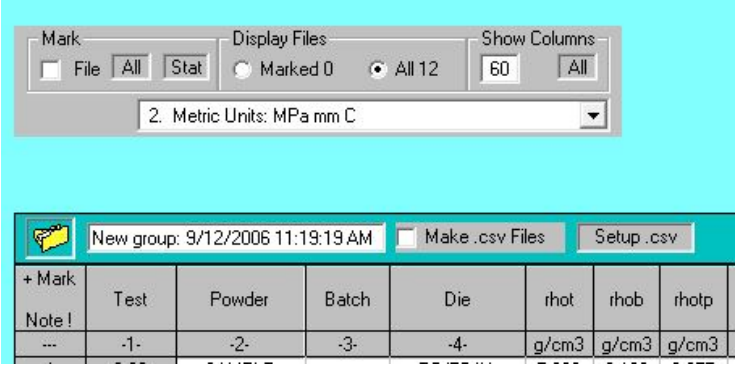
The order of the data (columns) displayed in the Table is determined by a table setup created by the user to fit specific needs. The program comes with a base table setup (metric) which may be copied and modified. The changes include different data (columns) and units arrangement. Each table setup is identified by a name. All setups are listed in the Table Setup list on the main screen for selection if desired (see picture below/next page).

The table setups are also used for printing standard outputs, tables, and filing of the screen table. The units and the text (language) selected for a given table are specific to that table. It is advisable to create separate table setups for screen display and various printing arrangements.

The specific modifications of the table setup are described in the Edit Menu section below.

4.1.2 Screen Frames

In the **Show Columns** frame, the user may select all available data entries to be listed in the Table or to display only a desired number of columns which may be typed in the text box.



In the **Display File** frame, when some files are marked, the user may select to display All files or the Marked files only. The available number of files is shown next to those options.

In the **Mark** frame, some files may be marked for printing and plotting purposes. One can plot several marked data files on a single plot for comparisons. Files may be marked individually or all at once. Pressing the M key corresponds to a single file marking. Repeating the steps reverses the marking process.

For marked files (3 or more), the **Stat** option calculates and displays for each table parameter (column) the following statistical values: minimum, maximum, mean and standard deviation.

4.1.3 Test Note Window

A presence of a Test Note in a file is indicated by the note mark (!) in the first column of the table. The note for the selected file is automatically displayed in the Test Note Window. Any changes to the note are combined with the original file and stored when the cursor is returned back to the data table.

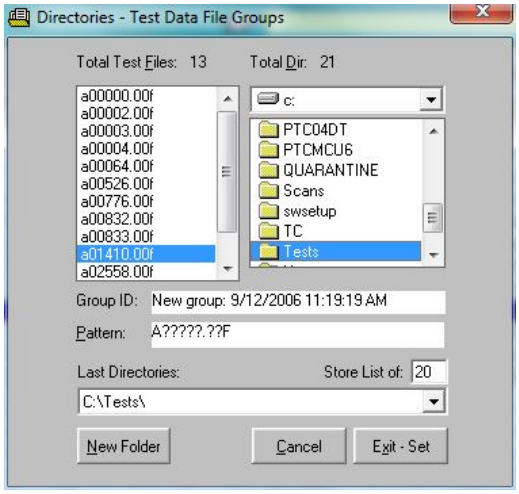
Note: There is a limit of 80 characters on each line and 10 lines total.

4.2 File Menus

The options are used for file and directory related operations.

4.2.1 Change Directories

The option displays the drive, directory and file lists for the current system.



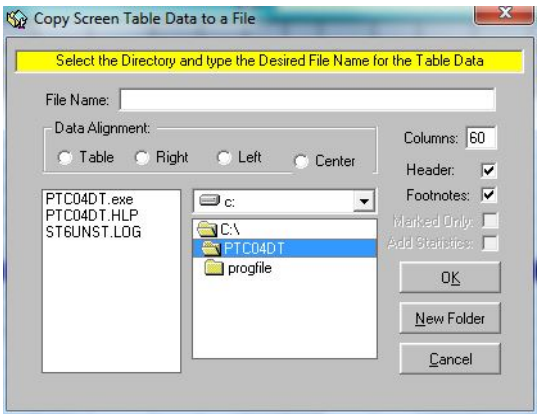
Only TDF files are searched for and displayed. Each directory with TDF files is considered a separate file Group with a specific name stored in the A00000.00F file. The name is displayed as a Group ID which may be changed if desired.

Note: To increase the efficiency during file search, this option shows all TDF files in any selected directory, not just the opened one.

The Exit-Set button assigns the selected directory as the target directory for the Main Table display.

4.2.2 Save Screen Table in a File

This option is used to create an ASCII file with a data table identical to the one displayed on the screen.



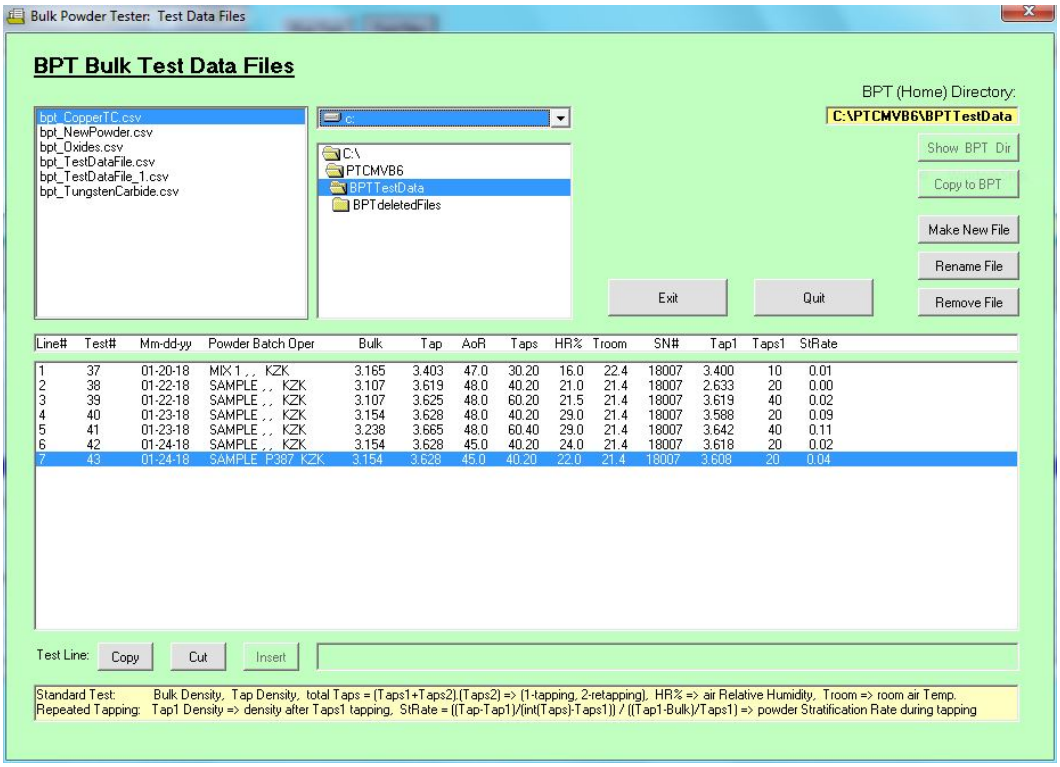
The check boxes offer choices for including/excluding the table's header and footnotes in the file. The footnotes consist of frame lines at the bottom of the table entries and full names for all the entries in the table.

The option displays the drive, directory and file lists for the current system. The user must select the destination directory for the new file and enter the file's name. The **New Folder** option establishes a new subdirectory in the selected directory. The subdirectory is not formally created until the option is exited.

The OK button creates the file with the table and exits the program.

4.2.3 Bulk Powder Tester Files

This option displays the **BPT Bulk Test Data Files** screen (BPT Files).



Using the **Quit** option exits the screen without any other actions. The **Exit** option copies the current data file path and the test data from the test line highlighted on the screen into a data buffer used for testing.

When in the BPTTestData ("Home") directory, data files can be renamed (**Rename File**) and deleted (**Remove File**). A new files can be created (**Make New File**) as well. By definition, the name of a data file always starts with "bpt_" followed by user provided FileName and ending with ".csv" (format compatible with spreadsheets.)

For the screen displayed file, single Test Data lines can be **Copied** or **Cut** (removed) and moved into a temporary buffer displayed to the right of the command buttons (below the main data display window). The data in the buffer cannot be deleted, it can only be replaced with another Copy/Cut command or **Insert**ed into any data file. This is used for rearranging the order of the tests in a file or moving test data between files. All **Cut** test data lines and **Removed Files** are moved to a **BPTdeletedFiles** folder in the Home directory where they can be accessed later if needed.

All data files in directories other than BPTTestData (including files on other computers or servers) are "read-only" files. Individual test data lines as well as files can be copied to home directory (**Copy** or **Copy to BPT**) . The **Show BPT Dir** option returns the focus back to the Home directory.

4.3 Edit Menus

When working with a test file, the program stores it in a buffer that is never cleared so the last file placed in the buffer is available until it is replaced by a new one.

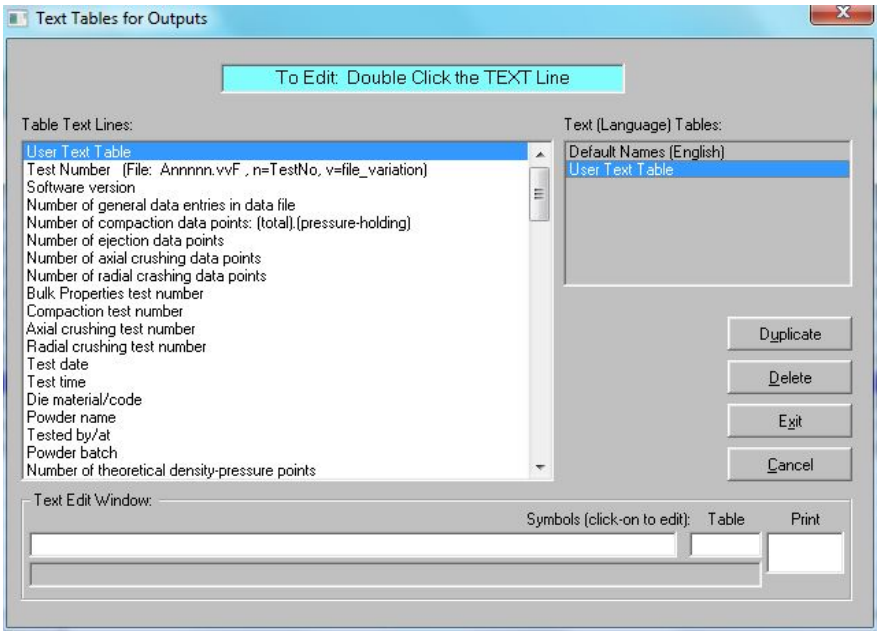
- The Cut Test File copies the selected file to the buffer and removes the original from the table and the group directory.
- The Copy Test File copies the selected file to a paste buffer.
- The Paste Test File copies the file from the buffer to the group directory.
- The Change Test/File # option changes the actual test number and the corresponding test data file name. The user must specify a new unique test number within the file Group. The entries in the display table will be automatically rearranged to reflect the new file/test number.

4.3.1 Edit Test File

This menu option is identical to the TDF command button and is described in Section 4.7. This option is also activated by double clicking on any data entry in the Screen Table display.

4.3.2 Edit Text Tables

The standard terms, symbols and definitions for all test parameters used in note boxes, printouts, and plot annotations are stored in a Text Tables file. The default language is English. The user may create additional text tables by duplicating existing tables and editing the entries. The changes may involve new parameter names, symbols, and local language.



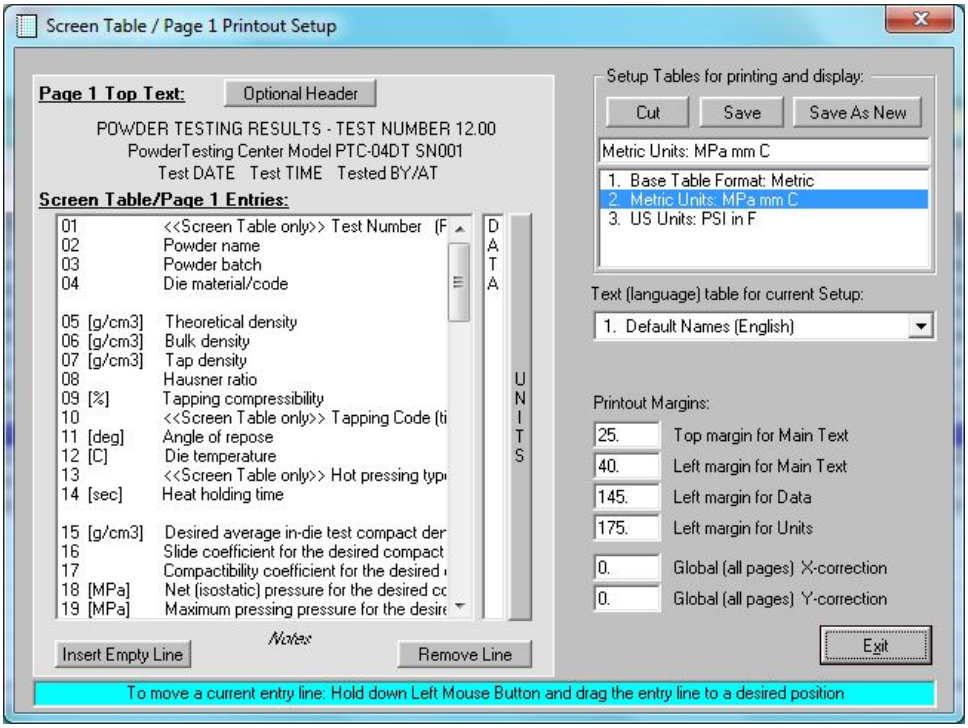
The option displays the Text Tables list with all currently defined Text Tables. The Table Text Lines list displays all text lines for the selected Text Table. Double clicking on any entry line displays that line in an Edit text box which allows editing of the text. The original (in English) definition of that particular entry appears in a box above and serves as a reference. Corresponding printing and table display symbols, if any, are shown in their respective boxes. Mouse clicking on them displays their code in a separate edit window for possible changes.

The user cannot change the base (default) text table. That table (and any other) can be **Duplicate**d which creates a copy of the selected Text Table at the end of the list. Any Text Table except the default one can by Deleted from the list.

Selecting a given Text Table and pressing Exit makes that table the current one for screen displays. The Cancel option exits without changing the original table selection.

4.3.3 Edit Screen Table

The Table Setup specifies the order in which test data parameters are shown on the screen and printed on outputs and in table files.

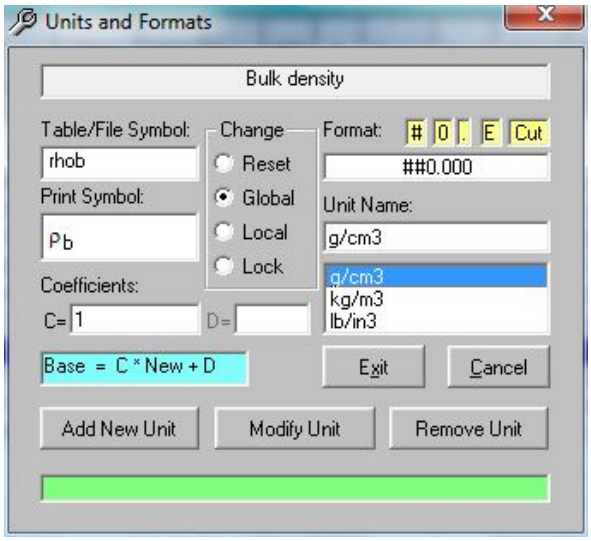


The user may group test parameters of interest together and create separate table arrangements that may be selected when needed. Each Table Setup preserves its local choice of units and, for printing only, the selected text table (language). The definitions of relevant options and buttons are displayed in the Note window when the mouse moves over them. *Note: The parameters that will show on screen but not print are indicated with the "Screen Table only" mark*.

This option is identical to the Page 1 Setup option - see details below in Section 4.4.3. When Exiting the Table Setup option, the current setup becomes the setup for the screen display.

4.3.4 Change Unit

The unit for each data parameter displayed in a specific column in the data table may be set to any predefined unit.



The setting is local to and stored in the current Table Setup file. Therefore, changing units in one table setup has no effect on the other setups. In addition, it is sometimes necessary to have the same type of data parameter expressed with different units within the same table setup (for example, compact density may be in g/cm^3 but bulk density may be in kg/m^3). The different options provide that capability. The Note window provides definitions and limits for these options.

The Unit Setup window shows the table entry name, the table/file symbol and the print symbol. Double clicking on any of them permits their editing and modifications. Those modifications are specific to the current Text (Language) Table. The Unit Name text box shows current unit name. All available units are listed in a Unit Name list. Each unit is defined with respect to the base unit which is the first unit on the list. The relation is expressed by the C coefficient except for temperatures where an offset coefficient D is needed. The relation between the units is shown in the box display.

The user may Add new units (provide a name and conversion coefficients) and Remove them from the list. The display and print format for each unit may be modified by clicking on the modification buttons.

Note: Do not make any changes until you determine the result they will bring.

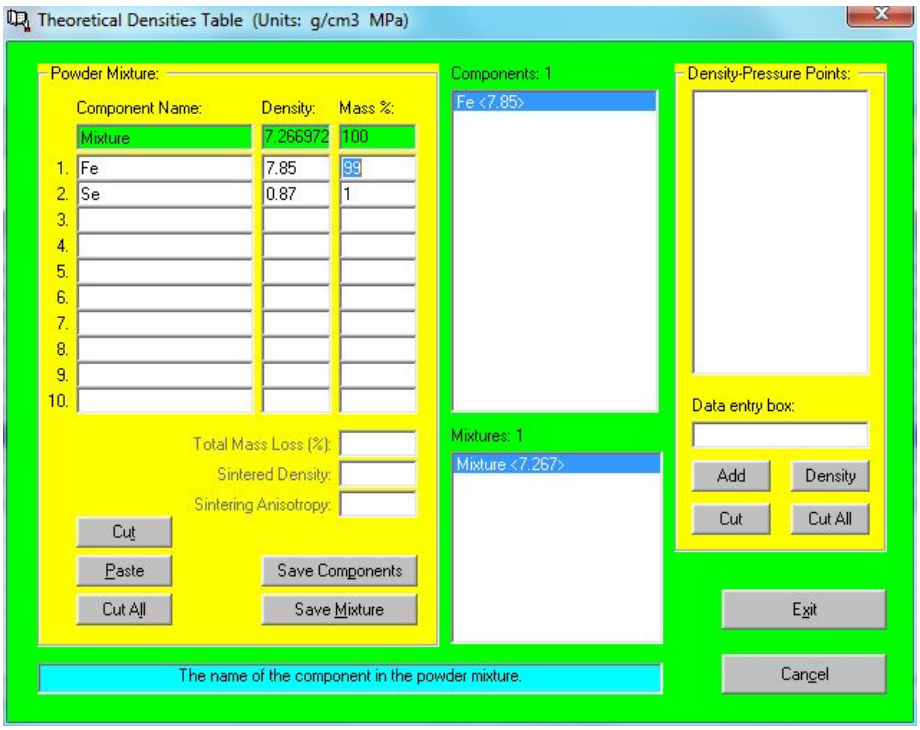
The Change frame defines the scope of the unit modification on the current Table Setup. The program checks the Table Setup and finds all columns with the same unit. How the unit setup for those columns is implemented depends on the selected Change option. The Lock option affects only the current column entry and locks that selection against future changes. The Local option affects only the current column. The Global option changes all like entries within the Table Setup except the locked ones. The Reset option affects all like entries and unlocks any locked columns.

The Exit option implements the selected changes.

4.3.5 Theoretical Densities Table

The Theoretical Density of a powder mixture is the mixture's density at full (100%) densification. The PTC program provides a table screen option where the user can enter all the components of a mixture with their densities and mass (%) contribution. Once the total reaches 100%, the mixture's density is calculated. The **Cut** option removes a component (line) from the table, the **Paste** copies the cut component into the table. The **Cut All** option clears the table. The **Exit** copies the mixture's theoretical density value into the corresponding entry in the Tests display.

The **Save Component** option saves all individual components and the **Save Mixture** option saves mixtures in a data base for future access. To insert a saved mixture/component from the data base into the current table is done by double clicking that entry.



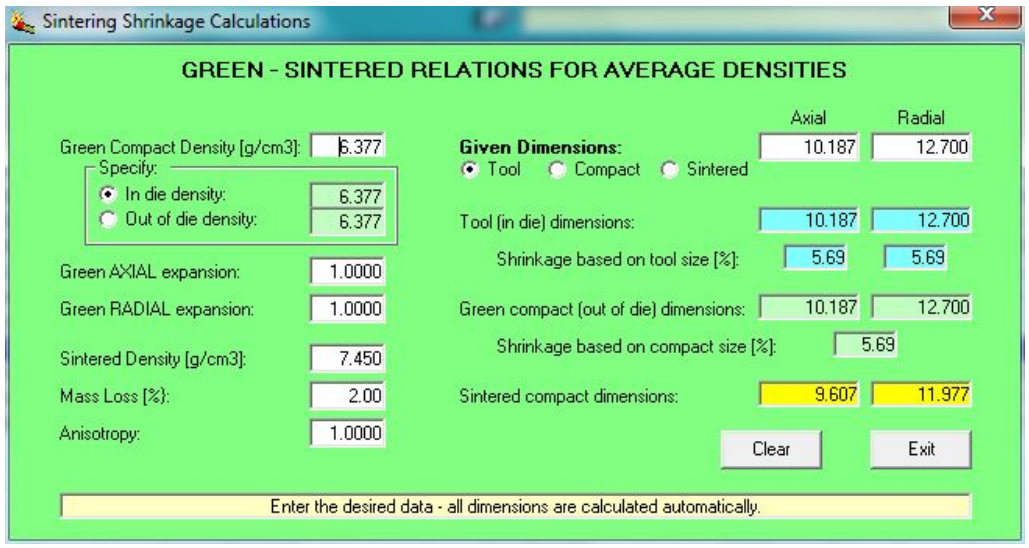
The sintering parameters (total mass loss, sintered density and sintering anizotropy) for the powder may be entered here as well to allow shrinkage calculations during a sintering process. The same parameters may be entered at the end of a test in the Edit TDF option (see below.) The **Total Mass Loss** accounts for the total mass change in a compact between compaction and after sintering. Any mass losses (moisture, lubricants, binders, ..) or gains (oxidation, ..) must be accounted for to assure accuracy. The **Sintering Anisotropy** is the axial to radial shrinkage ratio for isostatically densified compacts.

For powders that exhibit theoretical density variation with pressing pressure there is an option to enter the density-pressure characteristic defined by several points on that characteristic. The theoretical density and the corresponding pressure are typed in the **Data entry box**. For a valid characteristic, at least two points must be defined. The Add option saves the entry in the standard Test Data File.

With the characteristic defined, typing any pressure value within the characteristic and selecting the **Density** option will calculate the corresponding density and display it in the Data entry box.

4.3.6 General Sintering Calculations

The option provides basic relationships between sintered compact, green compact and tool dimensions for compacts with uniform density (average density). For compacts pressed in a rigid die, the PTC program calculates local shrinkage during sintering based on the density variations along the height of a compact.



The following data are necessary to conduct the sintering calculations:

- green compact density ρ_g, measured in die under full load (tool dimensions) or out of die (free compact)
- green axial expansion $\mathbf{e_a}$
- green radial expansion $\mathbf{e_r}$
- sintered density ρ_s
- total mass loss $\mathbf{m_l}$ (%) during drying and sintering
- sintering anisotropy **a** , *a = 1 for compacts with random grain orientations.*

The dimensions of the tool (in-die) and the free (out-of-die) compact are tied with the green expansion coefficients:

- axial: $h_{out\text{-}of\text{-}die} = e_a * h_{in\text{-}die}$
- radial: $d_{out\text{-}of\text{-}die} = e_r * d_{in\text{-}die}$
- density: $\rho_{out\text{-}of\text{-}die} = \rho_{in\text{-}die} / (e_a * e_r * e_r)$.

The **sintering process** occurs by **heating a free (out of die) compact**. The **radial shrinkage** during sintering can be calculated from the following:

$$S_d = 3 * (((1 - m_l) * \rho_g / \rho_s)\text{^}(1/3)) / (2 + a) .$$

The **dimensions** of a free green ("g") compact and the sintered ("s") compact are related through the following expressions:

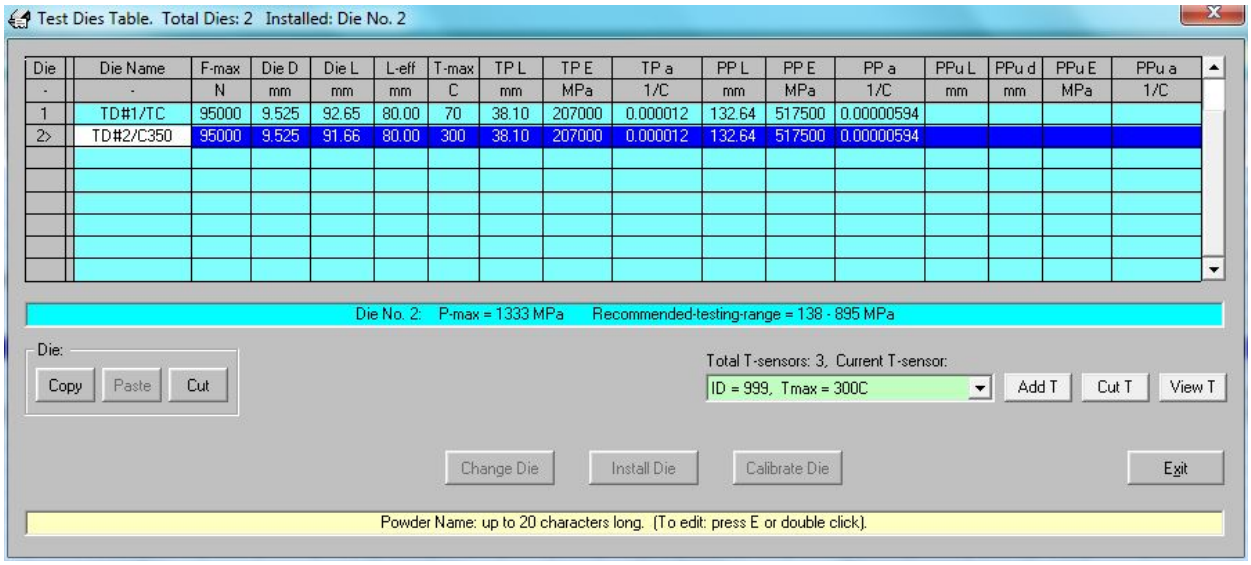
- axial shrinkage: $S_h = 1 - h_s / h_g$
- radial shrinkage: $S_d = 1 - d_s / d_g$
- anizotropy: $a = S_h / S_d$.

After entering the necessary data for a given compact into the first column, the user can enter the **given axial and/or radial dimension**, specify the given dimension type (**tool, compact,** or **sintered**) and the program calculates the other two dimension types with shrinkages based on the tool and the free compact size.

4.3.7 Test Die Table

The die table lists all dies on record and shows the parameters defining a die which could be modified by the user. To create a **new die**, first **Copy** an existing die (highlighted line), move to a line below which you want your new die to be listed, **Paste** it to make a new line entry and edit all relevant parameters. To edit a die parameter, double click on it. At first, the user must provide the **Operator Password** to make any changes. The selected parameter is displayed in the **Edit Window** and may be modified as needed. Pressing Enter or moving out of there automatically makes the change in the die table. The die parameters should be determined as accurately as possible, preferably within 0.01mm.

*NOTE: All die parameters are in **metric units**, regardless of what the general unit selection is.*



Die	Die Name	F-max	Die D	Die L	L-eff	T-max	TP L	TP E	TP a	PP L	PP E	PP a	PPu L	PPu d	PPu E	PPu a
-	-	N	mm	mm	mm	C	mm	MPa	1/C	mm	MPa	1/C	mm	mm	MPa	1/C
1	TD#1/TC	95000	9.525	92.65	80.00	70	38.10	207000	0.000012	132.64	517500	0.00000594				
2>	TD#2/C350	95000	9.525	91.66	80.00	300	38.10	207000	0.000012	132.64	517500	0.00000594				

The following parameters (metric units only) define a die:

Die Name - an ID or code of the die (20 characters), it will appear on printouts and displays

F-max - a maximum allowable force on the pressing punch (40,000-98,100 N)

DieD - the actual diameter of the die cavity (5-19.5 mm)

DieL - the total length of the test die (55-119 mm)

L-eff - the effective length of the pressing section (diameter DieD) of the die (50-119 mm)

T-max - the maximum temperature for the die (50-300°C)

TPL - the top punch length (37.5-38.25 mm)

TPE - a Modulus of Elasticity in [MPa] for the material of the top punch

TPa - thermal expansion coefficient for the top punch [1/°C]

PPL - the pressing punch **total length** (130-146 mm)

PPE - a Modulus of Elasticity in [MPa] for the pressing punch

PPa - thermal expansion coefficient for the pressing punch [1/°C]

PPuL - pressing punch's undercut length in [mm]

PPuD - pressing punch's undercut diameter in [mm]

PPuE - a Modulus of Elasticity in [MPa] for the undercut section of the pressing punch

PPua - thermal expansion coefficient for the undercut of the pressing punch [1/°C]

The top punch must be as shown on the punch drawing (Fig. 3). Most pressing punches are uniform in material and diameter so in such cases the data for the undercut parameters equal zero. In some cases, the pressing punch may have a pressing section with a nominal diameter DieD and an undercut section with a smaller diameter. Sometimes, the undercut section has the same diameter but is made of a different material. For those cases, the PPL refers to the total length of the punch, the PPu refers to the length of the undercut section, the PPuD is the diameter of the undercut section (equal or less than the nominal DieD), the PPE refers to the punch pressing section (with DieD) only and the PPuE refers to the undercut

section (with PPuD).

The die that is **actually installed** on the testing center is marked by ">" in the first column. That die cannot be removed from the table. Dies may be **Cut** from the list and moved to a buffer, **Copie**d to the buffer, and **Paste**d from the buffer to the table.

Before running a test, a given die must be first mounted (the **Change Die** option shows the mounting steps) in the PTC, it must be **Installed** (the data parameters must be checked for errors and all relevant constants must be calculated), and **Calibrated** (the position sensor must be initialized to correctly measure the compact length). *Note: The testing will not take place until the program first determines that the **die data are within limits** and then **installs** the die.*

IMPORTANT NOTE: *Changing a die parameter in the "Installed" die does not take effect until the button **Install** is activated. Only that makes the necessary changes in the control file that affect the operation of the testing center.*

The Die Table also lists the available **die temperature sensors**. The displayed sensor is the current sensor attached to the test die. Each sensor is identified by an ID inscribed on the sensor's plug and is defined by a specific calibration file. There are two basic types of sensors in use:

- thermistor type sensor for ranges 0-100°C or 80-300°C (individual calibration file required)

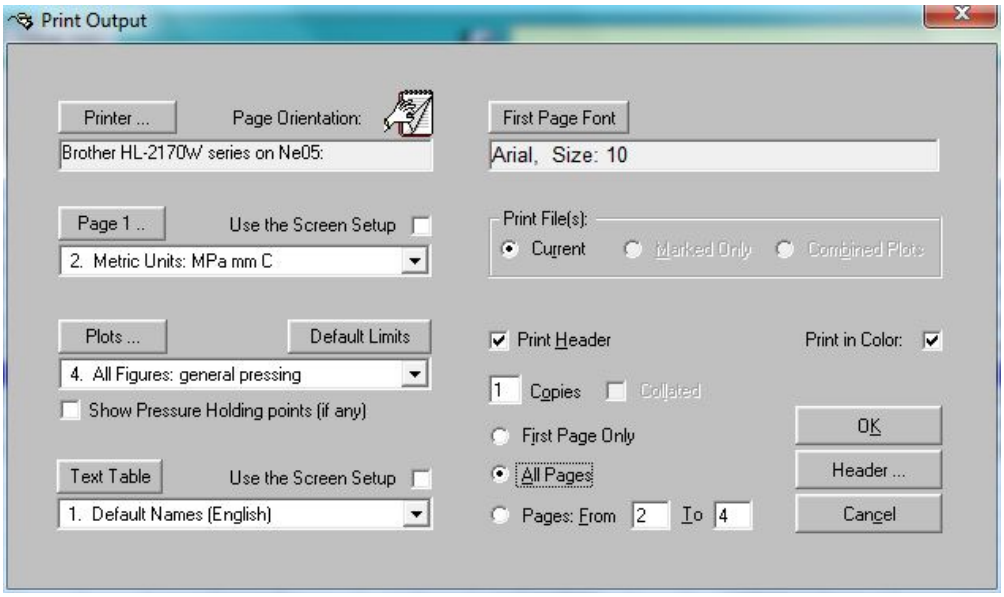
- platinum (RTD) type sensor (ID=999) for a range 0-300°C (general calibration file stored internally).

The user may **add** new sensors to the list, **cut** (remove) old ones, and **view** the calibration files.

4.4 Print Menu

The listed options define the printed page appearance for standard output and table printout.

4.4.1 Print Output (Ctrl-P)



This option generates the main printout. The arrangement of the first page is based on the current **Table Setup** in the setups list. If the **Use the Screen Setup** check box is selected, the current **Screen Table** setup is automatically selected for the printing. The Table Setup may be modified with the **Page 1** button which activates the Page 1 Setup display (see 4.4.3 below).

The plot arrangement in the output is defined by the current **Plots Setup** shown in the setups list. The setups may be modified with the **Plots** button which activates the Plots Setup display (see Section 4.4.4 below). The **Limits** button activates the Limits display which allows setting plot limits for each figure. Those limits are used when the Custom Limits option is selected. Selecting the Default Limits option activates the original limit selection which depends on the actual plotted data limits.

Note: The Custom Limits for figures are stored in the local Text (Language) Table file. Changing Text Tables during printing will change the Custom Limits as well.

In addition, for plots of local parameters (Standard Plots 8 to 19), the user may elect to use default densities for plotted density lines or it may specify up to 10 specific densities for the plotted lines. Again, for actual printing, the selection might be the default or the special densities. The Ga Number for the local plots may be changed here as well. That number is user selected and must be changed manually when desired.

Note: The user defined special densities are stored in a separate file.

The output's text appearance is based on the **Text Table** displayed in the Text Table window. The Text Table may be modified in the Text Table Setup (see Section 4.5.4) which can be accessed by clicking on the Text Table button. If the **Use the Screen Setup** check box is selected, the Text Table choice for the Screen Table display will be automatically selected for the printing.

The text font type and size for printing the Page 1 output are selected with the Page 1 Font option. The selected font's name and size are shown as printed in a display window.

The **Print Files** frame option allows printing the **Current TDF** file (as selected in the screen table), **All Marked** files (if there are marked files in the Screen Table Display) individually (complete output for each marked file) and **Combined Plots** from all marked files on a single output (this option is available only for plots). Selecting printing Page 1 with the last option will print the first page only for the current (selected in the Screen Table) TDF file and will combine plots from all the marked TDF files.

The **Header** check box, when selected, instructs the program to print a company header (logo), when available, on the Page 1 of the printout. The Header button accesses the Header display (see 4.4.5 below). All other buttons and choices are standard Windows options. During printing, activating a STOP button will delete all output in progress. The output

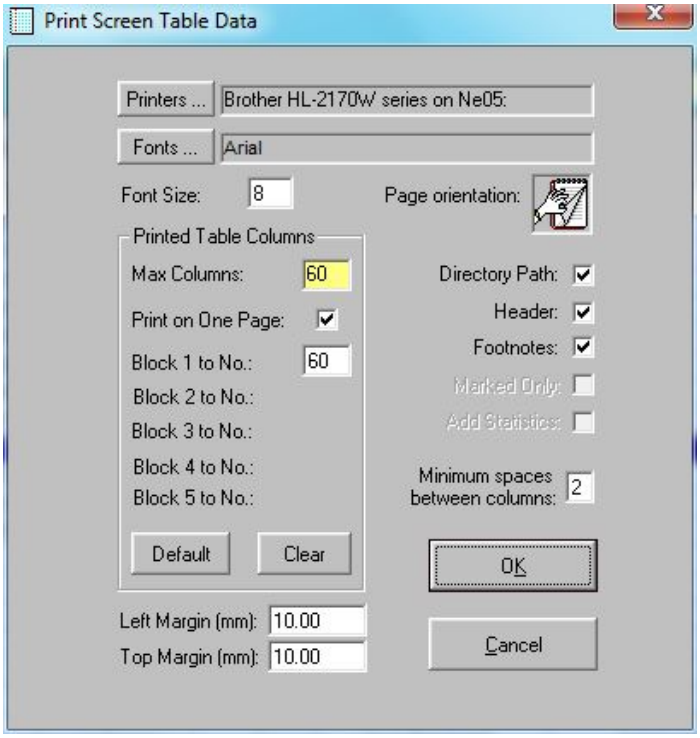
actually sent to the printer will be printed.

4.4.2 Print Table (Ctrl-T)

This option generates printouts of test data in a table arrangement for the current directory. The column arrangement is identical to the one in the screen table.

Note: To print a table with a desired Table Setup, one must first select that Table Setup for the Screen Table display and then print the table.

The **Columns** box specifies the number of columns for printing. The number cannot exceed the number of columns displayed on the screen. When the number of columns in the screen display is less than the desired number for table printout, adjust the screen display first and then print the table.



The **Printed Table Columns** frame specifies the page arrangement for the printout. Selecting the **Defaults** button displays the blocks (page) arrangements as defined in the Table Setup. The blocks correspond to collections of columns. The program will start a new block if the specified block size does not fit on a printed page. Specifying the size of the first block as equal to the total number of columns will result in a printout with maximum number of columns fitting a page printed in each block. Checking the **Print on One Page** box will result in all blocks to be printed one after another on the same page; otherwise, each block will be printed on a separate page.

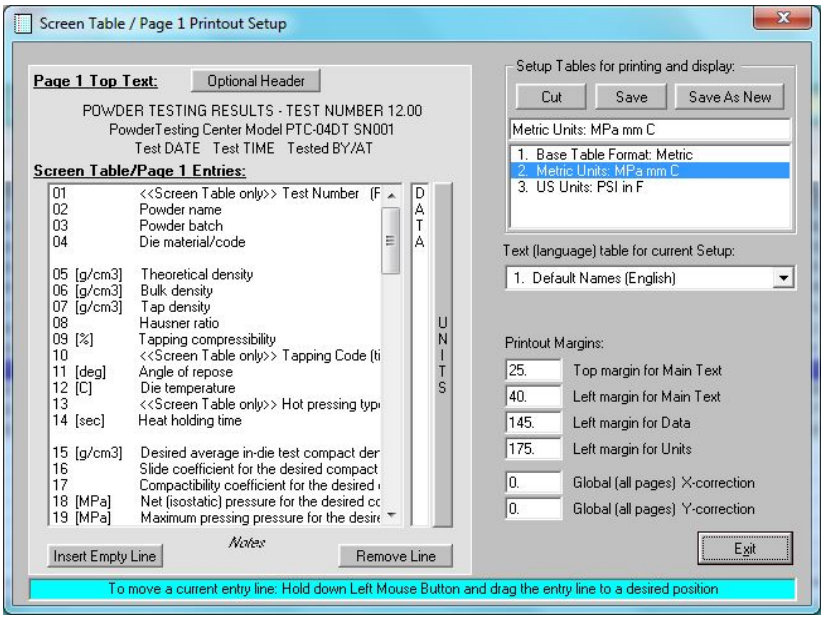
The **Header** option prints the file and directory names, the entries symbols, and unit names. If not selected, the numbers are printed from the top of the page. The **Footnotes** option prints the symbols and their full names below each block for blocks printed on separate pages or, for one page printing, it prints all symbols and their names below the last block. The **Left** and **Top** margins specify the margins for the printed page.

The **Printer**, text **Font** and **Font Size** can be adjusted when needed. The **printout orientation** (portrait or landscape) is selected by clicking on the page orientation icon. These selections are local to the table printing.

Note: The table printing may need few trials and adjustments before being acceptable to the user.

4.4.3 Page 1 Setup

This option defines the arrangement for the printed Page 1 with test results summary and defines the order of columns in the Screen Table display (note that the parameters that will show on screen but not print are indicated with the "Table Display only" mark.) The definitions of relevant options and buttons are displayed in the Note window when the mouse moves over them.



The **Setup Tables** frame lists all currently available setup arrangements for screen displays and printing. The **Cut** option will remove the selected setup from the list. The **Save** option saves all changes made on the screen to the selected setup. The **Save as New** option saves the currently displayed setup in a new Setup. The name of the selected setup in the list may be changed in the display window above the list (the changed name must be "saved" to take effect).

Selecting a Text Table from the **Text table** list selects that Text Table for printing purposes only. The choice for Screen Display is made individually in that display. *Note: Changing a Text Table affects the Special Limits for plotting purposes because those limits, if defined, are stored in a specific Text Table.*

The **Top** and **Left** margins are for the text on the printed page. The **Data** and the **Unit** margins define the placement of the data symbol text and unit text from the left edge of the printed page (there may be a need to change these settings to accommodate printing in different languages.) The above four margins apply only to the Page 1 printout and do not affect the pages with plots.

The Global corrections refer to printout position correction for all printout pages. Those corrections are in the horizontal and vertical directions, respectively. *Note: When changing paper formats, the global corrections are often necessary to make the output presentable.*

The Page 1 area shows the actual text that appears on the printout. The **Header** button activates the Header display (see 4.4.5 below). The initial lines at the upper part of the page cannot be changed. The **Screen Display / Page 1 Entries** list of parameters can be rearranged in any desired order by dragging-and-dropping parameter lines with a mouse. The **End of Printout** line defines the range of the printed parameters. The end line can be moved like any other line to be placed where desired. The parameter lines below the end line will not be printed. The number of displayed parameters (columns) in the Screen Table Display is set independently in that display.

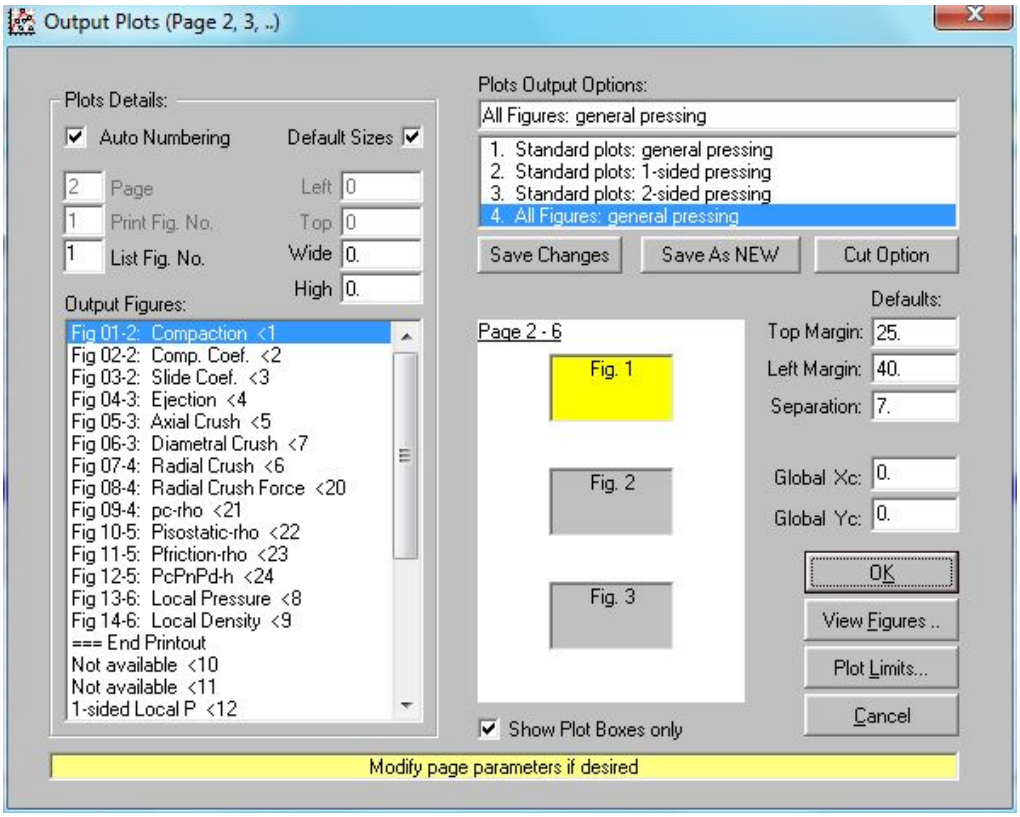
The **Units** button allows selection of units for highlighted parameter lines. The unit selection is local for a given table setup. However, changing the unit's name, print or table symbol will affect the current Text table where those unit definitions are stored (this is the same as editing the Text table). Switching Text tables for a given printout/table setup will not change the selected unit but it will display the unit's name as stored in that Text table.

The **Insert Empty Line** button inserts an empty line at a highlighted position. There is a limit of 4 empty lines in a printout. The **Delete Line** button removes the highlighted parameter line and places it just below the printout end line. The **Delete** and **Insert** keys perform similar function.

When trying to **Exit** the window without saving the changes first, the program will offer an option to save the changes before quitting.

4.4.4 Plots Setup

The specific Plot Arrangement Options are listed in the **Plots Output Options** list.



Each option should have a unique recognizable name. The **Save Changes** button saves the arrangement currently displayed on the screen in the highlighted Plot Output Option; the **Save as New** button stores it in a new Option. The **Cut Option** button removes the current Option from the list. The display window above the list is used to change the name of the current Option, the changes must be saved (Save Changes button) to be recorded.

Note: Removing all Output Options from the list will automatically reload the original default Plot Output Options.

The **Plot Limits** button activates the Limits display which allows setting plot limits for each figure. Those limits are used when the Custom Limits option is selected. Selecting the **Default Limits** option activates the original limit selection which depends on the actual plotted data limits. In addition, for plots of local parameters (Figures 8 to 19), the user may elect to use default densities for plotted average density lines or it may specify up to 10 specific densities for the plotted lines. Again, for actual printing, the selection might be the default or the special densities. The Ga Number for the local plots may be changed here as well. That number is user selected and must be changed manually when desired.

Note: The user defined special densities and the Ga number are stored in the main control file.

The Defaults: **Left Margin**, **Top Margin** and **Separation**, are used as defaults during printing to position plots on a printed page if a specific plot position is not defined. The Left and Top Margins refer to the absolute distance from the left and top edge of a printed page, respectively. The Separation is the actual distance between plots (as defined by a total plot height: the plot box height and the height of the text lines below it; default separation is set at 1" or 25.4 mm).

The **Global Xc** and **Yc** values correspond to independent position corrections for all pages of the printed output. They should be reserved to accommodate different paper sizes and to correct for default printing margins used by different printers.

The scaled plots are shown on the Page display for informational purposes only. Clicking the **Show Plot Boxes only** check box alternates between displaying the total areas occupied by the plots and just the plot boxes. The Page size is taken as the printed page size from the currently default printer in the Windows Operating system and may not always correspond to the actual paper size during printing.

The **Output Figures** list displays all available figures arranged according to the current Plot Output Option. The figures included in a printout are separated from the rest with an "**End of printout**" line. The list may be rearranged by

dragging the list lines with a mouse to a desired position on the list. The original figure (plot) numbers are always shown at the end of each figure name (list line).

Each figure definition includes default figure sizes which are used when not explicitly provided (specified as 0) in a given plot arrangement. The limits, default and custom, for the plotted parameters are included here as well. The default limits are the actual limits for the plotted parameters except for Figure 2 (Compactibility Coefficient's minimum limit is set to 0) and Figure 3 (Slide Coefficient limits are 0 to 1). The custom limits (see below) are provided by the user and may be used to fix specific plot ranges for direct comparisons (manual overlaying of printouts).

Note: The List Figures file is part of the Text (Language) Tables file and is copied to a new set when a new Text Table is created. Therefore, defining plot limits is local to a current Text Table selection where the limits are stored with the figure definitions. Changing the Text Tables during printing changes the special plot limits to those stored in that Text Table.

The **Plots Details** frame displays the highlighted Output Figure details: the **Page** where the figure will be printed, the **Print Figure Number** that will be printed below the plot box, the **List Figure Number** which refers to the figures in the List Figures list, and the **Left**, **Top**, **Wide**, **High** that describe the position and size of the total plot area (text and plot box area) on a printed page. Specifying any of plot size values as zero will result in a substitution with the default values as provided by the Defaults and the default figure definition.

Note: The program scales the default figure sizes based on the sizes provided by the user. However, the text on the plot is not scaled uniformly! It may take some experimenting to get the desired output.

The **Auto Numbering** option has effect only during editing of the Output Figures. It rearranges, if needed, the Print Figure numbering order. The **Default Sizes** check box option is also used during printing to position plots on the printed pages, one after another. If any plot sizes are defined as zero, the default rules apply regardless of the check box selection.

The use of the Default Sizes check box and the figure sizes boxes may be illustrated in the following three situations:

a) If the plots should appear one after another without empty gaps (if there is no test data for a specific plot), select the Default Sizes box.

b) If some plots must appear at fixed locations (such as at the top of a specific page), leave the Default Sizes check box unchecked, provide the necessary position for the desired plots, and use defaults (0 values) for all other plots. During printing, the program will place the desired plots as specified and put the rest of the plots with default arrangement. If for a specific page any plot is not available (no data), there will be a gap at the bottom of that page. However, the program will skip empty pages during printing.

c) If all plot sizes are provided, the plots will be printed were specified. There will be gaps when data is not available for a given plot. However, empty pages will not be printed.

The **figures in the Output Figures list may be rearranged by dragging them with a mouse** to a desired position. If the Auto Numbering is checked, the Print Figure Numbers will be automatically readjusted. Otherwise, the desired Figure Numbers must be typed in. If the Default Sizes box is checked, the pages on which the figures will be printed and their position parameters (Top, Left) are selected automatically. Otherwise, the user must provide the Page number and may specify the plot position and size parameters or use defaults (set them to zero).

To create a new **Plot Output Option**, follow these steps:

a) in the **Plots Output Options** window, type in the desired name for the new Output Option

b) click the **Save as New** button (new option is added to the list)

c) check the **Auto Numbering** check box

d) check the **Default Sizes** check box

e) rearrange the figures as desired (by dragging them with a mouse to a desired position)

f) use the **Save** button to save the new Output Option in a file.

The arrangement of plots on a given page appears concurrently, proportionally scaled, on the Page display. One must pay particular attention not to place multiple plots at the same position (it may happen in some cases). The Default Sizes option will always prevent that but it will also reposition plots if some plots are not printed. The user has a full control of the printing arrangement.

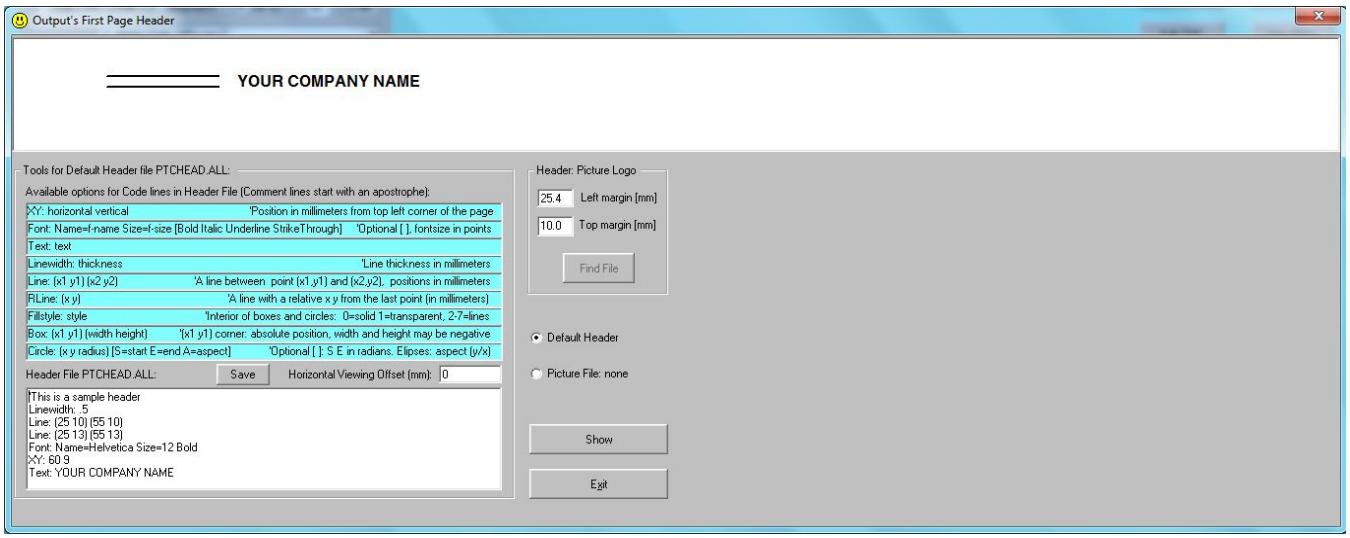
The **View Figures** option activates the figure view screen with the current Output Option figure arrangement. The figures in the output could be reviewed and, if needed, the Output Option may be rearranged by dragging the figure entries with a mouse to a desired position on the list. The **Save** button in the view screen saves the changes in the Output Option file.

The **OK** button sets the current setup as default for printing and exits the display.

Note: If a user exits or cancels without saving the changes, a reminder note will appear with options to save the changes.

4.4.5 Output Header

This option allows creation and viewing of the optional header for printing on the first page of a standard printout. There are two available choices: a **Default Header** and **Picture File**.



With the **Default Header** option, the header file may be created by using the on screen listed graphics and text options. The command lines must strictly follow the listed conventions. All dimensions are in millimeters and font sizes are in points (1 point = 0.353 mm). The user may view the coded lines on the screen and store them in the header file PTCHEAD.ALL. During printing, when the header option is on, the header file is accessed and the header will be printed on the first page.

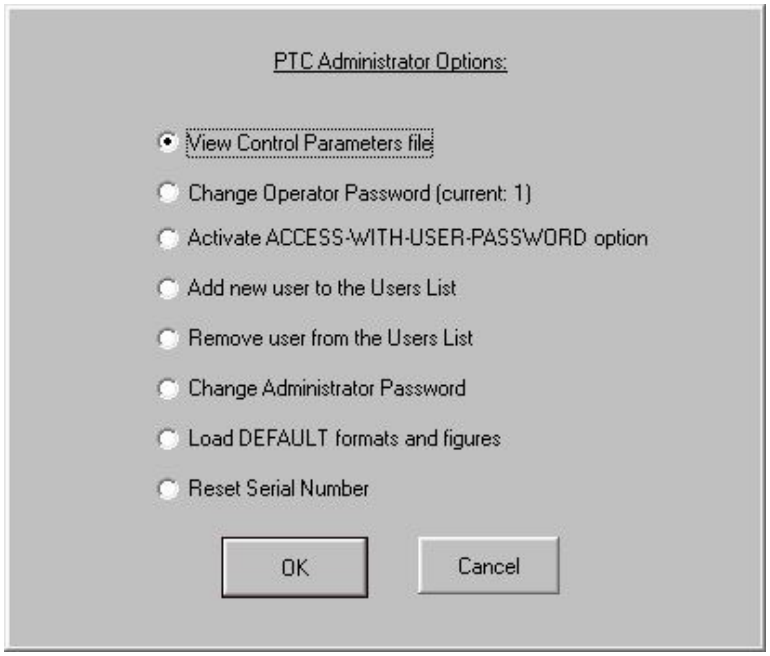
The **Picture File** option permits the use of any standard logo file (.BMP, .ICN, .WMF, ...) that can be placed on the printed page based on specified left and top margins. The picture file must be selected with the **Find File** option, its name is listed with the Picture File option.

Note: Some light colors may not print at all on black and white printers, distorting color logo pictures.

4.5 Setup-SN Menu

This is the system menu. The name includes the **Serial Number** of the testing center.

4.5.1 PTC Administrator

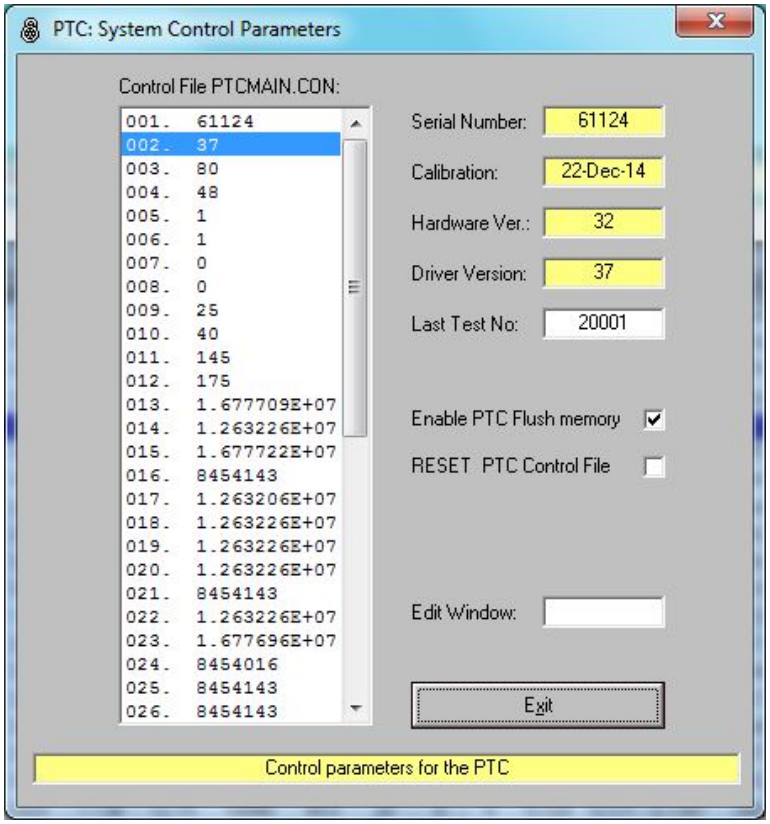


This option, protected by the **Administrator Password**, contains several options for managing the use of control data and files for the PTC:

- View Control Parameters File, see detailed description in 4.5.2 below
- Change Operator Password, this password protects the Die Table entries to prevent accidental or unauthorized changes. The initial password is number 1. This option allows to change the password to any number within the 1-32000 range. The password is stored in the control file. The **Serial Number** of the testing center is always recognized and may be used when the password is forgotten.
- Activate (Deactivate) Access-With-User-Password Option, when activated, this allows the PTC Administrator to limit access to the PTC program only to authorized users on the Users List. New users may be added or removed from the Users List. When this option is deactivated, the PTC program can be run by any user.
- Add New User to the Users List, this option adds new name to the Users List. The new name is by default the new user's initial User Password. That password can be changed any time by the user (Change User Password option in the main Setup-SN option).
- Remove User from the Users List, this option can remove a specific user name from the Users List.
- Change Administrator Password, this is the main password for the control data for the PTC.
- Load DEFAULT formats and figures, this option restores default (initial) setting for display formats and figures.
- Reset Serial Number, this is used only when changing the computer between different PTC units.

4.5.2 View Control File

The system constants are displayed in a list for service reviews and verifications. The entries in the list are protected by a service password available only to the service personnel. However, some entries may be changed by the user if needed. The control file contains data for all dies and all temperature sensors calibration points on record (as displayed in the Die Table).



The PTC keeps the main test counter in internal memory. Under certain conditions, the **Last Test Number** may need an update. The test number is used for the Test Data File name so the number must correspond to the actual last test number. Clicking on the test number allows to change it.

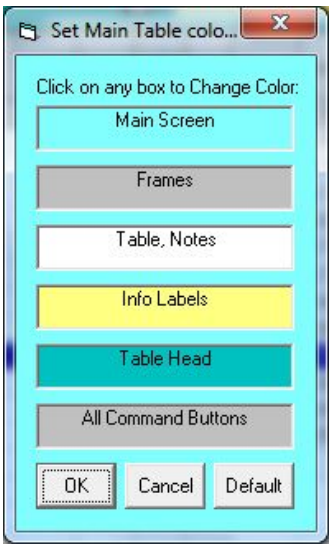
The **Enable PTC Flush Memory** option is for storing changes to the main control file (primarily updating the test counter) on the PTC's internal flush memory. The process is automatic.

The **Reset PTC Control File** option will restore the control file based on the last calibration of the PTC. The current test number is preserved. All other changes to the control file (new T-sensors, new dies,...) will not be preserved. This option should be activated only when the control file become corrupted and unworkable.

The **Code** option is visible only when there is a time limit on use of the PTC imposed by the manufacturer on new and/or leased units. The access to the testing options will be blocked after the time limit is exceeded. The time limit is removed by selecting the Code option and entering the **release code** provided by the manufacturer.

4.5.3 Set Colors

This option allows the user to set colors for the displays. The color selections will be automatically loaded into the control file.



4.5.4 Load Driver

The driver for the PTC's USB Interface is needed to access the Tests window and control the testing center. To activate the Tests window, follow the steps below:

- install the PTC04DM program
- open the PTC04DM Drivers folder and run the USBExpressInstaller.exe in the USBExpressInstal folder

Note: This program must be run in Windows XP compatibility mode: right-click the program, select Properties, set Compatibility to Win XP

- install micrometer USB driver
- connect the PTC's USB control cable to the computer
- run the PTC04DM program
- select the option Setup-SN## / Load Driver
- turn ON the testing center
- click the Run Tests button (the Tests window should appear)
- follow the initialization instructions
- operate the PTC.

When done with the software installation, store the installation disks in a safe place.

4.6 Run

This menu displays options for running attached devices:

- The **Run** option starts the **Tests** window for the PTC.
- The **Bulk Powder Unit** activates the Bulk Powder Tester
- The **Scale** option displays the reading of a scale that is linked to the computer. See section 6.4 for details.
- The **Micrometer** option displays the reading of a micrometer that is linked to the computer. See section 6.5 for details.

4.7 TDF: Edit Test Data File

This is the option for changing data in the TDF file. The option's window displays the test and desired values for the selected test file. The interactive **Note** displays the definitions and options for the specific parameters and buttons in the display.

Any of the **Desired** parameters may be modified and, by clicking the **Get Desired** button, the corresponding values are calculated based on the compaction characteristic. This procedure is often used to calculate test parameters for a specific desired compact density. First, one types in the desired density **rho** (all desired values are cleared), then clicking on the **Get Desired** option calculates the rest of the desired values. **Save/Exit** option will save the desired values in the Test Data File.

If one needs to compare powders at the same compact density or pressing pressure, the process can be like this:

- in the main Table Display, mark the test files you wish to compare
- go to the **Edit Test Data File** (TDF)
- type in the desired value and click the Get Desired option
- click the **Get Marked** to automatically do the same for all marked files, save the results and exit.

To restore the original (test default) settings for the desired parameters, mark the files, select the **Edit TDF** option and click the **Get Defaults**. That will restore the default (original) desired parameters for each of the marked files, save the changes and exit.

The **Sintered** parameters frame is used to provide sintering parameters for the program to calculate dimensional changes after sintering. The mass loss **ml** is the **total mass loss** (%) during drying and sintering. The anizotropy ratio **a** is determined on compacts **densified in an isostatic process**.

Note: The Anisotropy Ratio $a=S_h/S_d$, *where* $S_h=1-H_{sintered}/H_{green}$ *and* $S_d=1-d_{sintered}/d_{green}$, *H refers to a free (out of die) compact height and d to diameter. The value a=1 for all cases except for compactions with specific powder grain orientations.*

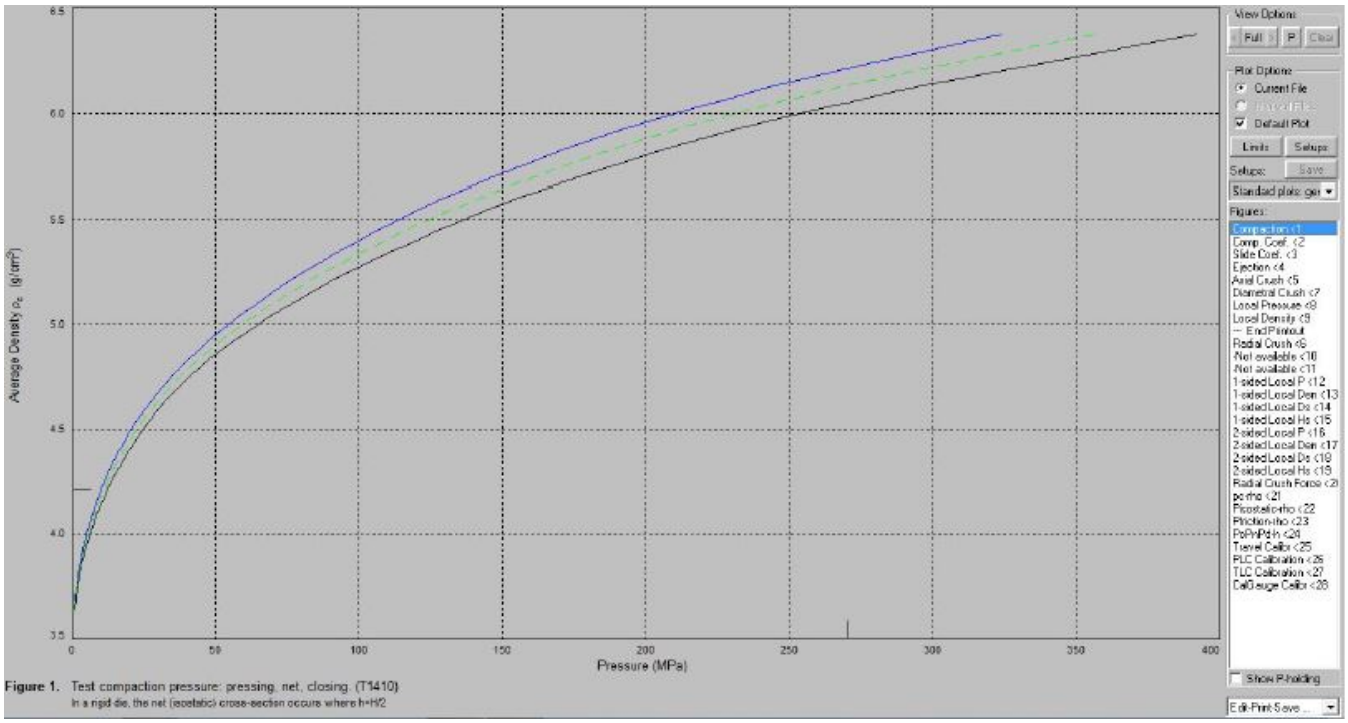
This option also provides the means to correct errors in the values of **theoretical** and **bulk** densities as well as the **green compact expansions**. Changing the value of any of these parameters will result in recalculation of the entire compaction characteristic and any other related parameters. For that reason, such changes should be made only if absolutely necessary. The **tap density**, the **Powder Name, Batch** and the **Die T**emperature may also be modified if necessary.

*Note: If needed, use the **Change Test/File Number** menu in the Table Display to change the test number and the corresponding test file name.*

The **Exit** option will save any changes in the original TDF file.

4.8 View Plots

This option displays figures on the screen and is used for editing and creating new figures, custom printing of figures and creating picture files of individual figures. When the mouse pointer is over the figure on the screen, the x and y parameters of the pointer's tip are displayed in the bottom left corner of the screen. This is particularly useful in quick analysis of specific details on the plots.



The defined figures are listed in the **Figures List** in an order specified by the selected **Output Setup**. The first figure displayed when the View option is activated is determined by the selection with the **Default** check box: checking the box makes the current figure the default figure. The plots may be for the **Current TDF file** as selected in the screen table or, if there are marked files, for all **Marked Files** combined on a single plot.

The default view shows a figure in a maximum size permitted by the display window. Selecting the **P** option displays the screen approximation of the actual printed figure as defined in the specific Figure file. The program allows to **create view boxes around any part of the displayed plot** by dragging the left mouse button. The new box expands to the full size of the display window. All view boxes are stored and may be displayed again using the "<" and ">" buttons. The **Full** option displays the original full size figure.

When displaying local plots (standard Figures 8 to 19), two additional data boxes appear on the screen: the $\mathbf{Ga_{max}}$ and the **desired compact density** for the plots. Setting the $\mathbf{Ga_{max}}$ value to -1 results in default selections for the two parameters that correspond to the desired compact as defined in the test data file. For details see the description of a specific local plot figure.

The **Limits** button opens a window for setting special (user defined) plot limits for each figure in the Figure List. The user can select to view (print) using default (actual) limits or the special limits. In addition, for local parameter plots (Figures 8 to 19), the user may select to use default densities for plotted density lines or it may specify up to 10 specific densities for the plotted lines. Again, for actual viewing (printing), the selection might be the default or the special densities.

Note: The user defined limits are stored in the current Text Tables file.

The "**Show P-holding**" option box at the bottom of the Figure List displays compaction "pressure holding" data (if available). The "pressure holding" compaction data are collected at the end of compaction when the pressing punch stops and is held in that position for a specified "holding" time.

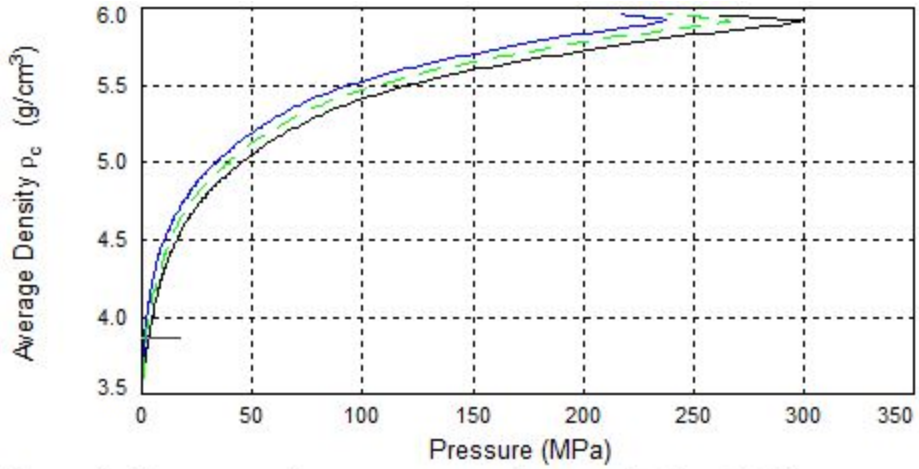


Figure 1. Test compaction pressure: pressing, net, closing. (T3.02)
In a rigid die, the net (isostatic) cross-section occurs where h=H/2

The **Edit-Print-Save**...drop-down list provides additional options:

1. **Set Screen Colors** allows modifications of the display colors.

2. **Edit Figure** opens options for editing, deleting and creating new figures. The current figure description is copied into an edit buffer. The **Save Changes** button saves all corrections to the edited figure. The **Save As New** button adds a new figure to the figure list and saves it in a file. The **Delete Figure** button removes a highlighted figure from the figure list. To delete other figure than the one loaded into the edit buffer, one should select that figure in the figures list and activate the delete button. This option allows deleting figures that cannot be edited directly because of errors.

The figure editing process involves several steps that affect every aspect of the figure. Each step provides editing directions and allowable choices. One should not attempt to make any changes unless really needed. As a practical matter, one should not change the standard figures (1 to 24) except to modify colors for the plot lines or box as needed. If any other modifications are needed, save the figure as a new figure and then make the desired corrections.

One practical option that may be easily edited involves plotting test data from multiple plots on a single figure. The plots from different test files are plotted in separate colors and, by default, identified by their test numbers listed at the bottom of the figure in matching colors. The user can adjust the colors in desired order and, more importantly, it can designate one of several test parameters as the test identification. For example, the tests can be identified by the test temperatures which will be listed at the bottom of the figure. Moreover, the user can specify if the tests should be arranged according to the increasing (default) or decreasing value of the identifying parameter.

3. **Print Figure** option displays printing frame which is used for positioning and printing displayed figures. The **Set Printer** button allows printer selection and setup. The **Top** and **Left** specify the top and left margins for the figure on the printed page. The **Wide** and **High** determine the printed size of the figure. Pressing the **Add Plot** button places the current figure on a printer page buffer without printing the page. One may add any number of figures to the printed page. The **Print** button sends the current figure to the printer. The **Clear Plots** button clears the printer buffer of all figures. The **Hide** button hides the Print frame.

4. **Save Figure Data** allows saving the plot coordinates (x, y1, y2,..) for the current plot in a file.

5. **Save as Bitmap** option displays an input window for the desired figure number and the size of the bitmap (the default size is the default printed size as defined in the figure file). The screen shows the actual bitmap size and the user may accept it or try a different size. The bitmaps are named **FIG##_##.BMP** and are stored in a folder called **BITMAPSF** created in the main application directory. The first two digits in the file name refer to the general figure number and the second two digits are extension numbers to prevent overwriting of files (there could only be 99 bitmap files for a given figure and the user is responsible for removing not needed files from the directory.)

6. **Save as EPS** (Encapsulated PostScript)**File** option displays an input window for the desired figure number and the size of the figure (the default size is the default printed size as defined in the figure file). The screen shows the actual figure size and the user may accept it or try a different size. The figures are named **FIG##_##.EPS** and are stored in a folder called **EPSFiles** created in the main application directory. The first two digits in the file name refer to the general figure number and the second two digits are extension numbers to prevent overwriting of files (there could only be 99 bitmap files for a given figure and the user is responsible for removing not needed files from the directory.)

The **Exit** button or the **Esc** key exits the View option.

5. TEST RESULTS OVERVIEW

The test results generated by the PTC and stored in test data files are:

- single parameter data for bulk powder properties and compact characterizations
- data set for compaction and ejection
- data set for axial crushing pressure
- data set for radial crushing pressure, diametral crushing pressure, radial crushing force.

5.1 Test Data File

The **Test Data File** ("**TDF**") is a standard ASCII file identified by a unique 5 digit test number (including leading zeros) and by 2 digit extension for any versions of the same test. The file name, **A12345.12F**, must follow the standardized convention to be recognizable to the program. Each directory with TDF files is considered a file Group. The user can specify a descriptive name for each group which is stored in that directory in a file named **A00000.00F**. That file also stores the number of the last created or accessed file in that Group. The program always searches directories for the TDF files and sorts them according to their test number before displaying them.

The TDF file may be accessed by other programs. ***It is imperative that the file is not modified in any way***. All files are stored using metric units called base units.

When writing interface routines to read the TDF file it is important to include in those routines the generality of the data arrangement to assure future compatibility. The file may start with Test Notes (up to 10 lines). The actual data block begins with a line containing the "Version" word. The interface program should start reading the file line by line until the "Version" is detected. That line contains all character test parameters: Test Date (mm-dd-yyyy), Test Time (hh:mm), Die Material (20 characters), Powder Name (20 characters), Operator (15 characters) and Powder Batch (15 characters). Each parameter occupies the designated length within the line.

The next line, for software version 27 and up, contains character test parameters, same as above, but listed as standard character data separated by commas: Test Date, Test Time, Die Material, Powder Name, Powder Batch, Operator. For versions earlier than 27, that line is a comment line and should be ignored.

The line is followed by a general text line (that is ignored) and the rest of the numeric data. The third number is the number of general test parameters (counting from the beginning). It is important to remember that the number of general test parameters may change in the future as needed. The file provides the total number of compaction, ejection, axial crush and radial crush points. The number of diametral crush and radial crush force points is the same as for the radial crush (both radial and diametral crush data points are calculated from the radial crush force data which are the actual data points from the test.) There are 2 numbers for each point except the compaction points which have 7 numbers.

The general parameters are followed by compaction points, ejection points, axial crush points, radial crush points, diametral crush points, and radial crushing force points. **There is a separate line for each data point** and the numbers on that line refer to that point only.

The arrangement of the data in the TDF file is as in the example below:

*****POWDER NAME	*The first line if NOTES are in the file*
NOTE LINES (UP TO 10)	*The actual NOTES*
Version#30Test-Date Time Die-Material PowderName Operator PowderBatch	*First line if no NOTES*
"Test Date","Test Time","Die Material","Powder Name","Powder Batch","Operator"	*Character Test Data (Version 27+)*
Data: general compaction ejection axial crush radial crush diametral crush crush force	*Comment line*
1	*1. Test number*
30	*2. Version*
80	*3. Number of general data in the file, from Test No to the beginning of the Compaction Data*
210	*4. Number of all Compaction data points (compaction and pressure-holding points (if any), the number's remainder times 1000 is equal to the number of pressure-holding points)*
450	*5. Number of Ejection data points*
380	*6. Number of Axial Crushing Points*
395	*7. Number of Radial Crushing Points*
1	*8. Test Number for Sub-Test#1*
1	*9. Test Number for Sub-Test#2*
1	*10. Test Number for Sub-Test#3: Axial Crushing Test*
1	*11. Test Number for Sub-Test#3: Radial Crushing Test*
1	*12. empty*
1	*13. empty*
1	*14. empty*
1	*15. empty*
0	*16. empty*
1	*17. Batch number (if expressed as a number)*
1	*18. Number of theoretical density - pressure points (for theor. density as a function of pressure)*
3	*19. Number of Radial Crush data sets (Radial Strength, Diametral Strength, Radial Force)*
2	*20. Pressing Mode: 1=compact density 2=pressing pressure 3=net pressure*
7.8	*21. Theoretical Density*
5.56	*22. Estimated Density*
0	*23. Heating Arrangement: 0=no heating 1=cold powder in hot die 2=hot powder in hot die*
22	*24. Die Temperature*
0	*25. Heat Holding Time*
5.499	*26. Desired Compact Density*
3.08	*27. Bulk Density*
3.68	*28. Tap Density*
20060	*29. Tapping Time and Taps: time=020 s taps=060*
39	*30. Angle of Repose*
0.409	*31. Slide Coefficient for the desired density*
0.1346	*32. Compactibility Coefficient for the desired density*
140.2	*33. Net Pressure for the desired density*
186.3	*34. Max Pressing Pressure for the desired density*
5.504	*35. Actual in-die Test Compact Density*
0.409	*36. Slide Coefficient for the test density*
0.1346	*37. Compactibility Coefficient for the test density*

3.84	*38. Cohesiveness*
21.3	*39. Average Ejection Pressure*
1.35	*40. Ejection Pressure Overshot*
11.619	*41. Total Ejection Energy*
8.374	*42. Unit Ejection Energy*
1.0024	*43. Radial Expansion Coefficient*
1.0039	*44. Axial Expansion Coefficient*
8.089	*45. Compact in-die Height*
12.7	*46. Compact in-die Diameter*
5.640	*47. Actual Mass of the Compact*
124.4	*48. Axial Green Strength*
35.1	*49. Radial Green Strength*
190.1	*50. Maximum Test Pressing Punch Pressure*
137.5	*51. Maximum Test Closing Punch Pressure*
1.06	*52. Average Pressing Speed*
6.45	*53. Sintered Compact Density*
0.0050	*54. Drying and Sintering Mass Loss*
1.00	*55. Anisotropy Ratio*
12.026	*56. Average Sintered Test Compact Diameter*
1001	*57. Serial Number of the Testing Center*
5.457	*58. Actual out-of-die Test Compact Density*
8.120	*59. Out-of-die Test Compact Height*
12.73	*60. Out-of-die Test Compact Diameter*
5.640	*61. Initial Mass*
180	*62. Initial Desired Max Pressure*
140.5	*63. Initial Desired Net Pressure*
5.640	*64. Desired Mass*
8.089	*65. Desired Compact Height*
175.8	*66. Two-sided Max Pressure for Desired Density*
22	*67. Initial Die Temperature*
0	*68. Pressure Holding Time*
288	*69. Strip Pressure*
12.76	*70. Diametral Green Strength*
178.23	*71. Two-sided Max-Pressure for the Test Density*
156.89	*72. Net Pressure for the Test Density*
12.7	*73. Desired Diameter of the Compact*
12.026	*74. Average Sintered Compact Diameter with the Desired Density*
6.23	*75. Energy at axial fracture*
0	*76. Empty*
0	*77. Pressing punch Temperature*
0	*78. Top punch Temperature*
0	*79. Empty*
....	*80. Original Test Data Version (during a test)*
....	*81. Theoretical density (Point #1) at the pressure below (if defined and available)*
....	*82. Pressure (Point #1) at the theoretical density above (if defined and provided)*
....	*83. Theoretical density (Point #2) at the pressure below (if defined and available)*

.... *84. Pressure (Point #2) at the theoretical density above (if defined and provided)*

....

....

210 lines:	(Ga Density PressingP ClosingP NetP SlideCoef Compactibility)	*Compaction Points*
450 lines:	(PunchPosition PunchPressure)	*Ejection Points*
380 lines:	(Position PunchPressure)	*Axial Crushing Points*
395 lines:	(Position Pressure)	*Radial Pressure Crushing Points*
395 lines:	(Position Pressure)	*Diametral Pres. Crushing Points*
395 lines:	(Position Punch Force)	*Radial Crushing Force Points*

5.2 Pressing Configuration

The standard test series on the PTC involves three separate test procedures to determine the following:

* ***properties of the bulk powder***
* ***compacting & ejecting characteristics of the powder in a die***
* ***green compact characteristics***

The tests are for dry powders only. The die wall temperature of a standard cold pressing die can be up to 70°C (158F). With hot dies, the die wall temperature can be up to 300°C (572F).

The test pressing configuration is one-sided to any desired length within 2 to 16 mm. However, only compacts with lengths between 7 and 16 mm are suitable for the crushing tests. ***All test densities are referenced to in-die condition which refers to a compact density in a die under load.*** This is the only fixed density reference since compacts expand differently after ejection from a die.

During compaction, all required measurements are taken at various punch positions and, for the corresponding actual intermediate compact densities, the compacting parameters are calculated and stored in the permanent test data file. **These parameters show ACTUAL compaction conditions at any density up to the actual final test compact density.** A complete data output with plots can be generated (with the standard driving program) for any ***desired compact density*** in that range.

5.3 Pressing Modes

There are three different selectable pressing modes:

- pressing to a fixed pressing pressure (fixed maximum punch pressure)
- pressing to a fixed average compact density (fixed average test compact density/length)
- pressing to a fixed net pressure (fixed net/isostatic pressure).

5.4 Test Data - Character Type

These powder characteristics are words identifying the powder and the powder test. They are part of the standard test data file. The PTC uses the following:

- **Powder Name** - powder identification, up to 20 characters long
- **Batch** - powder specification, up to 15 characters long
- **Die** - test die material, up to 20 characters long

The die material affects directly the friction between the die and the powder particles. For direct compatibility with production conditions, the test die material should be the same as the die material used in production dies. The test die is replaceable and typically one has several test dies with different die materials and different die surface finishes. That allows the user to optimize the compaction process with respect to the best choice of a die material for a specific powder type to minimize the die friction and the local variations of density and shrinkage.

- **Date** - test date
- **Time** - test time
- **By/At** - operator identification

5.5 Test Data - Single Value Parameters

The theoretical background for the main parameters: slide coefficient and compactibility coefficient, is provided in an article in Appendix B. All other specific information is provided with each parameter description listed below.

(1) Theoretical Density ρ_t

This is the density of the powder mixture with 100% densification. The composition of the powder mixture (the density of all components and their contribution by weight) must be known to calculate the density properly. The **Theoretical Densities Table** option simplifies the calculations and allows to store the densities of all components.

(2) Bulk Density ρ_b

This is the density of a loose powder. It is also referred to as the apparent density.

(3) Tap Density ρ_{tp}

This is the density of a loose powder subjected to a number of prescribed tappings. The output specifies the number of taps and the duration of tapping. The tap density provides an useful information on the packing of the loose powder during transportation and when it is in a container on a press before die filling.

(4) Hausner Ratio HR

This is the ratio of Tap Density and Bulk Density: $HR = \rho_{tp} / \rho_b$

(5) Tapping Compressibility C_t

This is a calculated loose powder parameter: $C_t = 100 * (\rho_{tp} - \rho_b) / \rho_{tp}$ [%]

(6) Angle of Repose β

This angle represents the actual ability of the powder to fill uniformly a cavity of a die. For liquids (ideal flowability) the angle β=0, for solids (no flow) β=90 degrees. Powders with high flowability have β around 30 degrees. The Angle of Repose could be measured in many ways and is quite independent from a given measuring technique.

(7) Relative Humidity of Air RH%

The relative humidity of the air in the testing room during a bulk properties test.

(8) Room Air Temperature

The room air temperature during a bulk properties test.

(9) Die Temperature

The die temperature during a compaction test. The die may be heated to reach the required temperature. The PTC offers three heating options:

- no heating - room temperature
- cold powder - the die is heated, then filled with cold powder and the compaction is performed
- hot powder - the die is filled with powder, heated and then the compaction is performed.

(10) Heat Holding Time

This is the time during which the desired die temperature is maintained before compaction.

(11) Desired Average In-Die Test Compact Density ρ_{gd}

This is the desired average green compact density measured in die under load and it is usually comparable with the density used in production. In industrial practice, the density of a free (out-of-die) compact is measured. A simple formula relates those two:

$$\rho_{\text{in-die}} = \rho_{\text{out-of-die}}\, e_r^2\, e_a$$

Here, e_r is the radial green compact expansion (in a direction perpendicular to pressing direction) and e_a is the axial green compact expansion (in a direction parallel to pressing).

That out of die density is not a reliable reference since it depends on the green compact expansions which can change significantly with pressing and ejection conditions and with time. The only reliable reference density is the in-die density. When calculating the density directly a special care must be taken in measuring the distance between punches under load to take into account the elastic deformations of the punches and other components.

(12) Slide Coefficient η for the desired density

This is a measure of the frictional interactions between powder particles and die walls during compaction (see Ref. 1). For a given powder and a given die material (with given surface conditions), it varies slightly with green density. The magnitude of η extends from 0 (infinite friction) to 1 (no friction) and relates directly the friction forces to the pressing forces.

The value of η around 0.7 is considered moderate. Values above that indicate good or very good compaction properties and are desirable. Values below that suggest difficult compaction process with relatively large frictional forces which lead to large density variations and, ultimately, large shrinkage variations. The magnitude of η could be modified by adding lubricants or changing the die material.

(13) Compactibility Coefficient α for the desired density

It is a material constant characterizing the ability of a powder to densify and it represents interactions between powder particles during compaction. In isostatic compaction, the relationships between compact density and pressure can be expressed as (see Ref. 1):

$$|\log|\log(\rho_c/\rho_t)|| = \alpha \log((p_n+p_o)/p_o) + |\log|\log(\rho_b/\rho_t)||$$

where ρ_c is the compact density at isostatic pressure p_n , ρ_b is the bulk density, ρ_t is the theoretical density, p_o is the atmospheric pressure.

In the absence of die friction, as is the case in isostatic compaction, the compactibility coefficient provides complete information about compaction pressures. In rigid die compaction, the compactibility coefficient and the slide coefficient are needed to determine all compaction pressures (pressures on punches and friction).

(14) Net (Isostatic) Pressure p_n for the desired compact

It is a pressure required in isostatic compaction (no friction between powder and die walls) to reach the desired green compact density. For pressing in rigid dies, the net pressure is a pressure equal to the local pressure at the location in a green compact where the local density is equal to the average green density of the entire compact. In practical terms, *the net pressure is the absolutely minimum compacting pressure needed for a given compact density*.

(15) Maximum Pressure p_{md} for the desired compact

It is the pressure on a pressing punch at the desired density.

(16) Two-Sided Maximum Pressing Pressure p_{mt} for the desired compact

It corresponds to the required pressure in a free floating die pressing arrangement resulting in a compact with an average density equal to the desired density.

(17) Desired Compact Length in-die under load

It is the length of a compact with the desired density.

(18) Desired Compact Diameter in-die under load

It is the diameter of a compact with the desired density. In practice, it is equal to the die diameter.

(19) Desired Compact Mass

It is the mass of a compact with the desired density.

(20) Actual Average Test Compact Density IN and OUT of the die

The density of the actual test compact:

- in die: **at the end of a compaction,** under load
- out of die: after ejection and free expansion.

(21) Slide Coefficient η for the test compact density

This is a measure of the frictional interactions between powder particles and die walls during compaction (see Ref. 1). For a given powder and a given die material (with given surface conditions), it varies slightly with green density. The magnitude of η extends from 0 (infinite friction) to 1 (no friction) and relates directly the friction forces to the pressing forces.

The value of η around 0.7 is considered moderate. Values above that indicate good or very good compaction properties and are desirable. Values below that suggest difficult compaction process with relatively large frictional forces which lead to large density variations and, ultimately, large shrinkage variations. The magnitude of η could be modified by adding lubricants or changing the die material.

(22) Compactibility α Coefficient for the test compact density

It is a material constant characterizing the ability of a powder to densify and it represents interactions between powder particles during compaction. In isostatic compaction, the relationships between compact density and pressure can be expressed as (see Ref. 1):

$$|\log|\log(\rho_c/\rho_t)|| = \alpha \log((p_n+p_o)/p_o) + |\log|\log(\rho_b/\rho_t)||$$

where ρ_c is the compact density at isostatic pressure p_n , ρ_b is the bulk density, ρ_t is the theoretical density, p_o is the atmospheric pressure.

In the absence of die friction, as is the case in isostatic compaction, the compactibility coefficient provides complete information about compaction pressures. In rigid die compaction, the compactibility coefficient and the slide coefficient are needed to determine all compaction pressures (pressures on punches and friction).

(23) Net (Isostatic) Pressure p_n for the Test Compact

It is a pressure required in isostatic compaction (no friction between powder and die walls) to reach the test compact density. For pressing in rigid dies, the net pressure is a pressure equal to the local pressure at the location in a green compact where the local density is equal to the average green density of the entire compact. In practical terms, *the net pressure is the absolutely minimum compacting pressure needed for a given compact density.*

(24) Maximum Pressing Pressure for the Test Compact

The actual pressure on the pressing punch at the end of compaction.

(25) Two-Sided Maximum Pressing Pressure p_{mc} for the test compact

It corresponds to the required pressure in a free floating die pressing arrangement, resulting in a compact with an average density equal to the actual average test compact density.

(26) Compact Height IN and OUT of a Die

The length of the actual test compact:

- in die: at the end of a compaction, under load
- out of die: after ejection and free expansion.

(27) Compact Diameter IN and OUT of a Die

The diameter of the actual test compact:

- in die: at the end of a compaction, under load (equal to the diameter of the test die)
- out of die: after ejection and free expansion.

(28) Green Compact Radial e_r and Axial e_a Expansions

The **radial expansion** is the ratio between the radial (perpendicular to pressing) dimension of the compact (out of die) to the corresponding dimension in die under a full load. Typically, this dimension is measured in the mid height of the compact. The **axial expansion** is the ratio between the axial (parallel to pressing) dimension of the compact (out of die) to the corresponding dimension in the die under a full load.

In the Green Compact Expansion test window, for informational purposes, the PTC program continually displays the time laps since the compact ejection. The actual expansions are functions of time. They are typically measured shortly after ejection from the die. For hot compacts, one may wait until they cool down before taking the measurements.

The expansion is significantly larger in the axial direction than in the radial direction. On an industrial press, it is relatively difficult to determine the true height of the compact under load unless the elastic characteristic of the pressing assembly is known. Therefore, most of the time in practice only the radial expansion is measured. The coefficients are helpful in tool design.

(29) Mass of the Test Compact

The actual mass of the test compact measured after ejection.

(30) Average Ejection Pressure p_e for the test compact

This is the compact ejection pressure (the ejection force divided by the cross section area of the compact) averaged over the first 2.54 mm of compact travel after the starting pressure overshot needed to initiate the move (averaged within the 0.01 to 2.55 mm of pressing punch position).

(31) Stripping Pressure p_s

Maximum ejection force at ejection start over a compact friction area (on die walls in contact with the compact).

(32) Ejection (start) Pressure Overshot e_o for the test compact

This is the ratio between the maximum initial ejection pressure needed to move the compact and the Average Ejection Pressure: $e_o = p_{emax} / p_e$

(33) Total Ejection Energy E_t for the test compact

It is calculated by integrating the ejection characteristic.

(34) Unit Ejection Energy E_u for the test compact.

This is the ejection energy per unit of the friction surface area needed to move the compact along a unit distance

within a die. It is calculated as the energy required to move the compact from the 0.01 mm to the 2.55 mm punch position divided by the friction area of the test compact and by the travel distance (2.54 mm). The unit is $N*m/m^2/m$ or J/m^3. Since this would result in large numbers, the base unit is MJ/m^3.

This unit energy can be used to estimate total energy needed to eject a compact from a die by multiplying it by the travel length of the compact within the die and by the compact's friction area.

(35) Axial Strength of the Test Compact w_{sa}

It is the maximum crushing pressure registered during compact crushing along the axial (parallel to pressing) direction. This is the green strength responsible for holding the compact together during ejection from a die.

Note: The green strength as defined in most standards is measured during compact crushing in a direction perpendicular to pressing by putting the compact on its side and crushing it. That green strength is useful in determining the strength of a compact during handling but it is not a proper value for determining the compact behavior during ejection from a die.

(36) Cohesiveness of a Green Compact C

The cohesiveness (Ref. 2) represents a ratio between the axial green strength of the compact and the maximum friction pressure between the compact and the die walls:

$$\mathbf{C = w_{sa}/p_{fm}}$$
$$p_{fm} = (F_c - F_d)/(3.14\ d\ h)$$
$$F_c = p_c\,(3.14\ d^2 / 4)$$
$$F_d = p_d\,(3.14\ d^2 / 4)$$
$$p_{fm} = (p_c - p_d)\ (d / h / 4)$$

where, for a cylindrical compact:
- w_{sa} is the green axial strength
- p_{fm} is the maximum friction pressure on a die wall
- F_c is the maximum force on the pressing punch
- p_c is the maximum pressure on the pressing punch
- F_d is the maximum force on the closing punch
- p_d is the maximum pressure on the closing punch
- d is the diameter
- h is the length of the compact.

It is directly related to cracking and lamination resistance during compact ejection from a die. If the cohesiveness is less than 1 (friction effects larger that the green strength), compacts will likely develop cracks during ejection unless special care is implemented such as slow ejection, hold-down pressure, or special die exit design. If the cohesiveness is above 1, a compact cracking during removal from dies should not occur under normal conditions.

The cohesiveness can be improved by increasing the compact green strength (addition of binders), by lowering the friction forces (addition of lubricants), or both at the same time. Many additives give both effects at the same time. As is the case with all additives, there is a problem how to determine the optimum amount of the additive. Several tests with varying amounts of a given additive will show their influence on the cohesiveness and typically it is easy to determine the saturation point after which adding more additives does not improve the cohesiveness significantly.

(37) Energy at Axial Fracture E_{fa}

It is the integral of the axial crushing curve until the maximum (crush) point.

(38) Radial/Diametral Strength of the Test Compact w_{sr}

It is the maximum crushing pressure registered during compact crushing along the radial (perpendicular to pressing) direction. There are different approaches to calculating the pressure or, specifically, the reference area due to the fact that actual contact area is changing rapidly during the crushing. Currently, the calculations are for two choices: radial and diametral. Other choices may be incorporated later if needed.

The **Radial Strength** (pressure) is calculated as a ratio of the crushing force and the instantaneous contact area between the crushing plane and the cylindrical surface of the compact assuming that the deformation occurs only at the contact area:

$$w_{sr} = F / A_c \ ; \qquad A_c = h_{in}\,(d_{in}^2 - s^2)^{0.5}$$

where F is the crushing force measured on the crushing punch, A_c is the contact area, h_{in} is the in-die height of the compact, d_{in} is the in-die diameter and s is the distance between the crushing faces. Theoretically, the initial pressure is infinite (contact

along a line). Due to a finite accuracy of force measurements and compact deflections, the initial pressure points are removed from the crushing characteristic and are not considered for the green radial strength.

The **Diametral Strength** (pressure) is calculated as a ratio of the crushing force and a reference area of the unstressed compact:

$$w_{sd} = F / A_r \;; \qquad A_r = 0.5\,(3.14\, h_{out}\, d_{out})$$

where the compact height and diameter are the measurements of a free (out of die) compact.

(39) Average Pressing Speed

The pressing speed is fixed for all hardware versions up to 26. The speed will decrease slightly with increase of the pressing pressure.

For hardware versions above that, the pressing speed is user defined in the range 0.5 to 1.5 mm/s. That pressing speed is constant during the pressing cycle.

(40) Pressure Holding Time

It corresponds to a set time at the end of compaction when the compact is kept under maximum pressure before release and ejection. During the holding cycle, the bottom of the pressing punch is at fixed position. As the air escapes from the compact, the spring energy in the punches keeps pressing the compact and increasing its density. In this process, the compact gets shorter, the punches expand and the pressure on the compact decreases. That behavior is recorded and stored as part of the compaction characteristic.

(41) Sintering Parameters

The program can calculate dimensional changes in a compact after sintering if the following data are provided:

- the desired average density after sintering
- the total mass loss during drying and sintering
- the anisotropic shrinkage ratio in isostatic compaction (constant density):

$$a = S_h / S_d$$

where $S_h = 1 - H_{sintered}/H_{green}$, $S_d = 1 - d_{sintered}/d_{green}$, H is the axial dimension, d is the radial dimension. The H_{green} and d_{green} are measured on a green compact out of die. For more details about the sintering calculations see 4.3.6 above.

The PTC program calculates and displays the following parameters for sintered compacts:

- average radial shrinkage (%) of the **test** compact based on the die diameter:

$$\mathbf{S_{d\text{-}td}} = (1 - D_{sintered} / D_{die}) * 100$$

- average radial shrinkage (%) of the **desired** compact based on the die diameter:

$$\mathbf{S_{d\text{-}dd}} = (1 - D_{sintered} / D_{die}) * 100$$

- calculated sintered test compact average diameter $\mathbf{D_{sa\text{-}c}}$
- calculated sintered desired compact average diameter $\mathbf{D_{sa\text{-}d}}$.
- minimal radial shrinkage (%) of the **test** compact based on the die diameter:

$$\mathbf{S_{dmi\text{-}td}} = (1 - D_{sintered\text{-}max} / D_{die}) * 100$$

- minimal radial shrinkage (%) of the **desired** compact based on the die diameter:

$$\mathbf{S_{dmi\text{-}dd}} = (1 - D_{sintered\text{-}max} / D_{die}) * 100$$

*Note: In practice, the **average sintered compact diameter $D_{sintered}$** is often calculated as the average of the measured minimum and maximum diameter.*

(42) Other Parameters

The other available parameters stored in a test data file are supplemental and include the following:

- **compaction test startup** (initial) **parameters** for repeating a previous test:
  - desired compact density ρ_i
  - desired net (isostatic) pressure $\mathbf{P}_{net\text{-}i}$
  - desired maximum compacting pressure $\mathbf{P}_{max\text{-}i}$
  - powder mass $\mathbf{m}_i$

- die temperature $\mathbf{T}_i$

- C_{rs} - number of radial crush data sets stored in the test file (default is 3: radial pressure, diametral pressure, crushing force)
- G_n - number of general data entries (single parameter data) in the test data file
- C_{pn} - number of compaction and pressure-hold data points in the test data file:

  $C_{pn} = (N_{compaction} + N_{hold}) + (N_{hold} / 1000)$

  Example: C_{pn} = 125.02 ; compaction =105 points; pressure-hold = 20 points
- E_{pn} - number of ejection data points in the test data file
- AC_{pn} - number of axial crushing data points in the test data file
- RC_{pn} - number of radial crushing data points in in a radial crush data set (total radial sets = C_{rs})
- Test - test number
- BTest - bulk properties test number
- Ctest - compaction test number
- ACtest - axial crushing test number
- RCTest - radial crushing test number
- ver - PTC software version when test was performed
- SN - PTC unit serial number
- TDFv - original (during the actual test) version for the test data file
- Tpress - pressing punch temperature
- Ttop - top punch temperature
- TDn - number of theoretical density-pressure points (see Theoretical Density Table).

5.6 Plots

The PTC program provides definitions for **plots** (or **standard figures**). Based on these plots, users may create (*edit* and *save as new*) custom plots to fit a specific purpose. The option to edit plots is available in the View Plots screen.

The **Standard Plot Number** is related to the order in which they were created. The **actual Figure Number** is based on their arrangement in the selected Plots List. In the Plots List, the standard plot number is displayed at the end of the plot's name (example: "*Compaction <1*" - plot 1).

ATTENTION: *If a given plot data set is not available, the program will inform the user and automatically disable all figures that are based on that plot data set.*

5.6.1 Test Data Comparisons & Geometrical Generalization

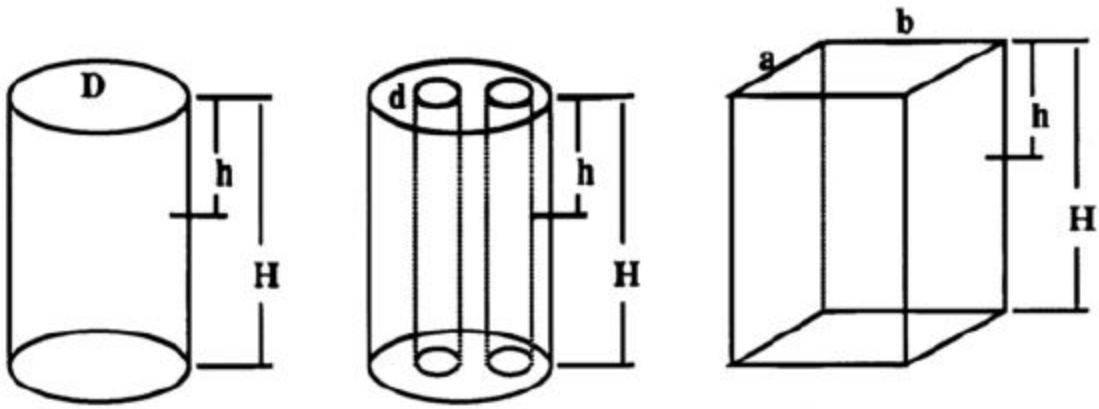
IMPORTANT: Compaction properties of powders **must be compared at** the **same average in-die density** and compact geometries **must have the same Ga number**

As the compaction results show, the compaction properties depend primarily on the average in die density of the compact. For comparisons of different tests, the results can only be evaluated at the same average density. Any other comparison, such as based on a maximum compaction pressure, would generate significant variations and errors.

The testing results may be **generalized** with respect to compact shapes and sizes. The geometry of a given compact is represented by a single number **Ga** (Gasiorek Number) defined as follows:

$$Ga = Sh/4F$$

where S is the total perimeter of the cross section at h, h is the distance of the cross section from the pressing punch (or from a selected end face of the compact), and F is the cross section area of the compact. For a given compact, Ga=0 at h=0 and $Ga=Ga_{max}$ at h=H.



$S = \pi D$	$S = \pi(D + 2d)$	$S = 2(a + b)$
$F = \pi D^2/4$	$F = \pi(D^2 - 2d^2)/4$	$F = ab$
$Ga = h/D$	$Ga = h(D + 2d)/(D^2 \cdot 2d^2)$	$Ga = h(a+b)/(2ab)$

For compacts with a constant cross section along the height, the calculation of the Ga at any height is quite simple. However, for compacts with a varying cross section along the height the calculations may be simplified by dividing the compact into slices and considering an average cross section for a given slice. More accurate relationship can be developed that involves mathematical integration; however, this may be needed only in very selective cases.

5.6.2 Pressure Holding Data

The **compaction data set** also includes the "pressure holding" compaction behavior when the pressing punch stops and is held in that position for a specified "holding" time. That part of the data is accessible through the "**Show P-holding**" option box at the bottom of the Figure List.

The compaction plot below shows the pressure holding data at the end of the compaction after the pressing punch stops. The other end of the punch is held in place but the spring energy in the punch exerts pressure on the compact. As a result, as the air escapes from the compact, it becomes shorter (the density increases) which expands the pressing punch and lowers the spring pressure on the compact. The net effect: the compact average in-die density increases and the pressure on the compact decreases.

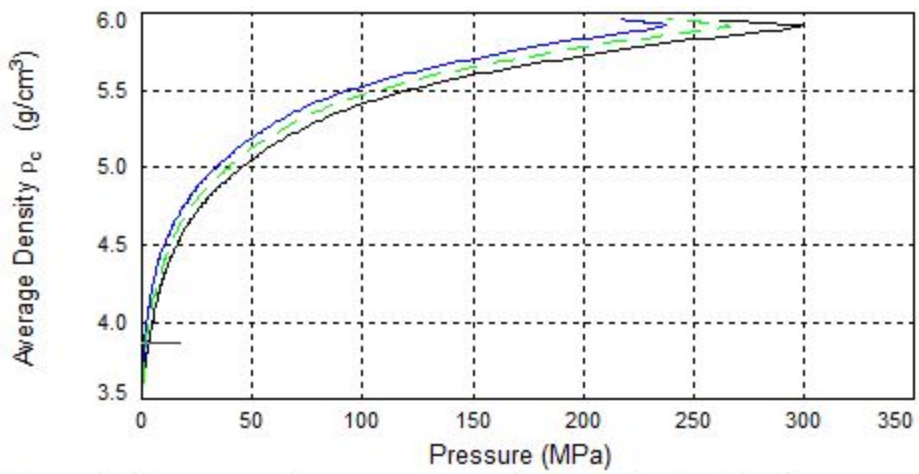


Figure 1. Test compaction pressure: pressing, net, closing. (T3.02)
In a rigid die, the net (isostatic) cross-section occurs where h=H/2

5.6.3 Enlarging Plot Details With View Box

For **detailed view** of any part of a plot, one can create a **view box** with a mouse by holding the left button and dragging it over an area of interest. When the mouse button is released, the view box fills the entire screen. The options in the top-right of the screen are used to move between view boxes and the original full view.

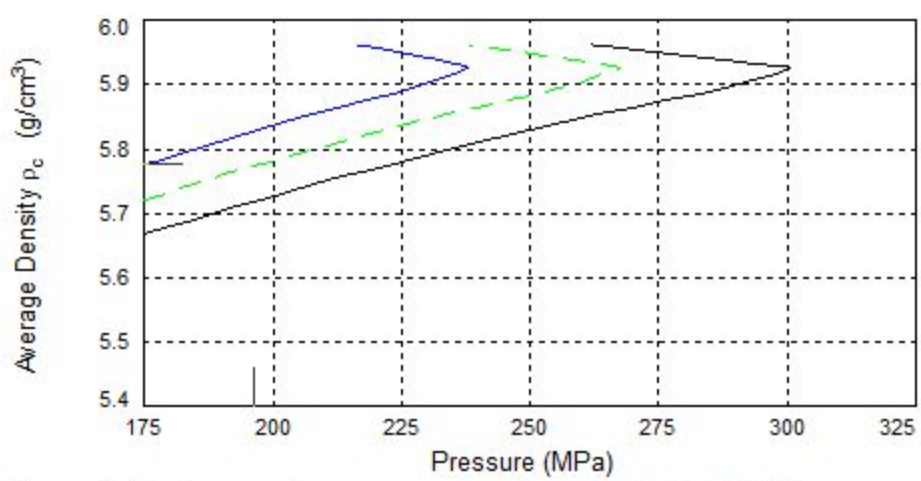


Figure 1. Test compaction pressure: pressing, net, closing. (T3.02)
In a rigid die, the net (isostatic) cross-section occurs where h=H/2

The coordinates of the tip of the mouse pointer are displayed in a box at the bottom left of the screen. Using the mouse pointer on the figure allows for speedy and accurate determination of test parameters.

5.6.4 General Compaction & Ejection Plots

A **standard compaction test** generates the following data sets for plotting:

- **compaction** data - point measurements, in die, during compaction: **Ga, ρ_a, p_c, p_d, p_n, η, α**
  - Ga=h/D_{die}, h is the compact height (distance between punches)
  - ρ_a is the average in die compact density
  - p_c is the pressing punch pressure
  - p_d is the closing punch pressure
  - p_n is the net (isostatic) pressure: $p_n = (p_c * p_d)^{0.5}$
  - η is the slide coefficient
  - α is the compactibility coefficient
- **ejection** data - point measurements during compact ejection after compaction: **s, p_e**
  - s is the punch in-die position relative to the position at the end of compaction
  - p_e is the pressure on the ejecting punch.

The data sets are part of the standard Test Data File.

Standard Plots:

Plot 1: Test Compaction Pressure: Pressing, Net, Closing

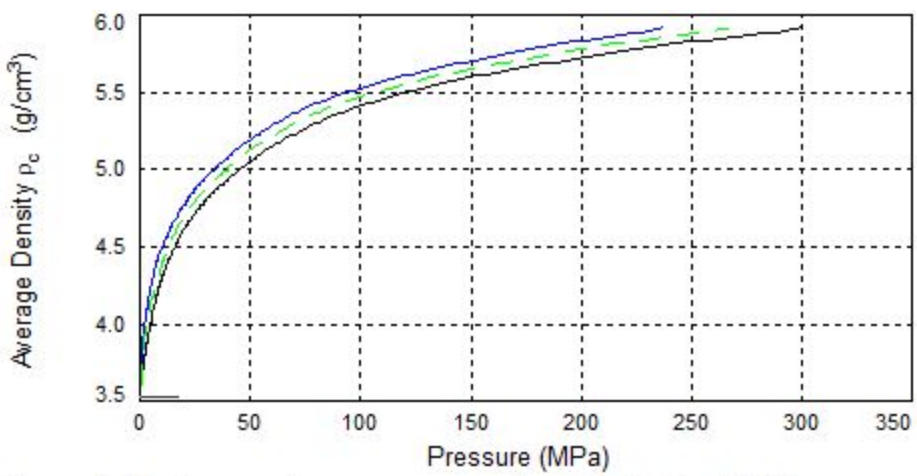


Figure 1. Test compaction pressure: pressing, net, closing. (T3.02)
In a rigid die, the net (isostatic) cross-section occurs where h=H/2

The figure shows the actual pressure on the pressing (bottom curve) and the closing (top curve) punches and the corresponding (calculated) net pressure (middle dashed line) versus compact density during compaction. On this figure, the compact is pressed horizontally with the closing punch (stationary) on the left and the pressing punch moving from right to left. For any average green density in the pressing range, the pressures are determined on a horizontal line intersecting the plot lines: pressing on the right, closing on the left, and net (isostatic) in the middle. The difference between the pressing and closing pressure constitutes the total friction pressure.

The net pressure curve is the **Isostatic Compaction Characteristic**. In isostatic compaction (in the absence of die wall friction) the local compacting pressure and the local density are uniform throughout the compact. The compactibility coefficient is the only parameter that relates the compacting pressure and the resulting green compact density.

The above characteristic is used frequently in a rigid die pressing to determine an optimum average green compact density for new processes. If the density is too low, the compaction process is hard to control since small variations in compacting pressure result in high density variations. Similarly, the flat part of the characteristic is not desired since a slight variation in compact density results in a large variation in pressure. Mechanical presses operating in that region could easily go beyond the maximum force that the press could deliver if more mass got into the die cavity.

*Note: For compacts pressed in a rigid die, the **local pressure** at the cross section where local density is the same as the average compact density is equal to the **isostatic pressure** for that density. That cross section is located at mid*

height and the pressure is called the ***net pressure****.*

Plot 2: Compactibility Coefficient Variations with Green Compact Density

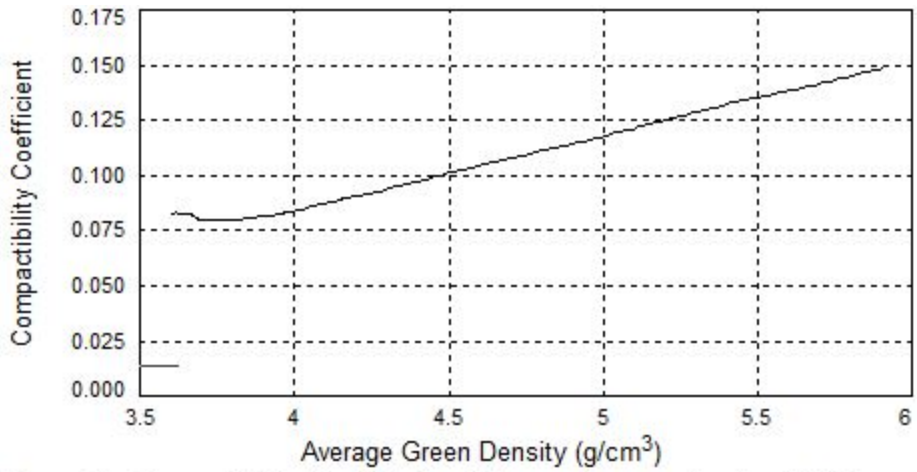


Figure 2. Compactibility Coefficient variations with green density. (T3.02)

The coefficient may vary with density. The initial variations at low densities are primarily due to initial powder grains reorientations and breakings. The elasticity of the powder grains as well as the elasticity of air trapped within the powder will typically increase the coefficient with density. This is most pronounced with metal powders. For ceramic powders, the density dependence is very often small.

Plot 3: Slide Coefficient Variations with Green Compact Density

The coefficient may vary with density.

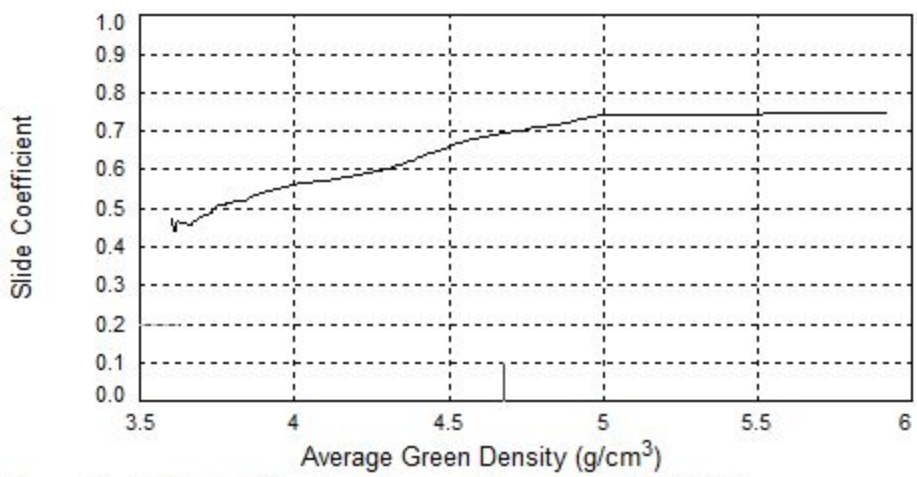


Figure 3. Slide Coefficient variations with green density. (T3.02)

Plot 4: Green Compact Ejection Characteristic

The ejection characteristic represents ejecting pressure on the compact during its removal from the test die. The characteristic is geometry dependent and varies for different compacts and die configurations. In the test die, the compact is initially located approximately 5 mm below the surface of the die. A typical graph shows an initial spike in ejecting pressure that is required to overcome the static friction of the compact when it is forced to move. Next stage involves the compact before it shows out of the die. The last part shows drop in ejecting pressure while the compact leaves the die.

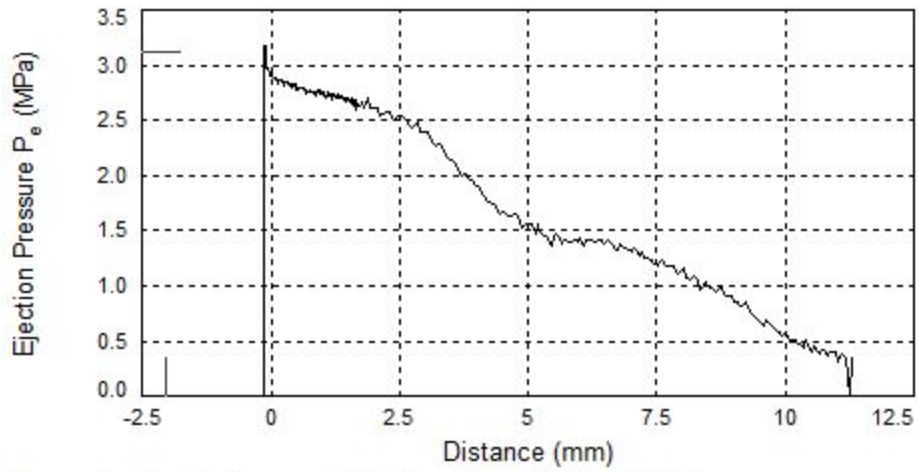


Figure 4. The test compact ejection characteristic. (T3.02)
The ejection pressure is measured on the ejecting punch.

On the graphs, the 0 position represents the position of the pressing punch face in the die under full load. When the pressure is released, the compact expands within the die in the axial direction. Typical ejection graph shows that the ejection starts before the 0 position which is the result of that green expansion.

Plot 21: Test Compaction Pressure

This is the general compaction characteristic generated by any compaction test. This figure is a simplified version of Plot 1 to show the pressure on the compaction face of the compact (compaction punch) only.

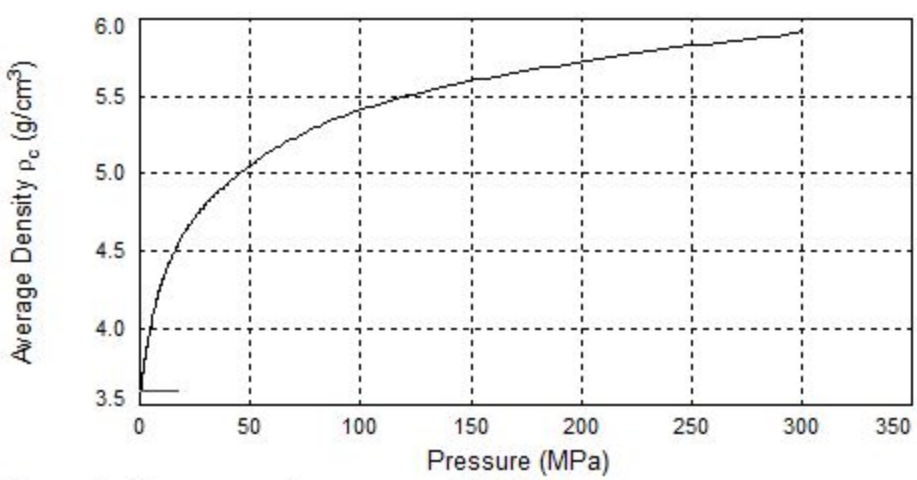


Figure 5. Test compaction pressure. (T3.02)

Plot 22: Isostatic (Net) Pressure

The isostatic (net) compaction pressure is the pressure as measured at the cross section of a compact that has the local density equal to the average density of the compact. In the absence of die wall friction, all cross sections of the compact would have uniform density and constant compacting pressure.

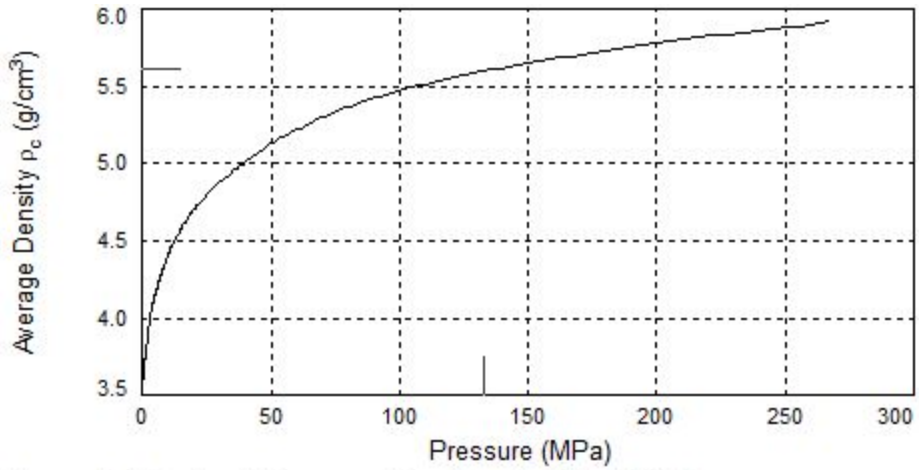


Figure 6. The isostatic compaction characteristic. (T3.02)
In a rigid die pressing, the net (isostatic) cross-section occurs where h=H/2

Plot 23: Total Friction Pressure

This is the difference between the pressing punch pressure and the closing punch pressure (between the faces of the compact). The pressure is lost to the friction on the die walls.

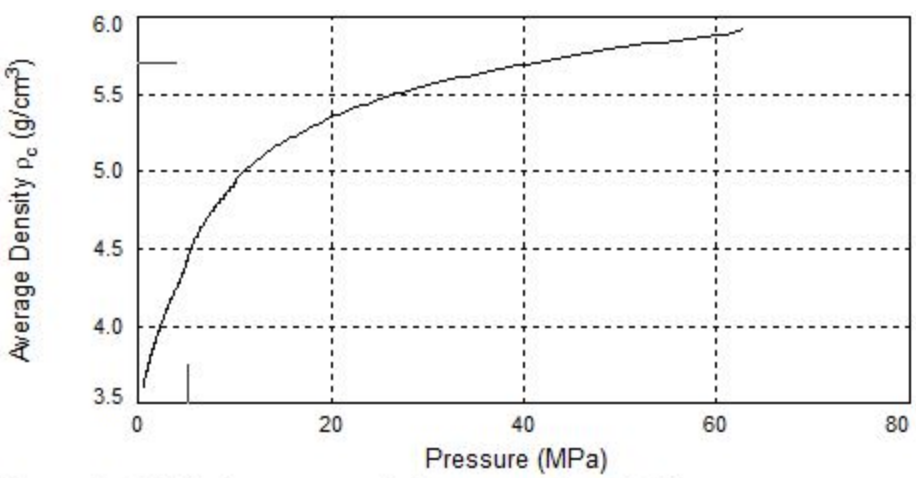


Figure 7. Die friction pressure during compaction. (T3.02)

Plot 24: Compact Height & Compaction Pressure

This figure represents changes in test compact height during compaction. It is similar to Plot 1. On the plot, the pressing pressure curve is on top, the closing pressure curve is on the bottom, and the net pressure curve (dashed) is in the middle.

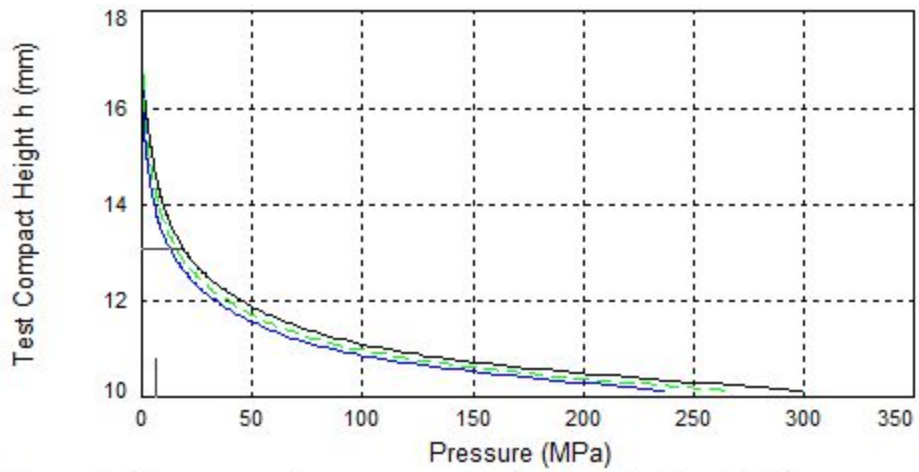
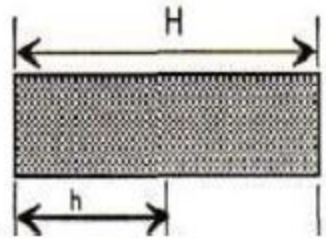


Figure 8. Test compaction pressure: pressing, net, closing. (T3.02)

5.6.5 Local Compaction & Sintering Plots

The graphical presentation, for compacts with constant cross section along the height, shows the local parameter at any cross section along the height of the compact. The mid hight cross section has a local density equal to the **average density** of the entire compact and the pressure there is equal to the **net (isostatic) pressure** for that density.

On the local plots, the compacts are "pressed" horizontally. The closing punch face is stationary at h=0 and the pressing punch face, at h=H, is pressing the compact from right to left.



ATTENTION:

*On all **local properties distributions plots**, the horizontal axis representing **h/H ratio uses $H_{compact}$ value equal to the actual height** of the current compact. As seen on the **left plot below**, the local h varies between 0 (at closing punch face) and 1 (the intermediate compact height at the pressing punch face).*

*In **older version of the PTC program**, local pressure and density distributions plots have the horizontal axis representing h/H ratio with $H_{desired}$ value equal to the H of the desired compact (at the desired density). As seen on the **right plot below**, the local h varies between 0 (at closing punch face) and the intermediate compact height (at the pressing punch face).*

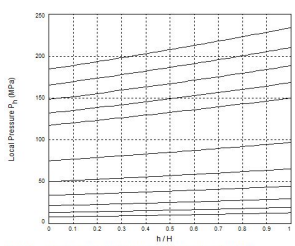


Figure 7. Local pressure distribution in a one-sided pressing. (T3.02)
Valid only for compacts with Ga = 0.0 and ρ = 5.8 at the nominal length H.
The solid lines represent average densities, the dashed lines are compaction curves.
Lines (g/cm³): 4.40 4.60 4.80 5.00 5.20 5.40 5.60 5.65 5.70 5.75 5.80

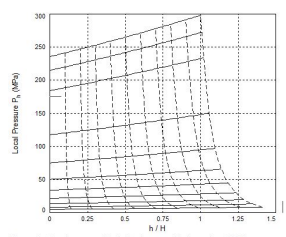


Figure 9. Local pressure distribution in a one-sided pressing. (T3.02)
Valid only for compacts with Ga = 0.797 and ρ = 5.925 at the nominal length H.
The solid lines represent average densities, the dashed lines are compaction curves.
Lines (g/cm³): 4.20 4.40 4.60 4.80 5.00 5.20 5.40 5.60 5.80 5.87 5.92

By default, the PTC program shows the local parameter distribution plots for the **desired test compact** based on the test starting parameters. For a **custom compact** or **part**, the steps **to find a local parameter distribution** are:

a) calculate Ga_{max}=SH/4F, type it in the **Ga_max box** (at top-right of the screen) and press Enter

b) type the average in-die density of the compact in the **Density box**, press Enter

c) if desired, type a different slide coefficient value in the **Eta-desired box**, press Enter.

Each time the Enter is pressed, the graph is recalculated with the new value. Entering "0" value for any parameter will restore the default value for the test compact. *Note: The type in density cannot be larger than the test density.*

Changing the value of the slide coefficient visualizes the influence of the die wall friction on compaction pressure and density changes within the compact and allows a determination of a target lubrication level. Changing the Ga value can provide a guidance on maximum compaction pressure requirements and expected variation range in compact density and local shrinkage.

Note: The graphs are based on an assumption that the local pressure is constant across a given cross section. In reality, there is a pressure increase near the die walls. The effect may be more significant in very complex parts with large frictional surfaces.

The slope of the curves depends on the slide coefficient. The higher the slide coefficient (lower friction), the lower the slope. The points on the curves in the mid height of the compact (isostatic pressure) are stationary and for slide coefficient of 1 (no friction) the curves will become horizontal lines passing through those points.

Standard Plots:

Plot 12: Local Pressure Distribution In One-Sided Pressing

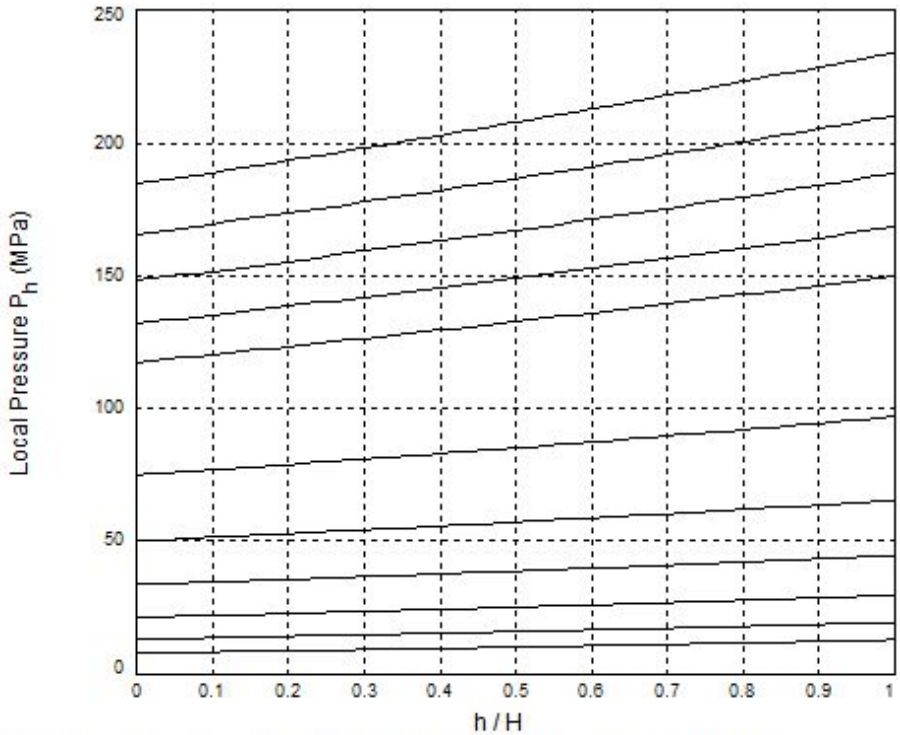


Figure 7. Local pressure distribution in a one-sided pressing. (T3.02)
Valid only for compacts with Ga = 0.0 and ρ = 5.8 at the nominal length H.
The solid lines represent average densities, the dashed lines are compaction curves.
Lines (g/cm^3): 4.40 4.60 4.80 5.00 5.20 5.40 5.60 5.65 5.70 5.75 5.80

The horizontal axis representing h/H ratio uses $H_{desired}$ value equal to the H of the desired compact (at the desired density) as defined on the plot by the **Ga** and the density **ρ**. The local h varies between 0 (at closing punch face) and the intermediate compact height (at the pressing punch face). Therefore, the ratio h/H is less than 1 for compact densities larger than desired and more than 1 for compact densities less than the desired. *This arrangement allows visualization of local compaction lines for any cross section of the pressed compact (dashed lines).*

The solid plot lines represent local pressure distribution at specific instantaneous average in-die compact densities listed at the bottom of the figure (the first value is for the bottom line and the last value is for the top line.) The dashed plot lines show the movement of fixed cross sections of the compact (at $h/H_{compact}$ = 0.1, 0.2, .., 1) during the compaction cycle. The last (on the right side) dashed line is the standard compaction characteristic (compaction pressure and compact height).

Plot 13: Local Density Distribution In One-Sided Pressing

To enhance areas of interest on a regular plot (below, left), one can enlarge particular sections of the plot for detailed analysis. The plot on the right shows enlarged top of the plot corresponding to the end of compaction. The top line shows local in-die density distribution in the test compact. The density variation on the pressing and the closing side of the compact can be evaluated.

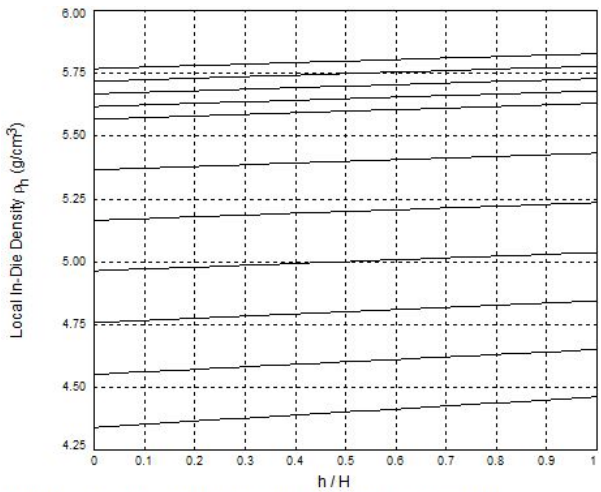


Figure 8. Local density distribution in a one-sided pressing. (T3.02)
Valid only for compacts with Ga = 0.0 and ρ = 5.8 at the nominal length H.
The solid lines represent average densities, the dashed lines are compaction curves.
Lines (g/cm^3): 4.40 4.60 4.80 5.00 5.20 5.40 5.60 5.65 5.70 5.75 5.80

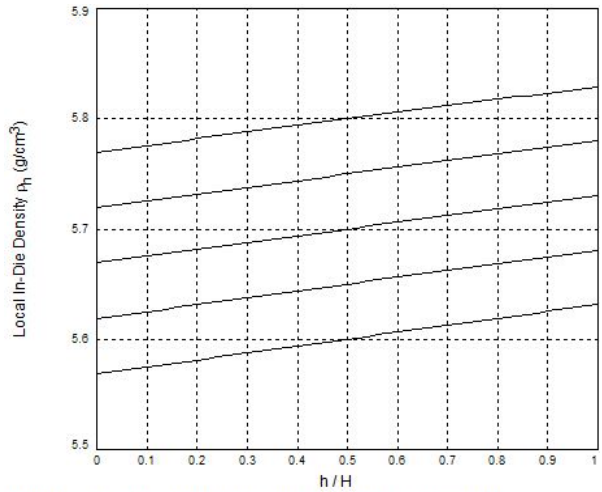


Figure 8. Local density distribution in a one-sided pressing. (T3.02)
Valid only for compacts with Ga = 0.0 and ρ = 5.8 at the nominal length H.
The solid lines represent average densities, the dashed lines are compaction curves.
Lines (g/cm^3): 4.40 4.60 4.80 5.00 5.20 5.40 5.60 5.65 5.70 5.75 5.80

The horizontal axis representing h/H ratio uses $H_{desired}$ value equal to the H of the desired compact (at the desired density) as defined on the plot by the **Ga** and the density **ρ**. The local h varies between 0 (at closing punch face) and the intermediate compact height (at the pressing punch face). Therefore, the ratio $h/H_{desired}$ is less than 1 for compact densities larger than desired and more than 1 for compact densities less than the desired. *This arrangement allows visualization of local compaction lines for any cross section of the pressed compact (dashed lines).*

The solid plot lines represent local density distribution at specific instantaneous average in-die compact densities listed at the bottom of the figure (the first value is for the bottom line and the last value is for the top line.) The dashed plot lines show the movement of fixed cross sections of the compact (at $h/H_{compact}$ = 0.1, 0.2, .., 1) during the compaction cycle.

Plot 14: Local Radial Shrinkage In One-Sided Pressing

The radial shrinkage, in the direction perpendicular to the pressing direction, is calculated as:

$$S_d = (1 - d_{sintered} / d_{green})\ 100\ [\%]$$

The radial dimension change represents a ratio between the sintered radial dimension and the green in-die radial dimension at the same corresponding location on the compact. The graphs are plotted **for specific compacts only**.

To determine the local radial dimension change based on a free (out-of-die) green compact size, use the following relation:

$$d_{out\text{-}of\text{-}die} = d_{in\text{-}die}/e_r \quad ; \quad e_r \text{ is the radial green compact expansion}$$

The plots are based on the assumption that the density after sintering is uniform throughout the compact. In many cases the sintered density is not uniform. However, assuming an uniform sintered density, the calculations result in a maximum possible dimension change which means that in practical cases the actual local shrinkage may be less but it will never be more that the one on the graph.

The program requires an additional information to plot the local dimension changes after sintering:

- the desired average density after sintering
- the total mass loss during drying and sintering
- the anisotropic shrinkage ratio (in isostatic pressing): $a=S_h/S_d$, $S_h=1-H_{sintered}/H_{green}$, H is the axial dimension.

Note: If the above information is not provided, the computer will not produce the local dimension change graphs.

To enhance areas of interest on a regular plot (below, left), one can enlarge particular sections of the plot for detailed analysis. The plot on the right shows enlarged bottom of the plot corresponding to the end of compaction. The bottom line shows local radial shrinkage in the test compact.

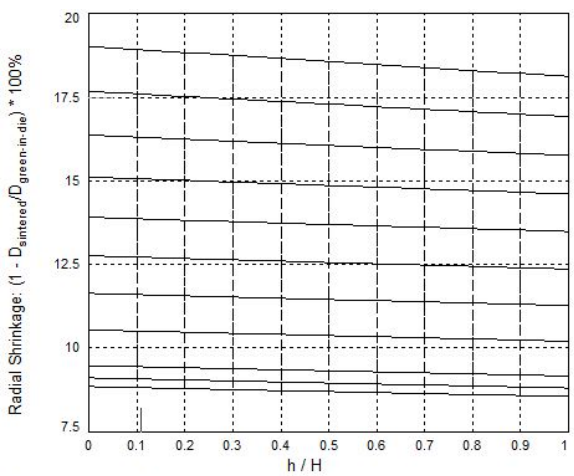


Figure 11. Local Radial Shrinkage during sintering (one-sided pressing). (T3.02)
Valid only when: Ga = 0.797 at the in-die average ρ = 5.925, er = 1.0036 , ea = 1.0269 .
The solid lines represent local shrinkage at listed below average in-die densities.
Line values from top to bottom (g/cm^3): 4.20 4.40 4.60 4.80 5.00 5.20 5.40 5.60 5.80 5.87 5.92

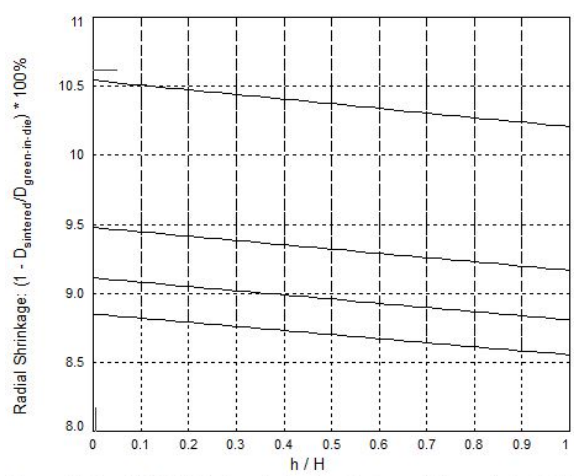


Figure 11. Local Radial Shrinkage during sintering (one-sided pressing). (T3.02)
Valid only when: Ga = 0.797 at the in-die average ρ = 5.925, er = 1.0036 , ea = 1.0269 .
The solid lines represent local shrinkage at listed below average in-die densities.
Line values from top to bottom (g/cm^3): 4.20 4.40 4.60 4.80 5.00 5.20 5.40 5.60 5.80 5.87 5.92

On this plot, the horizontal axis representing h/H ratio uses H value equal to the actual height of the current compact. The local h varies between 0 (at closing punch face) and 1 (the intermediate compact height at the pressing punch face). *This arrangement allows simple visualization of local changes during sintering.*

The solid plot lines represent local radial shrinkage variation at specific instantaneous average in-die compact densities listed at the bottom of the figure (the first value is for the top line and the last value is for the bottom line.)

Plot 15: Local Axial Shrinkage In One-Sided Pressing

The local density in a one-sided pressing is changing along the hight of the compact. As a result, the calculations for axial shrinkage are more complex than for the radial shrinkage. The lower density sections of the green compact shrink more than the higher density ones. The middle cross section of the green compact will migrate towards the low (green) density end.

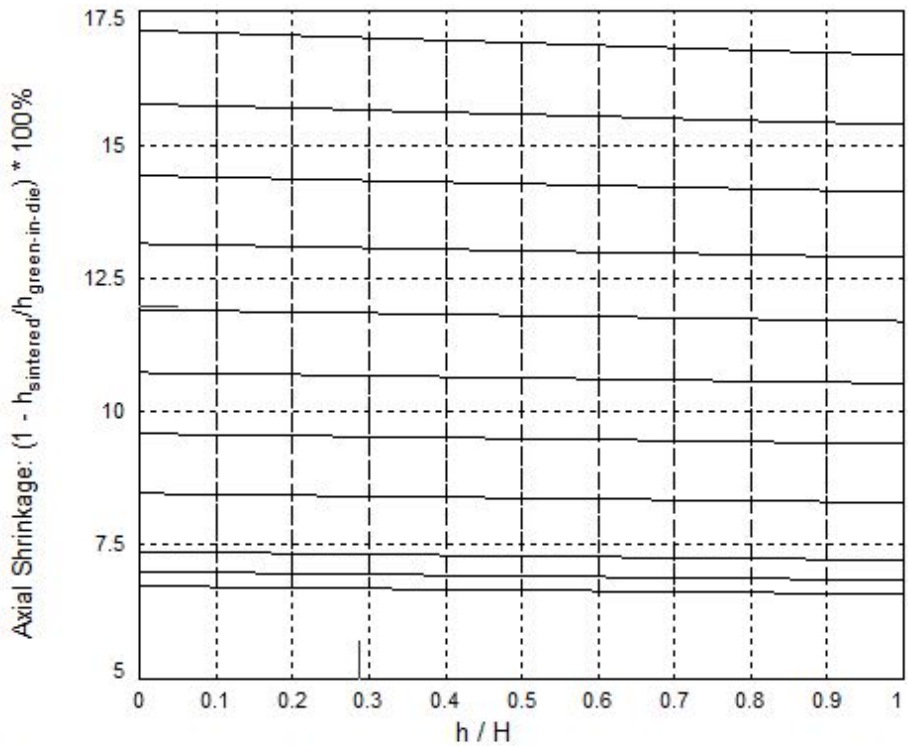


Figure 12. Local Axial Shrinkage during sintering (one-sided pressing). (T3.02)
Valid only when: Ga = 0.797 at the in-die average ρ = 5.925, er = 1.0036 , ea = 1.0269 .
The solid lines represent local shrinkage at listed below average in-die densities.
Line values from top to bottom (g/cm^3): 4.20 4.40 4.60 4.80 5.00 5.20 5.40 5.60 5.80 5.87 5.92

On this plot, the horizontal axis representing h/H ratio uses H value equal to the actual height of the current compact. The local h varies between 0 (at closing punch face) and 1 (the intermediate compact height at the pressing punch face). *This arrangement allows simple visualization of local changes during sintering.*

The solid plot lines represent local axial shrinkage variation at specific instantaneous average in-die compact densities listed at the bottom of the figure (the first value is for the top line and the last value is for the bottom line.)

Plot 16: Local Pressure Distribution In Double-Sided Pressing

The double-sided symmetrical pressing configuration is calculated based on the one-sided pressing test results. It represents a combination of two one-sided pressing arrangements with a common closing (stationary) cross section in the middle. The practical equivalent is the floating die compaction setup.

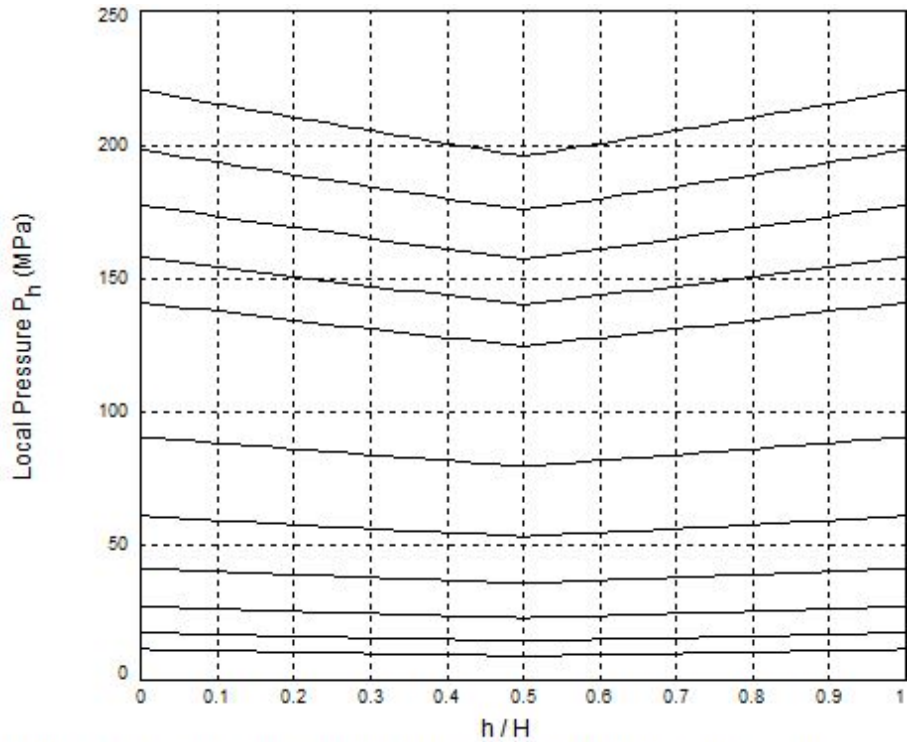


Figure 11. Local pressure distribution in a double-sided pressing. (T3.02)
Valid only for compacts with Ga = 0.0 and ρ = 5.8 at the nominal length H.
The solid lines represent average densities, the dashed lines are compaction curves.
Lines (g/cm^3): 4.40 4.60 4.80 5.00 5.20 5.40 5.60 5.65 5.70 5.75 5.80

The horizontal axis representing h/H ratio uses $H_{desired}$ value equal to the H of the desired compact (at the desired density) as defined on the plot by the **Ga** and the density **ρ**. The local h varies between 0 (at closing punch face) and the intermediate compact height (at the pressing punch face). Therefore, the ratio h/H is less than 1 for compact densities larger than desired and more than 1 for compact densities less than the desired. *This arrangement allows visualization of local compaction lines for any cross section of the pressed compact (dashed lines).*

The solid plot lines represent local pressure distribution at specific instantaneous average in-die compact densities listed at the bottom of the figure (the first value is for the bottom line and the last value is for the top line.) The dashed plot lines show the movement of fixed cross sections of the compact (at $h/H_{compact}$ = 0.1, 0.2, .., 1) during the compaction cycle. The last (on the right side) dashed line is the standard compaction characteristic (compaction pressure and compact height).

Figure 17: Local Density Distribution In One-Sided Pressing

To enhance areas of interest on a regular plot (below, left), one can enlarge particular sections of the plot for detailed analysis. The plot on the right shows enlarged top of the plot corresponding to the end of compaction. The top line shows local in-die density distribution in the test compact. The density variation on the pressing and the closing side of the compact can be evaluated.

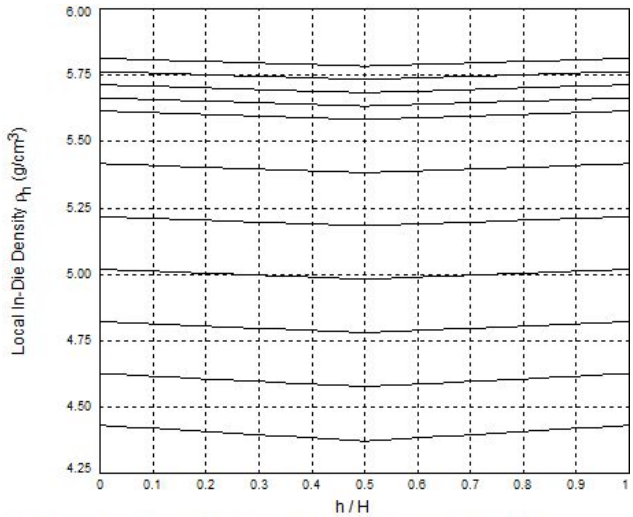


Figure 12. Local density distribution in a double-sided pressing. (T3.02)
Valid only for compacts with Ga = 0.0 and ρ = 5.8 at the nominal length H.
The solid lines represent average densities, the dashed lines are compaction curves.
Lines (g/cm^3): 4.40 4.60 4.80 5.00 5.20 5.40 5.60 5.65 5.70 5.75 5.80

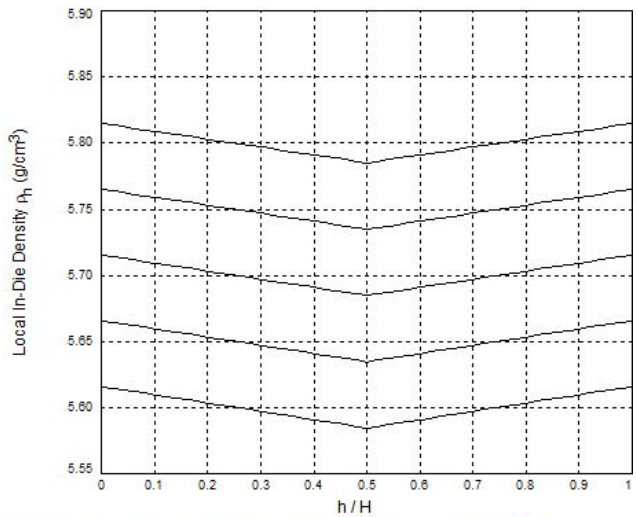


Figure 12. Local density distribution in a double-sided pressing. (T3.02)
Valid only for compacts with Ga = 0.0 and ρ = 5.8 at the nominal length H.
The solid lines represent average densities, the dashed lines are compaction curves.
Lines (g/cm^3): 4.40 4.60 4.80 5.00 5.20 5.40 5.60 5.65 5.70 5.75 5.80

The horizontal axis representing h/H ratio uses $H_{desired}$ value equal to the H of the desired compact (at the desired density) as defined on the plot by the **Ga** and the density $\boldsymbol{\rho}$. The local h varies between 0 (at closing punch face) and the intermediate compact height (at the pressing punch face). Therefore, the ratio h/H is less than 1 for compact densities larger than desired and more than 1 for compact densities less than the desired. *This arrangement allows visualization of local compaction lines for any cross section of the pressed compact (dashed lines).*

The solid plot lines represent local density distribution at specific instantaneous average in-die compact densities listed at the bottom of the figure (the first value is for the bottom line and the last value is for the top line.) The dashed plot lines show the movement of fixed cross sections of the compact (at $h/H_{compact}$ = 0.1, 0.2, .., 1) during the compaction cycle.

Plot 18: Local Radial Shrinkage In Double-Sided Pressing

Similar to the shrinkage in a one-sided pressing (Plot 14 above). To enhance areas of interest on a regular plot (below, left), one can enlarge particular sections of the plot for detailed analysis. The plot on the right shows enlarged bottom of the plot corresponding to the end of compaction. The bottom line shows local radial shrinkage in the test compact.

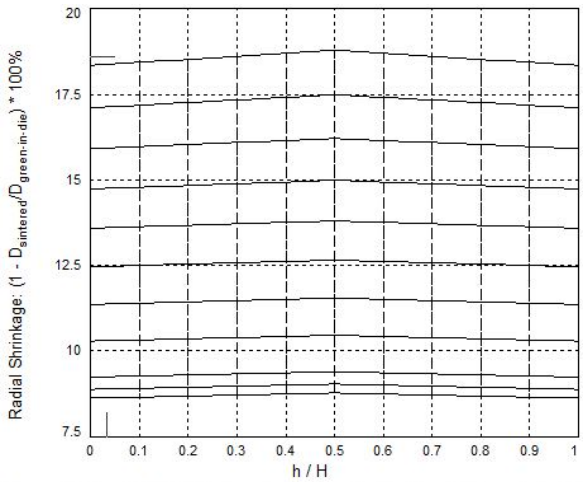


Figure 15. Local Radial Shrinkage during sintering (double-sided pressing). (T3.02)
Valid only when: Ga = 0.797 at the in-die average ρ = 5.925, er = 1.0036 , ea = 1.0269 .
The solid lines represent local shrinkage at listed below average in-die densities.
Line values from top to bottom (g/cm^3): 4.20 4.40 4.60 4.80 5.00 5.20 5.40 5.60 5.80 5.87 5.92

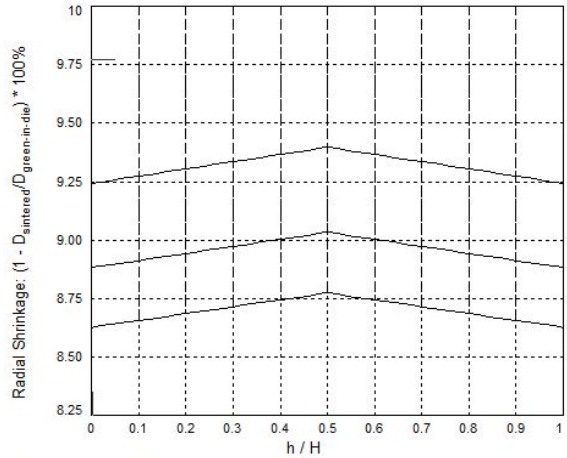


Figure 15. Local Radial Shrinkage during sintering (double-sided pressing). (T3.02)
Valid only when: Ga = 0.797 at the in-die average ρ = 5.925, er = 1.0036 , ea = 1.0269 .
The solid lines represent local shrinkage at listed below average in-die densities.
Line values from top to bottom (g/cm^3): 4.20 4.40 4.60 4.80 5.00 5.20 5.40 5.60 5.80 5.87 5.92

On this plot, the horizontal axis representing h/H ratio uses H value equal to the actual height of the current compact. The local h varies between 0 (at closing punch face) and 1 (the intermediate compact height at the pressing punch face). *This arrangement allows simple visualization of local changes during sintering.*

The solid plot lines represent local radial shrinkage variation at specific instantaneous average in-die compact densities listed at the bottom of the figure (the first value is for the top line and the last value is for the bottom line.)

Plot 19: Local Axial Shrinkage In Double-Sided Pressing

Similar to the shrinkage in a one-sided pressing (Plot 15 above).

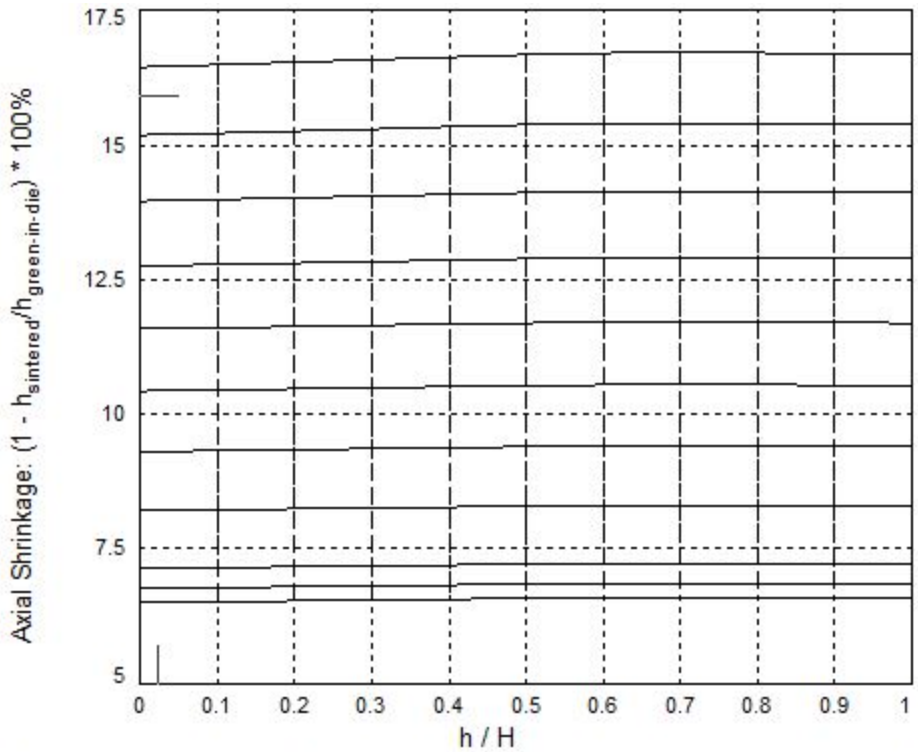


Figure 16. Local Axial Shrinkage during sintering (double-sided pressing). (T3.02)
Valid only when: Ga = 0.797 at the in-die average ρ = 5.925, er = 1.0036 , ea = 1.0269 .
The solid lines represent local shrinkage at listed below average in-die densities.
Line values from top to bottom (g/cm^3): 4.20 4.40 4.60 4.80 5.00 5.20 5.40 5.60 5.80 5.87 5.92

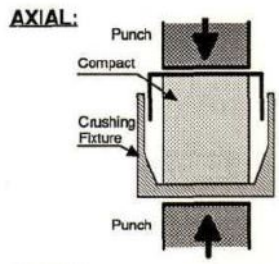
On this plot, the horizontal axis representing h/H ratio uses H value equal to the actual height of the current compact. The local h varies between 0 (at closing punch face) and 1 (the intermediate compact height at the pressing punch face). *This arrangement allows simple visualization of local changes during sintering.*

The solid plot lines represent local axial shrinkage variation at specific instantaneous average in-die compact densities listed at the bottom of the figure (the first value is for the top line and the last value is for the bottom line.)

5.6.6 Axial & Radial Crushing Test Plots

The Crushing Tests generate the following data sets:

- **axial crush** - point measurements during axial crushing test: **s, p_{ac}**
  - s is the crushing position
  - p_{ac} is the axial crushing pressure based on a cross section area of an in-die compact

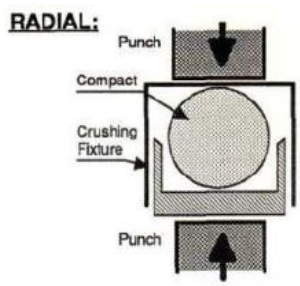


- **radial pressure crush** - point measurements during radial crushing test: **s, w_r**
- **diametral pressure crush** - point measurements during radial crushing test: **s, w_d**
- **radial crushing force**: **s, F**

The position **s** in the radial crushing test is expressed as:

$$s = d_{in} - x$$

where d_{in} is the in-die diameter and x is the distance between the crushing faces. During the test, the s=0 position is registered when the crushing force begins to rise.



The **radial pressure** is calculated as a ratio of the crushing force and the instantaneous contact area between the crushing plane and the cylindrical surface of the compact assuming that the deformation occurs only at the contact area:

$$w_r = F / A_c \;; \qquad A_c = h_{in} (d_{in}^2 - x^2)^{0.5}$$

where F is the crushing force measured on the crushing punch, A_c is the contact area, h_{in} is the in-die height of the compact. Theoretically, the initial pressure is infinite (contact along a line). Due to a finite accuracy of force measurements and compact deflections, the initial pressure points are removed from the crushing characteristic and are not considered for the green radial strength.

The **diametral pressure** is calculated as a ratio of the crushing force and a reference area of the unstressed compact:

$$w_d = F / A_r \;; \qquad A_r = 0.5\,(3.14\, h_{out}\, d_{out})$$

where the compact height and diameter are the measurements of a free (out of die) compact.

Standard Plots:

Plot 5: Green Compact Axial Crushing Characteristic

The graph shows the crushing pressure versus the crushing distance. The maximum pressure during crashing represents the corresponding Axial Green Strength of the compact. If there is no clear drop in crushing pressure at the end of the crushing cycle, the maximum pressure is meaningless and so is the Axial Green Strength.

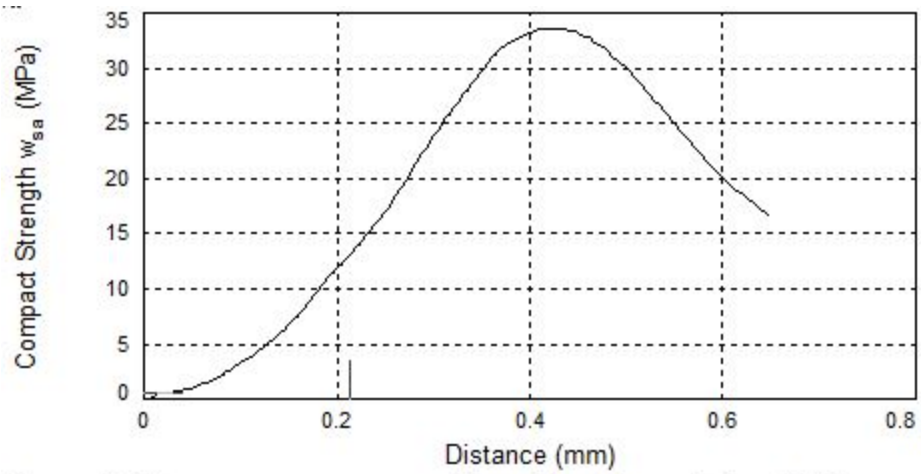


Figure 17. The green test compact axial crushing characteristic. (T3.02)

Plot 6: Green Compact Radial Crushing Characteristic

The graphs show the crushing characteristics for the Radial pressure versus the crushing distance. A few initial points in the crushing force are not considered for this graph to prevent an initial spike due to a division of a small force over a near zero contact area at the startup of the crush test.

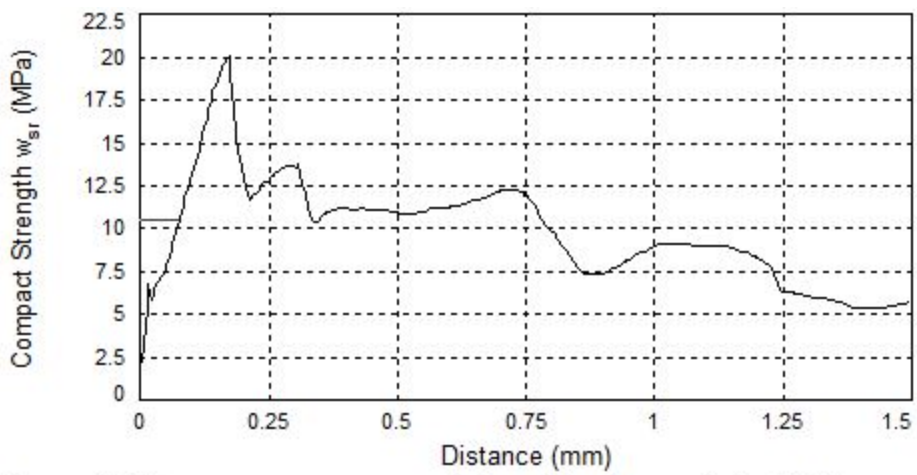


Figure 18. The green test compact radial crushing characteristic. (T3.02)

Plot 7: Green Compact Diametral Crushing Characteristic

The graphs show the crushing characteristics for the Diametral pressure versus the crushing distance.

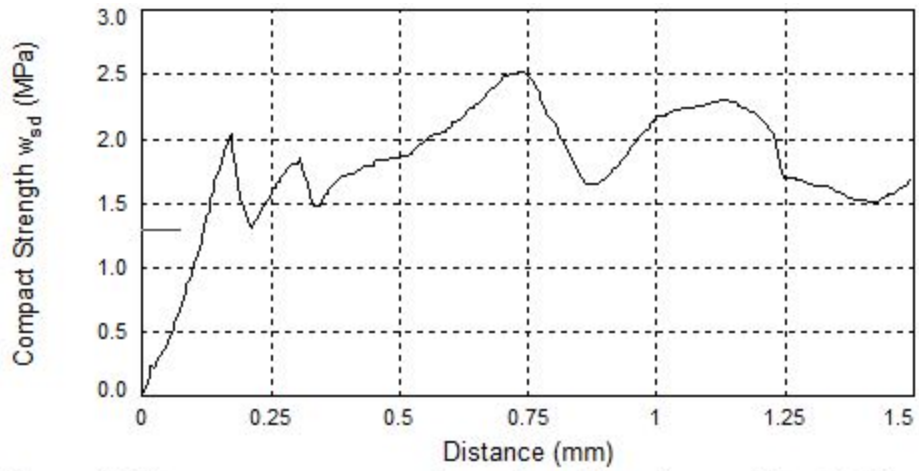


Figure 19. The green test compact diametral crushing characteristic. (T3.02)

Plot 20: Green Compact Diametral Crushing Force Characteristic

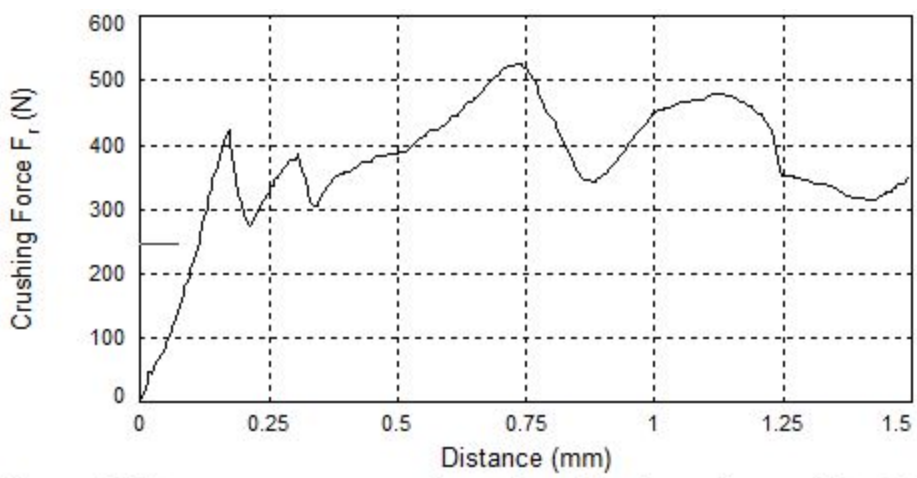


Figure 20. The green test compact diametral crushing force characteristic. (T3.02)

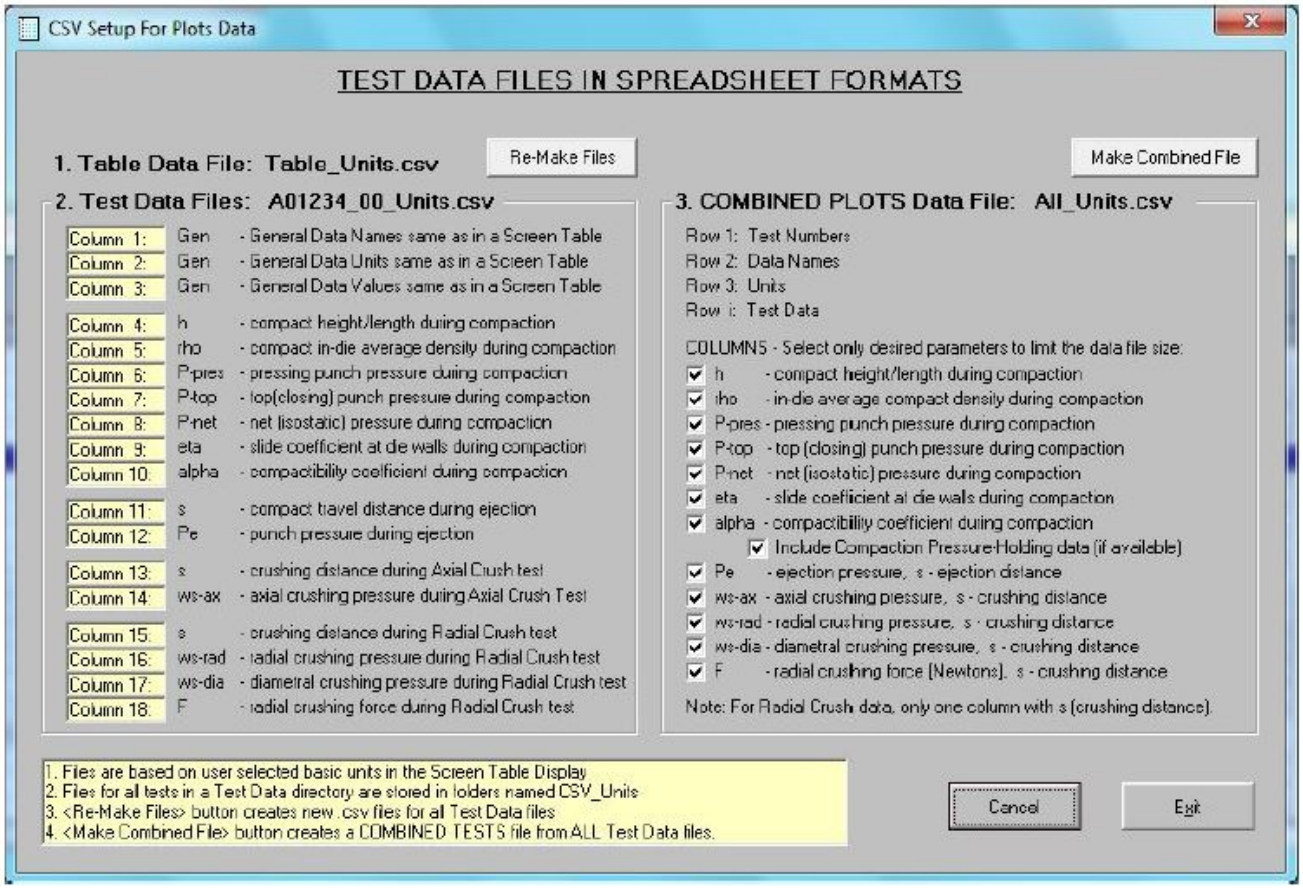
5.7 CSV Files - Test Data Files For Spreadsheets

Checking the **Make .csv File** box in the Screen Table Display screen will automatically generate individual csv (**comma separated values**) files for new test data files or for any test data file that does not have a corresponding csv file. The .csv (**comma separated values**) format is **compatible with spreadsheet programs**. Those files are created for currently selected units and stored in a unit-specific folder in the test data directory:

- Folder **MPa_mm_gpercm3** for files in metric units: MPa, mm, g/cm^3
- Folder **PSI_in_gpercm3** for files in US units: PSI, in, g/cm^3

Every time a setup for the Screen Table Display is changed, the PTC program updates the csv test files.

The **Setup.csv** option provides the details for the csv files:



The **Re-Make Files** option generates all csv files from test data files in a data directory. The **Make Combined Files** option creates the combined plot data file based on the current selections in the display.

The following files are available ("**units**" in the file names below refer to the currently selected units in the Screen Table Display, exactly the same as for the folder names above):

- **Table_units.csv** - table data file identical to the Screen Table Display:

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1	Test	Powder	Batch	Die	rhot	rhob	rhotp	HR	Ctap	Taps	beta	Temp	HPT	th	rhog-d	eta-d	alpha-d
2	-1-	-2-	-3-	-4-	g/cm3	g/cm3	g/cm3	-8-	%	-10-	deg	C	-13-	sec	g/cm3	-16-	-17-
3	2	SAMPLE		TC/TD#1	7.8	3.166	3.857	1.218	17.92	20060	41	28	0	0	6	0.4	0.1585
4	3	MIX 1		TC/1	7.8	3.115	3.665	1.177	15.01	15045	46	27	0	0	6.048	0.843	0.1613
5	4	MIX 1		TD-1/C-35	7.8	3.115	3.665	1.177	15.01	15045	46	47	0	0	6.05	0.744	0.1626
6	64	SAMPLE		TC/1	7.8	3.166	3.857	1.218	17.92	20060	41	27	0	0	6	0.812	0.1544

- **A00123_00_units.csv** - standard output Test Data File (for each A00123.00F test file) with General Test Data (names, units, values) and Plots for compaction (h, rho, Pc, Pd, Pn, alpha, eta), ejection (s, Pe), axial crushing (s, wa) and radial crushing (s, wr, wd, Fc):

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
1	Gen	Gen	Gen	h	rho	Pc	Pd	Pn	alpha	eta	s	Pe	s	ws-axial	s	ws-rad	ws-dia	Fcrush
2	Name	Unit	Data	mm	g/cm3	MPa	MPa	MPa	-	-	mm	MPa	mm	MPa	mm	MPa	MPa	N
3	Test	-1-	3	18.948	3.429	3.9	1.7	2.6	0.0334	0.574	-0.047	0	0	0	0	2.1	0	3
4	Powder	-2-	MIX 1	18.923	3.433	4.1	1.8	2.7	0.0335	0.5751	-0.044	1.2	0.002	0	0.002	2.9	0	6
5	Batch	-3-		18.898	3.437	4.2	1.9	2.8	0.0335	0.5747	-0.041	4.3	0.003	0.1	0.003	3.7	0.1	11
6	Die	-4-	TC/1	18.885	3.441	4.4	1.9	2.9	0.0336	0.5743	-0.038	7.8	0.005	0.1	0.005	5.4	0.1	20
7	rhot	g/cm3	7.8	18.86	3.445	4.5	2	3	0.0337	0.5739	-0.036	11	0.006	0.2	0.006	6.5	0.1	28
8	rhob	g/cm3	3.115	18.834	3.449	4.7	2.1	3.1	0.0338	0.5731	-0.033	12.5	0.008	0.3	0.008	9.7	0.2	46
9	rhotp	g/cm3	3.665	18.809	3.453	4.9	2.1	3.2	0.0338	0.5722	-0.03	12.2	0.009	0.3	0.009	8	0.2	42
10	HR	-8-	1.177	18.796	3.458	5.1	2.2	3.3	0.0339	0.5714	-0.027	12.1	0.011	0.2	0.011	6.8	0.2	38
11	Ctap	%	15.01	18.771	3.462	5.2	2.3	3.5	0.034	0.5711	-0.024	12	0.012	0.3	0.013	6.9	0.2	42
12	Taps	-10-	15045	18.745	3.466	5.4	2.4	3.6	0.0341	0.5708	-0.021	11.9	0.014	0.3	0.014	7	0.2	45
13	beta	deg	46	18.72	3.47	5.6	2.4	3.7	0.0342	0.5706	-0.018	11.9	0.015	0.3	0.016	7.3	0.2	50
14	Temp	C	27	18.707	3.473	5.7	2.5	3.8	0.0343	0.5709	-0.014	11.9	0.017	0.3	0.018	7.6	0.3	54
15	HPT	-13-	0	18.682	3.477	5.9	2.6	3.9	0.0344	0.5712	-0.011	11.9	0.018	0.3	0.019	7.9	0.3	59
16	th	sec	0	18.656	3.481	6.1	2.7	4	0.0345	0.5714	-0.007	11.9	0.02	0.3	0.021	8.3	0.3	65
17	rhog-d	g/cm3	6.048	18.644	3.486	6.3	2.8	4.2	0.0347	0.5711	-0.003	11.9	0.021	0.4	0.022	8.7	0.3	71
18	eta-d	-16-	0.843	18.618	3.49	6.4	2.8	4.3	0.0348	0.5708	0.001	11.9	0.023	0.4	0.024	9.3	0.4	77

- **All_units.csv** - a combined plots file for user selected test plot parameters from all tests:

	A	B	C	D	E	F	G	H	I	J	K	L
1	1382	1382	1382	1382	1383	1383	1383	1383	1384	1384	1384	1384
2	h	Pc	s	Pe	h	Pc	s	Pe	h	Pc	s	Pe
3	in	PSI	in	PSI	in	PSI	in	PSI	in	PSI	in	PSI
4	0.7155	123	-0.006	0	0.7215	91	-0.0059	0	0.7135	106	-0.0059	0
5	0.7115	133	-0.006	93	0.7175	101	-0.0058	101	0.7095	118	-0.0059	64
6	0.7075	144	-0.0059	193	0.714	112	-0.0058	220	0.7055	131	-0.0059	149
7	0.7035	156	-0.0059	211	0.7095	121	-0.0058	252	0.7015	144	-0.0059	172
8	0.6995	168	-0.0059	238	0.7055	130	-0.0058	276	0.6975	160	-0.0058	188
9	0.6955	182	-0.0059	253	0.7015	141	-0.0058	301	0.6935	169	-0.0058	215
10	0.6915	196	-0.0059	258	0.6975	153	-0.0057	321	0.6895	178	-0.0058	238
11	0.6875	211	-0.0059	264	0.6935	167	-0.0057	335	0.6855	189	-0.0058	270
12	0.6835	228	-0.0059	283	0.6895	181	-0.0057	355	0.6815	202	-0.0057	301

The desired parameters are selected in the parameter's list. The program will extract the data from each test data file in the folder and assemble them in columns. The number in the first row shows the corresponding test number for the data in the column. The second row shows the name and the third raw shows the unit for the data. The actual data starts in the forth row.

5.8 Applications In Process Control And Design

The tested powder parameters depend on the green compact density. Therefore, any comparisons between test data files **must be done at the same Desired Green Compact Density**. The desired density and few other parameters may be modified in the **Edit TDF** display (option in the main table screen display).

The test parameters are used for direct comparisons in powder developments and quality control evaluations. Test parameters of interest may be assembled in the desired order for display in the main table display on the screen. Implementing the option for filing the table data, one can select (mark) the specific test data files of interest and with that option create an ASCII file that contains the desired data in identical format as seen on the screen. The data from that file may be loaded into any third party program for a desired statistical analysis.

It is of utmost importance to correctly interpret the data selected for comparison. Since most of the parameters depend on the Green Compact Density, those parameters can only be compared at the same green density. That parameter can be changed to any value within the tested range. There are three steps to set the common base for comparison between test data files:

(1) - select (mark) the test data files to be compared

(2) - using the "Edit TDF" option, set the Desired Green Compact Density for the current test data file

(3) - using the options in the "Edit TDF" screen, set the desired density for all selected test data files.

By default during a test, the Desired Green Compact Density corresponds to the desired density used for testing. If the testing is done based on the desired pressure, the desired density will correspond to the one at the desired pressure. The actual compact density will be slightly different since the compaction cannot be stopped precisely at the desired point, there will always be some over- or under-shots. The user cannot change the actual test parameters in the test data file, however the desired parameters (density, pressure) can be changed at any time to the value at which one wishes to analyze the powder properties.

Since the test parameters corresponding to the final test compact cannot be changed, one must be careful when comparing such data between test data files. Even though the differences between the final test compact density might appear small, they might nevertheless be significant enough to make data comparisons inaccurate. One example might be the maximum compaction pressure which at the end of compaction change quite dramatically with very small variations in green density. Therefore, statistical comparisons of the actual (final) test compact parameters require some caution and may provide completely useless results. Only comparisons made at the same (desired) green density give valid results.

III. MANUAL OPERATION & DIE CHANGE

6. TESTS WINDOW: MANUAL OPERATION AND DIE CHANGE

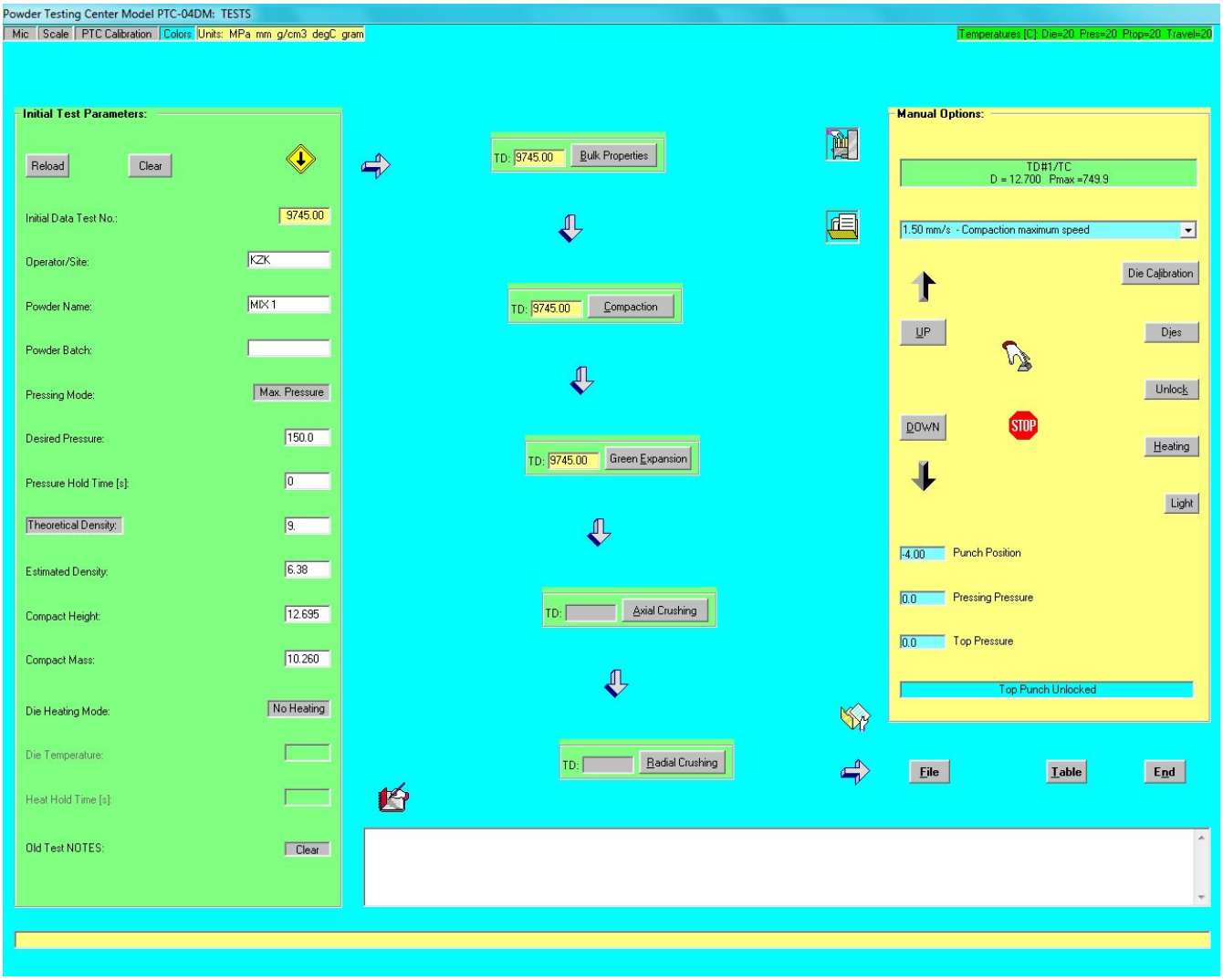
Always be aware of safety issues in dealing with the testing center:

* **MAKE SURE THAT THE DIE DOOR (front main cover) IS IN PLACE !!!**
* **CHECK IF THE TEST DIE IS MOUNTED PROPERLY !!!**
* **WEAR SAFETY GLASSES !!!**
* **USE EXTREME CAUTION WHEN THE DIE IS HOT !!!**

For new or serviced units, the following steps must be performed before or during the first test:

- make sure that the **Test Die** is installed
- release the die lock - using a 3 mm hex key, tighten the die lock screw through the hole on the top of the PTC and then turn it 1 **TURN** counterclockwise to release the die lock.
- check if the **Test Die** is mounted properly - the Top Punch should move in and out of the die without much resistance.
- calibrate the die (position sensor).

The **Manual Options** frame in the Tests Window displays all available options for direct control of the testing center.



The temperatures for the test die, the pressing punch base, the top punch fixture and the travel sensor are constantly monitored and displayed in the upper right corner of the Tests window. If the temperature of the die exceeds 45°C the program changes the color of the temperature display window. In addition, at the elevated temperature, the pressing punch must be at the bottom of the die all the time except during testing. The testing cycle withdraws hot punches to the bottom position. However, since the user may interrupt that cycle and leave the testing with punch too deep in the die, the temperature display will be flashing and a memo will be constantly asking to move the punch down to prevent sensors overheating. That reminder will stop as soon as the punch is moved to a safe level.

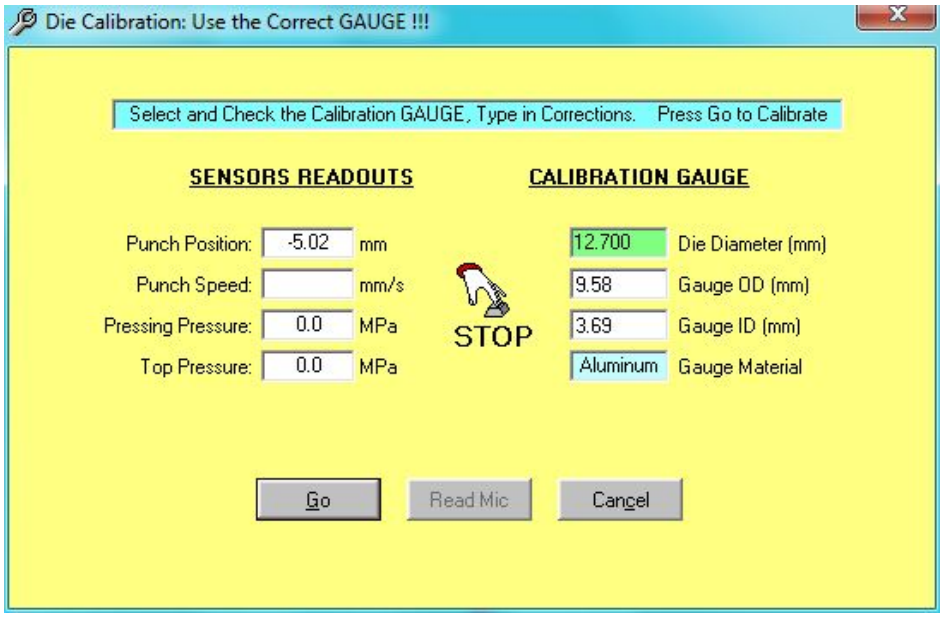
The **Up** button moves the punch slightly above the die's surface. The **Down** button moves the die to the bottom position. The **Spacer** button initiates the top punch unlocking step (the test die is moved down). The **Heating** button is used to heat the die to a desired temperature (see the Heating section below). The **Light** button turns on/off the test die illumination.

The punch position is measured with respect to the top surface of a compact during compaction and it represents the distance between the pressing and the top punch when the top punch is locked. Nominally, the "0" reference position is 5.08 mm below the top surface of the die. If the pressing punch is above that location, the reading is negative and it turns to positive when the punch is moved below it.

The readings from both pressure sensors are also displayed. One may check the sensors by pushing on the top punch or on the pressing punch. The readings should register change in pressure.

The position of the top punch is monitored by limit switches. The top punch must be **unlocked** during manual up movement to prevent direct punch contact and possible damage to punches and sensors.

6.1 Die Calibration



The **die calibration** determines the true length between punches and the absolute position of the compact in a die **at zero force**. To calibrate, an aluminum Die Calibration Gauge is placed between punches and pressed with a small force. The gauge must fit into the die's cavity and its length should be close to the desired compact length. The gauge material must be aluminum. The calibration should be performed frequently, preferably each time the testing center is turned on. The process is quick and provides accuracy assurance for the test results.

The calibration display shows sensor readouts (position, punch speed, and pressure on both punches). The display shows the current calibration gauge data. The gauge's outside diameter OD and inside diameter ID should be checked and retyped if necessary.

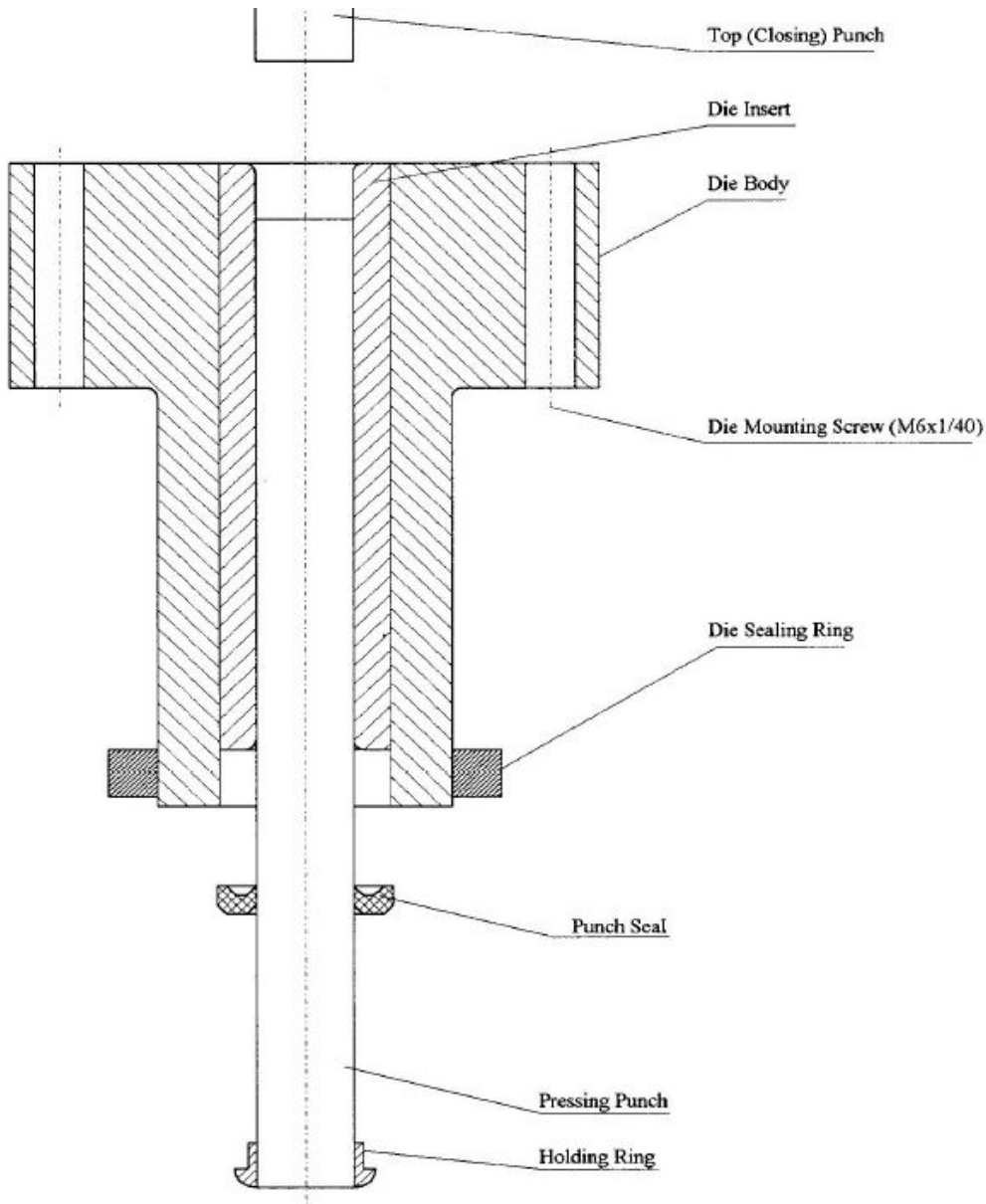
Pressing the **Go** button starts the calibration. The pressing punch moves to a position, the gauge should be placed on top in the center of the punch. The **Go** option moves the punch down. It is advisable to lower the top punch with the gauge as it moves down and lock the top punch as soon as possible. Locking the top punch will be detected by the program and the punch will move up to complete the calibration. If the top punch is not locked, the pressing punch moves down and stops. The message on the screen will instruct the user to lock the punch. If the gauge is not low enough which prevents the locking, selecting the **Go** button will move the gauge down again and again if necessary.

The calibration is successful when a force is detected on the pressing punch and the motor stops. The punch position is used to calculate the distance between the punches. That distance must be verified by measuring the length of the gauge itself. The calculated gauge length is displayed on the screen and must be corrected if the difference is larger than 0.01 mm.

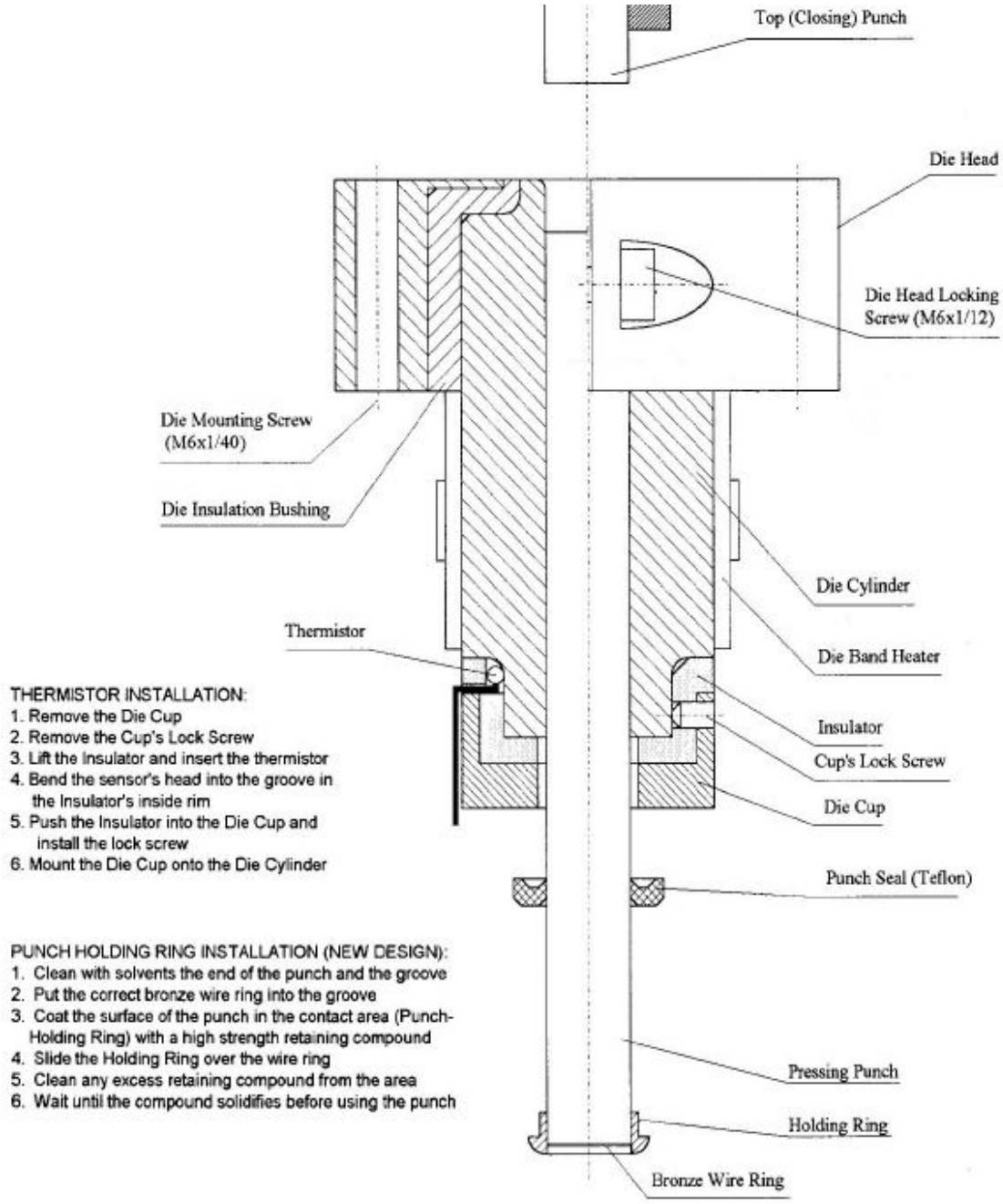
6.2 Dies

A typical user may have many dies with different diameters and materials. Each die must have a unique die name or number that can be used for identification. Often dies work at elevated temperatures and have temperature sensors attached for the measurements.

The most common die is a solid one-piece die as shown below. These dies typically have a steel casing and an insert made of tungsten carbide, ceramic or other die material. They can be used for cold and warm (up to ~70°C) pressing. A band heater mounts on the stem of the die and a temperature sensors is mounted at the bottom of the stem to monitor the temperature.



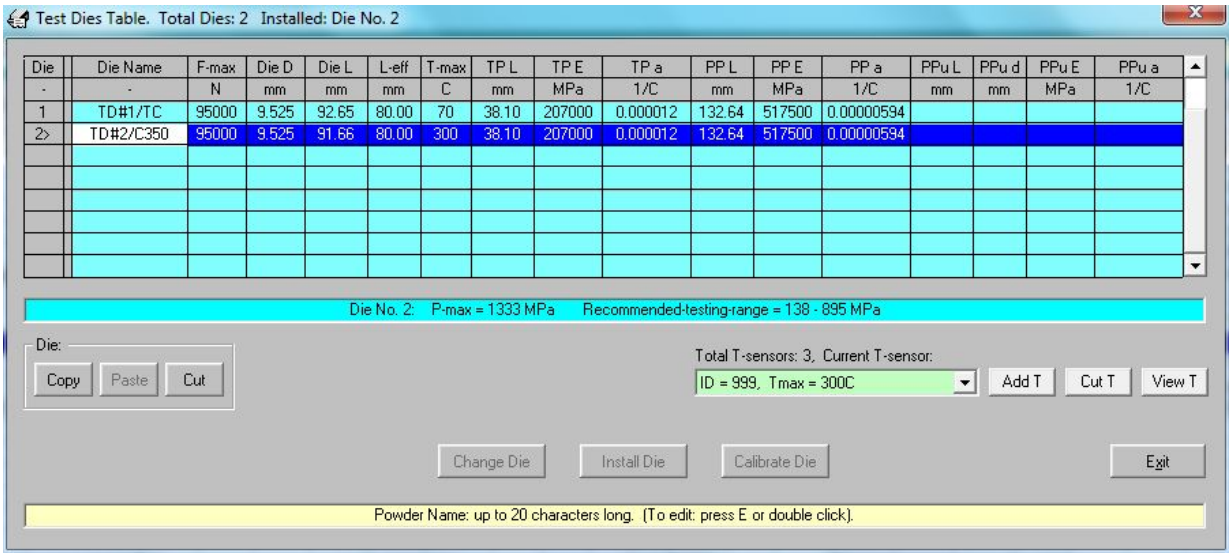
The cold/hot pressing die below uses die cylinders mounted in a universal (for various die diameters) mounting head. The die cylinder is surrounded by ceramic insulators that protect the PTC from heat. Depending on the material of the die cylinder, the die can be heated up to 300°C. This type of a test die is practical for experimentation with different die materials and compaction temperatures.



6.2.1 Die Table

The die table lists all dies on record and shows the parameters defining a die which could be modified by the user. To create a **new die**, first **Copy** an existing die (highlighted line), move to a line below which you want your new die to be listed, **Paste** it to make a new line entry and edit all relevant parameters. To edit a die parameter, double click on it. At first, the user must provide the **Operator Password** to make any changes. The selected parameter is displayed in the **Edit Window** and may be modified as needed. Pressing Enter or moving out of there automatically makes the change in the die table. The die parameters should be determined as accurately as possible, preferably within 0.01mm.

*NOTE: All die parameters are in **metric units**, regardless of what the general unit selection is.*



Die	Die Name	F-max	Die D	Die L	L-eff	T-max	TP L	TP E	TP a	PP L	PP E	PP a	PPu L	PPu d	PPu E	PPu a
-	-	N	mm	mm	mm	C	mm	MPa	1/C	mm	MPa	1/C	mm	mm	MPa	1/C
1	TD#1/TC	95000	9.525	92.65	80.00	70	38.10	207000	0.000012	132.64	517500	0.00000594				
2>	TD#2/C350	95000	9.525	91.66	80.00	300	38.10	207000	0.000012	132.64	517500	0.00000594				

The following parameters (metric units only) define a die:

Die Name	- an ID or code of the die (20 characters), it will appear on printouts and displays
F-max	- a maximum allowable force on the pressing punch (40,000-98,100 N)
DieD	- the actual diameter of the die cavity (5-19.5 mm)
DieL	- the total length of the test die (55-119 mm)
L-eff	- the effective length of the pressing section (diameter DieD) of the die (50-119 mm)
T-max	- the maximum temperature for the die (50-300°C)
TPL	- the top punch length (37.5-38.25 mm)
TPE	- a Modulus of Elasticity in [MPa] for the material of the top punch
TPa	- thermal expansion coefficient for the top punch [1/°C]
PPL	- the pressing punch **total length** (130-146 mm)
PPE	- a Modulus of Elasticity in [MPa] for the pressing punch
PPa	- thermal expansion coefficient for the pressing punch [1/°C]
PPuL	- pressing punch's undercut length in [mm]
PPuD	- pressing punch's undercut diameter in [mm]
PPuE	- a Modulus of Elasticity in [MPa] for the undercut section of the pressing punch
PPua	- thermal expansion coefficient for the undercut of the pressing punch [1/°C]

The top punch must be as shown on the punch drawing (Fig. 3). Most pressing punches (Fig. 2) are uniform in material and diameter so in such cases the data for the undercut parameters equal zero. In some cases, the pressing punch may have a pressing section with a nominal diameter DieD and an undercut section with a smaller diameter. Sometimes, the undercut section has the same diameter but is made of a different material. For those cases, the PPL refers to the total length of the punch, the PPu refers to the length of the undercut section, the PPuD is the diameter of the undercut section (equal or less than the nominal DieD), the PPE refers to the punch pressing section (with DieD) only and the PPuE refers to the

undercut section (with PPuD).

The die that is **actually installed** on the testing center is marked by ">" in the first column. That die cannot be removed from the table. Dies may be **Cut** from the list and moved to a buffer, **Copie**d to the buffer, and **Paste**d from the buffer to the table.

Before running a test, a given die must be first mounted (the **Change Die** option shows the mounting steps) in the PTC, it must be **Installed** (the data parameters must be checked for errors and all relevant constants must be calculated), and **Calibrated** (the position sensor must be initialized to correctly measure the compact length). *Note: The testing will not take place until the program first determines that the **die data are within limits** and then **installs** the die.*

IMPORTANT NOTE: *Changing a die parameter in the "Installed" die does not take effect until the button **Install** is activated. Only that makes the necessary changes in the control file that affect the operation of the testing center.*

The Die Table also lists the available **die temperature sensors**. The displayed sensor is the current sensor attached to the test die. Each sensor is identified by an ID inscribed on the sensor's plug and is defined by a specific calibration file. There are two basic types of sensors in use:

- thermistor type sensor for ranges 0-100°C or 80-300°C (individual calibration file required)

- platinum (RTD) type sensor (ID=999) for a range 0-300°C (general calibration file stored internally).

The user may **add** new sensors to the list, **cut** (remove) old ones, and **view** the calibration files.

6.2.2 Temperature Sensors

For hot or warm pressing, the computer expects to find the temperature sensor calibration data in the control file. The temperature sensor may be common to many dies. When a particular sensor is mounted on a die for testing, the sensor's ID must be selected in the sensors list.

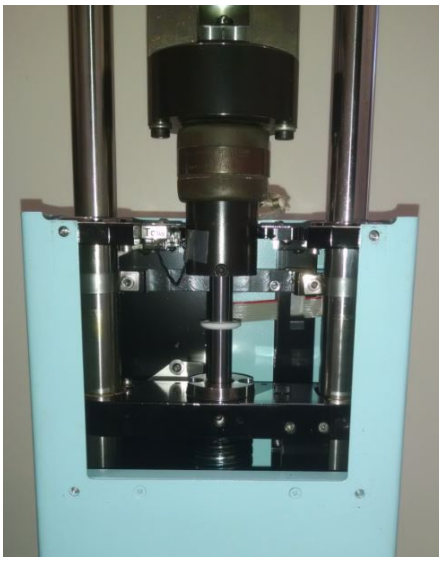
The PTC04DM uses **platinum temperature sensors** which are accurate in the 0-300^{0}C testing temperature range and do not require individual calibration. The sensors are identified with an **ID=999** and use a common calibration file identified as **T00999.CAL**. All PTC models can work with older thermistor sensors as well. All thermistor type temperature sensors are individually calibrated and the calibration files are kept on record. Each sensor has an ID number engraved on the plastic connector.

New sensors are delivered with a calibration file T#.CAL. The **Sensors** frame options are used to manage the calibration files. The **Load** button is used to find the calibration file and load it into the control file. Once loaded, the sensor is listed in the **T-Sensor List**. The **Cut** option removes the sensor data from the Sensor List.

6.2.3 Die Change

All PTC models have the same procedure for die changing. The only difference is the location of the power outlet for a Die Heater. The PTC-04DM model has the heating outlet attached to the back of the testing module behind the test die. All previous PTC models have the heating outlet in front, on the right, behind the die door.

Changing the test die requires the removal of the Die Door. The Die Door is mounted with thumb screws on the front of the PTC. Removing the screws and the door opens the access space for die change. MAKE ABSOLUTELY SURE THAT NOTHING DROPS INSIDE THE UNIT AND NOTHING IS LEFT HANGING ON OR STICKING TO THE SENSORS !!!



EXERCISE AN EXTREME CAUTION WHEN THE DIE DOOR IS OPENED !!!

The steps below are for a die change. Follow them in the order indicated. To dismount a die, reverse the steps.

a) Lock the Test Die base - tighten the locking screw through the opening on the top of the unit.

Note: Changing a die with the die unlocked WILL result in a serious die misalignment and can permanently damage the instrument!!

b) The punch mounting base should be positioned in mid-height of the die door. If necessary, move it up or down by pressing <U> or <D>, respectively.

c) Assemble the Test Die: the Test Die, the pressing punch, the teflon punch sealing ring (it prevents powder from getting below the mounting plate), the punch mounting plate and a die sealing rubber ring. For the sealing ring, use a silicon rubber o-ring or a sponge.

Note: The PTC-04DM model has a die heater outlet located on the back of the unit so the heater's power cable must be bent to the back of the die. For all older DT models, the power outlet is inside the unit and the power cable must be routed under the die sealing rubber ring (see picture above, on the right). The temperature sensor can be secured in the die with a piece of a teflon tape or a dedicated wire clip.

d) Push the pressing punch through the die above the top face and through the Die Installation Gauge. The gauge must be in the proper position (the letters on the gauge must be visible, on top). Lock the punch in the gauge with the locking screw to prevent it from dropping down on the bottom pressure sensor.

e) If the Top Punch is missing, install it into the Top Punch Sleeve and tighten the locking screw (first screw from the bottom.)

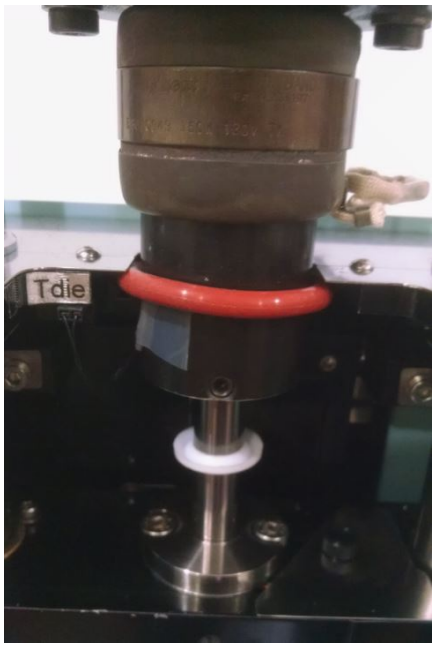
Note: For the PTC-03DT and PTC-04DT models, the Top Punch has a pin and a bearing strip on its side that keep the punch from rotating. Pull the handle all the way forward and down, insert the pin into the grove on the handle and move the punch up. The punch must be inserted into the fixture with the bearing strip on the right side.

f) Insert the die into the unit and slightly tighten one mounting screw. Use a 4 mm ball point hex key at an angle. The Die Installation Gauge should be pressed against the FRONT and LEFT wall of the die mounting base (see the red line below, on the right).

g) Tighten the other mounting screw.

h) Loosen both screws and press the die and the Die Installation Gauge against the FRONT and LEFT walls of the die mounting base, **see picture above, on the right**. Make sure that there is NO CLEARANCE BETWEEN THE WALLS AND THE GAUGE. Tighten both screws firmly.

i) Holding the pressing punch, release the lock screw in the Die Installation Gauge and gently lower the punch all the way down onto the pressing pressure gauge.



Install the punch mounting screws and tighten them. **When installed, the pressing punch must have some up/down clearance, one should be able to move it up/down slightly. If the punch does not have any up/down clearance, it is putting an**

initial pressure on the pressing load cell that could damage the load cell. To fix that, the test die has to be removed and bottom of the punch with the mounting plate thoroughly cleaned.

j) For PTC-04DM models only: keep the Die Installation Gauge on top of the die. For all older models, please remove the Die Installation Gauge and store it.

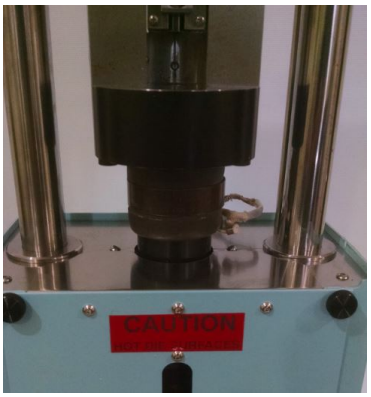
k) Position the Top Punch - NEW FOR MODELS PTC-04DM:

- slightly release the Top Punch Slide locking thumb screw on the back until the slide can be moved
- with the Die Installation Gauge on top of the die, move the Top Punch down and insert it into the gauge
- lock the Die Installation Gauge on the top punch and move the punch with the gauge up all the way
- press the Top Punch Slide and the Die Installation Gauge against the FRONT and LEFT walls of the die mounting base
- tighten the locking thumb screw on the back to lock the Top Punch Slide in place; *do not use excessive force*
- remove the Die Installation Gauge.

l) Move the rubber sealing ring to the surface of the die compartment bottom wall - see picture above. THE SEAL SHOULD PREVENT ANY CONTAMINANTS FROM ENTERING THE INSIDE OF THE UNIT WHEN THE DIE DOOR IS CLOSED. MAKE SURE THAT THE RING IS PRESSING AGAINST THE BOTTOM WALL.

m) Connect the temperature sensor to the connector on the left side. If needed, connect the heater's plug to the heating power outlet. For PTC-04DM models, the power outlet is on the back of the module. For other models, the outlet is inside as seen in the picture below:

n) Close the Die Door - tighten the mounting screws.



o) **RELEASE THE DIE LOCK. Turn the locking screw (on the top of the unit) 1 turn counterclockwise.**

Notes: Initially it may take some time to change a die. Typically changing the die takes about 3 minutes.
For new PTC models, the Top Punch can be changed without removing the test die.

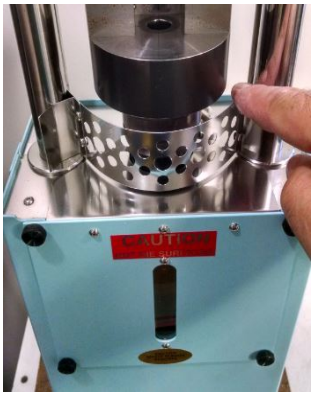
6.3 Die Heating and Heat Shield

This option allows the user to heat the test die to a specified die temperature. The temperature is typed in the **Desired T** box. During compaction tests in heated dies, the target temperature is provided by the program.

For all temperatures above 80°C, the top of the die must be covered with the **Top Die Heat Shield** accessory fixture to prevent heat radiation to the upper punch. The heating will not start unless the heat shield is inserted over the top of the die. However, pressing the confirmation several times allows the start of the heating even without the heat shield.

The heating cycle is controlled by constants that have to be determined during actual heating. Therefore, the first time after changing a heater or a die, the final temperature tolerance may be larger than desired. However, all following heating cycles should lead to an improved accuracy.

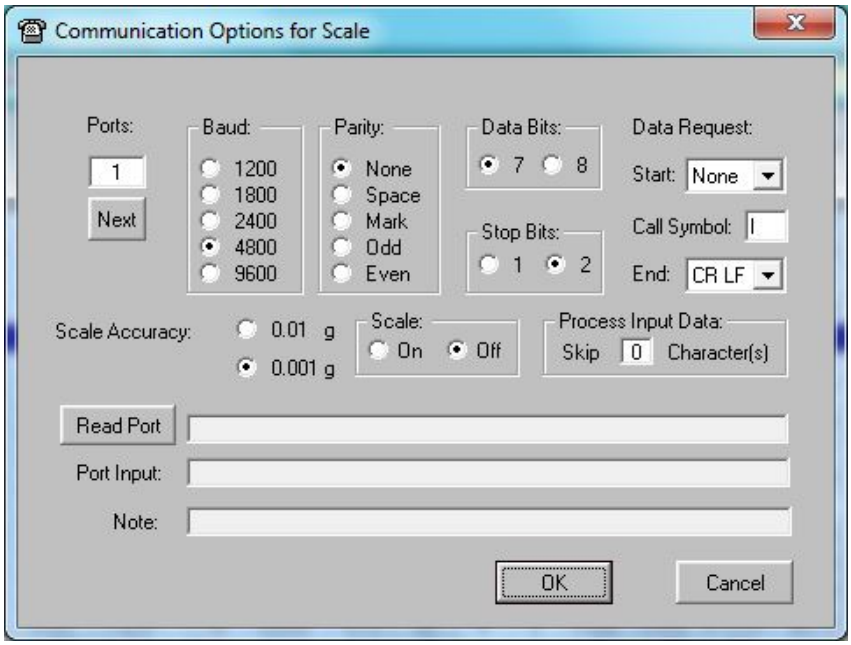
When testing with heat cycles, it is recommended to install the removable Heat Shield in front of the heater as demonstrated in the pictures below.



6.4 Scale

A scale (mass balance) may be connected to a USB or COM# port of the driving computer to allow direct readings of the mass of powder during testing. If the scale cannot be connected to a computer, a manual entry of the scale's reading is required when needed. The scale is called for during testing for bulk powder properties and during compaction.

The **Tests** window has a **Scale** button in the upper left corner. Activating it displays the scale window. To start direct readings, the communication parameters must be set correctly for the computer to establish a link. The **Setup** option displays the communication setup display.



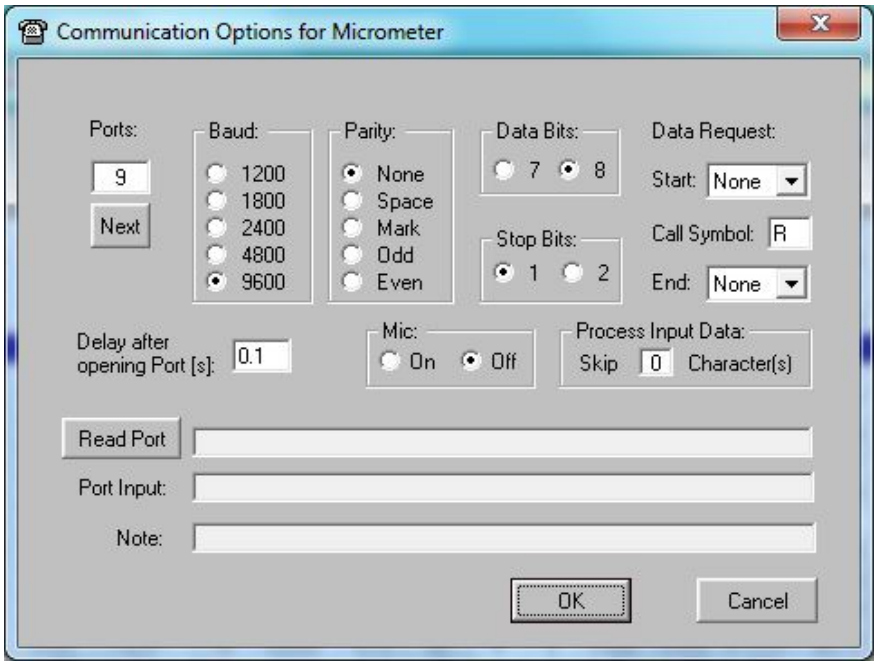
The manual for a scale must provide the required settings. The following settings are needed: **port, baud**, **parity**, **data bits**, **stop bits**, **calling symbol** to get the value, and **call ending** character. The connection port can be found by clicking the **Next** button which searches the next available port and tries to read from it, displaying the input in the **Read Port** window. One has to repeat the search until the input corresponds to the reading on the scale. If the input data starts with control characters, the **Skip** can be used to ignore them by the PTC program.

In addition, the **Scale Accuracy** should be selected based on the accuracy of the actual scale. The selection is needed to properly round off the needed powder mass for the compaction process. The scale calling routine may be turned on or off if needed. The program reads in units as set on the scale.

6.5 Micrometer

The micrometer is necessary for calibration and for the green expansions test. The necessary readings may be entered manually or, for the green expansions test, they may be taken directly from the micrometer by the program. A micrometer with a SPC capability and direct computer adapter may be connected to the computer. The program was developed for and tested with Starrett and Mitutoyo micrometers. Any other type may or may not work with this program.

The **Tests** window has a **Mic** button in the upper left corner. Activating it displays the micrometer window. To start direct readings, the communication parameters must be set correctly for the computer to establish a link with the micrometer. The **Setup** option displays the communication setup display.



The manual for a micrometer must provide the required settings. The following settings are needed: **port, baud**, **parity**, **data bits**, **stop bits**, **calling symbol** to get the value, and **call ending** character. The connection port can be found by clicking the **Next** button which searches the next available port and tries to read from it, displaying the input in the **Read Port** window. One has to repeat the search until the input corresponds to the reading on the micrometer. If the input data starts with control characters, the **Skip** can be used to ignore them by the PTC program.

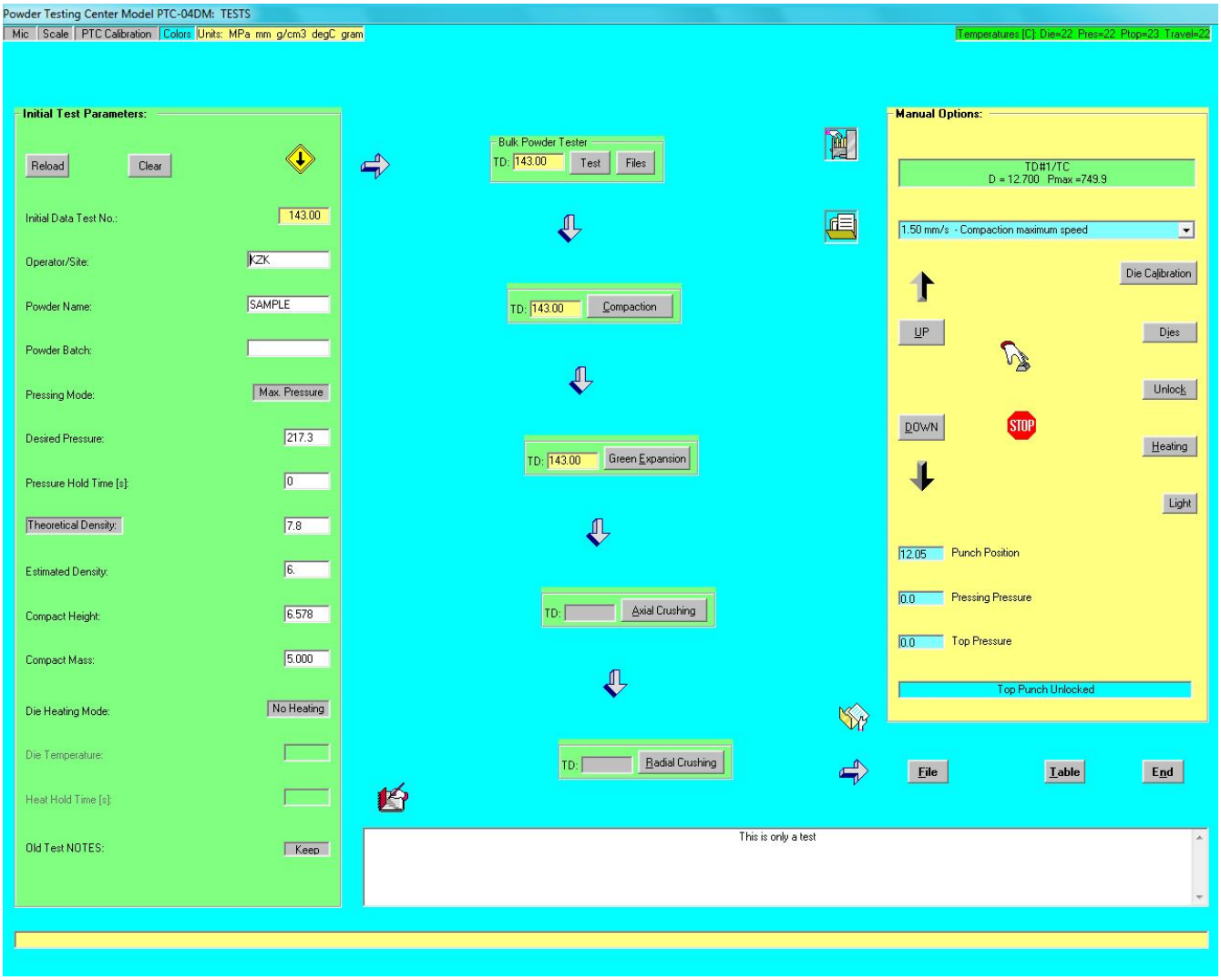
The micrometer calling routine may be turned on or off if needed. The program reads in units as set on the micrometer.

IV. TESTING

7. TESTS WINDOW OPTIONS

Always be aware of safety issues in dealing with the testing center:

* MAKE SURE THAT THE DIE DOOR (front main cover) IS IN PLACE !!!
* CHECK IF THE TEST DIE IS MOUNTED PROPERLY !!!
* **WEAR SAFETY GLASSES !!!**
* **USE EXTREME CAUTION WHEN THE DIE IS HOT !!!**



The **Tests** window display is the center point for all operations and procedures involving the testing center. The **Manual Options** frame provides access to all functions of the instrument (see Chapter 6 for details). The **Initial Parameters** frame contains all data necessary to conduct a test. There are several buttons that lead to separate windows to perform desired tasks.

The **access** frames to all individual tests performed on the testing center are arranged in a column connected with indicative arrows. A given testing may involve all the tasks on the screen (a **new** test) or it may be limited to a few selected tasks (a test **update**). Each access frame displays the test number for that portion of the test data. It is possible that a given test may have data from several tests (most often the Bulk Properties test is conducted for the first test on a new powder and

then several compaction tests may use that bulk data.)

The test data are stored in a buffer which is converted to a standard test data file with the **File** button option. The content of the buffer may be viewed by clicking on the "open file" picture button next to the **Manual** frame. The other picture button is a directory access button for test data directories.

The top of the screen provides white and red buttons for color setting (background, frames). The **Mic** button is a direct link to the micrometer option. The **Scale** button initializes the scale reading option.

The **PTC Calibration** option shows readings from all sensors and provides means to service and calibrate the testing center. One can use this option to verify sensor readings and positions of limit switches.

All temperature sensors are monitored by the program and displayed at the right top of the screen. All sensors are checked every second unless a specific test is conducted.

The current **units** are listed on top of the screen. To change any one of them, the user must click on the **Table** option to return to the Screen Table display and make the unit changes there.

The **End** button terminates the program preserving the current settings.

*At any time, the user may include test or personal observations in the **Test Notes** window. The notes will be attached to the test data file.*

7.1 General Requirements and Tolerances

There are many factors that affect the test accuracy, testing performance, and testing safety. Some of them are common to all powder pressings and some are unique to the PTC. A reliable and safe testing requires that users are familiar with the list below.

- **Die/punch tolerances**

Too tight tolerance between the die and the **pressing punch** can lock the punch inside the die. As a result, the punch holding ring (at the mounting end) will be sheared off and the punch will have to be repaired or replaced. On the other hand, a loose tolerance will cause some powder to get between the punch and the die and damage the die's surface. The correct tolerance must be selected for each powder and typically the judgment is based on experience. *New factory supplied test die set may require some polishing of the punch to get the desired tolerance.*

The **top (closing) punch** is stationary and can tolerate larger clearance which is needed to allow smooth closing of the die. If there are problems with closing the die, polishing the end of the top punch might be necessary. In addition, the die filling step may result in some powder coating of the die entry walls which may make die closing difficult. Again, increasing the punch clearance will typically remove the problem. Too large a clearance, on the other hand, will result in a sharp rim on the compact surface from the powder being pushed into the clearance during compaction.

- **Powder weighing**

The powder sample is weighted with finite accuracy. It is often surprising to see how big a change in pressing pressure the seemingly small amount of powder can make. One can use the options in the Edit TDF window to check it and get a measure of that change. That change will contribute to the accuracy of reaching the desired end point during compaction.

- **Die filling**

The die filling process can create nonuniform powder height in the die which can affect results, particularly for short compacts. The standard die filling fixture fills the die evenly with only slight powder elevation in the center of the die cavity. The relative error from the die filling nonuniformities is inversely proportional to the height over diameter ratio.

- **Compaction**

The end point of compaction is determined by sensor readings and the step motor is stopped. Due to the system inertial forces, there is always a small offset from the desired end point.

- **Punch friction**

The punch force measurements are direct by load cells beneath the ends of the punches. There is no direct die friction measuring sensor and the friction is calculated as the difference between the forces on the pressing and closing punches. It is assumed that the force measured at the pressing punch is entirely transmitted to the powder. However, the pressing punch experiences some friction at the die walls during compaction, particularly if the die/punch tolerance is incorrect, and that friction reduces the force transmitted to the powder.

- **Temperature effects**

The program compensates for thermal expansions of the punches based on temperature measurements of the die, the pressing and top punch ends, and the travel (position) sensor. For testing at elevated temperatures it is absolutely essential that the correct thermal expansion coefficients are entered for the given test die set. The program assumes a simplified linear temperature distribution along the punches which, in reality, depends on many factors. The thermal expansion correction may be off depending on the magnitude of those discrepancies. There will always be some discrepancies due to uneven punch cooling. In general, the magnitude of the possible errors is insignificant.

- **Position sensor errors**

The overall accuracy of the position is influenced by the electronic boards, temperature, and the ball screw mechanism that pushes the pressing punch (the sensor is attached to that mechanism and not to the center of the punch.) The sensor is calibrated at many points along the effective length. The program determines the actual position from linear interpolation between those points. In most cases, the overall accuracy is within the 0.01 mm range.

7.2 Initial Test Parameters

Test data from the last test file selected on the Screen Table Display or from a previous test is loaded into a test buffer file automatically and may be used as a background for a new test. A specific file may be loaded into the buffer by using the Directory (picture box) option.

The **Initial Parameters** frame provides a **Clear** button for clearing all entries and **Reload** button to load the initial background data. Two buttons at the bottom of the frame provide options for dealing with old Test Notes when starting a new test (**Keep** or **Clear**) and with the old crush data (Keep or Clear). The crush data options could be selected individually by clicking the buttons on the appropriate crush test frames.

The following parameters must be provided for a complete test:

- **Test Operator** or **Site** (name or an ID).

- **Powder Name**. Type in the given name or code for identification.

- **Powder Batch**. If needed, type in the specific powder batch number.

- **Theoretical Density** of the Powder Mixture. This is the density of a powder mixture with a 100% densification. All components and additives should be accounted for. (See 7.2.1 below.)

- **Pressing Mode**. Clicking on that button selects between three different compaction modes:

* Fixed **Maximum (Punch) Pressure**. All compacts will be pressed with the same pressure regardless of the compacting conditions.

* Fixed Green **Compact Density** - pressing to a fixed density (fixed compact length)

* Fixed **Net Test Pressure**. All compacts will be pressed with the same net pressure regardless of the compacting conditions.

The desired value for the corresponding parameter must be entered. When selecting the "Fixed Compact Density" option, the operator must provide a maximum allowable (safety) pressing pressure. This is needed to prevent over-pressing and test die damage.

- **Pressure Holding Time**. If needed, this is the desired time (up to 20 seconds) for holding the maximum pressing pressure on the compact before releasing and ejection.

- **Green Compact In-die Density**. This is the desired or reference density of the green compact measured IN DIE under load. For the fixed pressure modes, this density is used to determine the mass of the powder for the compaction. The actual compact density will be determined by the behavior of the powder. If the density of a free (out of die) green compact is known, it has to be recalculated based on green compact expansions:

$$\rho_{\text{in-die}} = \rho_{\text{out-of-die}} e_r^2 e_a$$

Here, e_r is the radial green compact expansion (in a direction perpendicular to the pressing direction) and e_a is the axial green compact expansion (in a direction parallel to the pressing direction).

- **Compact Length** - desired compact length The actual compact length must be between 2 and 16 mm.

- **Powder Mass** - the mass of the powder sample. The mass is rounded to 0.01 or to 0.001 gram according to the selected mass balance accuracy.

Note: The density, length and mass are interdependent and entering two of them will determine the third. The final values will be rounded according to selected accuracies and all parameters adjusted automatically to accommodate that. As a result, the specific combinations of parameters will be only those that are physically possible.

- **Die Heating Mode**. There are three die heating modes available:

* **No Heating** - testing at room temperatures

* **Cold Powder** - the die is heated, the heating stops, the die is filled with powder and compaction begins

* **Hot Powder** - the die is filled with powder, heated, the heating stops and the compaction begins.

- **Die Temperature**. For unheated dies, the die temperature will be provided by the program. For heated dies this is the desired test temperature. Clicking on the Heating Mode button changes die heating arrangement: no heating, cold powder pressed in a hot die, and hot powder that is heated with the die before compaction. Switching the heating arrangement is available only when a hot pressing die is installed.

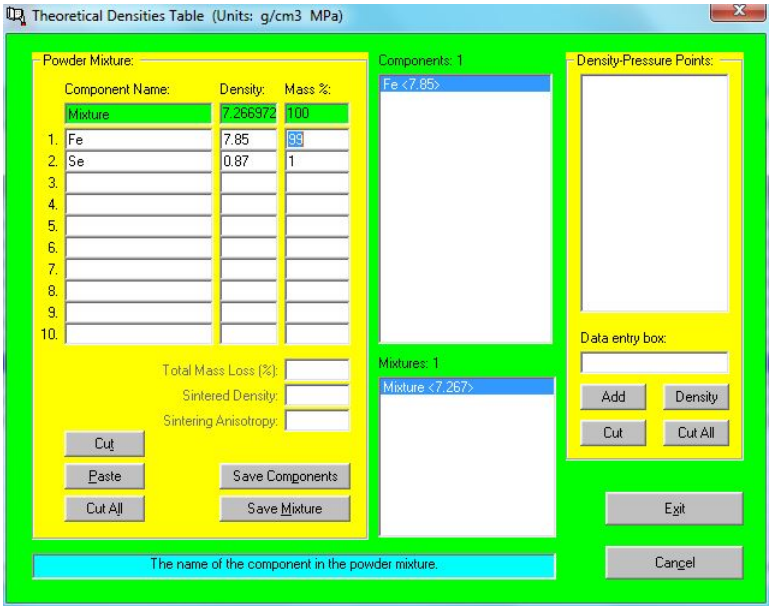
- **Heat Holding Time** - available only for hot pressing. This is the time interval in which the die temperature is maintained at the desired level before the test is initiated. It could be between 0 and 199 seconds.

If the test involves the Bulk Density test only, the only initial data needed are the first three entries in the above list. For tests involving compact crushing only, the first two entries in the above list are sufficient.

7.2.1 Theoretical Density Table

Clicking on the theoretical density button activates the Theoretical Density display. The theoretical density of a powder mixture is the mixture's density at full (100%) densification. The PTC program provides a table where the user can enter all the components of a mixture with their densities and mass (%) contribution. Once the total reaches 100%, the mixture's density is calculated. The **Cut** option removes a component (line) from the table, the **Paste** copies the cut component into the table. The **Cut All** option clears the table. The **Exit** copies the mixture's theoretical density value into the corresponding entry in the Tests display.

The **Save Component** option saves all individual components and the **Save Mixture** option saves mixtures in a data base for future access. Inserting a saved mixture/component from the data base into the current table is done by double clicking that entry.



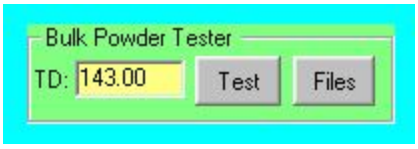
The sintering parameters (total mass loss, sintered density and sintering anizotropy) for the powder may be entered here as well to allow shrinkage calculations during a sintering process. The same parameters may be entered at the end of a test in the Edit TDF option (see below.) The **Total Mass Loss** accounts for the total mass change in a compact between compaction and after sintering. Any mass losses (moisture, lubricants, binders, ..) or gains (oxidation, ..) must be accounted for to assure accuracy. The **Sintering Anisotropy** is the axial to radial shrinkage ratio for isostatically densified compacts. In most cases, it is equal to 1.

For powders that exhibit theoretical density variation with pressing pressure there is an option to enter the density-pressure characteristic defined by several points on that characteristic. The theoretical density and the corresponding pressure are typed in the **Data entry box**. For a valid characteristic, at least two points must be defined. The Add option saves the entry in the standard Test Data File.

With the characteristic defined, typing any pressure value within the characteristic and selecting the **Density** option will calculate the corresponding density and display it in the Data entry box.

7.3 Bulk Powder Properties

The bulk powder properties that constitute an integral part of the powder test can be generated in two ways:



- select the **Test** option in the Bulk Powder Tester frame (BPT Testing) and run a bulk powder test with the Bulk Powder Tester

- select **Files** option in the Bulk Powder Tester frame (BPT Files) and import the bulk powder test data from a test run previously.

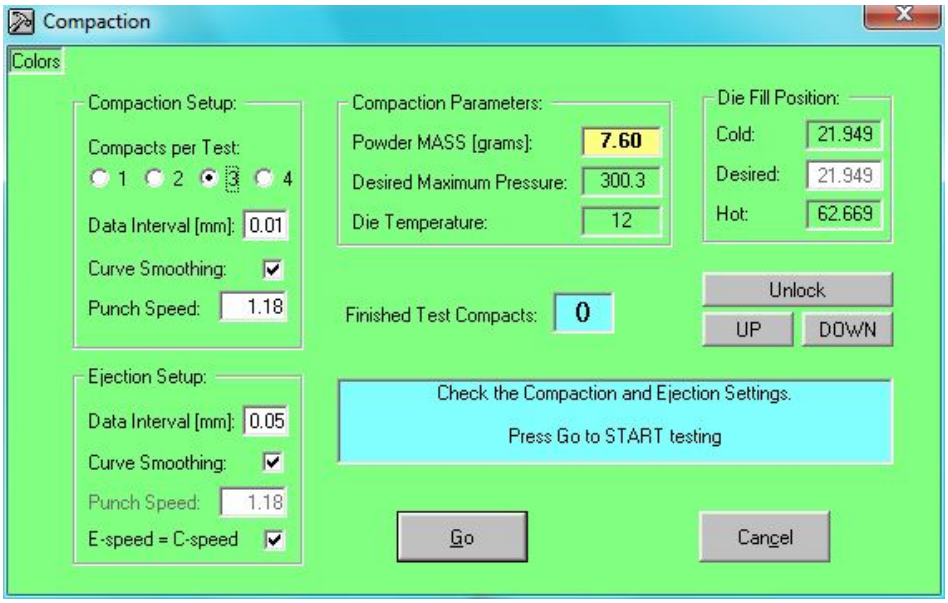
The basic properties of a loose powder needed are: the angle of repose, the bulk density and the tap density together with the number of taps. The PTC Test Data File also records the relative air humidity in the testing room as well as the room temperature. The Bulk Powder Tester stores all bulk powder test data in separate files which permits, if desired, the BPT tests to be run independently from the main PTC test.

7.4 Compaction and Ejection

THIS TEST INVOLVES HIGH FORCES - EXERCISE EXTREME CAUTION DURING TESTING!

The compaction test determines the relevant data and generates compacts for crushing tests. For a standard test, there are two compacts needed for axial and radial crushing. One may also wish to preserve one extra compact for sintering or other uses. The user specifies how many compacts should be generated (1 to 4) during a test. After each compaction is completed and the compact is ejected, the unprocessed data are saved and the next compaction begins. After the last compact is made (or if the process is interrupted and canceled), the user must determine which compaction data set to use (only one set will be used to calculate all necessary parameters and generate test data file). By default, the last compact is suggested. It is imperative to identify the correct compact before verifying its mass and determining green expansions.

There are several settings that affect the compaction and ejection processes. The Compaction Parameters frame displays the desired compaction parameters: powder (compact) mass, desired density or pressure, and the desired or actual die temperature. The powder mass is displayed on all screens during initial steps to allow the user to weigh the powder sample in advance and speed up the overall test.



The **Data Interval** specifies (in mm) the interval between data points that are stored during the compaction process. If the interval is smaller than the sampling capability of the system, all sampled points will be stored. (This option is used most often to limit the number of points in the compaction characteristic.)

The **Pressing Speed** sets the punch speed during compaction.

The **Curve Smoothing** option turns on and off the basic compaction data filtering procedure. The filtering is very limited and designed to eliminate random variations.

The **Ejection Setup** frame provides similar options to those above. The **Ejection Speed** sets the punch speed during compact ejection. The speed can be the same as compaction speed or set separately.

a) Initialization: Go

For testing, the test die must be unlocked (the Die Locking screw must be released to allow the die down motion). The PTC moves the pressing punch to the pressing position.

b) Powder weighing

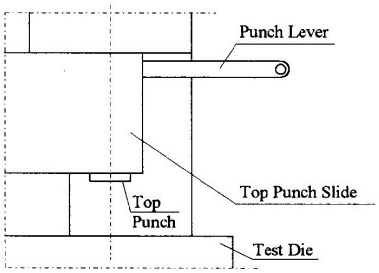
Note: The powder mass is displayed during initialization. Weigh the powder during the time when the punch moves to pressing position! There is no reason to wait.

The powder weighing is the most common cause of errors and discrepancies in test results! Use of an accurate and stable scale is required. The mass of the powder must be at least within 0.01 gram of the required one.

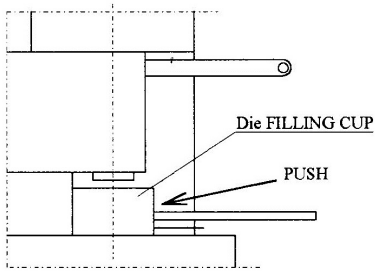
Note: If the required powder volume is higher than the volume of the cup, you may weigh only a portion of the required powder mass at a time, place the powder into the die, then repeat the operation.

c) Place the powder in the die and run the Compaction

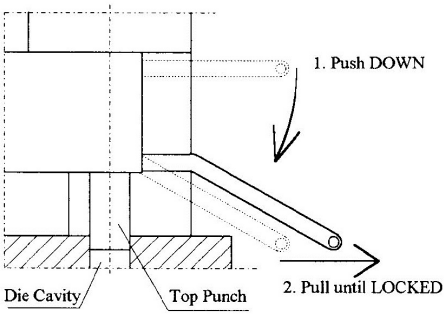
For pressing in heated dies, the option "cold powder" will first activate the die heater and, after the desired temperature is reached, the program will call for filling the die. The option "hot powder" will ask the operator to place the powder in the die first and then it will heat the die with the powder in it. During a die heating, the Top Punch must be in its upper position and the top of the die must be covered with the die's Heat Shield. WHEN FILLING A HOT DIE, USE EXTREME CAUTION NOT TO TOUCH THE EXPOSED HOT DIE SURFACES. RECKLESS OPERATION WILL LEAD TO SEVERE BURNS !!



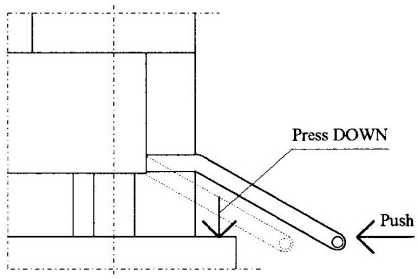
Ready for Die Filling



Die FILLING



Top Punch LOCKing



Manual Top Punch UNLOCKing

Follow these steps:

- Move the Top Punch in the upper position.

- The die cavity may be cleaned if necessary with the die cleaning pads and the cleaning rod. In extreme cases, the die may be removed from the PTC and cleaned outside.

- Fill the die. Place the filling cup with the powder on the surface of the die and slide it into the die base cavity by pushing it towards the PTC. The cup's shutter will open and the powder will fall into the die cavity.

Note: In some cases the powder will not fall easily into the cavity. Use the vibrator by touching the cup with the vibrating ball tip and turning it on. In extreme cases, use the teflon rod to push the powder into the cavity. Powders with a high densification ratio (green compact density over bulk density) will require the use of the teflon rod to densify the powder in the die cavity or the powder itself may be pre-densified into pellets prior to filling the die cavity.

- Lock the Top Punch. Press the punch lever down until the punch enters the die cavity. Lock the Top Punch by pulling the punch locking lever until a "click" is heard. If the lever does not want to go forward, the punch is not deep enough in the die. Press the punch down and lock it. DO NOT APPLY EXCESSIVE FORCE DURING THIS OPERATION. THE LOCKING MECHANISM IS DELICATE AND MAY BE DAMAGED IF OVERLOADED. The test will not begin until the punch is locked.

d) Compaction Test - Please Wait

Lock the Top Punch and select Go to start the compaction. If any problem develops, the compaction will be interrupted and appropriate message will appear on the screen. The pressing mode parameter (length or pressure) is

displayed continually as well as the punch speed, its position, the pressing pressure, the opposing pressure. The compaction may be stopped at any time by pressing any key on the keyboard.

Note: The compaction will always end within a tolerance range from the desired value and the tolerance is self adjusting. For repeated compactions, the tolerance is quite small. However, if the compaction conditions change significantly from test to test, the tolerance may increase for the first few tests before it adjusts to the new conditions.

e) Compact Ejection

The Top Punch should unlock automatically. If not, a message appears with instructions to unlock the punch manually. In such case, firmly press the die down and push the punch locking lever until it slides back. DO NOT USE EXCESSIVE FORCE!

During the ejection, the punch position and the pressure on the ejecting punch are displayed. At the very beginning of the ejection, the program executes fast data readout which shows as a temporary halt in screen displays. If the ejection process cannot be completed for some reason, use the manual UP option to remove the compact out of the die.

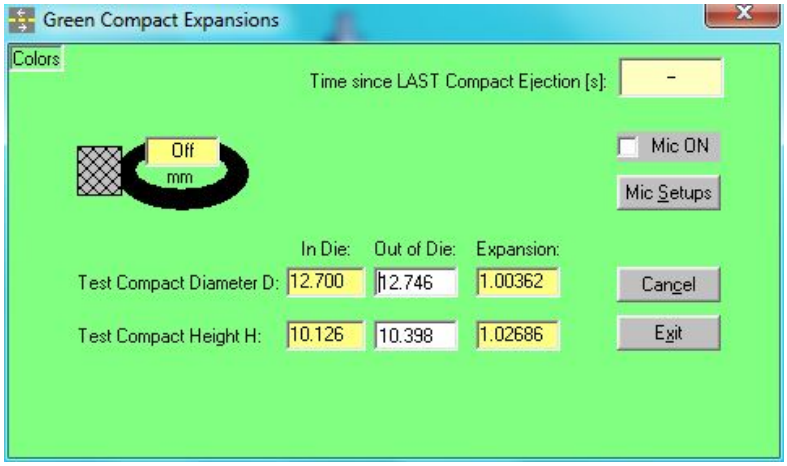
Use the tweezers to remove the compact from the top of the punch. The compacts must be put aside in an organized manner to prevent mixups. Once the compact is removed, the initialization for the next compaction is started immediately until all specified compacts are made.

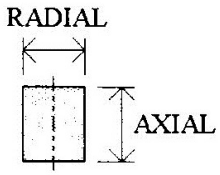
The Compact Mass Verification display is to determine the actual mass of the specified compact, calculate necessary compaction data and store the data in the data buffer. One must make sure that the compact selected on the screen corresponds to the actual compact being used for the mass verification and green expansions. The actual compact mass can be typed in or it may be taken directly from the scale by the program.

For hot pressing, the pressing punch will withdraw to the very bottom position. *STOPPING THE PUNCH AT A HIGHER POSITION WILL INCREASE HEAT TRANSFER FROM THE DIE TO THE PUNCH AND MAY CAUSE OVERHEATING AND DAMAGE THE PRESSING LOAD CELL. USE EXTREME CAUTION WHEN TESTING IN A HOT DIE. DO NOT TOUCH THE EXPOSED HOT DIE SURFACES OR THE HOT COMPACT. ALLOW THE COMPACT A SUFFICIENT TIME TO COOL DOWN.*

7.5 Green Compact Expansions

For cold pressing, this test is performed immediately after compaction. However, for hot pressing, this test may be conducted at a later time. The green compact dimensions after ejection from a die change with time. For that reason, the program displays the **time elapsed** from the last ejection.





The screen displays the actual dimensions of the compact in the die under load. Use a micrometer to measure the height and the diameter of the compact at mid-height. The actual measurements may be typed in or taken directly from a micrometer (if connected to the computer). For a direct reading option, pressing the **Space Bar** lets the program determine if a given measurement is the diameter or the height of the compact. For compacts with a diameter similar to the height, using the Space Bar may not assign the values correctly. Use the **D** or **H** keys instead to place the measured values in proper place. The **Green Expansions** are calculated automatically. The **Enter** key saves the data and exits.

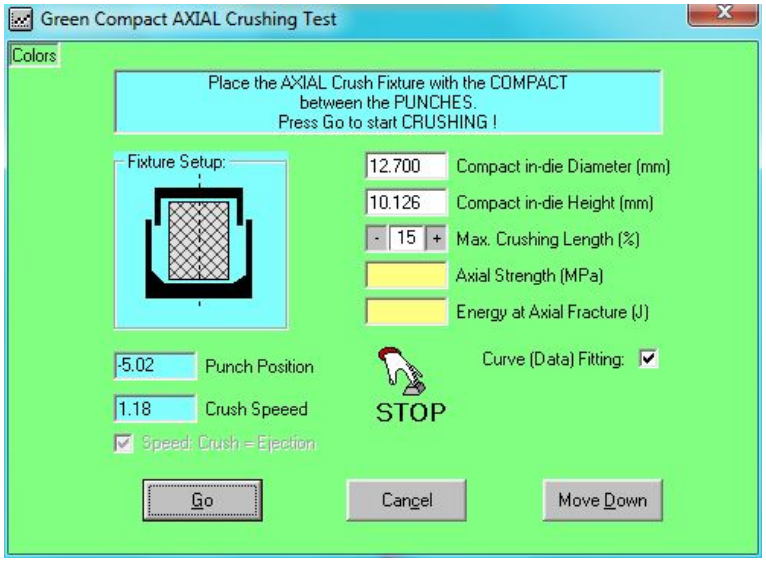
7.6 Axial Crushing

ATTENTION! *This test is only for compacts in the 7 to 16 mm length range. Compacts outside this range may not fit in the crushing fixture and, if tested, MAY CREATE HAZARDOUS CONDITIONS during the test.*

For the test to be successful, there must be a noticeable drop (at least 30%) in a crushing force after the compact crushes. The **Green Strength** value is not reliable if there is not a clear pressure drop after the crush of the compact (see the crushing characteristic).

When this test option is selected, the testing center automatically brings the punch to the proper crushing position. The user must wait until the motor stops and the full option's window appears. The crushing fixture and the compact orientation is displayed on the screen.

Although most crushing tests are performed immediately after compaction, the crushing test can be performed on any green compact (**DO NOT use the unit for crushing sintered compacts!**) as long as a proper crushing fixture is used. However, if the punch diameter is smaller than the compact's, the punch may be damaged during the crushing.



The **Compact Diameter** and **Compact Length** windows display the values as stored in a buffer. Those dimensions must be correct for the tested compact. They need to be changed only when crushing compacts with different diameters than the installed die diameter. When conducting the crushing tests alone, those values must be typed in.

The **Crushing Length** is the maximum length the punch will move after the crush (detected force on the punches) is initiated. If the length is too short, part of the crushing characteristic may not be captured. For short compacts, the crushing length must be short to prevent recompacting of the powder (short compacts may not fall apart and will be recompacted instead, possibly overloading the testing center.) The "+" and "-" buttons adjust the value within the allowable range. In any case, the actual crushing length will always be within 0.5 to 2.0 mm.

Checking the Data fitting (smoothing) option results in crush data filtering to eliminate random variations. One should remember that the distance between acquired crushing points is much smaller than the nominal accuracy of the position sensor. For that reason, the position values must be properly filtered and smoothed.

The steps for this test are:

a) Put the compact on its face inside the **Axial Crushing Cup** and put the proper cup's cover on top (the cover with highest thickness possible to let the Crushing Cup in position between punches)

b) Insert the Crushing Cup with the compact between the punches.

MAKE SURE THAT THE CRUSHING CUP IS ASSEMBLED CORRECTLY AND IS IN POSITION. THERE ARE VERY HIGH FORCES DURING CRUSHING THAT MAY CAUSE SERIOUS HARM IF THE TEST IS NOT CONDUCTED PROPERLY !

c) Activate the **Go** button or Press <Enter> to start the test. The computer performs rapid data readings during the crushing and displays the maximum crushing pressure after the test is done.

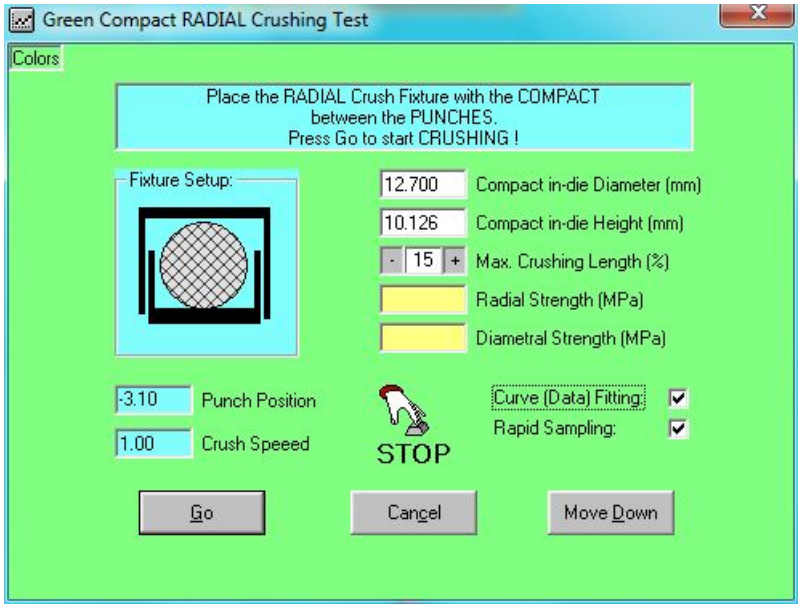
d) Remove the Crushing Cup after the test. Clean the cup and the test area.

The computer will move the punch down in position for the next crushing test.

7.7 Radial Crushing

Note: The Radial Crush Test may not be possible for very fragile compacts that break too fast to get sufficient readings. The program always tries to get the maximum breaking force which may provide the Diametral Strength even without the complete characteristic. This test also may not be possible for compacts that are too long to fit into the crushing fixture.

The options for the Radial Crushing are similar to the ones for the Axial Crushing above. The radial crush test generates the Radial crushing force characteristic. Based on that characteristic, the Radial and the Diametral crushing pressures and characteristics are computed. All three characteristics: the Radial pressure, the Diametral pressure, and the Radial crushing force, are stored in that order in the test data file.



The steps for this test are:

a) Put the compact on its side inside the correct **Radial Crushing Cup** and put the **Cover** on top (the cap's handle fits into the slot in the cover.)

b) Insert the crushing fixture with the compact between the punches.

MAKE SURE THAT THE CRUSHING FIXTURE IS ASSEMBLED CORRECTLY AND IS IN POSITION. THERE ARE VERY HIGH FORCES DURING CRUSHING THAT MAY CAUSE SERIOUS HARM IF THE TEST IS NOT CONDUCTED PROPERLY !

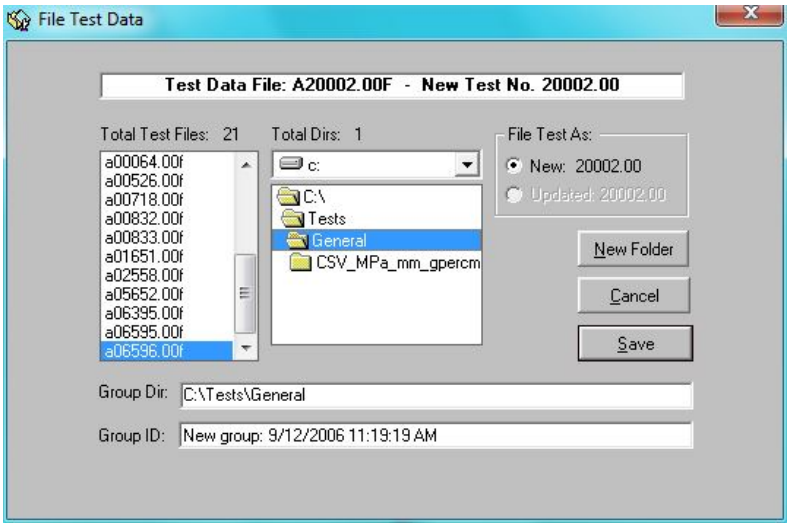
c) Activate the **Go** button or Press <Enter> to start the test. The computer performs rapid data readings during the crushing and displays the crushing pressures after the test is done.

d) Remove the crushing fixture after the test. Clean the cup and the test area.

The computer will move the punch down.

7.8 File Test Data

The control file keeps a global test counter and every new test is assigned a new test number. If a filed test data contain any data from a previous test, the program provides an option in the File Test As frame to save the new file in place of the previous one ("updated file") without increasing the test counter. The destination file name is always displayed on the screen.



The user has to select the directory where the file will be placed. The test data file directories should be distinctive and separate for similar powders. Do not put test data files in directories with other program files! With the New Group option a new directory may be created (at that point only the path is created). The user should change the new directory name as needed. The Group ID is a file content description text used to provide easy recognition for a given directory. That ID name appears in many places within the program (it is listed on the Screen Table Display). The ID may be changed if needed and, together with the new test data number, will be stored in a group file A00000.00F.

Note: There must be new test data parameters in the buffer to activate the filing option. If there is a new data in the buffer and the user attempts to exit or terminate, the program will display a reminder to save the data file

V. BULK POWDER TESTER

8. The Bulk Powder Tester.

The Bulk Powder Tester ("BPT") is an independent testing instrument for bulk powders. The BPT module is mounted to a bracket attached to the side (right or left) of the PTC testing module. The module can also be mounted on an independent stand and operated with or without the main testing module. The testing assembly on the stand can be moved up/down on the columns to a desired height.

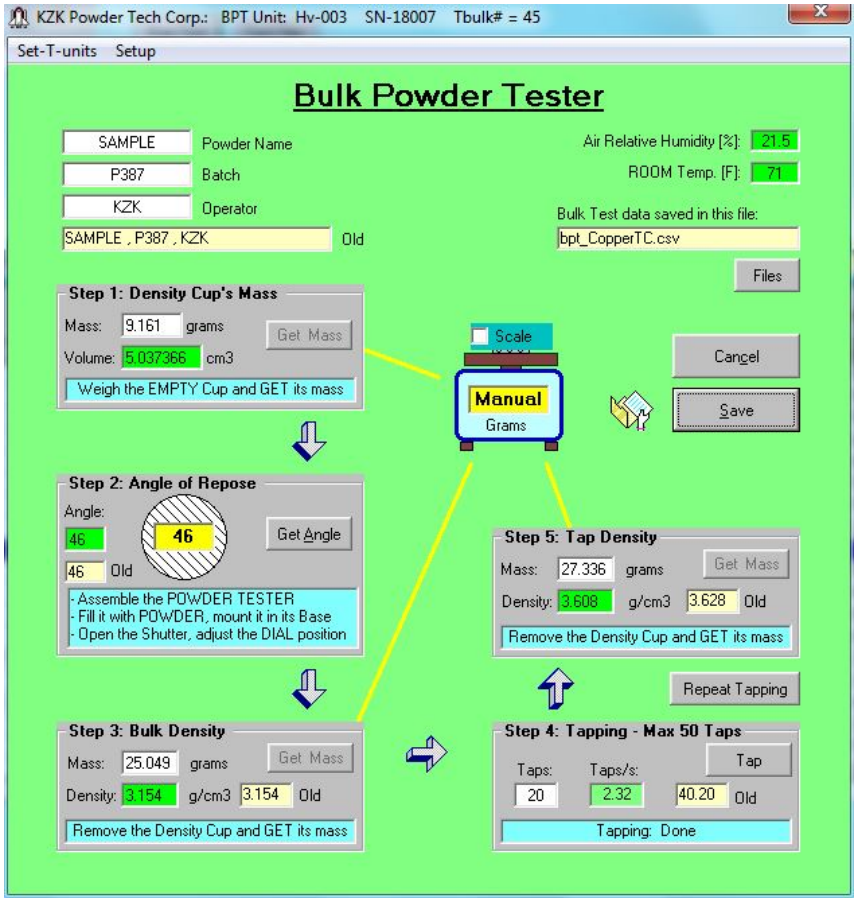
The BPT module is shipped fully assembled and ready for testing. The module is powered entirely by the USB connection with power requirement of around 0.3 A at 5 V. In a standard arrangement, the unit is plugged into a USB Hub with independent power supply to ease power drain from a computer (particularly important when connected to a laptop).

When in operation, the BPT activates an LED lamp to light up the angle of repose dial. In some arrangements, a micrometer holding arm is attached to one of the BPT's columns. The position of the micrometer is adjustable.

The test results are always saved in .csv (comma separated value) files compatible with spreadsheets. When run as part of a standard PTC test, the test results are transferred to the main testing window.

8.1 Bulk Powder Test

This test determines the properties of a loose powder: the angle of repose, the bulk density and the tap density. The test's display shows five separate frames corresponding to the steps necessary for completion of the test. Each frame displays instructions and the focus will automatically transfer from frame to frame. The tester has its own microcomputer that stores all setup data. The USB connection provides the power for all sensors and the tapping motor.



The options at the top of the display provide basic setups. The **Set-T-Units** option selects between F and C degrees for room temperature. The **Setup** provides the following options: **Set Scale** for scale setup options, **Adjust Room T** to initialize (determine the offset for) the room temperature sensor, **Initialize AOR** (initial offset), **Load Calibrations** (re-initialize the BPT) and **Control Data** for checking the calibration data.

By default, the current frame is displayed in yellow color. When computer establishes a communication link with the scale, the scale's reading is taken by clicking on the **Get Mass** buttons when needed. For scales not connected to the computer, the **Get Mass** buttons are disabled and the user must type in the specific mass values.

The bulk test data from a previous test are displayed as "Old" values for reference. The **Cancel** option exits the program without saving any test data. Any new control settings are always preserved as soon as they are made. The **Save/Exit** option performs the following:

- saves the bulk test data in a .csv format in the file listed in the window above the **Files** button

- with **Save/Exit** option, it transfers the bulk test data to the PTC compaction test and exits the program

- with **Save** option, it moves the new test data into "Old" display windows and clears all entries for a new test with the exception of Powder Name, Batch and Operator.

In addition to standard bulk test data, the BPT collects two general data: testing room humidity **HR%** and room temperature **Troom**. The BPT uses a gravity sensor for reading the angle of repose. Those type of sensors do not require any calibration beyond the initial one.

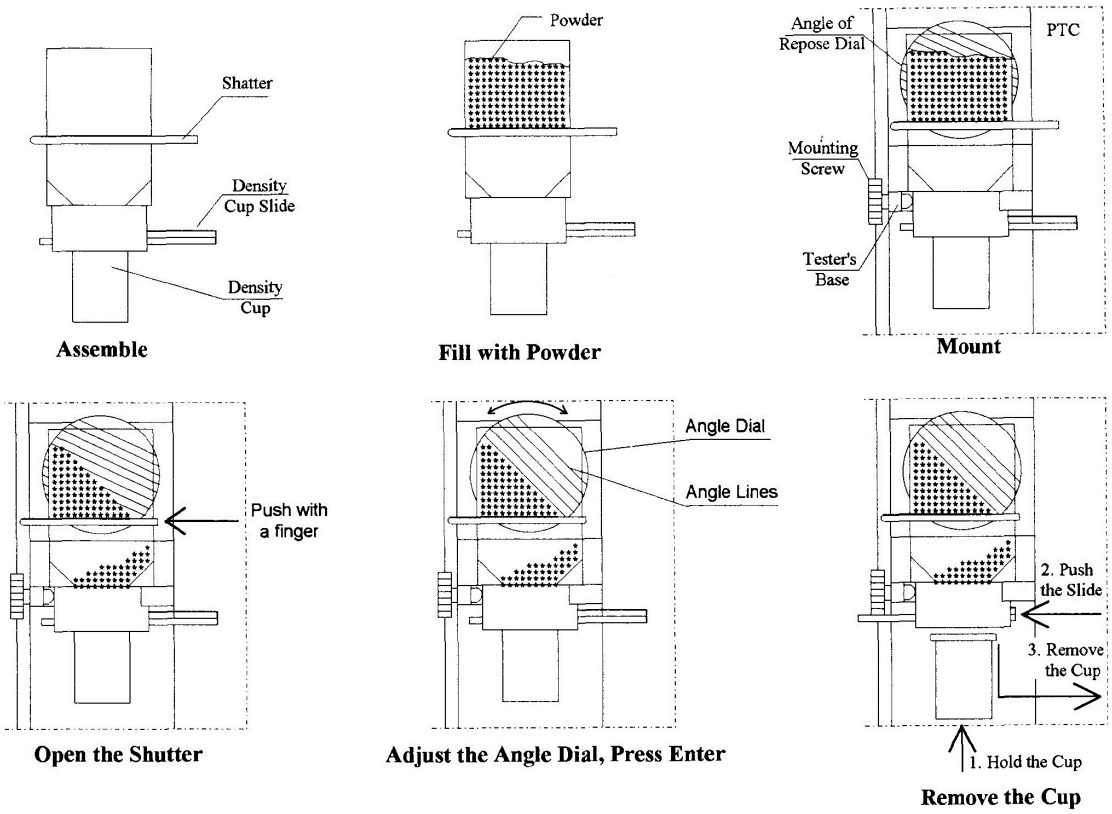
Step 1: The mass of the empty bulk density cup

It is highly recommended to weigh the bulk density cup before each test to account for possible mass changes due to deposits on the cup's walls. If necessary, the program will use the cup's mass stored in the control file. That value is updated whenever the cup is weighted. The user may also change the volume of the cup.

Note: The volume of the cup is engraved on the bottom of the cup. Any error in cup volume or mass will directly affect the test results.

Press **Tab** key to move to the next step.

Step 2: Measure the Angle of Repose



a) Assemble the Powder Tester: install the shutter and the empty density cup

b) Fill the tester with Powder, at least 70% of the volume above the shutter

c) Mount the tester on its Base on the BPT, tighten the mounting screw

d) Open the Tester's Shutter until the powder starts to flow

e) Wait for the powder to stop flowing

f) Set the Angle Dial parallel to the powder surface

g) Click the **Get Angle** button or press the Enter key.

Step 3: Bulk Density

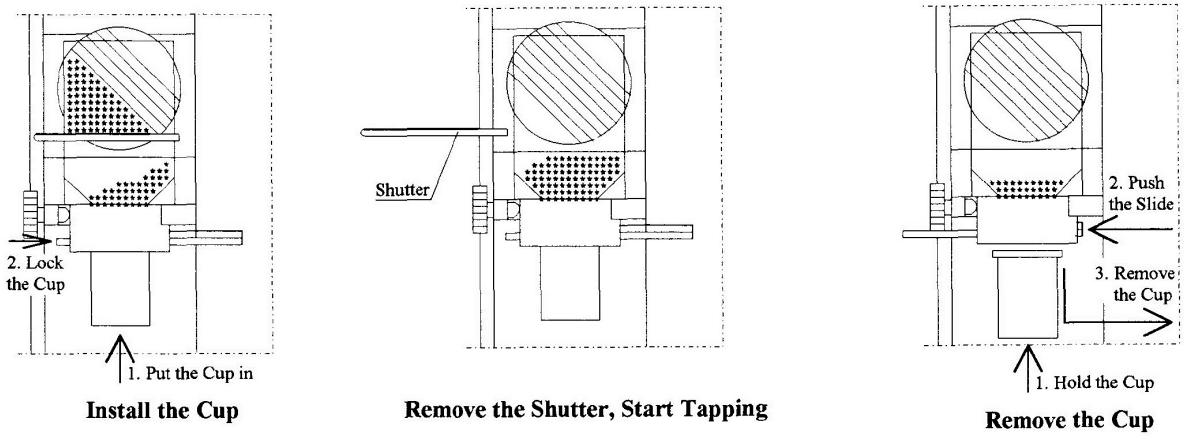
a) Push the density cup slide lock to the end. *HOLD THE CUP WITH YOUR OTHER HAND.*

THE CUP WILL FALL ON THE SHELF IF UNLOCKED AND NOT HELD.

b) Place the cup on the scale. In a manual mode, type in the weight

Press Enter key to move to the next step.

Step 4: Tapping



a) Install the density cup with the powder back into the Powder Tester.

b) Remove the Shutter from the Powder Tester.

c) Make sure the mounting screw holds the Powder Tester tight

d) Edit the tapping parameters if needed

e) Start tapping.

When done, the focus moves automatically to the next step.

Step 5: Tap Density

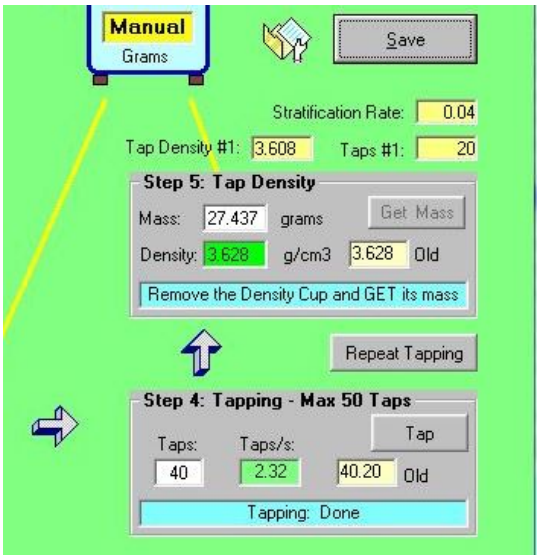
a) Remove the density cup from the tester

b) Weigh the density cup. In manual mode, type in the mass.

Step 6: Optional - Powder Stratification Rate

Once the **Tap Density** is determined, a new option **Repeat Tapping** appears. If selected, the current tap density is moved to **Tap Density #1** and the taps number is moved to **Taps #1**. Then, the focus goes back to **Step 4. Tapping** and the tapping test steps are repeated.

NOTE: *For this testing, it is suggested that one starts first with* ***Taps#1=20-30*** *taps repeated with* ***Taps#2=10-20*** *taps.*



When the new Tap Density is determined, the program automatically performs the following steps:

a) The number of taps in the **Tap** window changes to the total taps for both tests (Taps#1 + Taps#2), reflecting the total taps corresponding to the final tap density

b) A Stratification Rate is calculated:

$$StRate = [(TapD - TapD\#1)/Tap\#2] / [(TapD\#1 - BulkD)/Tap\#1]$$

where TapD is the Tap Density, BulkD is the Bulk Density, Tap#1 is the number of first taps, Tap#2 is the number of last taps. The StRate is displayed on the screen.

c) The final tapping number is combined as:

$$Taps = (Taps\#1 + Taps\#2) + 0.01 * Taps\#1$$

Example: Taps#1=20, Taps#2=10 => Taps=30.20 , that will be the taps number stored in test data files.

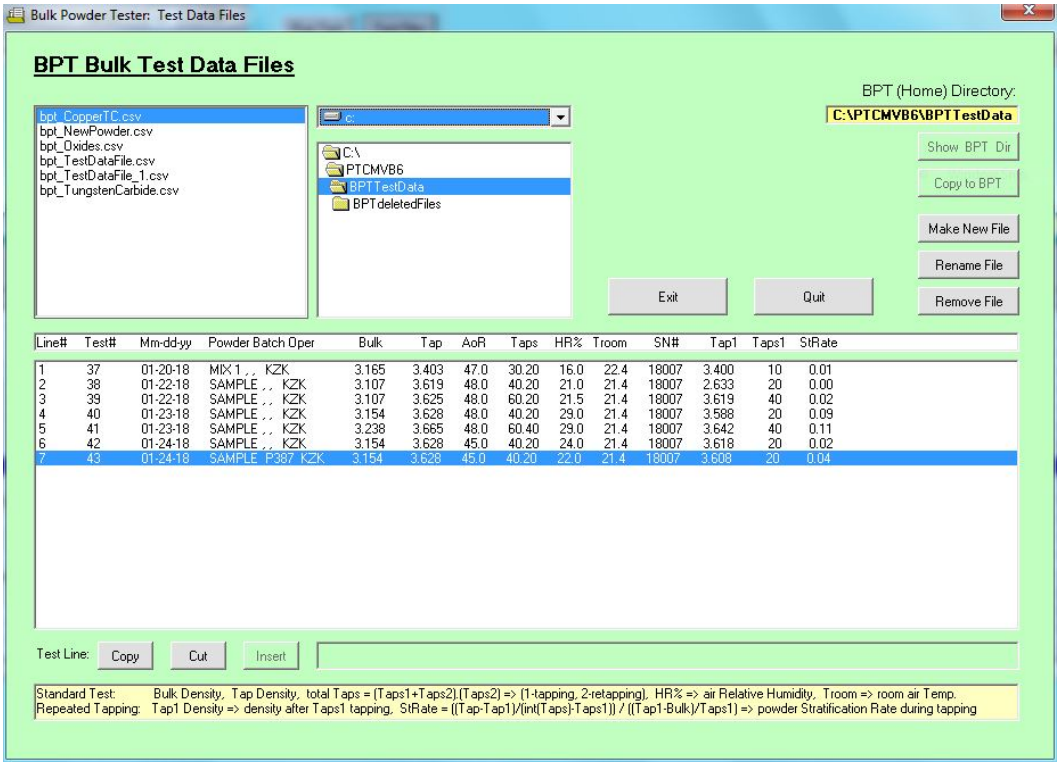
NOTE: *The bulk and tap density tests* ***use powder from the bottom*** *of the Powder Tester fixture. During tapping, at first the powder primarily settles down and then starts stratifying with smaller and heavier particles migrating down. The Stratification Rate reflects the change in powder density during tapping.* ***It is not recommended to tap for more than 40 taps total since the tap density will be influenced by stratification.***

End Step: Remove the Powder Tester from its base and clean the area - use the vacuum cleaner

That completes the test. The area should be kept clean at all times. *DO NOT BLOW AIR TOWARD THE PTC - ALWAYS USE THE VACUUM CLEANER.*

8.2. Bulk Test Data Files

The BPT program maintains in its application directory a **BPTTestData** folder for all test data files generated by BPT. The test data from a single bulk powder test is stored in a single line added to the end of a data file. The data file has the .csv (comma separated values) format that is compatible with most spreadsheets. It is advisable to create a separate data file for each different powder. All bulk data files in the current directory are displayed on the screen. The highlighted file's content is displayed in the center of the screen, each line representing a single test.



Using the **Quit** option exits the screen without any other actions. The **Exit** option copies the current data file path and the test data from the test line highlighted on the screen into a data buffer used for testing.

When in the BPTTestData ("Home") directory, data files can be renamed (**Rename File**) and deleted (**Remove File**). A new files can be created (**Make New File**) as well. By definition, the name of a data file always starts with "bpt_" followed by user provided FileName and ending with ".csv" (format compatible with spreadsheets.)

For the screen displayed file, single Test Data lines can be **Copied** or **Cut** (removed) and moved into a temporary buffer displayed to the right of the command buttons (below the main data display window). The data in the buffer cannot be deleted, it can only be replaced with another Copy/Cut command or **Insert**ed into any data file. This is used for rearranging the order of the tests in a file or moving test data between files. All **Cut** test data lines and **Removed Files** are moved to a **BPTdeletedFiles** folder in the Home directory where they can be accessed later if needed.

All data files in directories other than BPTTestData (including files on other computers or servers) are "read-only" files. Individual test data lines as well as files can be copied to home directory (**Copy** or **Copy to BPT**) . The **Show BPT Dir** option returns the focus back to the Home directory.

VI. SAFETY & TECHNICAL DATA

9. SAFETY

The PTC generates very high forces while in operation. The hardware and software incorporates several safety features designed to prevent unintentional (accidental) damage to the unit. Among them:

a) The program stops the PTC immediately after a maximum allowable force on the punches is exceeded. The maximum force is set by the user (a **Test Die Table** parameter) but it cannot exceed the absolute maximum for a given unit. It is highly recommended that the users set that value to a reasonable level for each die individually to prevent unnecessary overloading of the test dies.
b) The program will not move the pressing punch up if the top punch is locked except during compaction and calibration cycles. It will also stop the pressing punch up motion immediately when the top punch is locked at any time.
c) The program will stop the motion of the pressing punch if it determines that the punch moves in the wrong direction.
d) All tests with pressing punch motion will stop if interrupted manually (by pressing any key) or if any safety is disengaged.
e) The program will not start compaction or crushing tests unless the punches are in proper position.
f) There is a set of limit switches that determine the absolute maximum and minimum position of the pressing punch. Under normal operation, those switches are never activated. In case of control errors, those switches are the main safety features that will stop the motor. The working maximum and minimum position of the pressing punch for a given test die is calculated based on the die data as entered in the Die Table and incorporated when the die is "installed".

In an emergency, pressing the red **STOP** switch on the front of the unit will stop the main motor. In any case, the **PTC MUST ALWAYS** be monitored during testing and, in case of emergency, stopped manually. There is always a possibility of punches that will break or other component failure and the operator must be prepared to respond accordingly.

Any problems, suggestions and questions should be directed to:

KZK Powder Tech Corp.
E-mail: service@kzkptc.com

10. TECHNICAL SPECIFICATIONS

1. PTC Electrical Requirements:
   - AC Voltage: 100-240 VAC, 50/60 Hz
   - Power: 650 Watts max. (approximately)

2. Basic Test Unit Model: PTC-04DM (Desktop Modular)
   - Control: internal microcomputer, desktop/laptop PC with USB link
   - Testing Module: pressing and control unit, detachable from Power Module
   - Power Module: mechanical power unit with stepper motor
   - Max. Pressing Force: 98.1 kN (22,000 lbf)
   - Recommended Testing Range: 10-65% of Max. Force (for test die diameter selection)
   - Die Temperature Control: standard, 300°C (570 F) max., 600W max. heater outlet
   - Pressing Speed: user selectable, range: 0.50 - 1.50 mm/s
   - Dimensions (W/H/D): 180/584/279 mm (7.1/23/11 inch)
   - Weight: 16 kg (36 lbs) Testing Module, 9 kg (20 lbs) Power Module
   - Compact: cylindrical, length range: 2-16 mm (.079-.630 inch)
3. Bulk Powder Tester Module: independent unit, USB controlled and powered
   - Angle of Repose: inclinometer sensor
   - Tapping: selectable number of taps
   - Air Humidity: air humidity and temperature sensor

4. Standard Dies: testing must be conducted within the recommended pressure range with the max.

   pressing limit left for pressing overshots or occasional use

Die Diameter:	Maximum Pressure:	Recommended Pressure Range:
19.05 mm (0.750")	343 MPa (25 TSI)	34-225 MPa (2-17 TSI)
12.70 mm (0.500")	765 MPa (56 TSI)	76-500 MPa (5-37 TSI)
9.525 mm (0.375")	1295 MPa (94 TSI)	130-845 MPa (9-62 TSI)
6.35 mm (0.250")	3090 MPa (225 TSI)	309-2010 MPa (22-146 TSI)

5. Standard Die Set: PTC-DSS
   - Material: tungsten carbide die, tungsten carbide punches

6. Custom Die Set: Material: as desired

7. Vacuum Cleaner: PTC-VC, standard
   - Filter: HEPA type, min. 99.97% efficiency for 0.12 mic. min. particles

8. Micrometer: PTC-MB: range 0-25 mm, preferably electronic with SPC
   - Software: standard for electronic micrometers, transfers micrometer readings directly to main program, requires SPC option and adapter for direct computer connection

9. Scale (Mass Balance): 0.001 g readability, RS232/USB adapter
   - Software: standard, transfers readings directly to main program, requires a scale with adapter/option for direct computer connection

10. Computer: dedicated laptop PC with MS Windows 7 Pro

11. Main Software: standard, main program for testing and test data processing

12. User Manual: standard, electronic (pdf and direct Help file) version includes technical drawings of standard dies and punches

VII. MAINTENANACE & SERVICE

NOTE: It is advisable to recalibrate the PTC periodically.

The PTC must be kept clean and in a dry environment. When operated properly, it requires no maintenance. UNDER NO CIRCUMSTANCES IS THE CUSTOMER ALLOWED TO UNDERTAKE ANY UNAUTHORIZED REPAIRS OR MODIFICATIONS REQUIRING THE REMOVAL OF THE TESTING CENTER'S MAIN COVER. THE UNIT GENERATES VERY HIGH FORCES AND ANY DISRUPTION OF THE CONTROLS OR SAFETY FEATURES COULD RESULT IN PERMANENT DAMAGE TO THE INSTRUMENT AND POSE A SERIOUS DANGER TO THE OPERATORS. OPENING THE MAIN COVER WILL AUTOMATICALLY TERMINATE THE WARRANTY AND MAY RESULT IN A REFUSAL BY THE MANUFACTURER TO SERVICE THE UNIT.

For a service or repair the unit must be sent to the factory in a secure box, preferably the original one. An on-site service is available for a fee (not covered by the Warranty).

11. MAINTENANCE AND CLEANUP

11.1 Top Punch Slide

It houses the Top Punch and it may require periodic adjustments. As soon as a difficulty in moving the Top Punch up or down is detected, the following steps should be performed:

- version "A":

a) Turn once counterclockwise the locking screw inside the Top Punch Slide handle

b) Adjust the punch sliding pressure by turning the punch handle (make sure the punch does not fall down)

c) Lock the handle in place with the locking screw,

- version "B": Turn the spring loaded ball plunger screw (above the thumb screw) to adjust the friction.

11.2 Test Die

The die cavity may be cleaned using the Die Cleaning Rod and the Die Cleaning Felt Pad with a drop of a suitable solvent. (Excessive amount of a solvent on the cleaning pad will cause it to drip between the punch and the die wall which must be prevented.) Occasionally, the die may be dismounted and cleaned more thoroughly. In that case, remove the punch from the die and clean it and the die with a cleaning solvent.

The Top Punch may need cleaning if there is a problem with moving it into the die or moving it up and down in general. In case of difficult entry into a die, cleaning the tip of the punch may be sufficient. If there is a problem in general movement of the punch, the cleaning and lubrication of the Top Punch Slide is needed (see above).

Note: The tolerance between the punch and the die is quite small and normally only very small amounts of powder get through the die. There is a punch seal at the bottom of the die so the powder is trapped in the space above the seal. Typically, a complete cleaning of the die should be performed after approximately every one thousand of tests. In case of some powders, the cleaning may be performed more often. In extreme cases when the punch requires a significant force to move within the die, the die should be dismounted and cleaned thoroughly.

11.3 Vacuum Cleaner Maintenance

The Vacuum Cleaner is a stand alone unit with a HEPA cartridge filtration system. Under normal conditions, the filter should be replaced when the performance of the Vacuum Cleaner drops significantly.

To remove the filter, first remove the vacuum entry tube, then remove the screws holding the vacuum cleaner cover and slowly take the HEPA filter out of the unit. Place a new filter cartridge in the unit and tighten the screws on the cover. Install the vacuum entry tube.

DO NOT USE THE VACUUM CLEANER FOR MORE THAN 1 MINUTE AT A TIME!

12. PROBLEMS: WHAT TO DO?

In case of a problem please send an e-mail (service@kzkptc.com) with a detailed description of the problem to the factory. The problem will be evaluated and an action will be suggested to fix it by the customer or by the factory.

1) All readings and controls do not work correctly

- Check the control cable connection
- Reset the PTC by turning it off and on again
- Exit the main program and try again

If the above show negative response, the control board may be working incorrectly. The unit must be serviced by the factory.

2) Problems with compact ejection

- Use manual UP option until the compact is out

This type of problem might indicate that the die is dirty and needs cleaning. If this problem persists, the PTC requires factory service.

3) The punch's mounting ring separates from the punch during DOWN motion

- The punch withdrawal force exceeded the safety limit. Dismount the die, remove the punch from the die using outside press, reattach the ring to the end of the punch. There is a bronze wire ring in a groove at the end of the punch. Place new wire ring in the grove and push (press) the punch mounting ring over it. A retaining compound should be used to glue the ring to the punch at the final position to prevent its motion. *Note: If this problem occurs too often, it indicates that the punch clearance in the die is incorrect or the die and punch material are not hard enough for the tested powder.* If the die material is improper, the die walls will suffer serious damage during the withdrawal of the punch. One must use die material suitable for the tested powder.

The limit on the magnitude of the punch withdrawal force imposed by the way the ring is attached to the punch is a safety feature to prevent an extensive damage to the die and punch if the force is very high.

4) The top punch cannot move or moves with difficulty

The top punch and the top punch slide require cleaning. It may also require an adjustment. See the steps as outlined in the Maintenance section.

13. SENSORS CALIBRATION OUTLINE

All sensors are individually calibrated using multi-segment linearization. The calibration files are stored on the internal memory of the PTC.

The **travel (position) sensor** implements up to 80 points over the travel range. A calibration instrument (micrometer) tests the travel gauge at very small intervals taking hundreds of points. Those measurements are used to determine the final 80 (or less) calibration points based on a requirement that the accuracy within the range is better than 0.01 mm. A repeatability test is conducted for final accuracy checkup of the sensor.

The **Angle of Repose** sensor measures angles based on a gravitational reference. That sensor, following initial setup, does not need any calibration. Older PTC units incorporate potentiometer senors. Their range between 0 and 90° may be calibrated at up to 10 points. Typically, a simple linear calibration of the range with two points, 0 and 90 degree, is sufficient to provide an accuracy better than 1 degree.

Temperature sensors use individual calibration files. New PTC models use RTD platinum sensors for the 0-300°C range. These sensors are interchangeable and use a standard calibration file. Older thermistor sensors implement 10 point calibration for low temperature sensors (up to 130°C) and 20 point calibration for high temperature sensors (up to 300°C).

The **load sensors** (**load cells**) are calibrated with a special **PTC Calibration Gauge**. Due to very high loads during regular testing, the load cells may require more frequent calibrations than the other gauges. When desired, that calibration can be performed by the customer with a gauge provided by the manufacturer for that purpose.

13.1 PTC Load Cells Calibration Steps

ATTENTION: This calibration involves very high forces. The procedure requires a technician with technical abilities to perform the steps outlined below. Since the process is outside of the manufacturer's control, the **manufacturer does not assume any responsibility** for the safety and outcome of the calibration process.

Step 1. Set Punch Position.

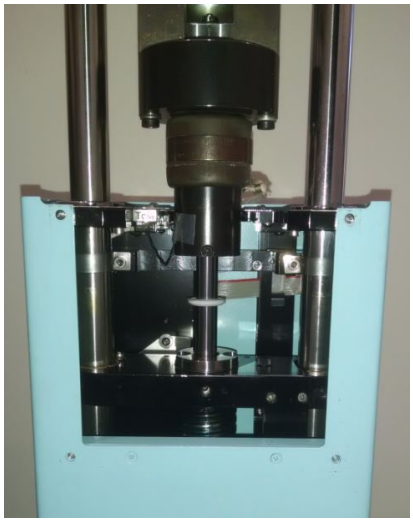
In the main TABLE display, select any setup with **metric units**. The PTC power must be turned on. In the TESTS window, move the pressing punch up/down to a Punch Position (compact length) **between 10 and 14 mm**. That position allows sufficient space for the mounting of the PTC Calibration Gauge. The up/down motion can be stopped by pressing any key on the keyboard.

Step 2. Install the PTC Calibration Gauge.

Lock the Die - tighten the Die Locking screw on top of the PTC. The die mounting base must be immobilized to assure proper gauge alignment for the calibration.

Remove the Die Door. The Die Door is mounted with two thumb screws on the front of the PTC. Removing the screws and the door opens the access space for die change.

MAKE ABSOLUTELY SURE THAT NOTHING DROPS INSIDE THE UNIT AND NOTHING IS LEFT HANGING ON OR STICKING TO THE SENSORS !!!



Remove the Test Die from the PTC. Remove the Top Punch Slide.

Install the PTC Calibration gauge in place of the Test Die. The control box on the gauge must be in front of the

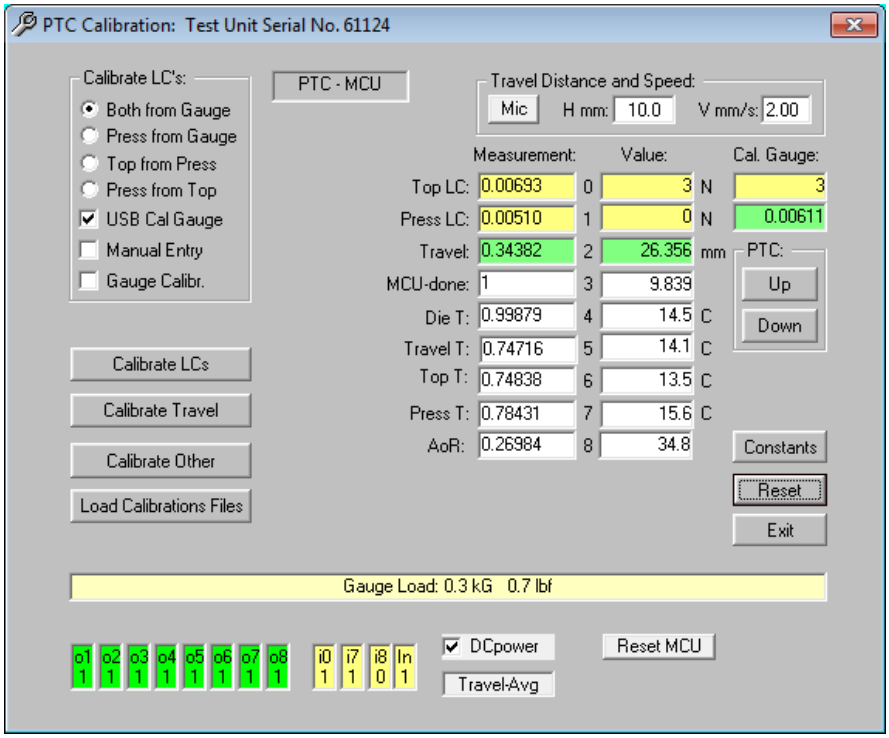
mounted gauge. *If necessary, move the pressing punch base slightly down to make space for the calibration gauge.* Before the mounting screws are tightened, the gauge must be pushed back and to the left for proper centering. The mounting screws must be tightened. Make sure that the gauge is rigidly mounted. If the bottom of the gauge (the gauge's load cell) moves when pressed, it indicates that the Die Locking screw is not in the locking position and it must be tightened.

Step 3. Warm Up.

Plug the gauge's control cable into the computer USB port. The gauge should **warm up for at least 5 minutes** before a calibration is conducted.

Step 4. Calibration.

In the TESTS screen display, select the **PTC Calibration** option in the upper left side of the screen. The PTC Calibration screen should appear.

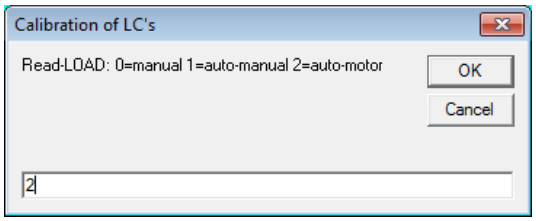


At first, click the **Reset** option and enter the operator's password. Originally, the password is "1". The serial number of the PTC (as listed at the top of the display) should work as well. The password should unlock all the options on the screen.

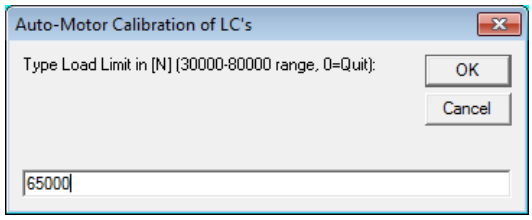
Select the **USB Cal Gauge** option in the Calibrate LC's frame on the left. Please also select the calibrated load cells option as **Both from Gauge** (calibrate both pressing and top punch load cells with the gauge). The readings of the calibration gauge should display in the **Cal Gauge** window on the right. Click the **Reset** option from time to time to initialize (zero) all gauges. When the calibration gauge is warmed up (ready), the reading of the gauge should oscillate around zero. *Note: If the calibration gauge reading is not oscillating at all, the gauge is not working and the calibration must be stopped.*

ATTENTION: The force readings are in Newtons, a small unit of force. Please do not expect accuracy or repeatability in single digits.

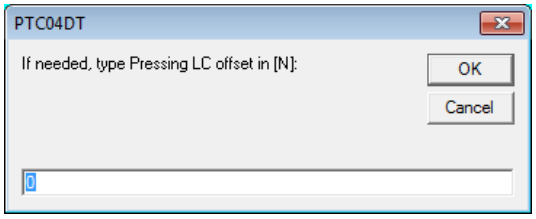
The **Calibrate LC's** option starts the calibration cycle. For PTC models with stepper motors, type "2" for auto-motor calibration:



Next, type in the maximum calibration load. **ALWAYS** start with a smaller value such as 50000 (N) and then repeat the calibration with a higher value. The maximum recommended value for the calibration is 75000. The PTC program always expands linearly the calibration to the full range.



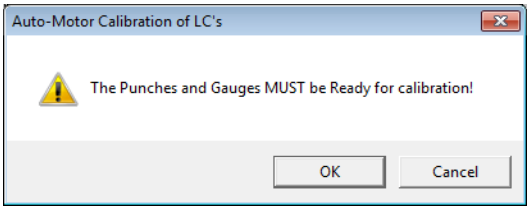
Type in "0" as offsets for the pressing and the top load cells.



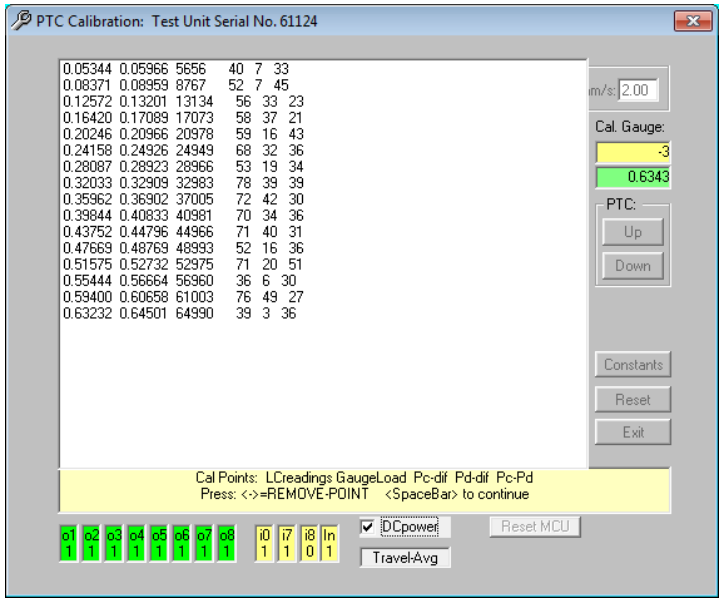
The system is ready to apply load and measure the forces. The pressing load cell will move up and press against the PTC Calibration gauge. The system will stop at about 6000 N and the readings will be taken. Then the process will repeat for more than 10 points with increasing force until the maximum limit is reached. After that, the pressing load cell will withdraw.

ATTENTION: The calibration may be stopped at any time by pressing any key on the keyboard.

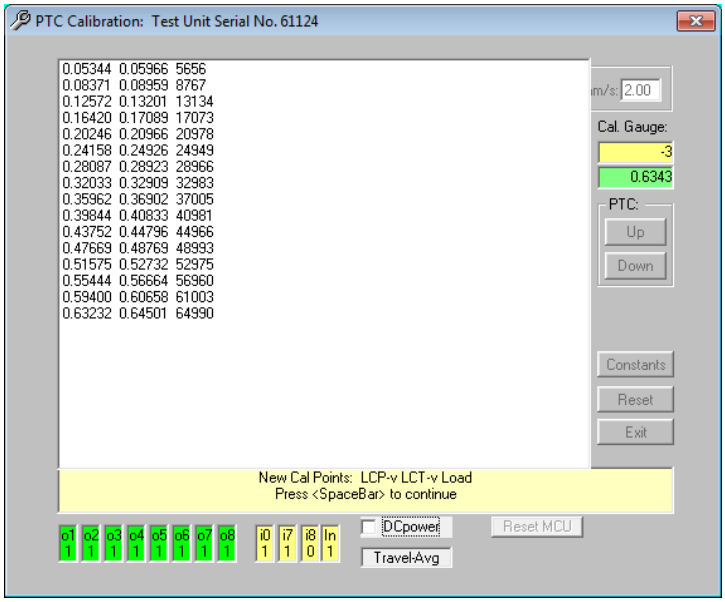
Check the alignment of the calibration gauge and the pressing and top load cells. If everything is in line, press **Enter** or click the **OK** button to start the load cycle.



The load cycle is a quick process that ends with the down motion of the pressing load cell which removes the force from the load cells and the gauge. The computer will display the readings of the load cycle. Press the Space Bar to move to the next screen.



When asked to save data for plotting, confirm the option. Next screen will display the new calibration points for the load cells. Press the Space Bar to continue.



The new calibration data for the pressing load cell (and next for the top load cell) can be saved or discarded. Selecting "Yes" for saving will save the new calibration data in the main control file and on the internal memory of the PTC.

The latest PTC hardware version has an option to add a correction for slow drift of the load cells. That drift correction can only be determined by the manufacturer. In any other case make sure that all the correction values are set to zeros (0, 0, 0, 0). Confirm the values and save the calibration data.

Step 5. Repeat the Calibration or Exit

It is recommended to repeat the load cells calibration once or twice.

14. SELF SERVICE

LEGAL DISCLAIMER: *Any service that requires the removal of the main enclosure is reserved for the official service of the manufacturer. There are numerous gauges and position sensors that need to be properly calibrated and adjusted. The PTC generates very high forces and any gauge misalignment could result in a catastrophic damage of the instrument with real life threat to the persons in close vicinity. The manufacturer does not authorize the removal of the main enclosure of the PTC by the customer. The manufacturer does not assume any responsibility for services performed by others.*

14.1 Testing Module Removal

The Testing Module can be removed from the base of the Power Module for service purposes. Please follow the following steps:

a) remove the Test Die from the PTC and close the Die Door
b) tighten the die locking screw on top of the PTC
c) disconnect the power cable from the PTC unit
d) disconnect the USB control cable from the PTC
e) remove the cable cover plate from the back side of the Testing Module (2 thumb screws)
f) unplug the flat ribbon control cable from the back of the Testing Module
g) remove the 4 mounting screws (2 on each side) at the bottom of the Testing Module (the screws will hang loose in place)
h) Lift the Testing Module UP and out of the Power Module.
i) MAKE SURE THAT NOTHING FALLS INSIDE THE OPENING IN THE POWER MODULE
j) if necessary, cover the base with the Cover Plate (remove it from the Power Module's front wall and attach it to the base)

The Testing Module has 4 pin legs at the bottom so it can stand on a flat even surface.

When installing the Testing Module onto the base of the Power Module, the key slot in the sprocket inside the base must be align with the key on the bottom of the Testing Module. Please follow these steps:

a) make the key on the Testing Module parallel to the (shorter) side of the module
b) align the key slot in the sprocket of the Power Module with the marks on the cover.

The unit must be connected to power and the power switch turned on. Pressing the Motor On switch turns the sprocket. The alignment must be as close as possible. The mechanism can tolerate small misalignment between the sprocket and the key. Once aligned, the Testing Module can be mounted on the base of the Power Module in reverse order to dismounting.

NOTE: PROTECT THE MOUNTING AREA OF BOTH MODULES FROM ANY CONTAMINATION !!!

14.2 Top Punch Slide Removal

The Top Punch Slide can easily be removed following the steps below:

a) remove the front safety screw located next to the left edge of the slide near its bottom
b) turn the thumb screw on the back of the slide until the slide moves sideways freely
c) remove the Top Punch Slide by pulling it out.

NOTE: During installation, the slide MUST be pushed UP and moved back in place. The TOP PUNCH must be centered with a Die Installation Gauge before The Top Punch Slide is locked in place with the locking thumb screw on the back.

15. REPLACEMENT AND SPARE PARTS

The up to date part's price list is available on the KZK PTC's web site at www.kzkptc.com. If needed part is not listed, email the description of the part. Most of the items are stock items and can be shipped out within two business days.

References

1. S Gasiorek, K Korczak, K Kaminski, "Compressibility of Metal Powders", Advances in Powder Metallurgy, vol.1, 1989.

2. S Gasiorek, K Korczak, "Cohesiveness Of A Compact", Advances in Powder Metallurgy, 1990.

Note: These references are available for downloading as **PTC_Articles.pdf**.

APPENDIX: WARRANTY AND SOFTWARE AGREEMENTS

WARRANTY CLAUSE
Equipment: **POWDER TESTING CENTER MODEL PTC-04DM**

KZK POWDER TECH CORP. ("**KZK**") warrants to the original Purchaser for the duration of the WARRANTY PERIOD, as specified in the sale contract, that the equipment offered or sold hereunder is free from defects in material and workmanship at the time of shipment.
The WARRANTY PERIOD extends for the time period as specified in the sale contract from the day of shipment and is based on a single shift equipment use. The parts and components of the equipment covered by the WARRANTY are as listed in the sale contract.
KZK will replace or repair at its expense at KZK's facility the equipment or components which are covered by the WARRANTY and which KZK's examination discloses to be defective in material or workmanship within the WARRANTY PERIOD, provided:

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2. The defects were not, in KZK's opinion, caused by accident, misuse, abuse, or neglect.
3. PURCHASER notifies KZK of the nature of the defect, in writing and with reasonable precision.
4. PURCHASER preserves the defective equipment and returns it to KZK, freight prepaid, securely packed to avoid damage in transit. Exceptions, if any, to this point are specified in the sale contract.
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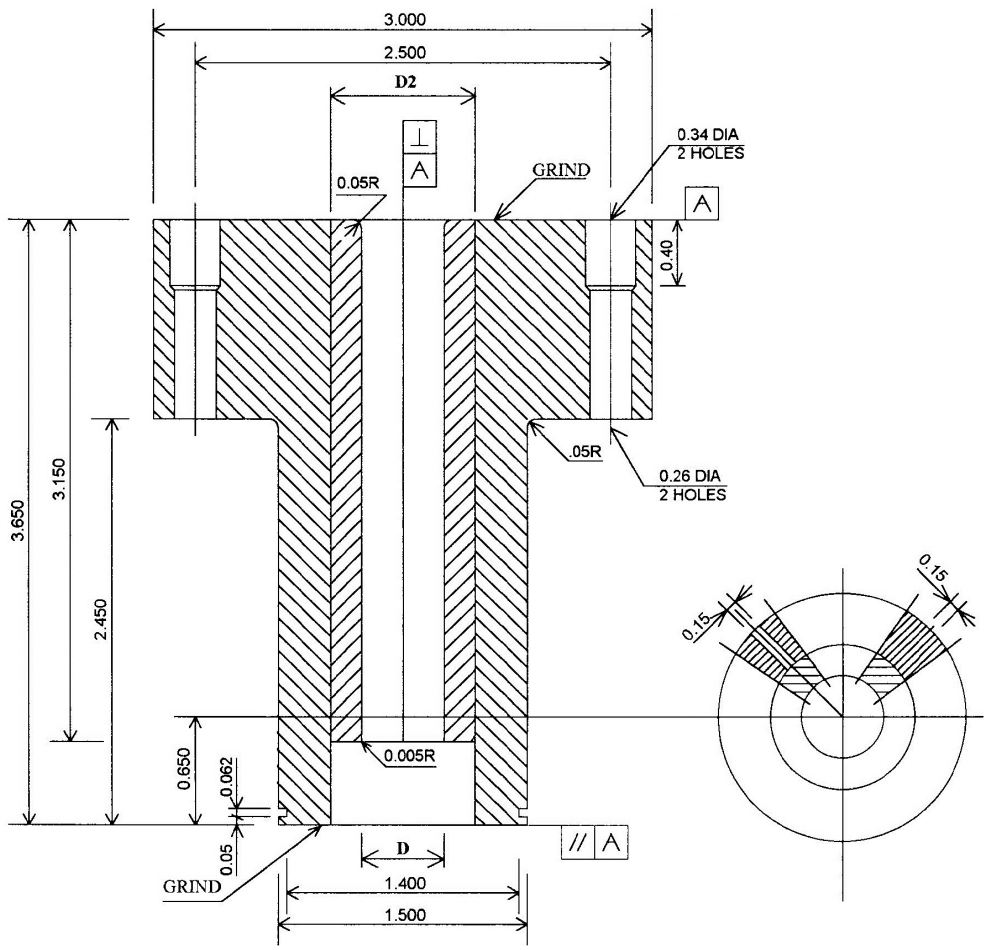
Technical Drawings

1. Figure 1. Standard Test Die
2. Figure 2. Pressing Punch
3. Figure 3. Top Punch
4. Figure 4. Test Die Cylinder

Figure 1. Standard Test Die



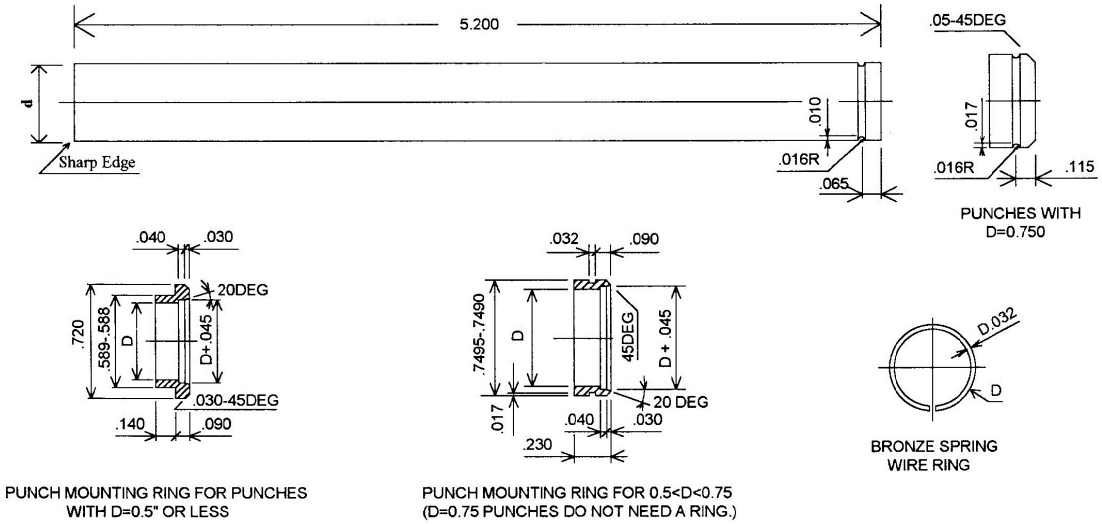
Nominal D	D	D2 Shrink-fit
0.5 in	.5003-.5001	.875
0.75 in	.7503-.7501	1.125
12 mm	12.008-12.003	22
10 mm	10.008-10.003	20
0.375 in	.3753-.3751	.750
8 mm	8.008-8.003	18
0.25 in	.2503-.2501	.625

NOTES:

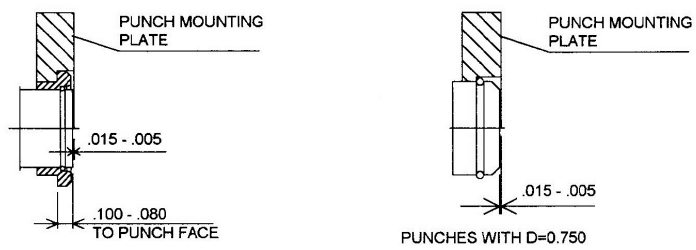
1. The die insert is shrink-fit into the die's body. The die may be made as one piece with no insert.
2. The center bore is critical. The surface finish must be comparable to the one on production dies.
3. The indicated surfaces must be ground. Any additional surfaces may be ground if desired.
4. All external surfaces (except the ground ones) should be painted with a high temperature paint.

Figure 2. Pressing Punch

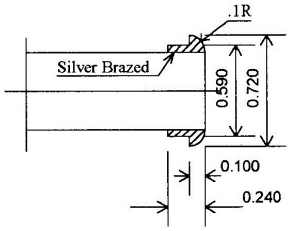
PRESSING PUNCH



IMPORTANT: WHEN ASSEMBLED, THE PRESSING PUNCH'S BOTTOM FACE MUST BE AT LEAST 0.005 INCHES BELOW THE SURFACE (INSIDE) OF THE PUNCH MOUNTING PLATE. IF NOT, THE PUNCH WILL COMPRESS THE PRESSURE SENSOR WHEN MOUNTED AND MAY CAUSE A PERMANENT DAMAGE.



Nominal Die D	Punch d
0.5 in	.4998-.4995
0.625 in	.6248-.6245
0.75 in	.7498-.7495
12 mm	11.99-11.98
10 mm	9.99-9.98
0.375 in	.3748-.3745
8 mm	7.99-7.98
0.25 in	.2498-.2495

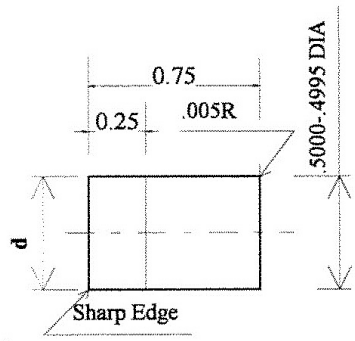


OLD TYPE OF PUNCH MOUNTING RING
IT MUST BE MACHINED AFTER BRAZING

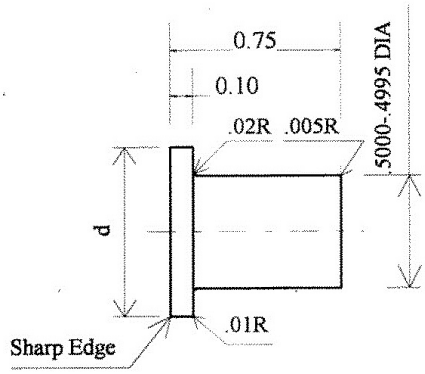
NOTES:

1. For punches with D<.750 there is a mounting ring for the pressing punch.
2. Use 0.032" diameter bronze spring wire rings for the pressing punch (the mounting ring snaps over the ring.)
3. The wire ring is an overload safety. The mounting ring with the wire should be bonded to the punch with compound.
4. INCORRECT INSTALLATION OF THE MOUNTING RING MAY DAMAGE THE PRESSURE SENSOR.
5. Punches MUST be precisely finished and polished on all surfaces.
6. The specific fitting tolerances between punches and dies may be changed if needed.
7. The length of the pressing punch should be within 5.150-5.250 inches.

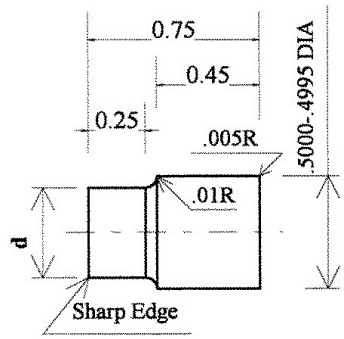
Figure 3. Top Punch



Top Punch for Nominal Die D=.5



Top Punch for Nominal Die D>.5



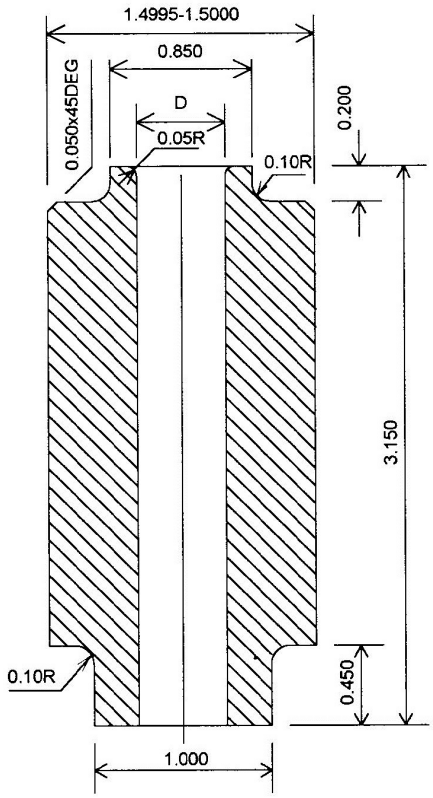
Top Punch for Nominal Die D<.5

Nominal Die D	Punch d
0.5 in	.4998-.4995
0.625 in	.6248-.6245
0.75 in	.7498-.7495
12 mm	11.99-11.98
10 mm	9.99-9.98
0.375 in	.3748-.3745
8 mm	7.99-7.98
0.25 in	.2498-.2495

NOTES:

1. Punches MUST be precisely finished and polished on all surfaces.
2. The specific fitting tolerances between punches and dies may be changed if needed.
3. The length of the punch must be as shown on the drawing.

Figure 4. Test Die Cylinder



NOTES:

1. THE CENTER BORE D IS CRITICAL.
   THE TOLERANCE FOR D: +0.0003, -0.0000
   IT MUST HAVE HIGH LUSTER FINISH.
   !!! THE GAUGE PIN FOR FINISHING THE CENTER BORE
   M-U-S-T PASS THROUGH UNDER ITS WEIGHT !!!

2. FOR D=0.7500", THE TOP ENTRY RADIUS IS R=0.020 INCH

3. ALL EDGES MUST BE ROUNDED WITH R=0.003-0.005 INCH
   INCLUDING THE BOTTOM ENTRY OF THE CENTER BORE D

4. ALL SURFACES MUST BE GROUND

5. ALL UNLISTED TOLERANCES ARE +/- 0.001 INCH

6. MATERIAL: AS NEEDED

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