Technical Article

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Measuring Position or Speed in Harsh Environments

Harsh environments come in many forms but their common feature is that they place heavy demands on control equipment. The failure of position or speed sensors in the field can have a massive technical or commercial impact. If you are the engineer that specified the sensors in the first place, sensor failure might also have an impact on your career. So how do you make sure your sensors won't let you down when the going gets tough? Mark Howard from Zettlex Ltd. examines the options.

Harsh environments come in many forms and are more common than might be expected. They are the norm in many sectors such as aerospace, defence, heavy industrial, utility, oil and gas. There is no hard and fast rule as to what constitutes a 'harsh environment' but, for the purposes of this article, we may define a harsh environment as one containing one or more of the following factors: high temperatures (>85^{O}C), low temperatures (<-20^{O}C), thermal cycling, high vacuum, high pressure (>10bar), vibration, shock, AC/DC noise, radiation, water, dirt, aggressive chemicals, long term immersion, extended life (>10 years), explosive dusts & gases (ATEX rated environments).

Despite their wide variety, such environments invariably make the selection of appropriate equipment both difficult and critical because performance and reliability will surely be tested. Nowhere is this more true than in the selection of electrical control equipment. Failures in the electrical systems of modern machinery typically account for >80% of all failures. Take your own motor car as an example - of all the breakdowns you’ve ever had how many have been related to the ‘electrics’ compared to main mechanical components. About 80% right? Other than cables and connectors, position and speed sensors are the most common elements in electrical control systems. That means selecting the right position sensor – one that will operate accurately and reliably - in your own particular harsh environment is key.

One option is to always specify ultra ‘high-rel’, fully qualified, redundant sensors with military style connectors, heavy duty housings and cables. It is certainly one way to ensure high reliability but unless you’re making civil aircraft or jet engines, it is seldom an economically viable approach. The smart approach is to specify a sensor that’s not going to let you down but – at the same time - one that’s not going to blow your budget.

Across all sectors, potentiometers are the most ubiquitous position sensor. There is a good reason - they are simple, compact, lightweight and offer remarkable value for money. In harsh environments, however, they have a poor reputation and are seldom chosen because they are susceptible to wear. Wear rates accelerate rapidly with vibration or the ingress of foreign matter such as sand or grit. The basic materials of most potentiometers are generally not well suited to extreme temperatures.

	High Temperature >85 °C	High Temperature >125 °C	Low Temperature <-20 °C	Low Temperature <-40 °C	Low Temperature <-55 °C	Liquid ingress	Dust ingress	High Vibration	High Shock	Explosive Dusts or Gases	Life of >10 years	Life of >20 years	Long term submersion
Potentiometer	✔	-	✔	-					✔	✔	✔		
Optical			✔					✔	-	✔	✔	✔	
Capacitive	✔		✔	✔				✔	✔	✔	✔	✔	
Magnetic - Hall	✔		✔	✔	-	-	-	✔		✔	✔	✔	✔
Magnetic - Magnetostrictive	✔		✔	✔	-	✔	✔	✔		✔	✔	✔	✔
Traditional Inductive	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
New Generation Inductive	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔

Fig. 1 – Comparison table of sensor types versus environmental factor.

Similarly, across all sectors, optical position sensors are a common choice but are seldom chosen for harsh environments. The reason is straightforward – their optical path is susceptible to obscuration by foreign matter, especially in higher resolution devices ($\geq$8 bits) where optical feature sizes compare with dust particles, fibres or hair. A further limiting factor is that silicon based electronics is required at the sensing point, effectively limiting the operating temperatures.

There is a wide variety of magnetic sensors – ranging from simple switch devices to high accuracy, long length magnetostictive sensors. Although they all operate using a magnet, a variety of techniques is used. Whereas, simple devices typically use the Hall effect, others use the time of flight principle – measuring the time taken for an ultrasonic pulse to travel and return along a magnetostrictive strip. As the magnet moves along the strip, the flight-time increases and vice versa. Magnetostrictive devices are best suited to long linear displacements of >100mm whereas Hall effect devices are more suited to rotary arrangements. Hall effect devices are widely used - especially in automotive - but require finely toleranced mechanical engineering for accurate measurement.

At first glance, magnetic devices offer a good solution to sensing position in harsh environments but, as with many things, the devil is in the detail. Practical experience shows there are significant issues limiting their use. Firstly, as with optical devices, their performance in extreme temperatures is limited because they require silicon based electronics at the sensing point. Secondly, magnetic hysteresis - inherent in any magnetic measurement - limits measurement performance to relatively crude applications. Third, there are significant temperature coefficients and all magnets are limited by their Curie point where their magnetic fields distort. There is also the issue of batch to batch variability - since the field generated by one magnet is never the same as that of a second due to small differences in composition. Shock and impact must be strictly limited since magnets are notoriously brittle. One, particularly nasty, failure mode is the gradual build up of magnetic particulates at the magnet (e.g. ferrous swarf, dust or particulates in engine oil) which effectively destroys measurement performance by distorting the magnetic field. All magnetic devices are susceptible to the effect of stray magnetic fields and even DC magnetic devices will also pick up lower frequency AC effects. These will be exhibited as noise on the sensor readings – e.g. a nearby mains cable is likely to induce 50Hz AC noise source.

Capacitive position sensors are not widely used in extreme environments. Although they are resilient to wear, shock and vibration, generally, they suffer from drift due to variation in temperature or humidity and are susceptible to foreign matter. This is because the capacitive sensing principle is fundamentally unable to differentiate between the capacitive target object and foreign material such as a grease smear, ice or water condensation.

Inductive devices such as resolvers and linearly variable differential transformers (LVDTs) are the traditional choice for the ‘high integrity’ applications in the aerospace, defence, oil and gas sectors. Such devices have a well deserved reputation for reliability and safety and have been in widespread use since World War II. In some cases, the use of inductive devices is mandated by regulations relating to safety critical or safety related applications. The text book application is aerospace actuators for ailerons – a harsh environment with extreme temperatures, vibration, foreign where reliable and accurate operation is essential.

Inductive position and speed sensors work on the same fundamental principles as a transformer which means that no silicon based electronics is necessary at the sensing point. Importantly, this means that any associated electronics can be displaced some distance away from the sensing point - typically, a more benign environment where temperature extremes are unlikely to exceed the -40 to 125^{o}C limits for most commercial electronic components. Nevertheless, the transformer windings of traditional inductive devices will tend to make them bulky and heavy. High accuracy devices requires precision wound spools and these are notoriously difficult and expensive to manufacture.

One inductive product – the Inductosyn^{TM}, from Farrand Controls in the USA - has an almost cult following in the aerospace and defence sectors for its fantastic levels of accuracy (<1 arc-second accuracy per rev), stability and phenomenal reliability even in the toughest environments such as those found on spacecraft. Instead of the traditional wire windings, Inductosyns^{TM} use a laminar winding arrangement. Although measurement performance and resilience is legendary, the price of such devices is out of the range for most mainstream applications.

A budget form of the laminar, inductive position and speed sensor has emerged in recent years in a new generation of inductive devices such as those made by Zettlex. These devices use compact, lightweight printed circuit boards rather than the traditional bulky transformer windings. This approach has led to a wide variety of shapes and sizes of sensor ranging from <1mm to >1000mm and covering linear, rotary, curvi-linear, 2D & 3D forms. The approach is unusual in that high levels of accuracy can be achieved without finely toleranced mechanical installation. The fundamental operating principles are similar to the traditional inductive devices and, similarly, any associated electronics can be located away from the harsh conditions surrounding the sensing point. The performance of the new generation of device is at least as good in harsh environments as the traditional inductive devices, offering up to 24bit resolution and accuracies of <20 arc-seconds over 360^{o}. Encapsulation of the main printed components makes the sensors extremely robust and ideally suited to intrinsically safe (ATEX) applications. Since there are no electrical contacts and the main components are lightweight, they offer remarkable performance in extreme vibration and shock environments. The aerospace and defence sectors have been quick to capitalize on the new technology and Zettlex devices are used for flight controls on several unmanned aerial vehicles as well equipment platforms in active service with UK, US and allied armed forces.

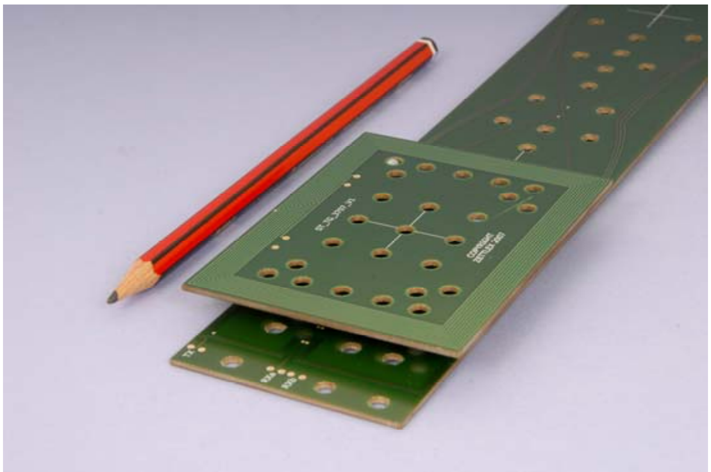

Fig. 2 – An example of a Zettlex linear encoder – ideally suited to harsh environments.

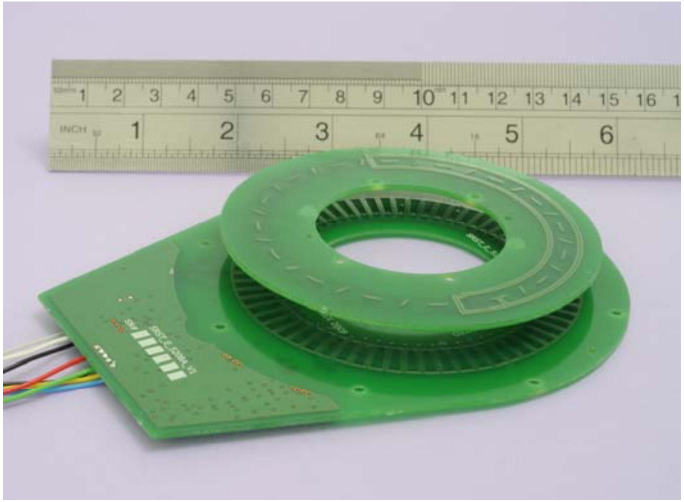

Fig. 3 – An example of a Zettlex rotary encoder – ideally suited to harsh environments.

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