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Why Is MEMS the Preferred Technology for High Shock Measurement?

Written By
Patrick L. Walter, Ph. D.

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Senior Measurement Specialist, PCB Piezotronics, Inc.
Depew, NY 14043

Professor of Engineering, Texas Christian University
Fort Worth, TX 76129

In 1947 the first piezoelectric accelerometer was designed in the United States[1]. Within 2-decades, piezoelectric accelerometers with their higher resonant frequencies, signal levels, and amplitude ranges had totally displaced previously used metal strain gage technology in accelerometers. Free fall and accelerated drop machine carriages, gas actuated horizontal actuators, rail road coupling tests, and more could now be quantified at levels to multiple thousands of Gs. However, piezoelectric accelerometers were subsequently observed to "zero-shift" (Figure 1) at high stress levels associated with high-amplitude, high-frequency mechanical shock. An unsung hero, a chemist named Ralph Plumlee at Sandia National Labs, researched this phenomenon. In 1971 Plumlee issued a 73 page report distributed to manufacturers of shock accelerometers detailing the dipole switching mechanisms responsible for zero-shift in the ferroelectric ceramics used in piezoelectric accelerometers[2]. As a by-product of this study, different type of piezoelectric materials were employed in accelerometers, each pushing the amplitude threshold level of zero-shift up just a bit.

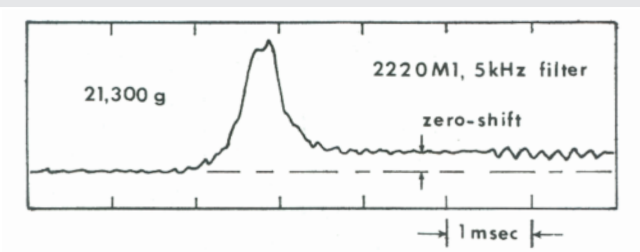

FIGURE 1: Typical Piezoelectric Accelerometer Zero Shift
note: High Frequencies are Filtered Away

In the 1970s, bulk semiconductor gages started to be used in accelerometers (synonym piezoresistive) largely because they afforded response to zero Hertz[3]. About this same time, underground nuclear testing eliminated piezoelectric accelerometers as a contender in radiation environments. Specially doped diffused semiconductor strain gages were then employed in accelerometers and were successful both in operating in radiation environments and in measuring to 10s of thousands of Gs. This increased the focus on piezoresistive accelerometers for high frequency mechanical shock. This was serendipitous as pyrotechnic shock was just beginning to emerge as a requisite test environment in the aerospace and defense communities. This success of semiconductor strain gages as sensors in accelerometers in the 1970s encouraged the development of the first all silicon (MEMS) high shock accelerometer in the 1980s. MEMS (miniature electro-mechanical systems) accelerometers, possessing linear amplitude ranges in excess of 100,000 Gs and resonant frequencies to multiple 100s of thousands of Hertz, enabled a further advance in high shock measurement. It was hoped that MEMS technology would preclude accelerometer resonant frequency excitation and resultant amplitude over ranging. Although measurement advances were made, the low damping in silicon resulted in sensor "Qs" in excess of 1000:1. Thus, MEMS shock accelerometers since the 1980s have enabled measurements to very high G levels at low frequencies, but displayed great fragility at high frequencies.

The next needed step in high-G MEMS shock sensing technology was apparent; it required the inclusion of damping. The challenge has been that damping requires energy dissipation, which is in turn dependent on motion. High-G MEMS accelerometers typically have mass motion from nanometers to microns. Previously, this small amount of motion has precluded the achievement of any significant damping. In the past year, advanced MEMS processing technology has enabled control of dimensional tolerances so that this next step has occurred. Robert Sill, an experienced PCB designer, along with PCB MEMS process engineers at the University of Washington, has evolved the Model 3991 (Figure 2) in ranges to 60,000 G[4]. Film damping has reduced the "Q" of MEMS accelerometers at resonance to 10:1 (factor of 100 improvement). The inclusion of mechanical stops has also been achieved. This "ruggedization" has occurred concurrent with increased measurement demands in pyroshock and ballistic shock as well as requirements for the fuzing of smart weapons. The next advancement in high-G shock measurement may again be years away, but it will certainly involve MEMS technology.

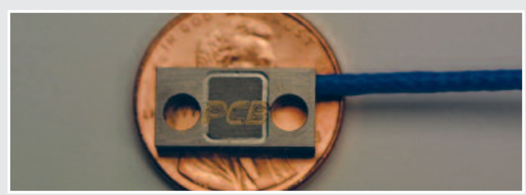

FIGURE 2: PCB 3991 High Shock MEMS Accelerometer

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3. Walter, Patrick L., "Lessons Learned in Applying Accelerometers to Nuclear Effects Testing", Shock and Vibration, Volume 15, Number 6, ISBN 1070-9622, pp 619-630, November 2008.

4. Sill, Robert D., "Test Results and Alternate Packaging of a Damped Piezoresistive MEMS Accelerometer", 52nd Annual NDIA Fuze Conference, Sparks, NV, May 13-15, 2008.

Who is Patrick L. Walter?

Patrick Walter graduated in 1965 with a BSME from The Pennsylvania State University and hired into a Component Test (shock, vibration, climatic, … and functional test) organization at Sandia National Laboratories in Albuquerque, NM. Concurrent with his employment, he completed his MSME in 1967 at the University of New Mexico. He subsequently became a Project Leader in a flight telemetry organization and was responsible for transducer calibration as well as both transducer and flight electronics development. Among other early accomplishments, he developed some of the first high shock sensing capabilities for large caliber guns and earth penetrators. In 1976, Sandia sponsored his doctorial studies at Arizona State University (ASU) with now Professor Emeritus Peter K. Stein, founder of ASU's Laboratory for Measurement System Engineering. Pat's PhD dissertation involved analyzing structural test data from the Trident I strategic missile system.

In 1978, Dr. Walter resumed full time employment at Sandia and was promoted into test management shortly thereafter. Among the many organizations/functions he supervised were Transducer Development and Calibration, Measurement Consulting, Telemetry Component Development, Telemetry System Packaging for Weapon System Stockpile Surveillance, Mass Properties, Test Facilities Development, and Precision Inertial Test System Development. In 1987 he was transferred as Supervisor Test Operations for the Kauai Test Facility, a rocket launch facility on the Pacific Missile Range Facility (PMRF), Kauai, HI. Subsequently he became responsible for developing and launching rocket systems from Sandia and NASA facilities. These rocket focused activities supported President Regan's Strategic Defense Initiative (SDI).

Post Cold War (1991-1995) Dr. Walter established a joint Sandia-Federal Aviation Administration (FAA) program as part of the FAA's congressionally mandated Aging Aircraft Program. He validated this program with the aircraft and engine OEMs, the Air Transport Association, and other organizations, and it remains contributory today on Albuquerque International Airport.

During his entire Sandia tenure (1965-1995), Dr. Walter's professional focus was on flight, field, and laboratory measurements (e.g., displacement, velocity, strain, accelerations from milli-gs to > 100,000 gs, acoustic level pressures to 10's of thousands of psi, temperature, flow, and much more) to support test and evaluation activities. His professional interests spanned the entire measurement chain: transducers, signal conditioning, acquisition systems, and end data analysis.

In 1995, Pat accepted a position in the Engineering Department at Texas Christian University (TCU). Professor Walter developed TCU's Experimental Mechanics and Structural Dynamics Laboratories and established an industry based Senior Design Program focused around test, calibration, and control activities. From 1996-2003, he consulted for Endevco Corporation, a major supplier of dynamic instrumentation. From 2003 through today he consults as Senior Measurement Specialist for PCB Piezotronics, the world's largest supplier of dynamic instrumentation. Occasionally, he also consults for various aerospace and defense contractors on test measurement applications. Through TCU's Engineering and Extended Education Departments, he has developed a Measurements Systems Engineering short course, which he teaches nationally and internationally.

Pat is a 30+ year member of both the Society of Experimental Mechanics and the International Automation Society as well as a member of the American Society of Engineering Educators. He has authored one book, numerous book chapters, and more than 100 journal articles and reports (see TCU Engineering website). During the late 1970s he chaired a working subgroup of the Telemetry Group of the National Test Ranges. In 1989, he received both a USDOE Albuquerque Office Quality Award and a joint Certificate of Appreciation Award from Sandia Labs and Allied Signal for his work on the Trident II program. In 1990 he received an Award of Excellence from the USDOE Nuclear Weapons Program, and in 1994 he received a Meritorious Achievement Award from Sandia Labs. In 1995 (upon his retirement from Sandia), he received a letter of commendation from Senator Pete Domenici, then head of the U.S. Senate Budget Committee. In 2002, Prof. Walter's TCU engineering seniors won the Design News national competition award ($20,000). In 2006, Prof. Walter received a Commander's coin from Aberdeen Test Center (U. S. Army) and in 2008 he received Edwards AFB Instrumentation Special Recognition coin (#19). In 2008, he was awarded the Shock and Vibration Information Analysis Committee's (SAVIAC's) Lifetime Achievement Award. SAVIAC represents the Department of Defense, Department of Energy, and the Defense Treat Reduction Agency in this subject area. Most recently (2009) he was recognized as a Senior Life Member of ISA.

PCB PIEZOTRONICS
AN AMPHENOL COMPANY

3425 Walden Avenue, Depew, NY 14043 USA

pcb.com | info@pcb.com | 800 828 8840 | +1 716 684 0001

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