White paper: Technical-scientific informative ITC-01 / ATCP

Piezoelectric ceramics test for crack detection

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Revision 1.2
October 4th, 2016

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1. Objectives and applications

Piezoelectric ceramics are fragile and sensitive components that may present internal cracks undetectable to a visual inspection. Ceramics presenting cracks, even if internal and invisible, must be discarded to avoid the premature fault of ultrasonic transducers and converter in which they are mounted, and the resulting losses from repairs and technical assistance.

This white paper presents a practical and effective methodology for detecting cracks in piezoelectric ceramics used in ultrasonic transducers and converters. This approach is a variation of the acoustic resonant inspection (ASTM – E2001), which obtains the frequency spectrum through impedance analysis. Manufacturers and final users of piezoelectric ceramics, ultrasonic transducers and converters may apply this methodology in the following cases:

- Quality control in manufacturing piezoelectric ceramics.
- Receipt inspection of new piezoelectric ceramic pieces.
- Checking of ceramics recovered from transducers and converters reproved in the production line.
- Checking of ceramics recovered from damaged and dismantled transducers and converters.

2. Introduction

Figure 1 shows a typical piezoelectric ceramic of 20 kHz converters for ultrasonic welding. Its dimensions are 38.1 x 19.1 x 5.15 mm and its material is the PZT-8. There are metallic electrodes on its two flat faces for the application of electrical voltage and on one of the faces shows the polarity mark (the positive is marked with a "+" and/ or a dot "•", which may be also on the side). These ceramics are made by pressing and sintering the powder Lead Zirconate Titanate (PZT). PZT can be found under diverse variations and denominations, confirm the correct application and specification with the manufacturer.

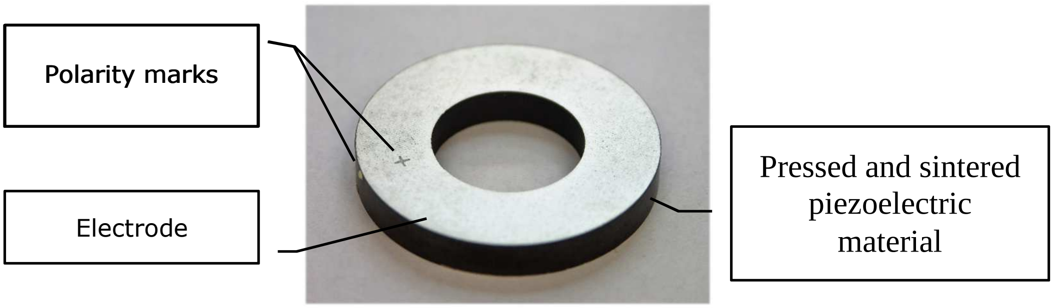


Figure 1- Typical piezoelectric ceramic for ultrasonic welding converters.

Piezoelectric ceramics are the main element of ultrasonic transducers and converters and are responsible for the electric energy conversion into ultrasonic waves and vice-versa through the piezoelectric effect. Cracks - even if internal and dimensionally small - trigger heating, loss of productivity and frequency variations of transducers or converters.

The presence of cracks on the piezoelectric ceramic compromises the symmetry of mechanical stress and deformation with the vibration and causes the concentration of stress, leading to the growth of the crack in a vicious cycle and, eventually, to a complete rupture. Figure 2 shows the comparison between an intact ceramic ring deformation and a cracked ring, both in the fundamental radial vibration mode. Figure 3 presents an illustrative sequence of the growth of an internal crack until the rupture of the piece.

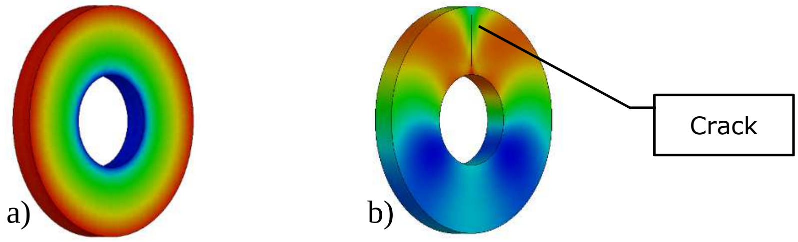


Figure 2 – Comparison between the deformation of an intact ceramic (a) in radial vibration mode and a cracked ceramic (b)

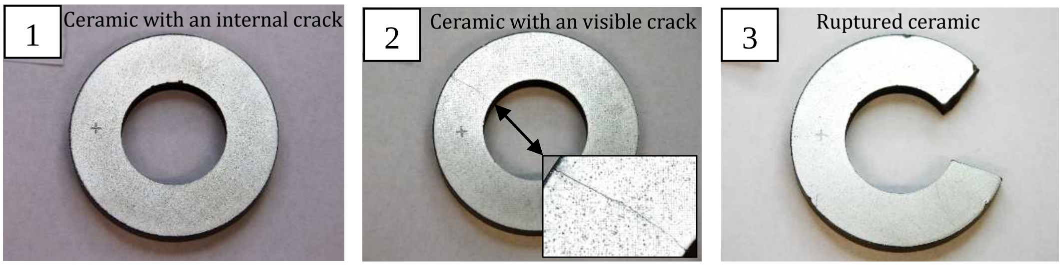


Figure 3 – Ilustrative sequency of the growth of na internal crack originated from mechanical strains: 1º) ceramic with an internal crack, 2º) ceramic with a visible crack, 3º) fractured ceramic.

Cracks may occur during:

- The manufacture of ceramic pieces because of the unequal distribution of power on pressing molds.
- The assembly of transducers or converters because of irregularities on the surface or excessive stress (>50 MPa) or abrupt tightening (>5 MPa/s)
- The transducer or converter use because of fatigue, overload, loss of pre-stress, overheating or electric arching.
- The transport or handling because of mechanical shocks and falls.

The number of new ceramics presenting cracks may be superior to 3%, depending on their origin and the rigorousness of the manufacturer quality control. This percentage is relevant because only one ceramic with a crack is enough to compromise the ultrasonic transducer or converter.

3. Foundations

Every rigid body presents resonant frequencies associated with vibration modes. Piezoelectric ceramics shaped liked rings and disks are mainly associated with the radial and thickness vibration modes.

Figure 4 shows the typical impedance curve of three common and intact commercial piezoelectric ceramic pieces. Note that the bigger the ceramics, the lower are their frequencies. In the case of the bigger ring, measuring 50.8 x 19.1 x 5 mm, there is a second resonance that corresponds to a harmonic fundamental radial mode. Other commercial ceramics with similar dimensions shaped like rings present the same pattern.

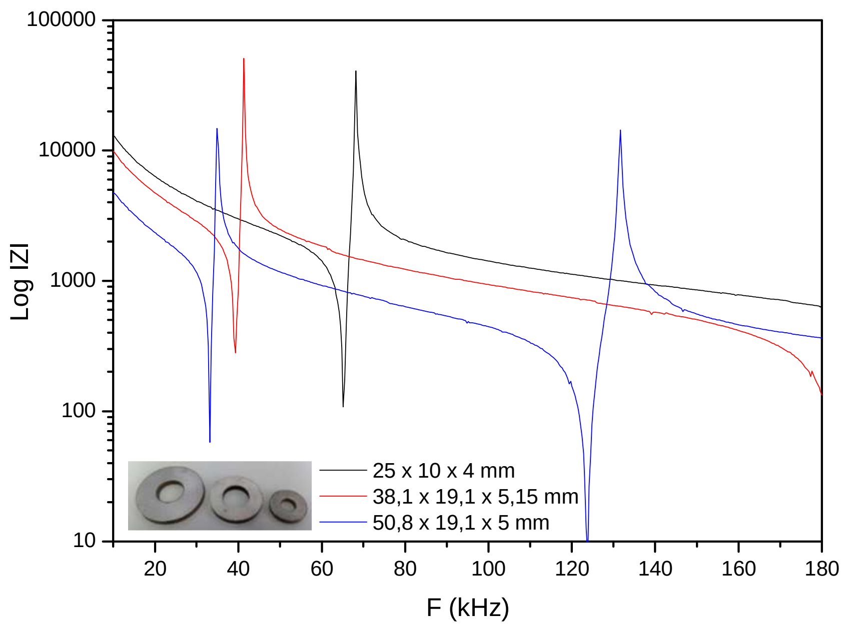


Figure 4 – Typical curves of the impedance module as a function of frequency for three typical and intact ceramic pieces of ultrasonic welding and cleaning converters.

The presence of cracks allows the occurrence of additional vibration and resonance modes, which are detectable by employing the TRZ Analyzer and Software. Figure 5 and 6 present the impedance spectroscopies (impedance module as a function of frequency/curve |Z(f)|) of two similar piezoelectric ceramics, being one of them intact (Figure 5) and the other cracked (Figure 6).

Judging the result is simple and straightforward: there must be no multiple resonances (from additional vibration modes allowed by the crack), and there must be a maximum of two vibration modes in the frequency range from 10 to 180 kHz for ceramics with the external diameter measuring between 20 and 60 mm. The intact ceramic (Figure 5) presents only one vibration mode (highlighted in blue), while the cracked ceramic (Figure 6) presents several additional vibration modes, besides the main vibration mode.

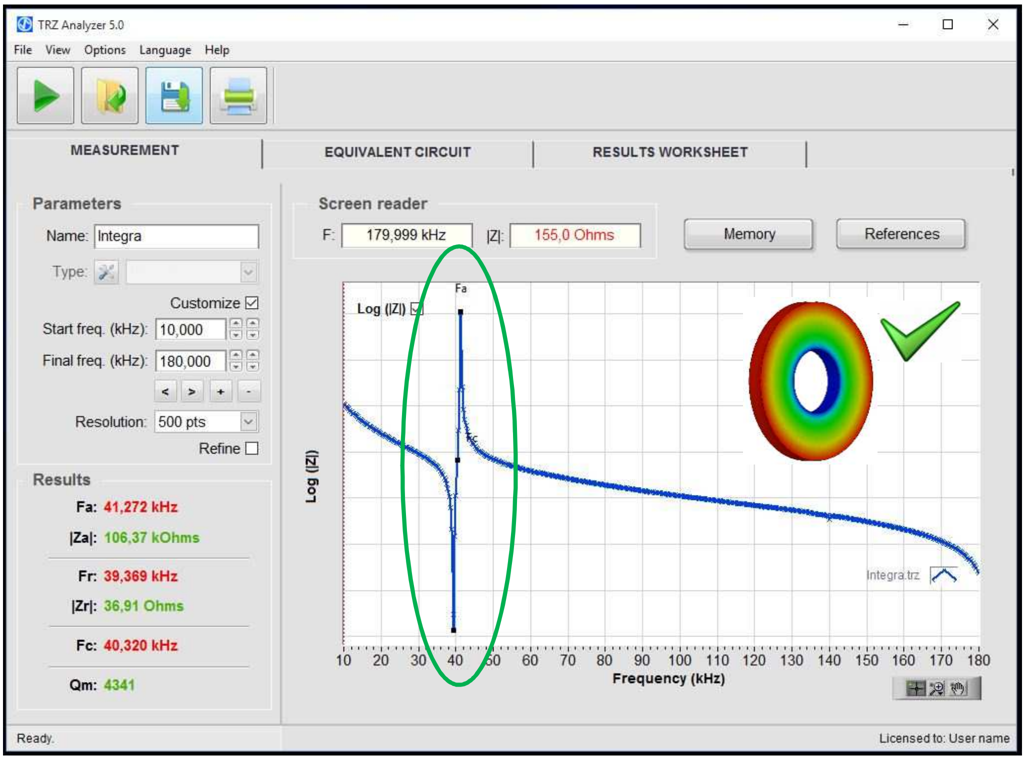


Figure 5 – Example of the impedance curve for an intact piezoelectric ceramic ring (a PZT-8 ceramic with dimensions measuring de 38.1 x 19.1 x 5.15 mm).

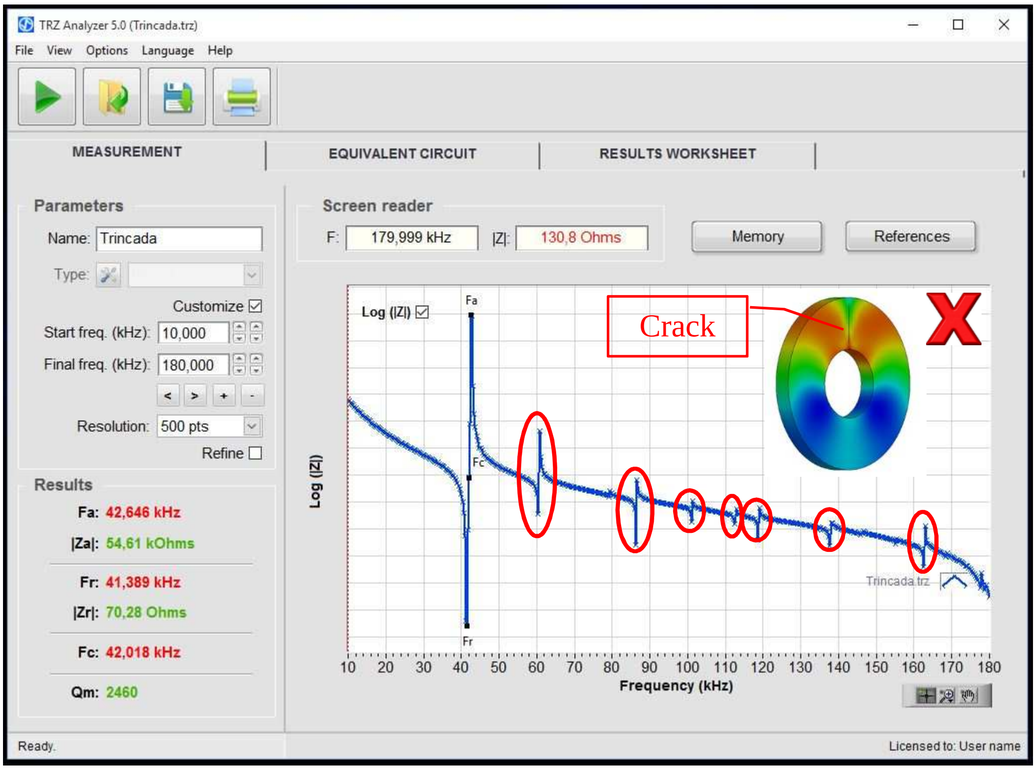


Figure 6 – Example of the impedance curve for a cracked piezoelectric ceramic ring (a PZT-8 ceramic with dimensions measuring 38.1 x 19.1 x 5.15 mm).

4. Methodology

The test methodology for crack detection in piezoelectric ceramics is very simple and can be easily carried by following the step-by-step instructions below:

Step 1 – Use the TRZ Analyzer and the PiezoHolder
Use the TRZ Analyzer together with the TRZ Software (5.0 version or superior) and the PiezoHolder support for ceramics (Figure 7). Select the option "Piezos" from the Software (Figure 8). Under this pre-configuration, the TRZ analyzer and Software set will perform a sweep between 10 and 180 kHz.

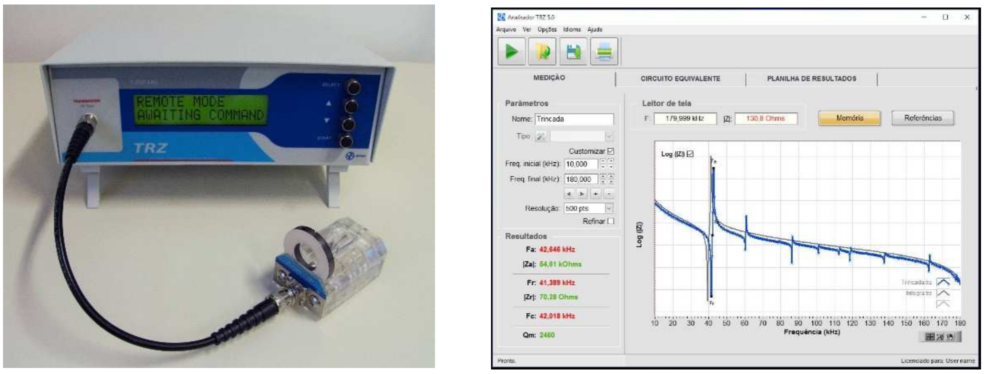


Figure 7 – TRZ Analyzer connected to PiezoHolder and the TRZ Software.

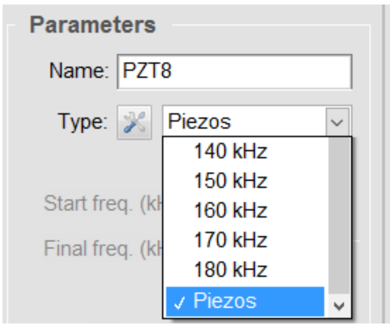


Figure 8 – Selection for testing the ceramics (TRZ Software, 5.0 or higher).

Step 2 – Insert the ceramic piece into the PiezoHolder
Insert the piezoelectric ceramic piece into the PiezoHolder (Figure 9). This accessory is capable of supporting ceramics shaped like disks and rings with thickness between 2 and 8 mm, and diameter between 20 and 60 mm. The polarity is not relevant.

Figure 9 – PiezoHolder support for the connection between ceramics and the TRZ Analyzer.

Step 3 – Carry out the measurement and analysis

Take the measurement by clicking on "Play" (Figure 10) or using the shortcut command Ctrl-N. Then, check if the obtained curve is subtle or if it has disturbances of low amplitude (see figures 5 and 6). If spurious modes are detected, the piezoelectric ceramic is cracked and must be discarded. The presence of cracks may be confirmed by non-destructive ultrasonic testing (pulse-echo).

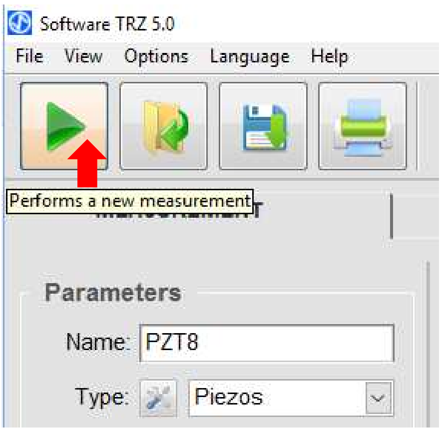


Figure 10 – Carrying out measurements.

Important observation: this methodology is not sensitive to chips on the edges of the ceramic pieces. Ceramics presenting this kind of defect must be discarded even if they are not cracked.

5. Examples

Table 1 shows the characterization results of a new and intact ceramic piece, of a new but internally cracked ceramic piece, of a used and internally cracked ceramic piece, and finally of a new ceramic piece presenting an unknown defect. Note that the pattern of additional resonances indicating the presence of crack varies.

The visual inspection of the ceramics were carried out by using an 8x magnifier. Before the visual inspection, the surfaces of the used ceramics were sanded with a 1500 sandpaper and cleaned with a solvent for removing dirtiness.

Table 1 – Example of tests involving intact, internally cracked or defected ceramics.

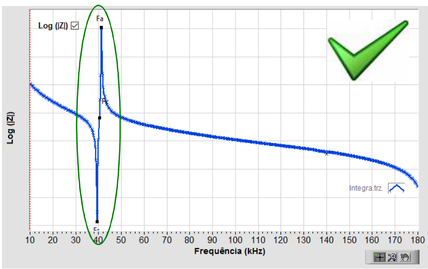
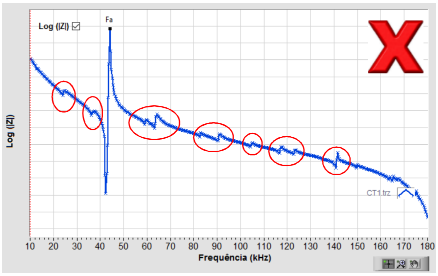
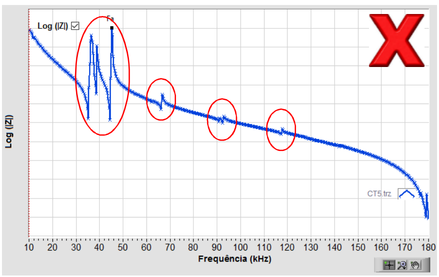
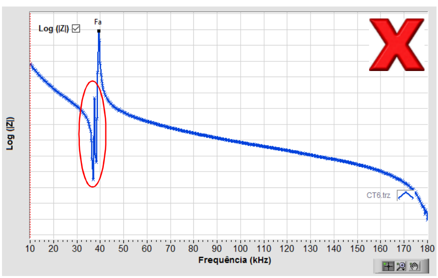
Description	**Curve obtained with the TRZ Analyzer**	**Observations**
New and intact ceramic 		This new ceramic was approved because there is no additional resonances and because of a well-defined main resonance. *Curiosity: the ATCP Physical Engineering logo was inspired by the shape of this wave pattern.*
New ceramic with internal crack 		This new ceramic was not approved because multiple additional resonances were detected. The existence of crack was confirmed by the non-destructive ultrasonic testing for the detection of discontinuities.
Used ceramic with internal crack 		This used ceramic was not approved because there are multiple additional resonances besides disturbances on the main resonance. The existence of crack was confirmed by the non-destructive ultrasonic testing for the detection of discontinuities.
New ceramic presenting a unknown defect 		This new ceramic was not approved because there is a disturbance on the main resonance, however it was not possible to confirm that it has an internal crack by non-destructive ultrasonic testing. The defect that generated this disturbance may be a density inhomogeneity of the pressed material.

Table 2 shows detailed results of the characterization of a used and visibly cracked ceramic, and of a used and fractured ceramic. These are extreme situations in which the visual inspections would have been enough to reprove and discard the pieces. The goal of presenting them here is only to enrich the exemplifications.

These cases present more accentuated additional resonances, but they are not too different from the additional resonances observed in internally cracked ceramics (refer to Table 1 curves).

Table 2 – Example of tests involving used and visibly cracked ceramic and fractured ceramic (extreme situations in which the visual inspection would have been enough).

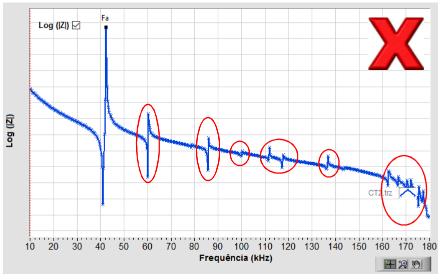
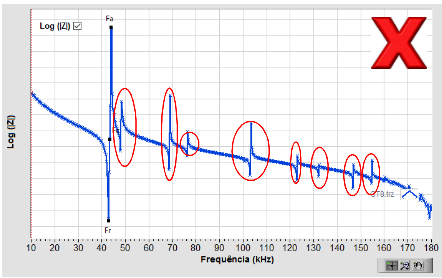
Description	**Curve obtained with the TRZ Analyzer**	**Notes**
Used and visibly cracked ceramic  		This used ceramic was not approved because it shows a visible crack, besides multiple additional resonances.
Ruptured used ceramic missing a segment 		The presentation of the test for this fractured ceramic missing a segment aims to illustrate the application of the methodology in an extreme condition.

Table 1 and 2 ceramics are available at ATCP for the performance of training for the advance use of the TRZ Analyzer.

6. Piezoelectric ceramics recovery and reuse

The fracture of ceramics is the main cause for faults of transducers and converters. Figure 11 exemplifies a 35 kHz damaged converter, highlighting the ruptured piezoelectric ceramic piece. However, not all ceramics of damaged transducers are necessarily compromised. On the contrary, some may be recovered to reduce maintenance costs, mainly when it comes to premature faults during manufacturing tests. For that, it is necessary to use a methodology that guarantees the inexistence of cracks in the ceramics that will be reused.

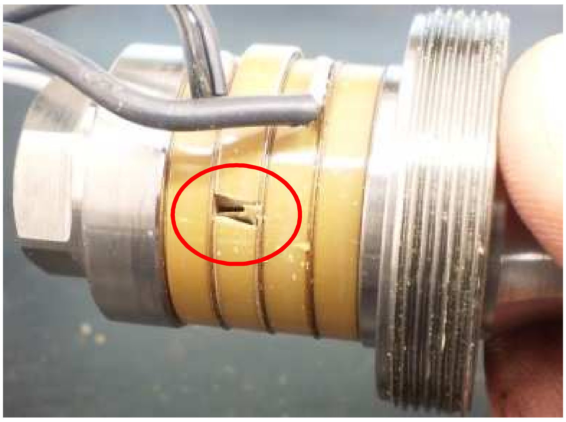


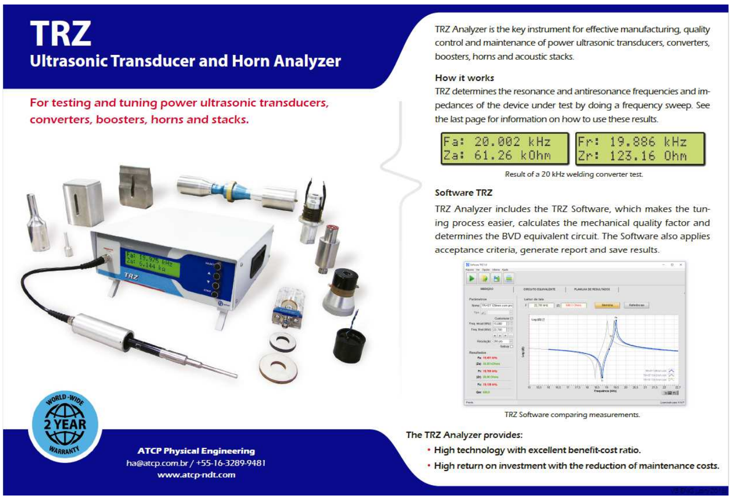
Figure 11 – Ultrasonic converter with a fractured piezoelectric ceramic piece. The other pieces were recovered and used after being tested for internal cracks.

For transducers and converters that have failed after long period of use, it is quite probable that the intact ceramics may present a reduced lifespan and occasional changes to the piezoelectric constants. However, that does not stop these ceramics from being refurbished.

To recover used ceramics, besides testing them for crack detection, it is necessary to remove the insulating varnish or epoxy resin that might be occasionally present on the sides of piece. It is also advisable to lightly sand the ceramic electrodes using a 1500-grain or superior abrasive pad to eliminate marks and dirtiness. It is important to be careful to avoid excessive sanding and the consequent removal of electrodes.

TRZ Analyzer brochure:

http://www.atcp-ndt.com/images/products/trz/manual/Brochure_TRZ.pdf



TRZ Analyzer video:

https://youtu.be/EAFNjyx3uX0

TRZ Analyzer webpage:

http://www.atcp-ndt.com/products/piezo-and-ultrasonics/trz-horn-analyzer.html