Advanced Fiber Gratings Technology and products can help solve many difficult industrial problems for sensor applications in the hostile environment

Peter Kung

QPS Photronics Inc , 217 St. Louis Ave , Pointe Claire , Quebec, H9R 5L7, Canada

1. Review of all the difficult problems related to industrial applications

1.1 Signal conditioning

Nowadays, most sensors have built in signal conditioners at the point of measurement, in so doing, we try to minimize the noise pick up, ending up not being able to share the cost of a common signal conditioning unit . Sensors derived from fiber gratings do not have the same issue, they are made of glass material, fiber optics are immune to electromagnetic interference.

1.2 Cabling

Electrical sensors require one cable connection per sensor. This has become the most difficult issue to manage. There is now a tendency to develop wireless sensors that can transmit data over a comfortable distance . Wireless sensors look promising but might also introduce other problems like the need to replace the battery from time to time. We will discuss more about that in a later section. With respect to fiber optics, they offer a potential for a hybrid solution: since they have low loss, they can extend up to distances of several kilometers . Whereas electrical cables with similar lengths will have excessive attenuation and a lot of noise pickup. For long length proprietary cables, the cost will also become prohibitive. Today, fiber cables are available at much lower cost. Further cost reduction and easier cable management can be achieved by using the multi fiber composite cables which support up to 96 fibers. These are all standard components in the telecom industry.

1.3 Sensor nonlinearity

Traditional sensors like thermocouples (TC), resistance temperature detectors (RTD) and Thermistors all suffer from high degrees of nonlinearity. When they are manufactured, each sensor comes with its small difference and needs to be individually calibrated. Sensors based on resistive measurement are prone to self heating, degrading its accuracy. They also show poor interchangeability. Some of them like thermistors are small in size but their small size comes with a higher susceptibility to self heating. In contrast, Fiber gratings are inherently linear devices. They are passive and draw no power at all. In general they are much easier to design and install. In terms of reliability, electrical sensors all suffer from eventual electro migration failures, and fiber gratings do not have such draw back . They are inert and therefore inherently long life. Their reliability has been proven by use in the Telecom industry with a minimum life performance of 25 years. On the other hand, the expected life of electrical sensors often depend on the bias current and may vary with respect to system configuration and signal conditioning circuit design.

A new advanced fiber gratings technology involves material compaction in the writing process. As a result, these gratings show super reliability performance lasting up to more than 100 years. At the same time they work at extreme temperatures of up to 500 deg C. Another advanced Technology involves the formation of molecular water grating structures inside the fiber core. These gratings will work up to 1000 deg C.

Finally, if we connect these sensors in series in the same fiber, we can perform distributed sensing, for example, provide detailed temperature profile of large furnaces and boilers and achieve better control of the combustion process to reduce NOX and other environment pollutants.

1.4 High temperature, high pressure and high G vibration environment

Cavitation in compressors and high voltage in generators are tough problems for electrical sensors. Piezoelectric vibration sensors require complex packaging to ease installation and provide protection from the hostile environment. The additional mechanical structure adds to the weight and the forces applied to the sensor head. These strong vibrations can shorten the life of these vibration sensors. Fiber gratings sensors are built into the optical fiber. They have the weight of a hair. The end result is that no matter how high the acceleration is, there is hardly any force exerted on the sensor head.

Other difficult problems relate to high temperature, high pressure and nuclear irradiation. These are all easy applications with fiber grating technology because of the nature of the raw material.

1.5 Sensor networks

The biggest obstacle in the implementation of large scale sensor network stems from the cost and logistics of cable installation: Each electrical sensor must be connected by its own cable to a multiplexing hub, and many of these hubs are to be connected together into a server. This is usually the case in the typical structural health monitoring of very large assets such as bridges, tunnels and dams. Other more severe examples involve monitoring of flying helicopters and aircrafts, where several hundred sensors might be required to study the strain and fatigue distribution in their structures during flight. The sheer weight of these cables would have made such projects impractical. Development of wireless sensor networks based on the technology of telecom wireless networks could mean a total freedom from cables. People imagine the benefits of millions of these wireless sensors sprinkled all over the place like STAR DUST, and these sensors will be smart enough to do the necessary signal and data processing. They will only communicate the summary data and conditions of exception such as alarms and warnings.

The movement towards wireless sensors started in early 2000 and is gathering momentum. First driven by military and defense, they are now spreading rapidly. Wireless sensors have been the theme at Sensor Expo for the last four years. However, people are beginning to realize that they still have a problem. Each of the wireless sensors is powered by a battery; unlike cell phones where users can recharge, these batteries would need to be replaced when they are drained of the charges. If the wireless sensors run out of power, then they will stop working. The logistics of tracking the locations of millions of sensors and periodically replacing the battery can be a big nightmare. In fact, the smarter you make these wireless sensors, the more power they consume and the shorter their useful life is.

There is now a move towards shrinking the size of the wireless circuit in the hope that they will consume less power. There is also a new interest in the development of energy scavenging devices. We witnessed this new theme in the 2007 Sensor Expo: people are still looking for remote energy supply for these remote wireless sensors.

2. Fiber gratings vibration sensor, a new invention

Much of the fiber gratings products were designed for the telecom industry, these products are slowly being adapted into other sensor applications. One area is vibration sensors for machine condition monitoring, especially in hostile environments of high temperature, high pressures, or high radiation: like power generators, transformers and machinery used in mining. The basic sensor structure is shown in Figure 1.

Figure 1. *Picture of the vibration sensor head, 15mm by 10mm Courtesy of QPS*

Figure 2 shows the basic sensing element: the sensor is a fiber grating with a gentle slope. This slope is
sensitive to changes in temperature and strain, which will cause changes in the intensity of the reflected light from an interrogating laser. By placing another grating with

similar design within close distance, we can create a cavity. Shown below as Fig.3

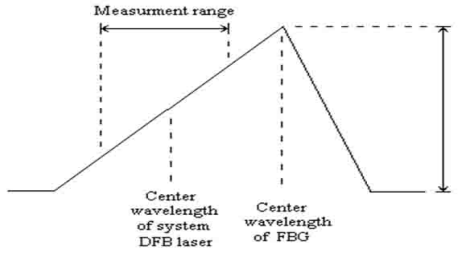

Figure 2 Basic element of the vibration sensor

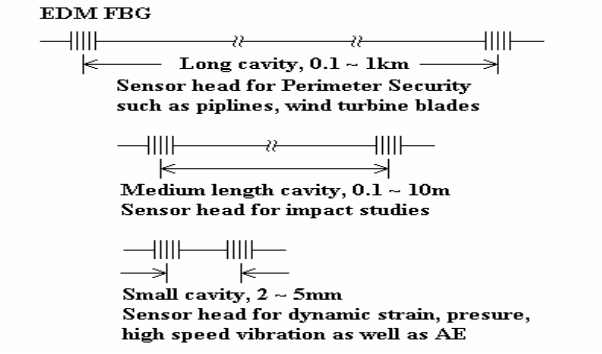

Figure 3. *Design of the Multiple Edge sensor and the gratings cavity Courtesy of QPS*

This slope is sensitive to temperature and strain and will move relative to a stationary interrogating laser, causing light from the laser to become trapped between this grating pair, forming an interference pattern. Vibration causes changes in the optical path and the interference pattern generated follows the vibration signal. Short cavity structures are suitable for machine vibration measurement, longer cavity length devices would be good for impact, explosion studies and automotive crash tests. The longest cavity would be useful as hydrophones, seismic sensors and sensors for pipeline monitoring and border security applications.

This new invention has been patented by QPS Photronics Inc. The company has just released two sensors and system product families: A four channel HPS system with full vibration monitoring function and an eight channel interface system which plugs into any data acquisition unit. These systems are ideal for the hybrid solution as explained below.
This technology is already deployed in the measurement of stator end winding vibration to monitor the degree of delamination in the insulating layers of the turbine generators. A power point presentation will be given at the conference explaining this application in details.

3.3 The hybrid solution

Fiber gratings sensors are passive, long life, immune to electromagnetic wave interference and work well under high temperature and pressure.
Each sensor is cable of self referencing because it works on its unique wavelength. Through WDM and TDM, a large number of these sensors can be connected to one interrogating hub. A fully loaded hub can handle up to 1600 sensors. You can identify the location of the sensor by its unique wavelength. Furthermore, wireless technology can interconnect all these fiber optics hubs; where each hub supports up to hundreds and thousands of fiber gratings sensors covering a large area, unlimited by the length of the cable. (up to a distance of 25 Km.)

In other words, it might be a good idea to use wireless as a hub technology, rather than wireless sensors. We can use wireless to connect many hubs together in a mesh network. Via the web technology, users can build a national or regional sensor network: yet be able to know changes happening at each sensor level. Figure 4 shows a hybrid solution with a star sensor network where there is only one sensor per channel.

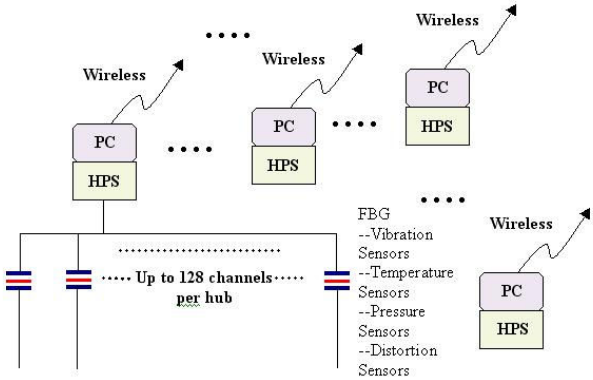

Figure 4. *Phase 1 of the hybrid Solution Sample Star Sensor Network interconnected by Wireless*

Alternatively, fiber grating interrogation units can be made into interface boxes with analog outputs which can be connected seamlessly to existing data acquisition systems; customers select the type of sensors they want. Where it makes sense, they can use fiber gratings sensors, or they can place both types of sensors side by side to compare their performance. Fiber gratings might not be able to be

converted into all kinds of different sensor functions in a short time. This arrangement will give the customer total freedom of choice, use FBG sensors to cover large area sensor networks where power is hard to come by or in an hostile environment. Such a hybrid solution is shown in Figure 5.

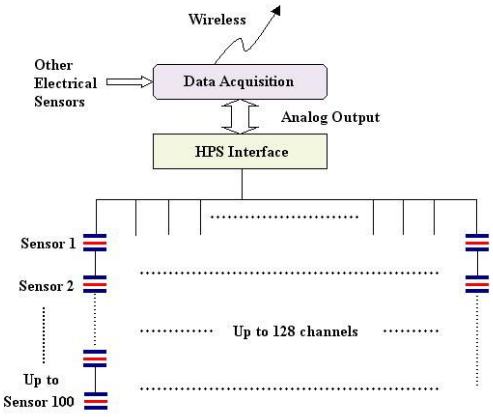

Figure 5. *Phase 2 of the hybrid Solution Massive Sensor Network, each hub is an interface box supporting up to 100 sensors per channel.*

4. The benefits

By tapping the strength of each technology, we can eliminate the power issues of the wireless sensors; take advantage of their economy of scale and growing momentum, but apply these advantages at the hub. Each of the hubs supports a star sensor network with several hundred fiber gratings sensors, each is expected to work for 25 years, without the need to replace defective sensors, recalibration of the replaced sensor, or the replacement of wireless sensor batteries. With this proposed hierarchy, fiber gratings can be designed into many structural health monitoring applications. The price will come down as the volume eventually builds up.
The benefits can be summarized below:

4.1 Lowest cost of ownership

Eliminate replacements of defective sensors, their calibration and installation. Eliminate the cost and logistics of replacing several batteries to the wireless sensors during their useful life

4.2 Distributed Intelligence

With the hybrid solution, signal conditioning and processing will be done at the hub level. Their electrical circuits will be shared by many sensors that belong to the same channel in the star network. It will be a more cost effective solution than having the intelligence built into each sensor .

4.2 Optimized use of bandwidth

The sensor industry is a 40 billion dollars market in 2007, up to 250 million of this 40 billion is going to the wireless sensors. If every single sensor is to be converted to wireless, we might have billions of wireless sensors, these will eventually exceed the growing number of cell phones. Cell phone and wireless sensors will start to compete for the same bandwidth. Adapting a hierarchy ensures a reasonable growth rate in bandwidth demand by the wireless sensor networks.

4.3 Manageable logistics

Since fiber grating sensors can be connected by long fiber optics cables. The interrogation unit does not need to be placed in the same hostile environment together with the sensors; it can be placed where there is power, normal room temperature and where access is easy.
The hybrid solutions offer an intermediate solution; instead of eliminating all the cables, we can eliminate 95 to 99 % of the cables with their associated weight and logistics. (each optical cable now carries 40 to 100 sensors) In addition, fiber optical cables have a variety of sizes and weight: giving customers many choices based on their constraints. In fact sensors array can be directly embedded into composites structures and modules during their manufacturing. Essentially we turn these structures into SMART STRUCTURES. These hybrid arrays can also perform condition monitoring in a large manufacturing facility with many large rotating machines like motors and compressors.

5. Need for more partnerships and cooperation in the sensor industry

Each of the innovative technologies has its strength and weakness, there must be a matching of technology with the customers need. Unfortunately the sensor industry is still very much product oriented. In a product oriented company, one would try to get its products designed in everywhere - even when it does not make sense! What customers want is a solution to a problem. It would be better if companies in the sensor industry could extend their horizon into other sensor technologies and see how people can work together to give the end customer the best solution. Semiconductor companies who tried to be all things to all people have already disappeared. Everybody now occupies a unique value added niche. Be

it MEMs , fiber optics, magnetic , ultrasound and Nano-sensors, we all fit somewhere but not alone. The problems are getting more and more complicated and we should work together as a team of experts, in full cooperation, to do the best for our customers.

Peter Kung is the President of QPS Photronics Inc, a company specialized in fiber grating based vibration sensors and systems for machine vibration monitoring and other related fields like pipeline and border security monitoring . He can be reached at;
peter@qpscom.com phone 514-697-4728 SKYPE: peter.kung.qps