Installation and Operation Manual

PiezoClamping® - Prestress and charge meter for piezoceramics (PCG5)

ATCP Physical Engineering

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Manufactured by:

ATCP do Brasil – Alves Teodoro Cerâmicas Piezoelétricas do Brasil Ltda. ME.

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1. Introduction

This installation and operation manual contain important and necessary information for the correct use and maintenance of the PiezoClamping® prestress and charge meter for piezoelectric ceramics.

Read this manual carefully before using the equipment. Its misuse can compromise results and cause damage.

PiezoClamping® allows measuring the prestress in piezoelectric ceramics of bolt-clamped Langevin-type transducers and converters during the bolt preloading. PiezoClamping® assists the user in a practical and accurate way by providing the real-time prestress applied to piezoelectric ceramics as they are progressively compressed with bolt preloading. It also provides real-time electric charge values displaced by piezoelectric ceramics.

Besides the main purpose of instructing the user on how to install, set and operate the equipment, this manual also aims to contribute to a better understanding of the basic concepts of ultrasonic engineering and of the usual procedures for ultrasonic transducers and converters manufacturing.

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2. Definitions and symbology

2.1. Definitions

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Ultrasonic transducer or converter: Resonant element used to convert alternate electric energy into ultrasonic vibration with a specific frequency. "Transducer" is a general denomination; "converter" is a denomination for the ultrasonic welding area.

Note: The transducer comprises piezoceramic rings stressed between metallic masses by a bolt; the electric contact is through electrodes. This type of transducer, also known as bolt-clamped Langevin-type transducer [1], was originally developed for sonar applications and it had its use later expanded to industrial applications for ultrasonic welding and cleaning [2].

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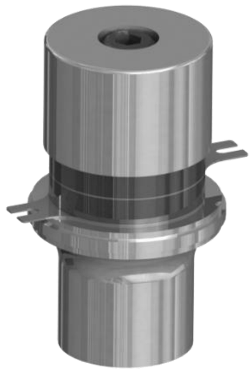

Typical power ultrasonic transducer/converter

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Piezoceramic: Also known as piezoelectric ceramics, it is the active element that converts electric energy into ultrasonic vibration in ultrasonic transducers and converters. They are usually employed in the ring geometry with flat and metalized surfaces.

Note: The sensitivity of a piezoelectric ceramic piece is given by the charge constant d_{33}.

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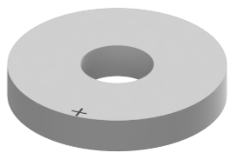

Typical piezoceramic ring.

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Piezoelectric charge constant d_{33}: The coefficient between the total electric charge displaced and the force applied to the piezoceramic. The usual unit of the charge constant d_{33} is pC/N (pico Coulombs per Newton). Typical values for the most common PZT piezoceramics:

- PZT-8 *(Navy type III)*: 245 ± 35 pC/N;
- PZT-4 *(Navy type I)*: 290 ± 35 pC/N;
- PZT-5A: *(Navy type II):* 390 ± 35 pC/N.

Note: For exact values of the piezoelectric charge constant d_{33}, consult the manufacturer or perform the measurement with a d_{33} meter. PZT-8 is usually used in medical and ultrasonic welding converters, and PZT-4 in transducers for ultrasonic cleaning.

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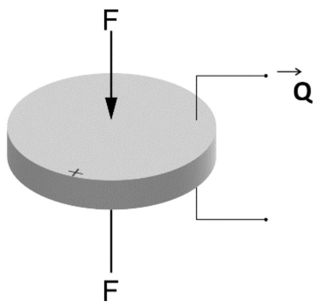

$$d_{33} = \frac{Q}{F}$$

Charge constant d_{33}.

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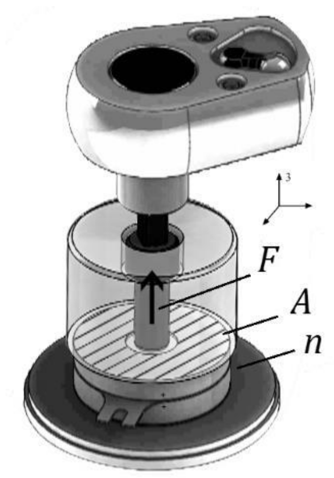
Bolt preload: Bolt preload is the traction force "*F*" created on the transducers' bolt by elastic elongation due to the application of torque and threading. Bolt preloading is the process of applying the preload by threading the bolt with a torque wrench or other tool.

Note: The preload is proportional to the torque applied, however, the proportionality coefficient is unstable because of the surface's friction coefficient high sensitivity. For instance, any moisture adsorbed is enough to lubricate it and change the proportionality coefficient. That is the reason why prestress control by torque is no reliable.



Bolt preloading.

Piezoceramics prestress: Prestress is the mean stress applied to the piezoelectric ceramics by bolt preloading. Its function is to simultaneously maximize the operating power and the mechanical coupling of the piezoceramics ensuring they do not move when vibrating.

Notes:

The optimum prestress depends essentially on the maximum mechanical stress supported by the piezoelectric material [3,4], differently of the optimum bolt preloading torque, that varies with the area of the ceramics and with the friction coefficient of the bolt with the metallic masses. The typical values for well-designed transducers are 45 MPa (6,5 ksi) for PZT-8 piezoceramics, used in welding converters and medical equipment, and 35 MPa (5,1 ksi), for PZT-4 piezoceramics used in ultrasonic cleaning transducers.

Prestress is a key factor for the lifespan, maximum power and efficiency of the transducer. Nonetheless, the excess of prestress changes the properties of the ceramics and can cause crushing. On the other hand, the lack of it let the piezoceramics move sideways during operation, leading to the occurrence of cracks, electric arcs and short circuits.

2.2. Symbology

⚠	Attention! Danger!	**VAC**	Alternating voltage	**VA**	Volt-Ampere
VDC	Direct voltage	**I**	Switches the equipment on	**O**	Switches the equipment off

3. Applications, testable elements, electric connection and tools

3.1. Applications

PiezoClamping® is a robust and easy-to-use solution to manufacture, recover and develop power ultrasonic transducers and converters. Its functions and characteristics have been designed to offer an accurate and standardized prestress procedure for the following areas:

- Manufacturers of power ultrasonic machines and equipment;
- Repair service providers of ultrasonic welding machines and power ultrasonic equipment in general;
- Research groups, educational institutions, and R&D departments.

3.2. Testable elements

PiezoClamping® can be used to measure the prestress of Langevin-type [1] piezoelectric transducers and converters and of similar devices in which prestress is applied to piezoelectric ceramics, such as in the followings:

- Converters for ultrasonic cutting and welding machines;
- Ultrasonic transducers for medical and dental equipment;
- Transducers for ultrasonic cleaning machines;
- Ultrasonic transducers for sonoreactors and sonochemistry;
- Transducers for spraying and atomization;
- Transducers for die polishing machines.

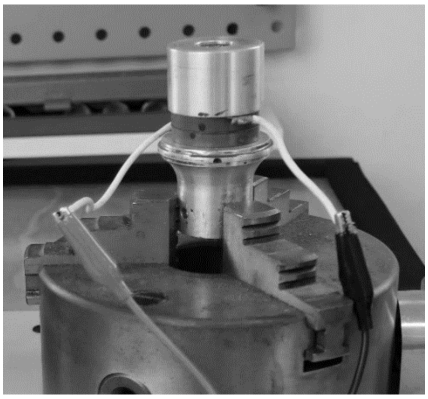
3.3. Electric connection

PiezoClamping® must be connected to the transducer using the test probe that comes with the equipment, and has the configuration parameters set for the specific characteristics of ceramics and transducer being assembled.

The alligator clips must be connected to the transducer electrodes or to the wires attached to them, as shown on the right. The red clip must be connected to the positive electrode (live) and the black one to the electrode in electric contact with the metallic masses (ground).

⚠

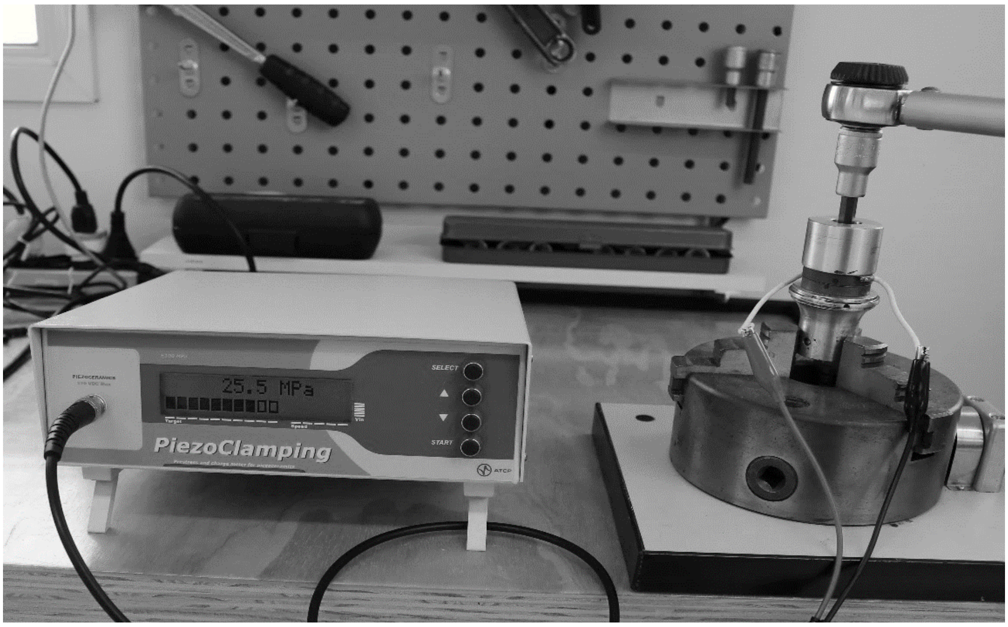
Connect the PiezoClamping® before start preloading.
A high voltage discharge from the transducer preloaded on open circuit can damage the equipment.



Electrical connection between PiezoClamping® and the transducer.

3.4. Tools

The preloading of transducers and converters can be done by using a key or a torque wrench set for a torque equal to 120% of the average torque value to achieve the target prestress. Using a torque wrench is optional and it aims to protect the bolt from excessive preloading in the case of locking.



PiezoClamping® connected to measure the prestress of a converter during bolt preloading.

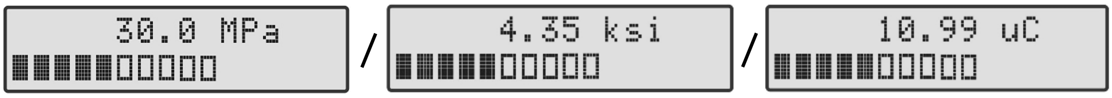
Do not connect PiezoClamping® to ultrasonic power generators or to energized circuits because it will get damaged. PiezoClamping® must be connected to passive elements only.

It is also recommended using a lathe jaw, vise or similar fixture that allows fixing the transducer to avoid rotation during preloading without damaging it.

4. Operation principles and measurement ranges

4.1. Operation principles

The operation principles of PiezoClamping® consists in integrating the electric charge displaced by the piezoelectric ceramics during the transducer or converter bolt preloading and then, based on the charge constant d_{33} and other characteristics of the ceramics, calculate the prestress is Mega Pascals (MPa) or kilopound per square inch (ksi). When compressed, piezoelectric ceramics displace an electric charge proportional to the stress, and this proportionality is given by the charge constant d_{33}. PiezoClamping® employs an advanced measurement process that provides a reproducible result, stable over time and independent of the preloading speed. The user can change the preloading speed and perform pauses with no significant loss of data. Besides the prestress, the PiezoClamping® also reports the total electric charge in uC.



Example of PiezoClamping® screens with bargraph proportional to the target: prestress in MPa on the left, prestress in ksi on the center and total electric charge measured in uC on the right.

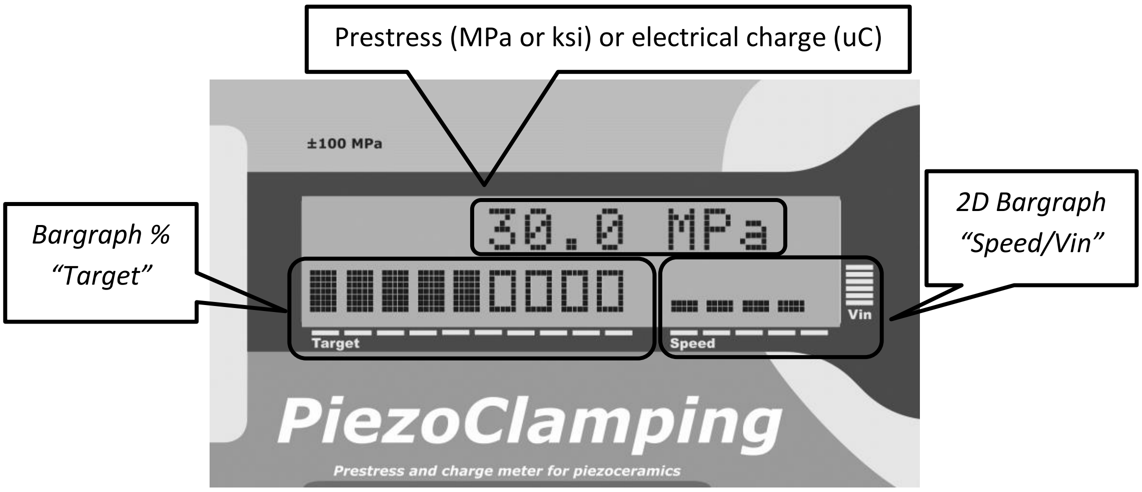
Note: One of the traditional approaches for prestress control consists in control the bolt preloading torque. Nevertheless, this method presents low accuracy because the ratio between torque and prestress varies greatly as a function of the surface finishing, lubrication, and possible locking [5]. Another traditional approach involves using a capacitor with a voltmeter to measure the electric charge displaced during the preloading. This arrangement is better than the control by torque only, but it also presents low accuracy because the charge displaced by the piezoceramics and stored by the capacitor is consumed by the meter, making the measurement unstable. Additionally, the obtained value is an electric voltage proportional to the force and it is necessary to perform calculations to determine the prestress [4].

4.2. Measurement ranges

PiezoClamping® prestress ranges are from 0.0 to ± 99.9 MPa and from 0.00 to ± 99.99 ksi, and the charge range from 0.0 to ± 190.0 uC. If the bolt is loosened instead of preloaded, or the test leads are inverted, the prestress and charge indication will be negative.

PiezoClamping® is suitable for testing transducers and converters that use from 1 to 99 piezoelectric ceramics in their assembly, with the d_{33} charge constant from 1 to 999 pC/N. To make its use easier, PiezoClamping® displays the prestress value in MPa or ksi, or the charge in uC, and its modulus in percentage referenced in the target set by the user. The percentage information is provided by means of the target bargraph with ten rectangles, which indicates from 0 to 100% with steps of 10%.

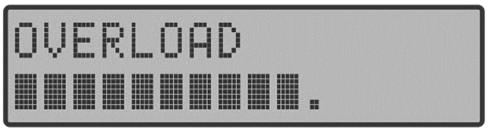
In addition to the target bargraph, the display also has a two-dimensional *Speed/Vin* bargraph in its bottom right corner, where the horizontal axis is proportional to the preloading speed (*Speed*) and the vertical axis to the input voltage. The *Speed/Vin* bargraph appears only during the preloading process, whilst there is electric charge displacement in progress.



Example of a screen displayed during the measuring process.

The Speed/Vin bargraph should not reach its limits whilst the prestress is being applied. If that occurs for Speed, the user will be alerted by a beeping; if it occurs for Vin, the message "overload" will be displayed and the measurement interrupted.

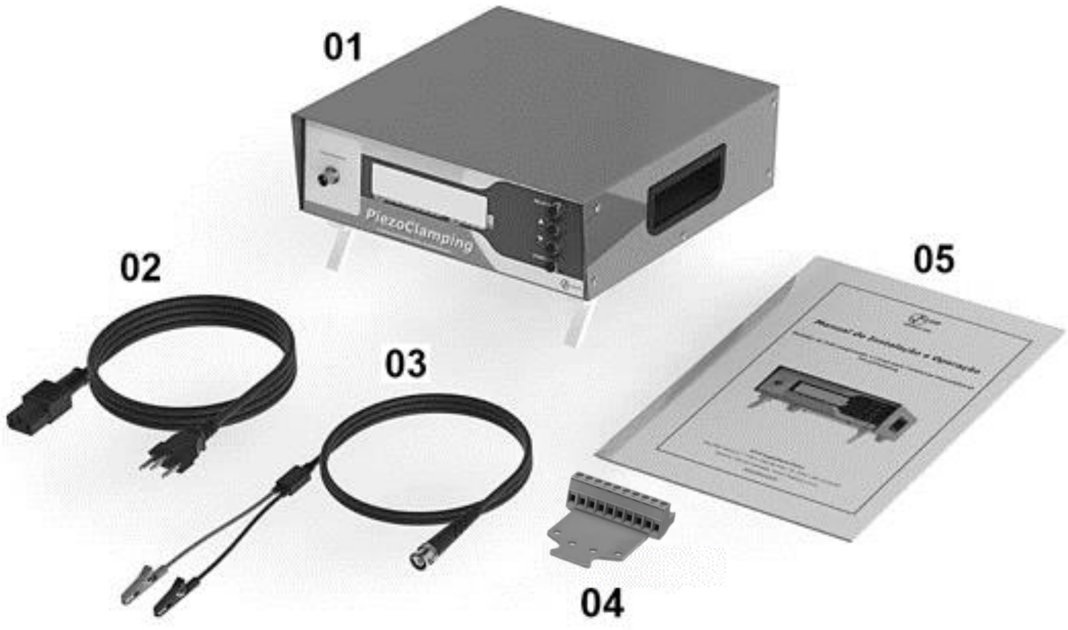
PiezoClamping® comes with a self-protection system that activates a relay for the piezoceramics discharge when the input voltage is exceeded (when the vertical axis of the *Speed/Vin* bar graph reaches its full scale). In that case, PiezoClamping® restarts the measurement automatically by resetting the prestress and electric charge data. In addition, the OVERLOAD screen (pictured below) is displayed and a warning sound follows.



Screen informing overload.

5. Parts, accessories, and optional items

PiezoClamping® is provided with the items described next.



Parts:
01 - PiezoClamping®.

Accessories:
02 - 1.8-meter tri-polar power supply cable;
03 - 1.0-meter probe with alligator clips;
04 - Connector MSTB 2,5/10-STZ-5,08 1764303 Phoenix Contact or similar;
05 - Installation and Operation Manual.

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6. Technical specifications, elements' identification, and installation

6.1. Technical specifications

Measuring ranges, precision, and accuracy

Prestress in MPa .... 0.0 - ± 99.9 MPa

Prestress in ksi .... 0.00 - ± 99.99 ksi

Electrical charge .... 0.0 - ± 190.0 uC

Precision .... ± 1 %

Accuracy .... ± 3 %

Setting parameters

Outer diameter .... 1.0 - 99.9 mm

Inner diameter .... 0.0 - 98.9 mm

Number of piezoceramics .... 1 - 99

Charge constant (d_{33}) .... 10 - 999 pC/N

Target prestress in MPa.. 1.0 - 99.9 MPa

Target prestress in ksi .... 1.00 - 99.99 ksi

Preloading time.. 0.1 - 10.0 seconds

Dimensions input mode .... T. sizes and Custom

Trigger level .... 0.4 - 10.0 mV

Electric charge measurement adjust (*Z adjust*) .... 0.950 - 1.050

Target Vout adjust at 2.75 V (*Cal. Vout @2.75V*) .... 0000 - 0470

Target Vout adjust at 5.00 V (*Cal. Vout @5.00V*) .... 0480 - 1023

Other specifications

Electrical shock protection .... Class I

Protection level IP IP40

Operation mode .... Continuous

AC input .... 90 - 260 VAC

Frequency .... 50 - 60 Hz

Maximum power consumption (stand by) .... 16 Watts rms

Maximum power consumption (in operation) .... 50 Watts rms

Equipment dimensions (L x P x A) .... 260 x 250 x 100 mm

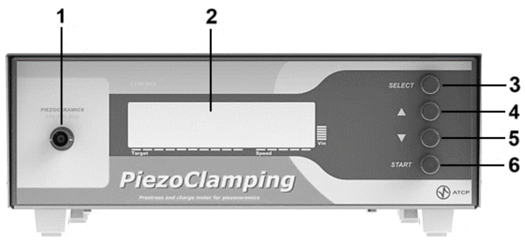
Packaging dimensions.. 370 x 330 x 140 mm

Equipment weight without packaging.................................. 3.8 kg

Equipment weight with packaging .... 4.4 kg

Working temperature range.. From - 10 to + 45 °C

6.2. Elements identification

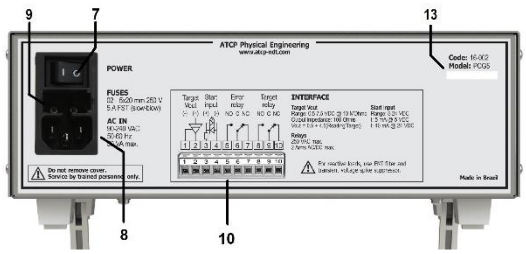


[1] PIEZOCERAMICS connector: BNC-type connector for connecting the transducer. The maximum input voltage is ± 10 VDC.

[2] Display: Alphanumeric interface of 2 lines by 16 characters.

[3] "SELECT" button: Pushbutton-type button to choose between the measuring screen and the other configuration screens available.

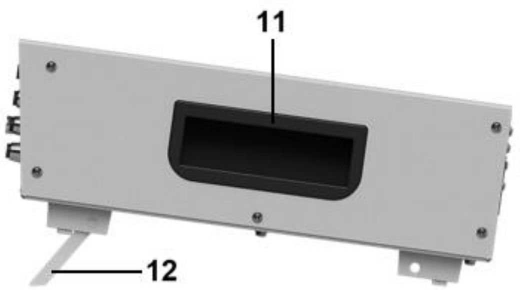
[4] and [5] buttons "▲" (up) e "▼" (down): Pushbutton-type buttons to increase and decrease values. in the measurement screen, allows to select between "**MPa**", "**ksi**" and "**uC**" modes. In the configuration screens, allows to decrease and select values.



[6] START button: Pushbutton-type button to start a new measurement. When pressed, the system automatically performs the equipment reset for a new measurement.

[7] "POWER" switch: Switch to turn the equipment on and off.

[8] AC IN: Input connector for the power cord (90-240 automatic VAC - 50/60Hz)



[9] FUSES: Fuses (02 units of 5x20 mm, 250 V, 5 A, slow type).

[10] Interface: Connector for external communication and automation.

[11] Side handle: Handle for handling and transportation.

[12] Tilt legs: Movable legs located on the front feet for the equipment frontal elevation.

[13] Serial number.

6.3. Installation

Minimum requirements:

- Firm, flat and spacious enough bench for the PiezoClamping® equipment and transducer to be preloaded;
- Electric power outlet of 90-260 VAC 50-60 Hz with grounding. If the mains are not grounded, use an isolating transformer for safety;
- Lathe jaw, vise or similar fixture attached to the bench to fix the transducer front mass during bolt preloading.

Step-by-step procedure:

Step 01 Place the equipment on the workbench and set the tilt legs [12] to the most appropriate position for visualizing the display.

Front view of the PiezoClamping® highlighting the tilt legs.

Step 02 Connect the power supply cable to the AC IN connector [8] on the rear panel and into a properly grounded outlet or isolated surge protector.

Step 03 Connect the BNC connector of the probe supplied with the equipment to the PIEZOCERAMICS connector [1] located on the left side of the front panel.

PiezoClamping® front panel BNC connector.

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7. Configuration, measurement, and flow chart

7.1. Configuration for prestress or charge measurement

Step 01 Turn the equipment on using the POWER [7] switch. The opening message will be presented first, and then it will be followed by the measuring screen in MPa (it can also be prestress in ksi or charge in uC).

PiezoClamping.. www.atcp-ndt.com	⇨	0.0 MPa □□□□□□□□□□

Step 02 Use the [▲] or [▼] buttons to choose between the available options for prestress unit (MPa or ksi) and control variable (prestress or electrical charge) shown in the following table.

0.0 MPa □□□□□□□□□□	0.00 ksi 000000000	0.00 uC 000000000

Step 03 Press SELECT [3] to access the "Piezo diam. (mm)" configuration screen. It presents the outer diameter (OD) and inner diameter (ID) options previously set to facilitate the equipment operation. Use [▲] or [▼]to choose between the available options as shown:

Piezo diam. (mm) OD 10.0 ID 4.0	Piezo diam. (mm) OD 10.0 ID 5.0	Piezo diam. (mm) OD 11.0 ID 5.5	Piezo diam. (mm) OD 15.0 ID 6.0
Piezo diam. (mm) OD 20.0 ID 9.8	Piezo diam. (mm) OD 20.0 ID 10.0	Piezo diam. (mm) OD 25.0 ID 10.0	Piezo diam. (mm) OD 25.0 ID 12.0
Piezo diam. (mm) OD 30.0 ID 10.0	Piezo diam. (mm) OD 32.0 ID 10.0	Piezo diam. (mm) OD 32.0 ID 12.0	Piezo diam. (mm) OD 35.0 ID 15.0
Piezo diam. (mm) OD 38.0 ID 15.0	Piezo diam. (mm) OD 38.1 ID 12.7	Piezo diam. (in) OD 1.1/2 ID 1/2	Piezo diam. (mm) OD 38.1 ID 19.1
Piezo diam. (in) OD 1.1/2 ID 3/4	Piezo diam. (mm) OD 40.0 ID 12.0	Piezo diam. (mm) OD 40.0 ID 15.0	Piezo diam. (mm) OD 40.0 ID 17.0
Piezo diam. (mm) OD 40.0 ID 20.0	Piezo diam. (mm) OD 45.0 ID 15.0	Piezo diam. (mm) OD 45.0 ID 20.0	Piezo diam. (mm) OD 46.0 ID 15.8
Piezo diam. (mm) OD 50.0 ID 16.0	Piezo diam. (mm) OD 50.0 ID 17.0	Piezo diam. (mm) OD 50.0 ID 20.0	Piezo diam. (mm) OD 50.8 ID 19.1
Piezo diam. (in) OD 2 ID 3/4	Piezo diam. (mm) OD 50.8 ID 25.4	Piezo diam. (in) OD 2 ID 1	Piezo diam. (mm) OD 55.0 ID 20.0
Piezo diam. (mm) OD 55.0 ID 25.0	Piezo diam. (mm) OD 60.0 ID 20.0	Piezo diam. (mm) OD 60.0 ID 30.0	Piezo diam. (mm) OD 69.0 ID 33.0
Piezo diam. (mm) OD 70.0 ID 30.0	Piezo diam. (mm) OD 70.0 ID 33.0		

Attention: The options for "Piezo diam. (mm)" are accessible only if the configuration parameter "Dim. input mode" is set to “Typical sizes "(factory default). The parameter configuration "Dim. input mode” for the "Custom" option will be described in details later.’

Step 04 Press SELECT [3] to access the "Number of piezos" configuration screen and enter the number of piezoelectric ceramics of the transducer to be assembled (from 1 to 99 units).

```
Number of piezos
4
```

Step 05 Use [▲] or [▼] to change the quantity.

Step 06 Press SELECT [3] to access the "d_{33}" configuration screen and enter the d_{33} value of the piezoelectric ceramics. Typical values are 245 pC/N for PZT-8, 290 pC/N for PZT-4, and 390 pC/N for PZT-5A.

```
d33
225 pC/N
```

Step 07 Use [▲] or [▼] to change the d_{33} value.

Step 08 Press SELECT [3] to access the “Target prestress” or “Target charge” screen. Enter the target prestress in MPa (from 1.0 to 99.9 MPa), ksi (from 0.10 to 99.99 ksi) or charge in uC (from 0.10 to 190.00 uC). The typical values are 45 MPa (6.5 ksi) for PZT-8 and 35 MPa (5.1 ksi) for PZT-4.

```
Target prestress
45.0 MPa
```
,
```
Target prestress
6.53 ksi
```
or
```
Target charge
32.10 uC
```

Step 09 Use the [▲] and [▼] pushbuttons to change the target.

Step 10 Press SELECT [3] to access the "Preloading time" configuration. Enter the min. time required to preloading the transducer (from 0.1 to 10.0 seconds).

```
Preloading time
0.4 s
```

Step 11 Use [▲] or [▼] to change the minimum preloading time.

Step 12 Press SELECT [3] to the last configuration screen, "Dim. input mode". Select the input mode of the ceramic dimensions. There are two options: "Typical sizes", for pre-configured dimensions, and "Custom".

```
Dim. input mode
Typical sizes
```

Step 13 Use [▲] or [▼] to switch between the two available options.

Step 14 After all parameters have been set, press SELECT [3] to finish the configuration and return to the measurement screen.

Attention: If the user chooses the "Custom" configuration option in the "Dim. Input mode", the equipment will present the "Outer diameter" screen at the beginning of the configuration (previously described in *Steps 02 and 03*). After that, by pressing SELECT [3], it will display the "Inner Diameter" screen. In this case, follow the steps below to inform the ceramic dimensions instead of following steps 02 and 03 previously described.

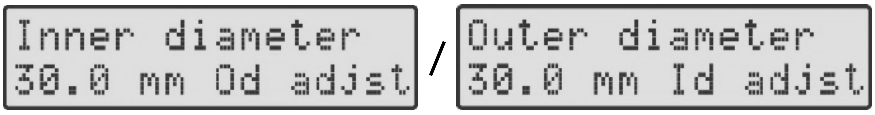
Step 02a Press SELECT [3] to access the first configuration screen named "Outer diameter". Insert the piezoceramic outer diameter, the accepted range is from 1.0 to 99.9 mm.

Step 02b Use [▲] or [▼] to inform the outer diameter (OD) value.

Step 02c Press SELECT [3] to access the first configuration screen named "Inner diameter". Insert the piezoceramic inner diameter, the accepted range is from 1.0 to 98.9 mm.

Step 02d Use [▲] or [▼] to inform the inner diameter (ID) value.

Note: If the outer diameter is configured to values smaller than the inner diameter + 1.0 mm, the inner diameter will be set automatically by displaying the "Id adjst" warning and vice-versa, as shown next:



The values of d_{33} and prestress ("Target prestress") should be obtained from the ceramics manufacturer. In the absence of this data, consider d_{33} equal to 245 pC/N for PZT-8, and 290 pC/N for PZT-4; and the target prestress 45 MPa for PZT-8 and 35 MPa for PZT-4.

7.2. Prestress and charge measurement during bolt preloading

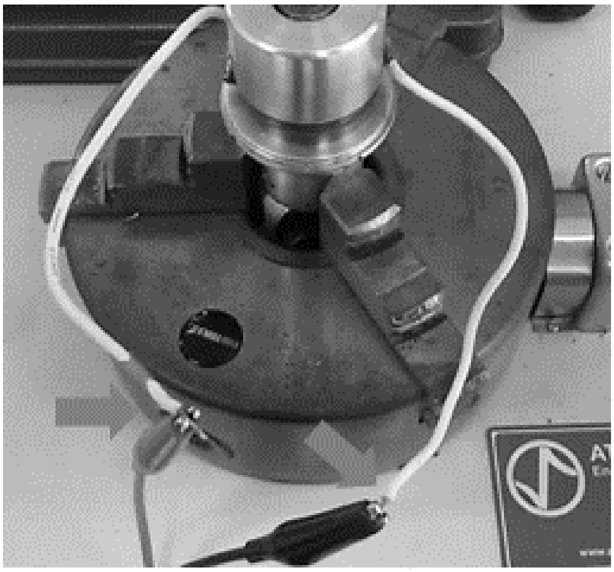
Step 01 Use the POWER [7] switch to turn the equipment on. The PiezoClamping® opening message will be displayed followed by the measurement screen. Use [▲] or [▼] to select MPa, ksi or uC. In this example the selection was MPa.

```
PiezoClamping..
www.atcp-ndt.com
```

→

```
      0.0 MPa
□□□□□□□□□□
```

Step 02 Observing the polarity, connect the probe alligator clips to the transducer terminals, that should be with its metallic front mass fixed to enable the bolt preloading until reaching the target prestress or target charge.



Step 03 Configure the piezoceramics parameters in the PiezoClamping®. Section 7.1 describes the configuration process in details.

Step 03 Press START [6] to begin the measurement. At this moment the equipment will reset the values, presenting the “STARTING…” screen. I will also present the ceramics configured quantity and dimensions for a few seconds in order to help the detection of mistakes.

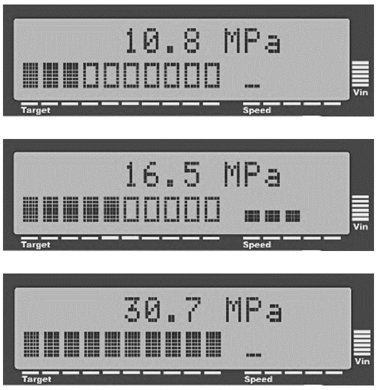
```
STARTING...
4 38.0 X 19.1 mm
```

After that, the equipment will present the measuring screen automatically and the user can start the transducer bolt preloading. This screen may also be in ksi or uC, depending on the selection made by the operator.

```
      0.0 MPa
□□□□□□□□□□
```

Step 04 Connect a tool or torque wrench to the bolt of the transducer and preload it progressively paying attention to the PiezoClamping® display.

As preloading progress, the prestress or charge will be presented in real-time on the display first line. On the second line, the bargraph will be filled progressively as the target prestress or target charge is reached. Each filled square corresponds to 10% of the target.

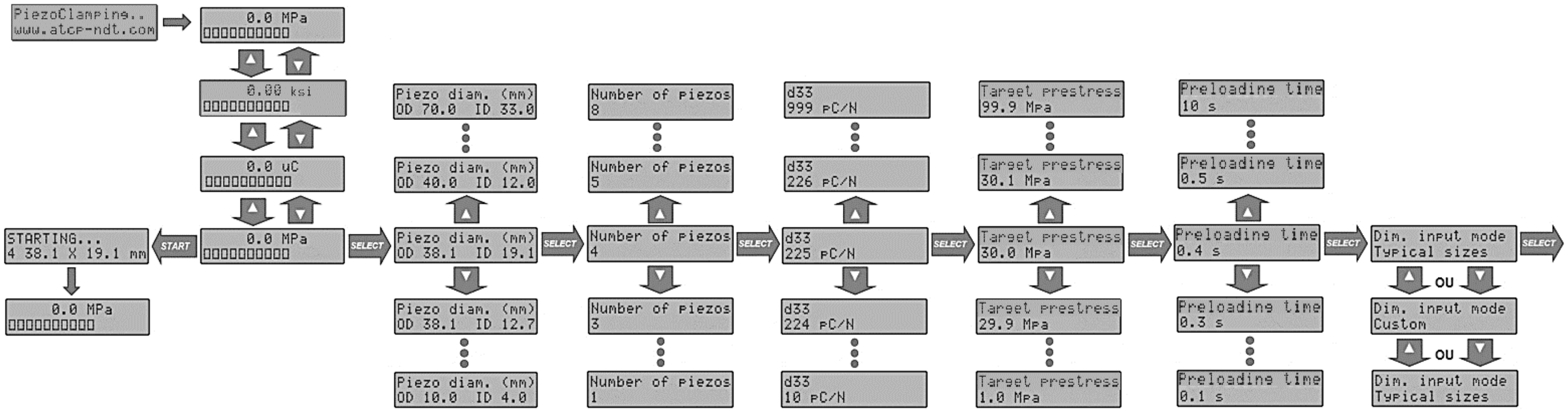


At the same time, the display screen will present a second bargraph to the left of the target bargraph. It is a 2D bargraph proportional to the prestress application speed (horizontal axis), and to the input voltage generated by the piezoelectric ceramics (vertical axis). If the maximum speed (calculated as a function of minimum loading time) or input voltage exceeds the equipment's acceptable limits (± 10 VDC), the bi-dimensional bar graph will be fully filled and a sound will warn the user. If it occurs for voltage, the message "overload" will also be displayed and the measurement interrupted.

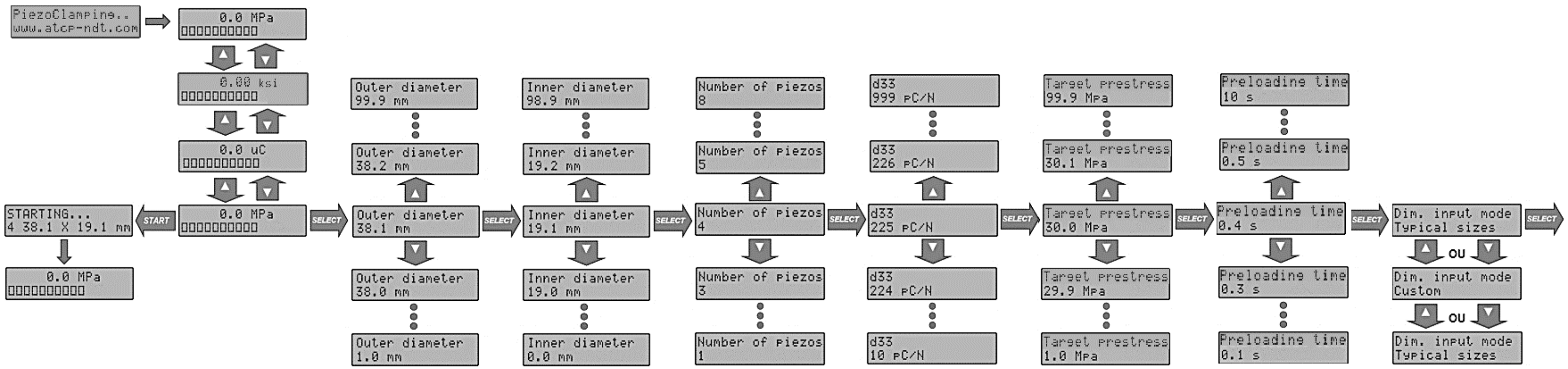
The pressure or charge indication will be negative if the bolt is loosened instead of preloaded, or if the test leads are inverted.

7.3. General flowchart for prestress control in MPa

Below, the equipment screens flowchart with the option “Dim. input mode” set to “Typical sizes” and having the prestress target in MPa as the control variable. Note: The flowchart for prestress in ksi and for charge in uC are analogous to this one.



Below, the equipment screens flowchart with the option “Dim. input mode” set to “Custom” and having prestress target in MPa as the control variable. Note: The flowchart for prestress in ksi and for charge in uC are analogous to this one.



8. Troubleshooting

Problem	Possible cause	Solution
PiezoClamping® does not turn on.	The power outlet lacks electrical power.	Use a power outlet with electrical power available.
	The power cord is not connected to the power outlet and/or to the equipment.	Connect the power cord.
	The [POWER] switch is on the "Off" position.	Move the switch to the "On" position.
	The power cord is damaged.	Replace the damaged power cord by a good one.
	There is a blown fuse.	Change the fuses (02 units of 5x20 mm, 250 V, 5 A, slow type).
PiezoClamping® do not measure, or The results are inconsistent, or The results are not reproducible.	The probe is not connected to the equipment.	Connect the probe to the "PIEZOCERAMICS" connector.
	The probe presents poor contact or one of the wires is broken.	Change or fix the probe.
	The probe is incorrectly connected to the transducer under test.	Check if the probe is connected to the correct pins or terminals (red clip to live and black clip to ground).
	The configuration parameters are incorrect.	Configure the parameters of the ceramics correctly and confirm that the equipment is in the required mode (prestress in MPa, prestress in ksi or charge in uC).
	PiezoClamping® lacks adjustment.	Carry out the self-test, calibration, and adjustment if necessary (see topic 9). If the problem persists, contact ATCP Physical Engineering: www.atcp-ndt.com
PiezoClamping® detects signal at the absence of preloading, or even without probe.	PiezoClamping® is detecting environmental electromagnetic noise.	Verify the grounding and increase the trigger level if necessary (topic 9.4). If the problem persists, contact ATCP Physical Engineering: www.atcp-ndt.com

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9. Self-test and calibration

PiezoClamping® was designed with features and accessories to facilitate troubleshooting and the fulfillment of demanding Quality Management Systems, such as the medical equipment manufacturers ones. The table below presents the alternatives to test and calibrate PiezoClamping®.

Alternatives for testing and calibrating PiezoClamping®.

#	Description	Charge(s)	Uncertainty
1	Self-test	47.0 uC	± 12.0 %
2	Calibration with PiezoClamping® Cal. Kit	5.5, 11.0, 16.5 e 22.0 uC	± 12.8 %
3	Calibration with capacitor and precision voltage source	Arbitrary(s)	Depends on capacitor and source characteristics.
4	Calibration by ATCP	5.5, 11.0, 16.5 and 22.0 uC	Typical ± 3.1 %

PiezoClamping® “Self-test” feature consists of measuring an internal discharge of 47.0 uC ± 12 %. This feature is enough for quick functional tests as part of the production process, for example, at the start of each work shift. However, it is limited to a single charge (47.0 uC) with much greater uncertainty than the PiezoClamping® nominal accuracy and precision combined (± 4 %). *Note: The PiezoClamping® charge measurement range is from 0.0 to ± 190.0 uC.*

The calibration with the PiezoClamping® Calibration Kit accessory has uncertainty similar to the self-test, but is more robust because it includes four charges (5.5, 11.0, 16.5 and 22.0 uC) in the charge range of transducers with 2 piezoelectric ceramics. For example, a transducer with two PZT-8 ceramics and 45 MPa prestress will displace a charge of approximately 18.75 uC with bolt preloading. The PiezoClamping® calibration with the Calibration Kit accessory can be performed sporadically by the user, which allows extending the equipment calibration interval or even sending the Calibration Kit for calibration instead of the PiezoClamping®.

The capability of calibration with a capacitor and a precision voltage source is similar to the PiezoClamping® Calibration Kit, but with greater flexibility regarding the calibration charges to encompass the typical charge of the transducer being manufactured. However, the experimental procedure is more elaborate and requires specific items, which limits this option to users with good metrological infrastructure.

The calibration service provided by ATCP Physical Engineering is the simplest from the customer execution standpoint and provides the lowest uncertainty (typical of ± 3.1 %). However, it is a more expensive service and requires the interruption of use and shipment of the equipment. The recommended calibration interval by ATCP is 3 years when the equipment is used in a laboratory environment and 1 year when used on the production floor. *Note: The ideal interval should be determined by the user based on the particularities of their application.*

9.1. Self-test

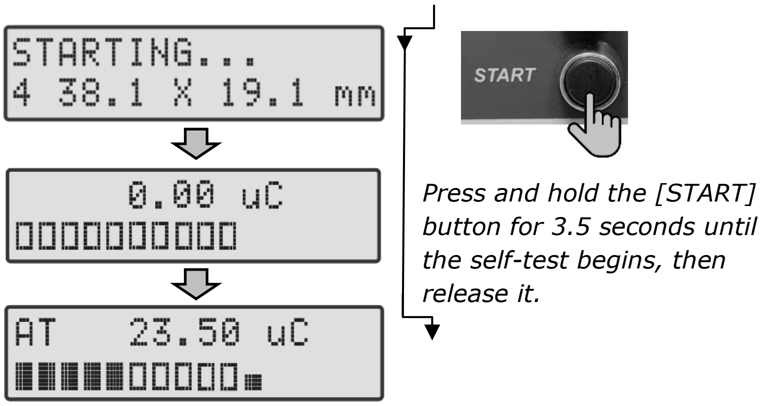
To ensure quality in critical applications, PiezoClamping® is capable of self-testing, which involves internally discharging and measuring a charge of 47.0 uC ± 12 %. The result evaluation by the equipment is automatic.

Step-by-step for the self-test:

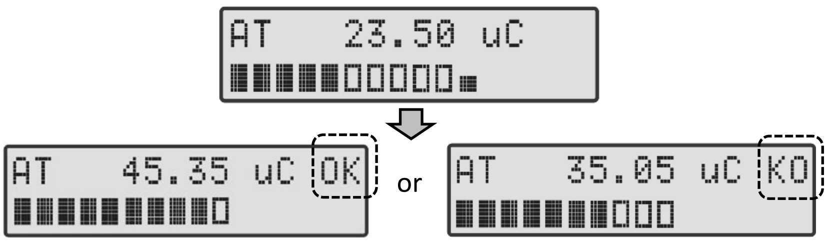
Step 01 Turn the PiezoClamping® on and disconnect the probe from the BNC connector. *Note: For the self-test, do not connect anything to the BNC connector on the equipment panel.*

Step 02 Press and hold the [START] button for 3.5 seconds until the last screen in the sequence below appears (the one with the letters "AT" at the beginning of the first line). Once the self-test has started, release the button. *Note: The second screen may differ depending on the last configuration.*

Step 02 video.
https://youtu.be/oozNdXDlLdA



Passo 03 Verify the information displayed at the end of the first line after the 5-second internal discharge time has elapsed. If it indicates "OK," the equipment has passed the self-test, whereas if the displayed message indicates "KO", the equipment has failed. After displaying the result, the equipment will automatically restart.



Notes: The result is "OK" if the measured charge is in range from 41.36 to 52.64 uC (47.00 uC ± 12%). Because the discharge uncertainty is ± 12 %, it is possible that the bargraph is not full or a ">" symbol is after it, and yet the result be "OK". If the result is "KO", send the instrument for calibration by ATCP Physical Engineering.

9.2. Calibration

This topic describes the typical procedure for calibrating the PiezoClamping®. To perform the calibration, you will need the PiezoClamping® Calibration Kit accessory or the following items: a precision capacitor with a nominal capacitance of 2.2 uF and known uncertainty, and a precision voltage source with a voltage between 2.5 and 10,0 VDC and known uncertainty. The PiezoClamping® Calibration Kit and the combination of capacitor and voltage source mentioned provide charges in the range of 5.5 to 22.0 uC, which coincides with the typical range of loads for transducers with 2 piezoelectric ceramics. For example, a transducer with two PZT-8 ceramics and a prestress of 45 MPa will displace approximately 18.75 uC with preloading. For calibration with other charges, larger or smaller capacitances can be used as needed.

Step-by-step for calibration using the Calibration Kit:

The image below shows the PiezoClamping® Calibration Kit. Following is summarized the steps for its use. For more details, please refer to its manual.

PiezoClamping® Calibration Kit

Step 01 Turn the PiezoClamping® on and press the [▼] button to access the charge option, as shown below.

```
     0.00 uC
□□□□□□□□□□
```

Step 02 On the Calibration Kit, select the charge (5.50, 11.00, 16.50 or 22.00 uC). On the PiezoClamping®, press the [SELECT] button to access the "Target charge" screen and enter the expected charge value (Q_E). *Note: The expected charge value Q_E is equal to the selected charge value on the Calibration Kit or the reported one on its calibration certificate.*

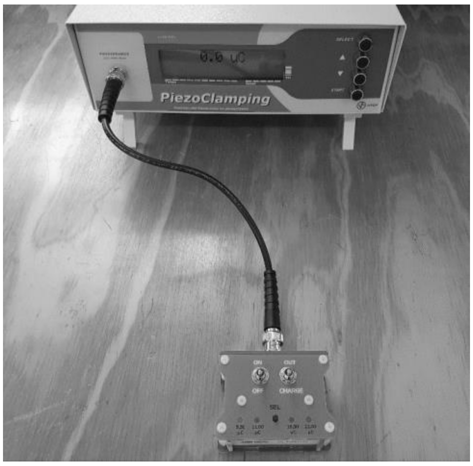
```
Target charge
5.50 uC
```

Step 03 Use Equation (1) to calculate the combined uncertainty (I_{QE}) of the charge that will be discharged on the PiezoClamping® by the Calibration Kit, considering the measurement uncertainty of the PiezoClamping® itself.

$$\mathrm{I_{QE}} = 2 * \mathrm{Q_E} * \sqrt{\left(\frac{I_{CK}}{100}\right)^2 + \left(\frac{I_{PZC}}{100}\right)^2} \qquad (1)$$

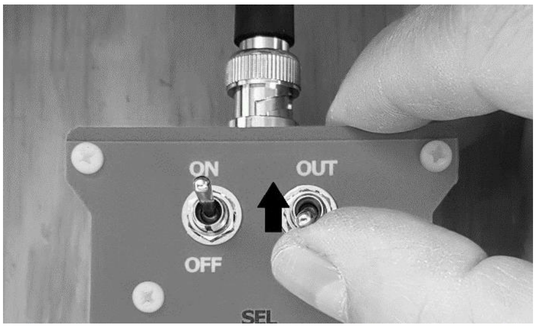
Where I_{CK} is the percentage uncertainty of the PiezoClamping® Calibration Kit and I_{pzc} is the percentage measurement uncertainty of the PiezoClamping®. The uncertainty of the PiezoClamping® can be 4% (accuracy + precision). The uncertainty of the Calibration Kit is 5%, but it can be lower if it has been calibrated with a reference of higher precision (verify the respective calibration certificate).

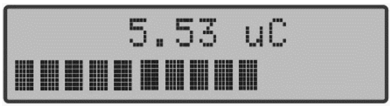
Step 04 Turn the Calibration Kit on and connect it to the PiezoClamping® using a BNC-BNC cable. *Note: If the Calibration Kit is discharged, recharge it using a smartphone charger and a micro-USB cable.*



Step 05 Press the [START] button to reset the equipment and start a new charge measurement.

Step 06 Discharge the Calibration Kit into the PiezoClamping® and record the charge measured by the equipment. Repeat steps 05 and 06 five times and calculate the results mean ($\overline{Q_m}$).





Step 08 The measurements mean ($\overline{Q_m}$) must be within the range given by Equation 2:

$$(Q_E - I_{QE}) \leq \overline{Q_m} \leq (Q_E + I_{QE}) \qquad (2)$$

Repeat steps 1 through 8 for the remaining Calibration Kit charges. If the measurements mean by PiezoClamping® is outside the above range or the desired accuracy, it is necessary to adjust the PiezoClamping®. See topic "10. Adjustments" or send the equipment for calibration and adjust by ATCP Physical Engineering.

Calibration example using the PiezoClamping® Calibration Kit

Parameters and range for the 5.50 uC charge:

Parameter	*Value*	*Note*
Q_E	5.50 uC	
I_{CK}	5%	
I_{PZC}	4%	
I_{QE}	0.704 uC (12.8 % de 5.5 uC)	Calc. by eq. (3)
$Q_E + I_{QE}$	6.204 uC	
$Q_E - I_{QE}$	4.796 uC	
Acceptance range	$\mathbf{4.80} \leq \overline{\boldsymbol{Q_m}} \leq \mathbf{6.20}\ \mu\mathbf{C}$	

Parameters and range for the 11.00 uC charge:

Parameter	*Value*	*Note*
Q_E	11.00 uC	
I_{CK}	5%	
I_{PZC}	4%	
I_{QE}	1.408 uC (12.8 % de 11.00 uC)	Calc. by eq. (3)
$Q_E + I_{QE}$	12.41 uC	
$Q_E - I_{QE}$	9.59 uC	
Acceptance range	$\mathbf{9.59} \leq \overline{\boldsymbol{Q_m}} \leq \mathbf{12.41\ uC}$	

Parameters and range for the 16.50 uC charge:

Parameter	*Value*	*Note*
Q_E	16.50 uC	
I_{CK}	5%	
I_{PZC}	4%	
I_{QE}	2.112 uC (12.8 % de 16.50 uC)	Calc. by eq. (3)
$Q_E + I_{QE}$	18.61 uC	
$Q_E - I_{QE}$	14.39 uC	
Acceptance range	$\mathbf{14.39} \leq \overline{\boldsymbol{Q_m}} \leq \mathbf{18.61}\ \mu\mathbf{C}$	

Parameters and range for the 22.00 uC charge:

Parameter	*Value*	*Note*
Q_E	22.00 uC	
I_{CK}	5%	
I_{PZC}	4%	
I_{QE}	2.816 uC (12.8 % de 22.00 uC)	Calc. by eq. (3)
$Q_E + I_{QE}$	24.82 uC	
$Q_E - I_{QE}$	19.18 uC	
Acceptance range	$\mathbf{19.18} \leq \overline{\boldsymbol{Q_m}} \leq \mathbf{24.82}\ \mu\mathbf{C}$	

Measured charges versus acceptance ranges:

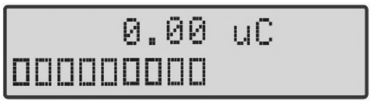
Nominal charge	*Acceptance range*	*Mean charge* ($\overline{Q_m}$)	*Evaluation*
5.50 µC	$4.80 \le \overline{Q_m} \le 6.20\ \mu C$	5.53 µC	In the range
11.00 µC	$9.59 \le \overline{Q_m} \le 12.41\ \mu C$	11.30 µC	In the range
16.50 µC	$14.39 \le \overline{Q_m} \le 18.61\ \mu C$	16.93 µC	In the range
22.00 µC	$19.18 \le \overline{Q_m} \le 24.82\ \mu C$	22.58 µC	In the range

As the values measured by PiezoClamping® are within the expected ranges, the equipment is most likely in order. If it was off, it would be necessary to adjust the PiezoClamping®, as described in topic 10.

It is recommended that the PiezoClamping® Calibration Kit is calibrated.

Step-by-step using a capacitor and a precision voltage source:

Step 01 Turn the PiezoClamping® on and press the [▼] button to access the charge option shown below.



Step 02 Use equation (3) below to calculate the expected charge (Q_E) as a function of the capacitance (C) and voltage (V) used.

$$Q_E = C \text{ x } V \qquad (3)$$

Press the [SELECT] button to access the "Target charge" screen and enter the calculated expected charge (Q_E) as shown below.

Step 03 Use Equation (4) to calculate the combined uncertainty (I_{QE}) of the charge that will be discharged in the PiezoClamping® and the PiezoClamping® own uncertainty.

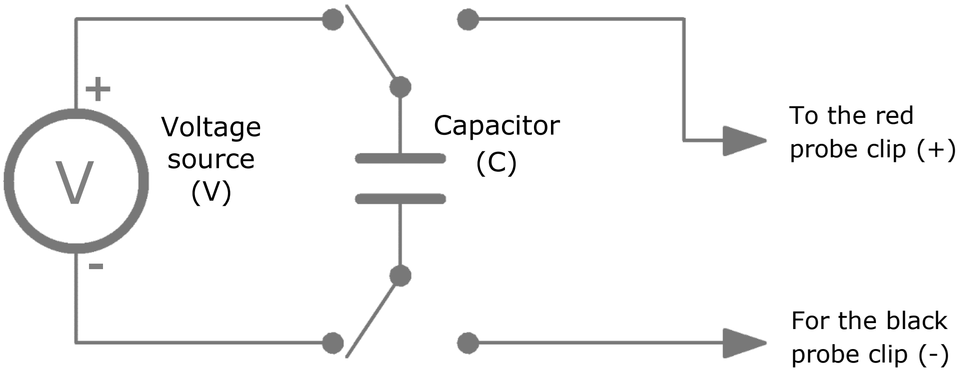
$$I_{QE} = 2 * Q_E * \sqrt{\left(\frac{I_V}{100}\right)^2 + \left(\frac{I_C}{100}\right)^2 + \left(\frac{I_{PZC}}{100}\right)^2} \qquad (4)$$

Where I_V is the voltage source percentage uncertainty, I_C is the capacitor percentage uncertainty of the and I_{pzc} is the PiezoClamping® measurement percentage uncertainty. The PiezoClamping® uncertainty can be considered equal to 4% (its accuracy plus its precision).

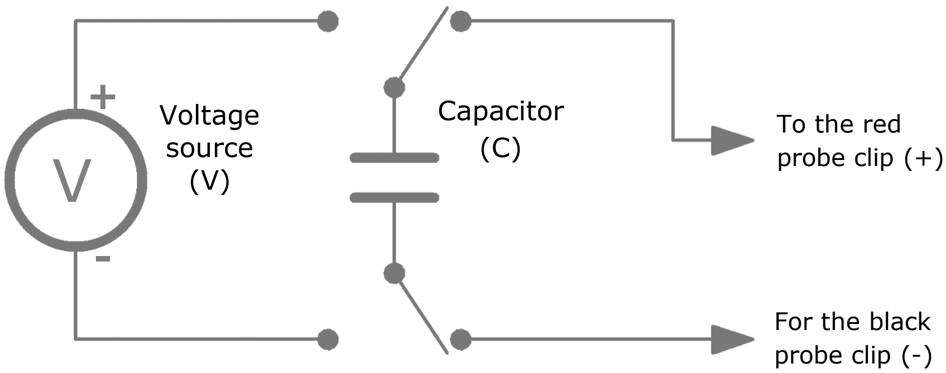
Step 04 Connect the test lead supplied with the equipment to the "PIEZOCERAMICS" connector located on the front panel of the instrument.

Step 05 Press the [START] button to reset the equipment and start a new charge measurement.

Step 06 Charge the capacitor by connecting it to the voltage source as shown below.



Step 07 Disconnect the capacitor from the voltage source and connect it to the PiezoClamping® input as shown below, the capacitor charge will be discharged and measured by the PiezoClamping®. Do not touch the capacitor terminals during the process. After unloading, write down the value obtained. Repeat steps 06 and 07 five times and calculate the mean ($\overline{Q_m}$).



Step 08 The PiezoClamping® measurements mean ($\overline{Q_m}$) should be in the range given by Equation 5:

$$\left(\mathrm{Q}_E - I_{QE}\right) \leq \overline{Q_m} \leq \left(\mathrm{Q}_E + I_{QE}\right) \qquad (5)$$

If the PiezoClamping® measurements average is outside of the equation (5) range, it is necessary to adjust the PiezoClamping® for charge measurement. See topic “10. Adjustments” or send the equipment for calibration and adjust by ATCP Physical Engineering.

Example of calibration with capacitor and voltage source

Devices used:

- Bipolar capacitor of 2.1630 uF with 2.7% uncertainty (commercial equivalent model: KEMET F461DO225G250L).
- Voltage reference model AD584-M (4 selectable output voltages: 2.5000 V; 5.0000 V; 7.5000 V and 10.0000 V with 0.1% uncertainty).

Calculation of the acceptance range:

Parameters and range for the 5.41 uC charge:

Parameter	*Value*	*Note*
C	2.1630 uF	
V	2.5000 V	
Q_E	5.41 uC	
I_V	0.1 %	
I_C	2.7 %	
I_{PZC}	4%	
I_{QE}	0.522 uC (9.65 % de 5.41 uC)	Calc. by eq. (3)
$Q_E + I_{QE}$	5.932 uC	
$Q_E - I_{QE}$	4.888 uC	
Acceptance range	$\mathbf{4.89} \leq \overline{\boldsymbol{Q_m}} \leq \mathbf{5.93}\ \mu\mathrm{C}$	

Parameters and range for the 10.81 uC charge:

Parameter	*Value*	*Note*
C	2.1630 uF	
V	5.0000 V	
Q_E	10.81 uC	
I_V	0.1 %	
I_C	2.7 %	
I_{PZC}	4%	
I_{QE}	1.043 uC (9.65 % de 10.81 uC)	Calc. by eq. (3)
$Q_E + I_{QE}$	11.85 uC	
$Q_E - I_{QE}$	9.77 uC	
Acceptance range	$\mathbf{9.77} \leq \overline{\boldsymbol{Q_m}} \leq \mathbf{11.85\ uC}$	

Parameters and range for the 16.22 uC charge:

Parameter	*Value*	*Note*
C	2.1630 uF	
V	7.5000 V	
Q_E	16.22 uC	
I_V	0.1 %	
I_C	2.7 %	
I_{PZC}	4%	
I_{QE}	1.565 uC (9.65 % de 16.22 uC)	Calc. by eq. (3)
$Q_E + I_{QE}$	17.78 uC	
$Q_E - I_{QE}$	14.56 uC	
Acceptance range	$\mathbf{14.56} \leq \overline{\boldsymbol{Q_m}} \leq \mathbf{17.78}\ \mu\mathrm{C}$	

Parameters and range for the 21.63 uC charge:

Parameter	*Value*	*Note*
C	2.1630 uF	
V	10.0000 V	
Q_E	21.63 uC	
I_V	0.1 %	
I_C	2.7 %	
I_{PZC}	4%	
I_{QE}	2.087 uC (9.65 % de 21.63 uC)	Calc. by eq. (3)
$Q_E + I_{QE}$	23.71 uC	
$Q_E - I_{QE}$	19.54 uC	
Acceptance range	$\mathbf{19.54 \leq \overline{Q_m} \leq 23.71\ uC}$	

Measured charges versus acceptance ranges:

Nominal charge	*Acceptance range*	*Mean charge ($\overline{Q_m}$)*	*Evaluation*
5.50 μC	$4.89 \leq \overline{Q_m} \leq 5.93$ μC	5.54 μC	In the range
11.00 μC	$9.77 \leq \overline{Q_m} \leq 11.85$ uC	11.06 μC	In the range
16.50 μC	$14.56 \leq \overline{Q_m} \leq 17.78$ μC	16.75 μC	In the range
22.00 μC	$19.54 \leq \overline{Q_m} \leq 23.71$ uC	22.04 μC	In the range

As the values measured by PiezoClamping® are in the ranges, the equipment is most likely in order. If it were out of range, it would be necessary to adjust the charge measurement as described in topic 10.

It is recommended that the capacitor and voltage source are calibrated.

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10. Adjustments

10.1. Electric charge measurement adjustment

It is possible to adjust PiezoClamping® for charge measurement. This adjustment is necessary when the PiezoClamping® fails the self-test or calibration. For this, a precision electrical charge source is required. At ATCP, as part of the manufacturing process, we adjust the PiezoClamping® with a discharge of ± 21.63 uC ± 3%.

Step-by-step:

Step 01 Access the adjustment menu by turning the PiezoClamping® on using the [POWER] switch while keeping the [SELECT] and [▲] buttons pressed simultaneously. Release the [SELECT] and [▲] buttons only when the equipment shows the "Z adjust" correction factor on the first line as shown below. Set the "Z adjust" factor to 1000 and cycle power to save and exit adjustment mode.

Notes: Values may differ from those illustrated. The second line informs the equipment firmware version.

Step 02 Measure the reference charge 10 times, 5 times with reversed polarity, and calculate the mean and standard deviation of the results absolute value to obtain $\overline{Q_m}$ by equation (6).

$$\overline{Q_m} = \frac{1}{10}\sum_1^{10}|Q_m| \qquad (6)$$

Step 03 Calculate the new "Z adjust" factor using equation (7). The "Z adjust" is a multiplicative factor of the charge/prestress measurement and must be changed in the inverse proportion of the deviation observed in the measurement of the electrical charge using equation (6). Q_e is the expected charge and equal to the discharged electrical charge.

$$Z\ adjust_{new} = \left(\frac{Q_e}{\overline{Q_m}}\right) Z\ adjust_{current} \qquad (7)$$

Note: The maximum value for the "Z adjust" parameter is 1050 and the minimum 950. If the required value is outside this range, the equipment may be broken and the adjustment will be impossible without repair.

Step 04 Access the adjustment menu again by turning the PiezoClamping® on using the [POWER] switch while keeping the [SELECT] and [▲] keys pressed simultaneously. Enter the new "Z adjust" factor calculated by equation (7). Cycle power to save and exit adjustment mode.

Step 05 Perform a self-test or calibration to confirm that the adjustment was successful.

Adjustment example

The devices used for the adjustment were the charge switcher, the capacitive decade and the voltage source shown below. The capacitive decade was selected for 0.2219 uF and the voltage source for 10.0000 Volts. Both the decade and the source were calibrated with traceability to the International System of Units. This arrangement can generate a reference charge of ± 21.63 uC ± 3% and is used at the ATCP in the PiezoClamping® adjustment.

Charge switcher, capacitive decade, and precision voltage source.

The table below presents the results of the charge measurements after the equipment has the "Z adjust" parameter set to 1000. *Note: As the nominal precision of PiezoClamping® is 1.0%, it is expected that the standard deviation of the measurements is less than 1.0% (it was 0.7%).*

Results after the equipment has the "Z adjust" parameter set to 1000

Measurement	1	2	3	4	5	6	7	8	9	10
Charge (uC)	22.25	22.28	22.49	22.41	21.99	-22.30	-22.28	-22.42	-22.19	-22.08

- Mean of the measured charge absolute value: 22.27 uC;
- Standard deviation of the modulus of the measured charge: 0.15 uC (0.7 %).

Calculation of the ideal value for the "Z adjust" factor by equation (7):

$$Z\ adjust_{new} = \left(\frac{21.63}{22.27}\right) 1000 = 971$$

$$Z\ adjust_{new} = 971$$

The following table presents the results of the reference charge measurements after the equipment has the "Z adjust" parameter adjusted to the calculated value of 971.

Results after the instrument has the "Z adjust" parameter set to 971

Measurement	1	2	3	4	5	6	7	8	9	10
Charge (uC)	21.54	21.86	21.73	21.53	21.73	-21.52	-21.33	-21.71	-21.39	-21.39

- Module average: 21.57 uC (0.3% below the reference charge, which is much lower than the equipment's nominal accuracy of 4%);
- Module standard deviation: 0.18 uC (0.8 %).

Note that the deviation from the average measured charge to the reference charge was only -0.3%, which is much less than the nominal accuracy of the equipment (4%) and less than 1/3 of the nominal accuracy (1%).

10.2. Measurement trigger level adjustment

It is possible to adjust the trigger level for signal acquisition by PiezoClamping® by changing the "Trigger level" parameter. This procedure may be necessary in environments with electromagnetic interference levels capable of triggering the measurement without a transducer connected or being preloaded.

Step-by-step:

Step 01 Access the adjustment menu by turning the PiezoClamping® on using the [POWER] switch while keeping the [▼] and [▲] buttons pressed simultaneously. Release the buttons only when the equipment shows the "Trigger level" parameter as below (the factory setting is 4.8 mV):

Step 02 Adjust the "Trigger level" parameter using the [▼] and [▲] buttons. The "Trigger level" is the reference parameter used by PiezoClamping® to determine whether the voltage at the input connector is a real signal or noise.

Step 03 Cycle power to save the new "Trigger level" and exit adjustment mode.

Trigger level adjustment is rarely necessary. Usually, the problems with the measurement of noise are related to the lack of grounding in the power socket, which is easily correctable without the need to work around it by adjusting the trigger level.

The "trigger level" parameter must be kept as close as possible to 4.8 mV; values above will cause loss of information and decrease of the equipment accuracy.

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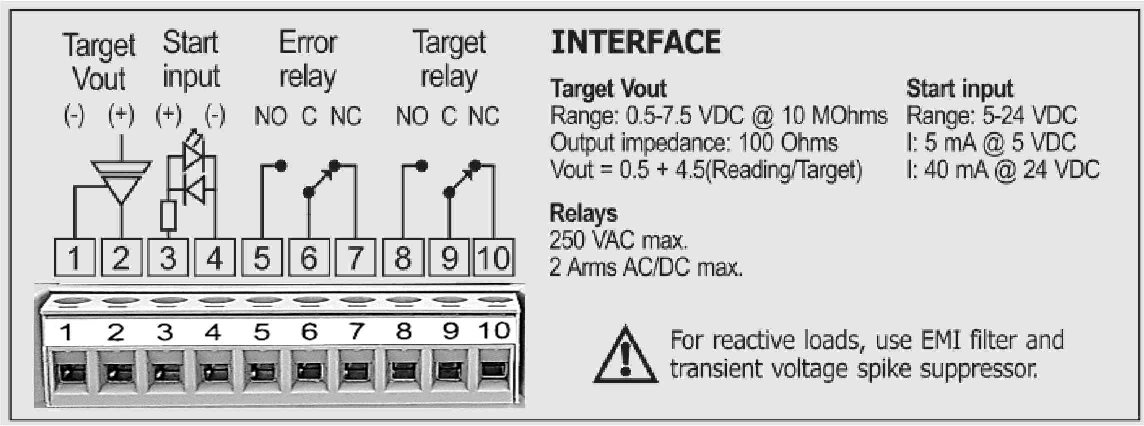
11. Interface for automation

11.1. Inputs and outputs description

The equipment PiezoClamping® has an interface for automation, as detailed following. This interface allows remote control of the equipment and real-time transmission of percentual prestress and charge in relation to the target.



The PiezoClamping® interface at the rear panel.

Inputs and outputs:

"Target Vout": Isolated analog voltage output proportional to the selected variable (prestress or charge). The output voltage range is from 0.5 to 7.5 VDC for high impedance load (for 1 k Ohms, the maximum output voltage is approximately 7.3 VDC). Equation (8) describes the correlation between Vout at high impedances, the selected variable (*Reading*) and the target (*Target*).

$$Target\ Vout = 0{,}5 + 4{,}5\left(\frac{Reading}{Target}\right) \qquad (8)$$

The signal measurement must be performed in the connector position '2' (+), position '1' is the reference (-). *Note: This output can be calibrated in dependence of the coupled circuit impedance, according to the procedure described in topic 11.2.*

"Start input": Isolated input to start a new measurement. Acts in the same way as the START button [6]. The input voltage range is from 5 to 24 VDC. The signal must be injected in the connector position '3' (+), position '4' is the reference (-).

"Error relay": Isolated output where an SPDT relay is activated when an error or overload occurs. It is possible to use either the normally closed contact (NC, connector position '7') or the normally open contact (NO, connector position '5'). The common contact (C) is available in the connector position '6'.

"Target relay": Isolated output where an SPDT relay is activated when the target ("Target") is reached. It is possible to use either the normally closed contact (NC, connector position '10') or the normally open contact (NO, connector position '8'). The common contact (C) is available in the connector position '9'.

For the external electrical connection with the PiezoClamping® interface, use the connector provided as an accessory (connector model MSTB 2.5/10-STZ-5.08, PN# 1764303, Phoenix Contact).

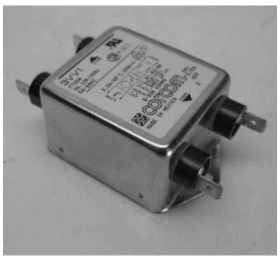
Below is a table with the input and outputs specifications.

Inputs and outputs specifications.

Target Vout	Positions '1' (-) e '2' (+). Output voltage range: 0.5 – 7.5 VDC @ 10 MOhms. Output Impedance: 100 Ohms. *Note: It is recommended that the impedance of the coupled circuit is equal or greater than 1 k Ohms.*
Start input	Positions '3' (+) e '4' (-). Input voltage range: 5-24 VDC. I: 5 mA @ 5 VDC / I: 40 mA @ 24 VDC.
Error relay	Positions '5' (NO), '6' (C) e '7' (NC). 250 VAC max. / 2 Arms AC/DC max.
Target relay	Positions '8' (NO), '9' (C) e '10' (NC). 250 VAC max. / 2 Arms AC/DC max.

For the switching of reactive loads using the "Error relay" or the "Target relay", include transient suppressors and EMI filters in the external circuit to prevent from affecting the operation of the PiezoClamping® and compromising its integrity and reliability. Below are shown some examples.

Examples of "snubbers" that can be used in the external circuitry in the case of switching reactive loads with the PiezoClamping® interface.



Example of EMI filter that can be included in the external circuit in the case of switching reactive loads with the PiezoClamping® interface.

11.2. Calibration of the "Target Vout" analog output

It is possible to calibrate the PiezoClamping® proportional analog output "Target Vout" to compensate the impedance of the coupled circuit. This calibration is performed at two points, at 2.75 and 5.00 VDC as detailed below. We recommend that the impedance of the coupled circuit is equal or greater than 1 k Ohms.

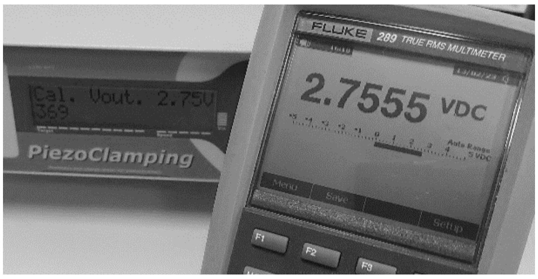
Step-a-Step:

Step 01 Connect a calibrated DC voltmeter to the "Target Vout" output (pins '1' (-) and '2' (+) of the interface connector) in parallel with the automation circuit or an equivalent resistance.

Step 02 Access the adjustment menu by turning he PiezoClamping® on using the [POWER] switch while keeping the [SELECT] and [▼] buttons pressed simultaneously. Release the [SELECT] and [▼] buttons only when the equipment displays "Cal. Vout 2.75V" on the display as below.

Note: The second line shows the value of the equipment 10-bit analog-to-digital converter.

Step 03 Adjust the value shown on the second line until the voltage measured by the voltmeter equals 2.75 VDC, as shown below.



Note: The value of the second line for the output to be equal to 2.75 VDC will depend on the impedance of the circuit connected to the output. In the example, the impedance was 1k Ohms and the value 369 (the adjustment range is from 0 to 470).

Step 04 Press the [SELECT] button to access the next menu "Cal. Vout. 5.00 V" as shown below.

Note: The second line shows the value of the equipment 10-bit analog-to-digital converter.

Step 05 Adjust the value shown on the second line until the voltage measured by the voltmeter equals 5.00 VDC, as shown below.

Note: The value of the second line for the output to be equal to 5.00 VDC will depend on the impedance of the circuit connected to the output. In the example, the impedance was 1 k Ohms and the value was 706 (the adjustment range is from 480 to 1023).

Step 06 Power cycle PiezoClamping® to save adjustments and exit calibration mode.

Step-by-step video for calibrating the "Target Vout" analog output

https://youtu.be/s8xzTZ3yo0g

12. Technical support, warranty terms and statement of responsibility

If the equipment is defective or malfunctioning, verify if the problem is related to any of those listed in topic 8 and follow the troubleshooting instructions. If the problem remains or is not listed in topic 8, contact the ATCP Physical Engineering for further analysis and repair.

ATCP Physical Engineering offers two-year warranty from the date of purchase. The warranty covers material and/or manufacturing defects. After the end of the warranty period, services, parts, and other expenses will be charged. Factors that may invalidate the warranty agreement:

- Lack of recommended care in this manual regarding the installation and operation of the equipment;
- Accidents, falls, improper installation or any other damage caused by incorrect use or action of natural agents;
- Violation, repair or any other modification or alteration made to the equipment or its parts by personnel not authorized by ATCP Physical Engineering.

ATCP Physical Engineering takes full technical and legal responsibility for the PiezoClamping® prestress and charge meter for piezoceramics and guarantees that all the information contained in this Installation and Operation Manual is true.

⚠ Reading all the information contained in this installation and operation manual is indispensable for the correct use of the equipment.

⚠ Do not use the equipment for any other purposes other than the ones that have been indicated by this manual.

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13. References

[1] LANGEVIN, P.; Procédé et appareils d'émission et de réception des ondes élastiques sous-marines à l'aide des propriétés piézo-électriques du quartzProcédé et appareils d'émission et de réception des ondes élastiques sous-marines à l'aide des propriétés piézo-électriques du quartz, French Patent 505.703,1920.

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[3] PROKIC, M.; Piezoelectric Converters Modeling and Characterization, 2° edição, MPI Interconsulting, august 2004.

[4] PIEZOELECTRIC CERAMICS Properties & Applications. Morgan Advanced Materials.

[5] BUNAI, C.; The Torque-Tension Relationship Gets Stretched, American Fastener Journal, May/June 2012 Issue - Vol. 28 No. 3.