Shear Mode Quartz Shock Sensor

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Abstract

Quartz crystal, an almost perfect material, widely used in piezoelectric sensor technology is being reconsidered for shock measurement due to its inherent stable physical characteristics. For over three decades of use and testing, this almost perfect piezoelectric material has not shown any sign of depolarization after exposure to extreme shock events or drastic temperature changes. Consequently, the stability and repeatability of the shear mode quartz shock sensor has been historically proven.

Described in this paper is a “Shear Mode Quartz Shock Sensor” made of a unique array of quartz crystals featuring extremely low transverse sensitivity. This shear quartz crystal configuration, combined with a rugged base, reduces the errors typically introduced by flexure at the mounting interface. Base strain is usually a predominant cause of error in shock measurement. Particular attention was given to the 10-32 connector which in most other shock sensors is the main cause of erratic output. The novel “FOUR CRYSTAL SERIES” element configuration provides a stiff crystal assembly with a minimized seismic mass that is in the order of 0.08 grams. This extends the resonant frequency to 120kHz providing a usable bandwidth of 30kHz and a sensor with negligible zero shift. The sensor also has an encapsulated internal impedance converter making it impervious to shock from any direction and providing a low impedance voltage output. Another key feature of this design is the simplicity which drastically increases the sensor’s reliability and stability.

Introduction

The fifties played an important role in the development of general purpose piezoelectric accelerometers. Since that time two schools of thought existed about what is the best material for this technology. Quartz and ceramic have been competing in the industrial markets on merits and price. Since the sixties, compression mode quartz sensors have been playing an important role in dynamic measurement with little competition from the producers of ceramics piezoelectric compression units particularly, at frequencies below 5 Hz, where quartz material is more thermally stable.

Companies producing ceramic accelerometers understood the limitation of their products and consequently they revolutionized the market by developing shear mode ceramic elements, with characteristics superior to the quartz compression mode. These are: thermal stability at low frequencies, reduced strain sensitivity and lower transverse response.

During the sixties and the seventies respectively the ceramic annular shear and the ceramic Delta Shear™ posed a serious threat to the producers of accelerometers utilizing quartz in compression mode. The initial reaction was that the quartz accelerometers, combined with internal electronics, was an adequate competitor to lower cost high impedance ceramic accelerometers. The manufactures of quartz sensors were eventually impressed with the superior performance of the shear ceramic elements. Now challenged with a serious competitive problem they started looking for solutions to compete with the ceramic structure in a shear mode. The alternatives were to design a competitive quartz shear transducers or clone the generic ceramic accelerometers. Another challenge came when some of the high impedance ceramic accelerometers were being changed into low impedance by inserting small electronic components inside the sensors. Competitive pressure forced the quartz-based companies to develop quartz-sensing elements operating in a shear mode.
This is the basic history behind the evolution of generic ceramic and quartz accelerometers from the compression mode high impedance to low impedance shear mode. Shock sensors have been going through the same evolution as general purpose accelerometers, with the exception that a shear quartz shock sensor was not available at the same time as the generic low impedance quartz and ceramic shear designs.

Description

As explained above, traditionally the high shock transducer market has been dominated primarily by companies who provided shear ceramic elements particularly the style using annular shear elements because the simplicity of the design, ruggedness, stiffer construction and ultimately improved reliability. The companies manufacturing quartz sensors before 1987 had difficulty making a generic shear quartz design, and could not even conceive a shear mode quartz shock sensor to compete with ceramic units. The only thing the quartz industry had to offer for a long time was four or five ranges of less attractive compression designs typically in the 5,000; 10,000; 20,000; 50,000 and 100,000 *g* range. The limitations with these designs were the marginal frequency range typically 10,000 Hz, lower resonance typically – 60,000 Hz, higher transverse and strain sensitivities when compared to the shock ceramic shear design. The compression mode quartz would only accommodate limited test measurements. Attempts in designing shear mode quartz shock sensors with improvements in transverse and strain sensitivity were made. Nonetheless the frequency response and resonance were still unacceptably too low. The following design evolution describes and summarizes the progress to the present. It should be noted that some may not have been commercialized. These conceptual designs were conceived with the restrictions of maintaining the same transducer weight, external physical size and with the objective of minimizing the seismic mass and crystal's size. Thus a maximized ratio between stiffness and seismic mass was maintained.

Figure 1 compression quartz mode - preloaded with a screw

The earliest design considered, it was very popular for the longest time and it is still successfully used for less demanding applications. It was not well suited for high level shock application because the quartz plate tended to dislocate producing spurious outputs. The relatively large seismic mass used in the preload mechanism drastically reduced the frequency response, which is often critical in shock measurements. The high strain sensitivity also adversely effects the performance. The preloading screw marginally withstands the load generated by the high shock applications. The popularity of this sensor was driven by internally encapsulated electronics. Overall it performs well up to 10,000 *g*'s, 10,000 Hz with the major resonance in the order of 50,000 Hz. The easily achievable time constant of 2 seconds is favorable for low frequency measurement.

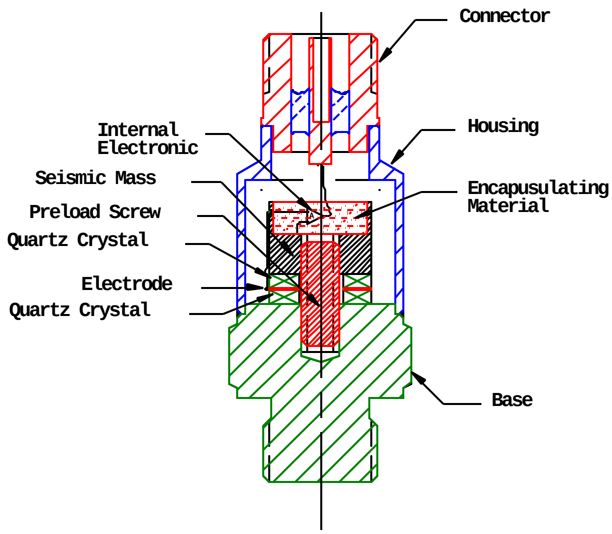


Figure 1

Figure 2 compression quartz mode/ preloaded with a sleeve

A definite improvement of the compression quartz design with screw preload came from a switch to a sleeve preload. All the same good features were retained. Additionally a wider frequency response, higher resonance frequency and a reduction in strain sensitivity was achieved by rearranging the sensing element. The reduction in strain sensitivity could be achieved mounting the sensing structure to the upper part of the housing, just below the connector, also known as inverted structure. It is capable of withstanding shocks in the order of 100,000 *g*'s but it still poses problems in mid field pyrotechnic applications because the relatively low resonance, typically 60,000 - 70,000 Hz, could cause overload of the internal amplifier. The improved performance is a consequence of the relatively small seismic mass and a good clamping mechanism in the form of a preload sleeve. If necessary even the base could have been made shorter because the innovative clamping method used for this design. The strain sensitivity is still too high for a good shock measurement.

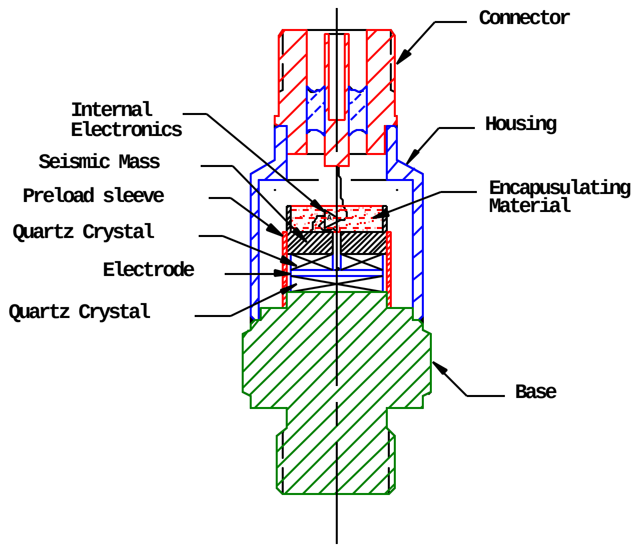


Figure 2

A solution to reduce the effects of overloading of the internal amplifier is to use an internal first or second order low pass electrical filter that can be added inside the transducer before the impedance converters. This will definitely improve the overall performance.

This design does not perform as well as the shear ceramic shock sensors. Some users dedicated to the quartz sensor even used mechanical filters to accommodate more complex measurements. Around the nineties the manufactures of quartz sensors started reacting and attempts were made to design shear mode quartz shock sensors with significant improvements in transverse and strain sensitivity. Nonetheless the frequency response and resonance were still sub standard and not acceptable in the industry. These key performance weaknesses were the causes of the poor acceptance of the quartz shear shock sensor.

Figure 3 shear quartz mode - preloaded with a screw

This shear quartz shock sensor, with the crystals preloaded with a screw, shows only marginal improvement compared to the compression mode design. The major improvements were a reduction in transverse sensitivity and strain sensitivity, but left much to be desired in frequency response and maximum *g* range capacity because the two large and heavy seismic masses screwed in the center post. This type performs well in the 10000-*g* range from far to mid field pyrotechnic applications. This construction has been successfully used for the original shear accelerometers, whether ceramic or quartz elements. The general purpose acceleration lines are well suited to accommodate these types of construction because of the relative inexpensive production cost and good performance.

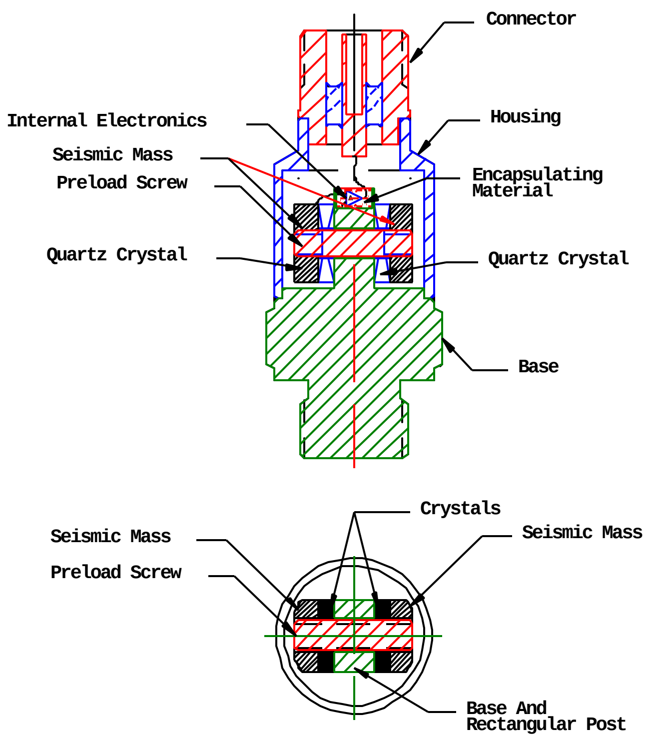


Figure 3

Figure 4 shear quartz mode - preloaded with a sleeve

The features of this design are similar to the previous design, with the exception of an improved preloading mechanism. However the extra non-desirable interface between the seismic mass and the preloading sleeve add on another spring to the system reducing the overall stiffness and frequency response. The only improvement in performance, when compared to the previous design, is the possible extended 50,000 *g*'s range,

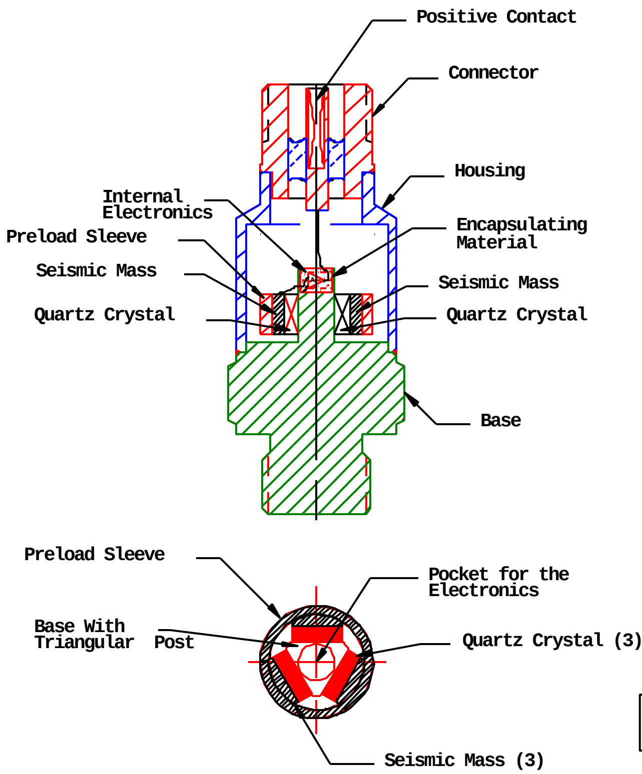


Figure 4

Figure 5 shear quartz with element cemented in place

This design has all the sensing components cemented in place thereby minimizing size and weight of the seismic mass. Another feature of this design is the reduction of interfaces between the components associated with the sensing element. The obvious results are an improved frequency range and a resonance, greater than 110,000 Hz. This design is suited for near, mid and far field applications. Durability is a concern because the parts are cemented together. This method was effectively used to improve the ratio between stiffness and seismic mass and also to reduce the number of parts used in the sensing element.

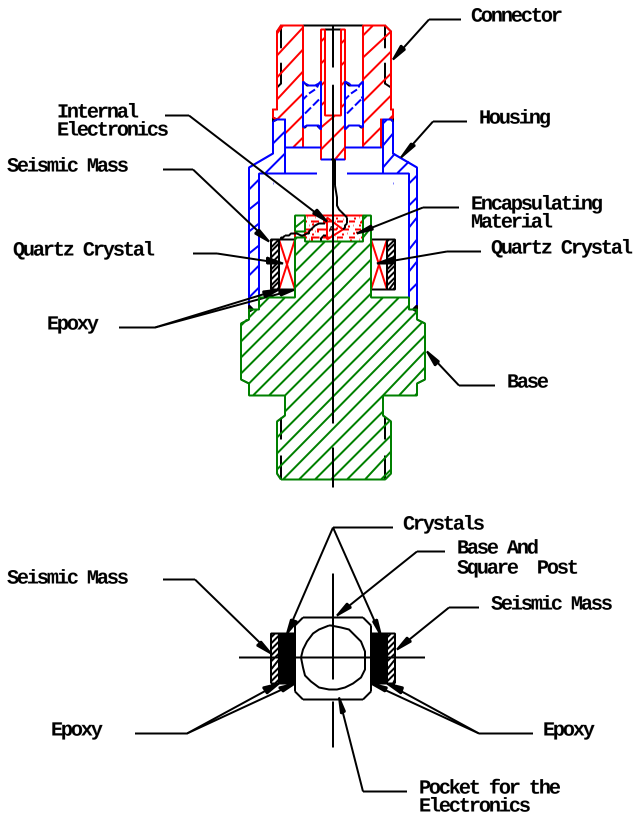


Figure 5

This epoxied element was a starting point toward a final solution for a quartz shock shear sensor. The engineering was quite correct because the construction limited the number of interfaces, the number of parts, and ultimately the weight of the seismic mass.

Drawing 6 annular ceramics shear

At this point it is opportune to introduce the ceramic annular piezoelectric accelerometer. It is a significant advance and deserves a detailed review. This ingenious concept has been dominating the market for almost three decades. The common quartz shock accelerometer, whether in compression or in shear mode lacked compared the annular ceramic ring. This design provides a minimum number of interfaces, a stiff sensing element and ultimately a very small seismic mass system. The resulting resonant frequency is 120,000 Hz or higher. It is particularly suited for near field pyrotechnic applications when an electrical and mechanical filter is built in.

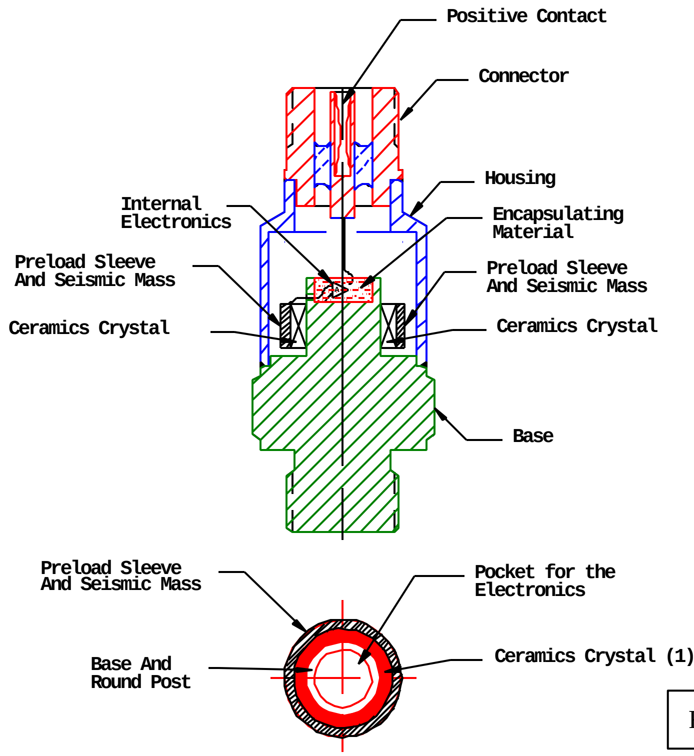


Figure 6

This design also lends itself to a smaller physical size. This accelerometer has been providing useful information in shock measurements up and above 100,000*g*'s, and is well respected for its superior performance.

Figure 7 shear quartz mode - preloaded with a sleeve FOUR CRYSTAL SERIES

Having essentially the same structural characteristics as the annular ceramic design, this novel approach yields similar performance. If the same crystal dimensions and seismic mass were used for both the quartz and ceramic annular shear, the quartz would exhibit a higher resonance due to the higher modulus of elasticity of the quartz crystal. Another improvement of the overall performance is the fact that quartz will not depolarize if exposed to high shock and it's insensitive to thermal transients. As far as the construction, they are very similar in concept. In fact the Four Crystal Series actually derives its essence from the combination of an annular ceramic shear and the version of quartz shear using cemented components. The other difference is the cylindrical base versus a cubical shape. The ceramic crystal is shaped as a hollow cylinder while the quartz Four Crystal Series is shaped as a segment of a circle.

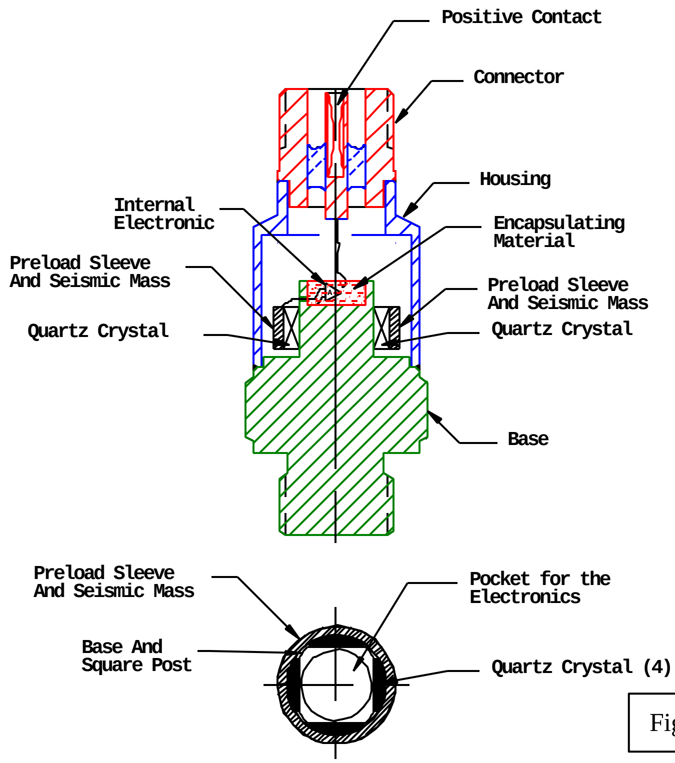


Figure 7

Figure 8 is a 3D view of the above sketch

Figure 8

Re introducing the quartz shock sensor in the market to compete with the ceramic annular shear, has prompted focus to the weak link between the sensor and the cable.

Test engineers are very familiar with the loss or inconsistency of data during test measurements. Other than the element structure, poor data can also be attributed to the transducer mounting, cable breakage, loose connector, internal electronics failure, piezoelectric element loss of preload, small internal parts becoming loose, sensing crystal chipping, mis application and so on. The transducer and cable connector is a typical, yet invisible, problem in shock measurement. In most cases, after several mounting-dismountings of the transducer to the cable connector the constant pressure between the critical parts may weaken. These components are detailed in figure 9.

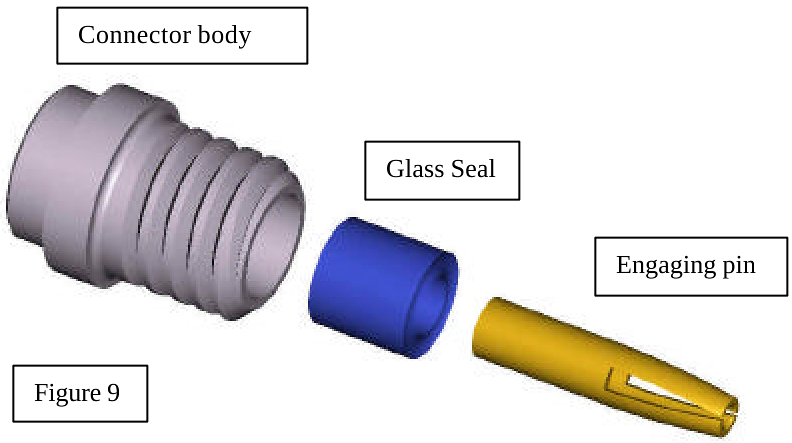


Figure 9

Under shock, a momentary loss of continuity with the power supply often occurs partially cutting off the event to be measured. This problem is the engaging pin material fatigue. The high temperature process involved in manufacturing the glass sealed connector reduces the stiffness of the pin material causing pin enlargement.

To improve the poor continuity problem the engaging pin is substituted with an improved spring insert made of a gold plated Beryllium-Copper, see figure 10. This improved design has an overall flexible, spring like shape that engages a range of pin diameters.

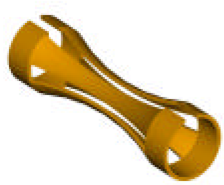


Figure 10

Beryllium Copper provides the elastic physical properties that promote positive contact and resists aging. Also, the Beryllium-Copper spring is installed inside the connector pin after the connector is complete and glass sealed. Inserting the spring after the glass has been fired at temperatures higher than 900 degrees Celsius eliminates the yielding of the spring material maintaining the highest possible reliability. See figure 11

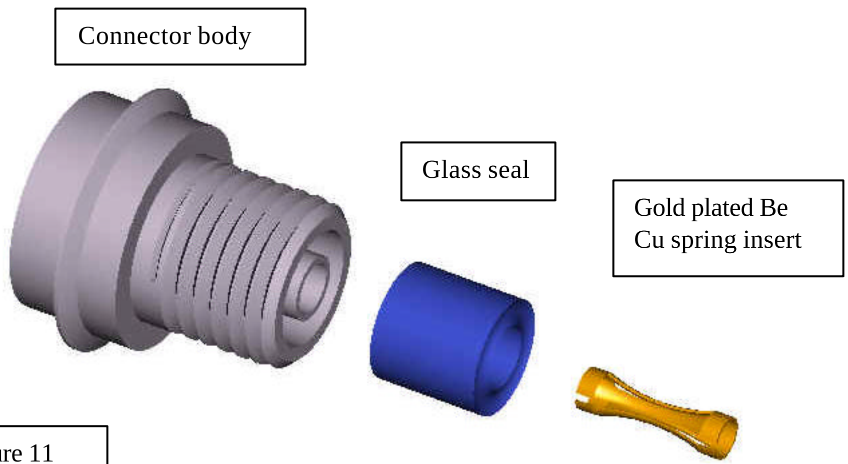


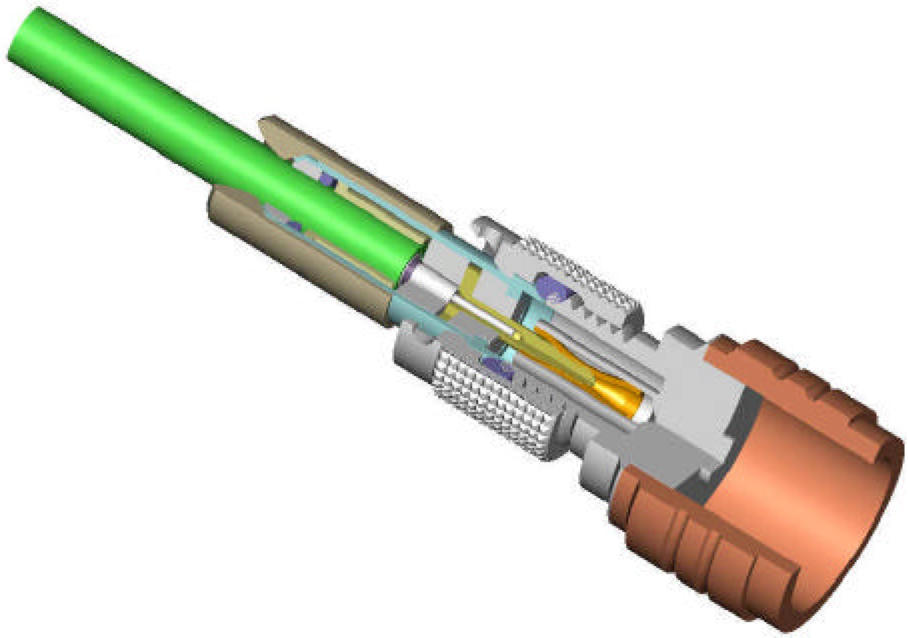
Figure 11

To further improve and maintain a positive connection under shock measurement conditions, an improved connector coupling design is needed.
Figure 12, shows a receptacle of stainless steel that allows connection to the transducer with a larger torque as opposed to the usual hand tightened brass version. This reduces the possibility of loosing contact during high shock.

Figure 12

In figure 13 the sectional view of the complete connector shows the combination of the cable connector engaged to the transducer connector using the leaf spring positive contact option.

Figure 13



Also note that coaxial connector shown as above does not require the addition of shrink tubing to strain relieve the cable. This concept includes several mechanical-clamping mechanisms that preclude breakage. This construction minimizes the whipping effects that cause measurement errors. Figure 14 shows this improved cable-connector design compared to a conventional cable.

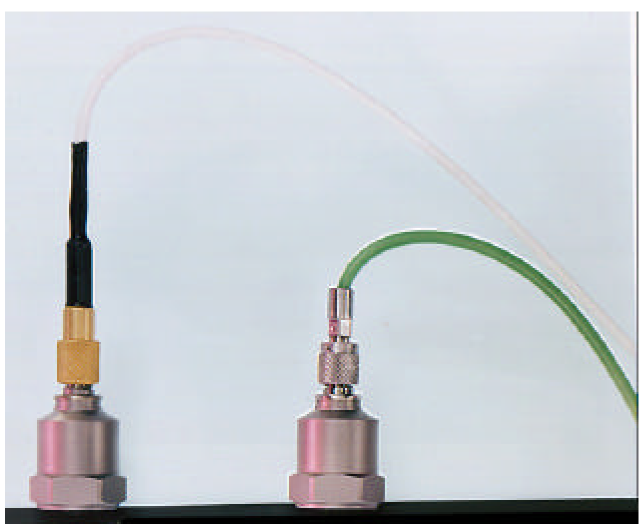


Figure 14

Conclusion:

These new shear mode quartz shock sensors are making a come back in a sector of the industry that has been dominated by ceramic sensor manufactures. This new quartz concept is competing well in the mid and far field pyrotechnic measurements, and with the added features including internal mechanical and electrical filters. For near field applications, the addition of a case isolation where the internal piezoelectric element is electrically isolated from the test fixture will provide suitable measurements.

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