COLIBRYS
SMART SENSING SOLUTIONS

APPLICATION NOTE

Gun-hard accelerometers for advanced munitions

30N.GunH.C.04.12

The HS8030.D gun-hard accelerometer

Features

- Extreme shock survivability
- Excellent post shock stability
- Best MEMS long term stability
- Harsh environment (shock, vibration, temperature)
- Small size
- Low weight
- Product under Swiss export control but ITAR free

Introduction

Some new technologies such as Extended Area Protection & Survivability (EAPS) are being developed to counter incoming enemy attacks. These programs require increasing utilization of long-range artillery and can represent an unacceptably high risk of civilian causalities. Therefore, more precise artillery systems, smart munitions and smart missiles are increasingly required and accuracy of ammunitions must be enhanced to meet “Smart Artillery” performances independently of any GPS control. Such projectiles also integrate independent, reliable and redundant self-destruct mechanism that can also be based on sensors such as accelerometers that have to perform not only after the initial shock but also after impact. If a target is not detected or not attained, the weapon either self-destructs, eliminating the threat to civilian from explosive remnant or render itself inert. Note that increased accuracy means also that fewer rounds are needed, resulting in a big reduction in the logistics tail of artillery units.

In addition to usual high performance of the required sensors, namely, gyros and accelerometers, the challenge for Colibrys is to provide the right range of gun-hard sensors to meet high shock survivability and post shock stability of the sensors as required by the guidance and fuse systems.

Fig 1: Guided munitions

One of the best example of utilization of the MEMS sensor technology in a very rugged defence environment is the M982 Excalibur, a 155mm extended range guided artillery shell, developed by United States based Raytheon Missile Systems and BAE Systems Bofors, a Swedish defence company and a subsidiary of BAE Systems Land and Armaments. This product includes an inertial control system with the goal to increase accuracy and to minimize collateral damages and to improve the efficiency when complex terrain limits the effectiveness of conventional projectiles and makes it difficult in term of logistic and supply. A major challenge for the control system is the inertial sensor that has to operate at full accuracy even after the extremely harsh launch environment.

This smart munitions, integrating Colibrys MEMS accelerometers, is capable, after an initial launch characterized by a gun hard shock of about 20’000g, to be guided by a GPS and/or an inertial unit to the target within a precision of few meters or less at a distance of approximately fifty kilometers.

Gun-hard shocks

A shock is an extreme acceleration that can be defined by amplitude (generally expressed in g), a time duration (generally expressed in ms) and a profile (generally half a sine). Standard applications generally face shocks of quite high amplitude but very short as artillery applications tend to present extreme amplitude and very long time duration, representing a larger energy.

Usually, standard automotive grade accelerometers have to face quite a high shock survivability requirement. However, Gun-Hard accelerometers for inertial applications not only have to survive higher level of shocks but also have to perform with a high degree of stability and accuracy after the initial shock. Therefore, we distinguish between **survivability** and **post shock stability**

A gun-Hard shock is generally a combination of a “long shock” of high amplitude (typ. 20’000g, 8ms, half sine) and some very short shocks of medium amplitude called “high frequency shocks” (typ. ±5’000g to ±10’000g, 0.2ms, half sine) generally specific to the projectile size, the form, the material and the launcher specifications. These two different regimes have very different impacts on the sensors and must be considered very carefully.

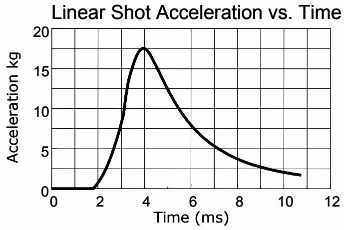

Fig 2: Theoretical shock

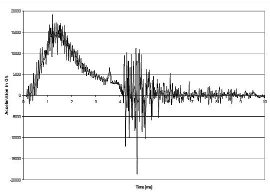

Fig 3: Real gun-hard shock profile

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Long shock

At the level of the sensor, such a shock can be considered as a quasi continuous acceleration. This means that centrifuge equipments can be used to reproduce the impact of such a shock and demonstrate the survivability and post shock stability of a sensor. This acceleration must of course be applied in all three degrees of freedom and both positive and negative acceleration to demonstrate a complete capability.

High frequency shocks

The high frequency shocks carry much less energy but are potentially affecting the resonant frequencies of the sensor. In some cases, without appropriate filtering, some combination of shock amplitude and frequencies will impact the specifications and ultimately even destroy the sensor or the ceramic package itself. The use of a standard hammer test will only provide a partial replication of this high frequency shock impact.

Gun-hard sensor testing

A gun-hard shock profile depends on the type of launcher and on projectile load, form and material. Various testing configurations can be used to qualify a gun-hard sensor knowing that none will fully reproduce a real artillery shock. The first possible test is the combination of centrifuge acceleration with a standard hammer test.

Fig 4: Aerobutt test equipment

This simple configuration is generally used during development and initial qualifications. The second and best development test is certainly the Aerobutt test. This heavy tool is one of the only tests combining both shocks regimes and allowing a simple and safe recovery of the tested samples.

Altogether, hundreds of Colibrys HS8000 / HS9000 accelerometers have been tested using this method, providing relative good statistics and extremely good results. Note that this equipment provides almost similar results as electromagnetic rail gun fire test.

Fig 5: 155mm G5 Howitzer and precision munitions

Finally, the ultimate test is the real 155mm fire test combined with soft recovery in sand. Accelerometers mounted in IMU have been successfully shocked with amplitude ranging from 11’800g’s to 19’500g’s. On the units fired with the highest shock, the accelerometers have shown full survivability and very little bias shift.

Aerobutt results

Many tests have been performed at the sensor level to get confidence about survivability and to determine the performance change due to shock. Several shock campaigns have been made using high g Aerobutt test equipments. As this equipment allows recovering of the sensors just a few minutes after the firing shock, many accelerometers Fig. 5: 155mm G5 howitzer have been measured before and after shock to determine the real impact of a shock to the specifications.

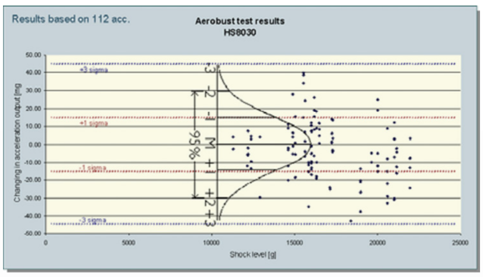

Fig 6 : Bias shift due to Aerobutt firing test, ranging from 11’000 g to 22’000 g’s along 3 axis

Colibrys HS8030.D have regularly demonstrated a bias stability within 15mg and a scale factor within 1200ppm following such shocks.

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Assembly constraints

MEMS bulk micromachined accelerometers present inherent high shock tolerance. Sensors have been centrifuged up to 40'000g without any degradation.
A major feature of Colibrys gun-hard accelerometers is the die-attach technology, which reduces the stress level on the MEMS die to extremely low levels, insuring minimum bias shift. To ensure a minimal offset even under gun shocks, Colibrys has developed a proprietary die attach technology that survives the shock and minimizes the stress level to the sensing die. This new technology is applied to create the high shock HS8000 and HS9000 product families.
Regardless of this, special attention must still be taken during the sensor assembly within the IMU or sub-system. Indeed, during the potting and final assembly process, special care must be taken in the design and selection of
material to isolate and reduce at best any vibration. The use of adequate isolators prevent the balloting shock during gun-hard shock and any level of vibration from exciting potentially harmful resonances within the structure of the sensor. The combination of a HS8000 or HS9000 with an anti-vibration material is the key to success for a gun-hard navigation system.

Fig 6 : HS8000 and HS9000 Colibrys accelerometers

Conclusion

Colibrys has successfully developed a gun hard accelerometer, which has been proved to survive the shocks and perform satisfactorily post gun shot. This product has been extensively tested both as stand alone accelerometer and in an IMU formation. The obtained results confirm the mechanical ruggedness and high sensitivity of the sensor and the IMU under such harsh environment. This accelerometer is now commercially available as part of Colibrys extensive acceleration sensor product portfolio.

Maladière 83 | 2000 Neuchâtel | Switzerland
P +41 32 720 58 11 | F +41 32 720 57 84
www.colibrys.com