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WHITE PAPER

Foundation monitoring – resistive versus fibre-optical strain gauge systems

Technology and costs compared

Foundation monitoring – resistive versus fibre-optical strain gauge systems. Technology and costs compared.

The role foundations play in the deployment of larger, heavier, more powerful wind turbines, in deeper waters and further from shore, has perhaps not received the attention it deserves. But it is crucial in driving down offshore wind's levelised cost of energy to the point where it can compete with fossil fuel and nuclear sources.

Fixed foundations, whether monopile, jacket or gravity base designs, now support towers and turbines that weigh well over 1,000 tonnes and have a tip height of more than 200 metres. The foundations need to be able to do this, in high winds and heavy seas, for at least the 25 years of the turbine's anticipated operating life.

Monitoring the structural integrity of the foundations, especially in the critical areas of greatest strain – just above and below the seabed – requires high expertise and state-of-the-art test and measurement technology.

This is a field where industry development has outstripped design standards. There is no easy guide for offshore developers. In this report, technology leader HBK Test and Measurement compares resistive and fibre-optical gauge systems for offshore wind foundations.

To help design verification, or as a system to provide long-term assurance that the foundations in offshore wind turbines are in the intended condition, measurement in the foundations of offshore wind turbines is vital.

The place of greatest bending in the foundation typically lies where the structure meets the seabed. Measurements above and even below the seabed are possible, with the correct design and protection, using strain gauge technology. In monopiles this may consist of concentric rings of protected strain gauges placed around the circumference, inside the foundation. In gravity base structures and jackets, there are other 'hotspots'.

These temperature-compensated measuring points route to a dedicated DAQ system for logging and – combined with readings from accelerometers, inclinometers and other sensors in the structure – provide a complete measurement system. This system then either works with the operator's SCADA network or reports remotely via GSM or satellite. Despite the technical challenges, the value of accurately measuring in the position where the structure faces its greatest forces (below the waterline) is great. Future standards may provide clarity on measurement types, location and logging frequency, but at present a lack of standards means that close technical liaison with those experienced in measurement in such harsh environments, particularly subsea, is key.

In an industry that has developed quicker than the standards designed to help guide it, there is much reliance on historical performance of products - such as strain gauges. But what kind of strain gauge should be used?

HBK has many years' experience in the design, manufacture and supply of both resistive and fibre optical strain gauges with a strong track record of successful installations, subsea and below the seabed. So, we've put together a simple technical and commercial comparison of typical optical and resistive strain gauge packages:



Strain gauges from HBK



Optical weldable strain sensors from HBK FiberSensing

The technical comparison

In offshore wind turbine foundations, a well-established and thoroughly proven method of protecting the strain gauge against the dangers of water ingress and damage during installation (particularly piling) is critical.

HBK uses the same protective method for both optical and resistive gauges and, therefore, this is not detailed here; for comparison between the two types of gauges, the cost and performance of the protective material are near-identical, and therefore negated.

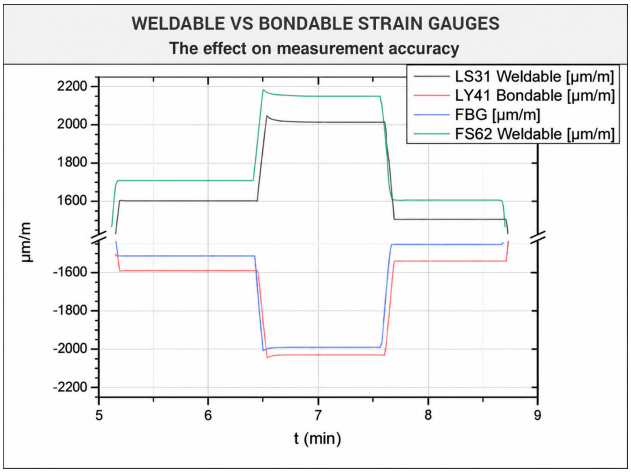
The key difference between the basic measurement principles is as follows: the resistive gauge measures electrical resistance; the optical measures the change in the wavelength of light, using Fiber Bragg Gratings (FBGs). In the environment of offshore wind, how the sensing element is fixed and protected is important. Either type of strain gauge can be bonded directly onto the foundation structure, following the appropriate surface preparation. In essence, fixing the gauge directly to the structure makes it into a giant load cell.

The bonding process has the finest layer of adhesive between the structure and the strain gauge itself that makes the actual measurement. Alternatively we can spot-weld the gauges onto the structure (where permitted), but because we first fit the gauge to a steel plate, before welding onto the structure itself, this technique adds another layer between the item to be measured and the 'sensor'.

Here we make a comparison between glued gauges and spot-welded gauges. HBK's FiberSensing subsidiary in Porto tested the effect on measurement accuracy, with the results in the graph below.

Strain gauge type LS31 is a resistive gauge, welded onto side A of a sample structure. FS62 is an optical gauge, welded onto the same side. On the reverse of the same sample we have two bondable (glued) strain gauges: LY41 is resistive and FBG is optical.

These were subjected to changing loads over different time periods at different temperatures (here c.10 minutes at 60 °C) in an environmental chamber.



There are certain benefits from fibre optical technology in this application. For short-term measurement programmes – such as those for design validation purposes – the issue of drift may not matter.

For long-term monitoring the very low levels of drift inherent in fibre optical measurement offer performance advantages over resistive gauges. In addition they are also totally immune to the effects of EMI and RFI and do not suffer from degradation as a result of higher fatigue at higher frequencies. Furthermore, in the unwanted event of water ingress into the cable, the core fibre carrying the signal is waterproof and does not affect the signal.

The fibre optical gauges are configured in arrays and there are advantages and disadvantages to this. The array (or cable) runs in a loop from DAQ to measurement position, and back, with a number of measurement points along its length. This, in large structures such as offshore wind turbine foundations, means much less cable is required - bringing significant cost benefits. In the event of a single cable break in one array, it is sometimes possible to continue to measure, by sending the light from the other end of the array. However, resistive gauges, wired individually, offer less risk of losing an entire section of the measurement chain in the event of a single cable break.

From a calibration perspective, the HBK fibre optical interrogator has an in-built calibration reference – self-checking before measurement to aid long-term accuracy.

The cost comparison

Fibre-optical technology, as stated above, lends itself well to large structures with many measurement points. In addition to the technical benefits there are cost advantages, too. HBK's first installation in an offshore wind turbine was in 2003 and there have been many since, from jackets to gravity base to monopile structures.

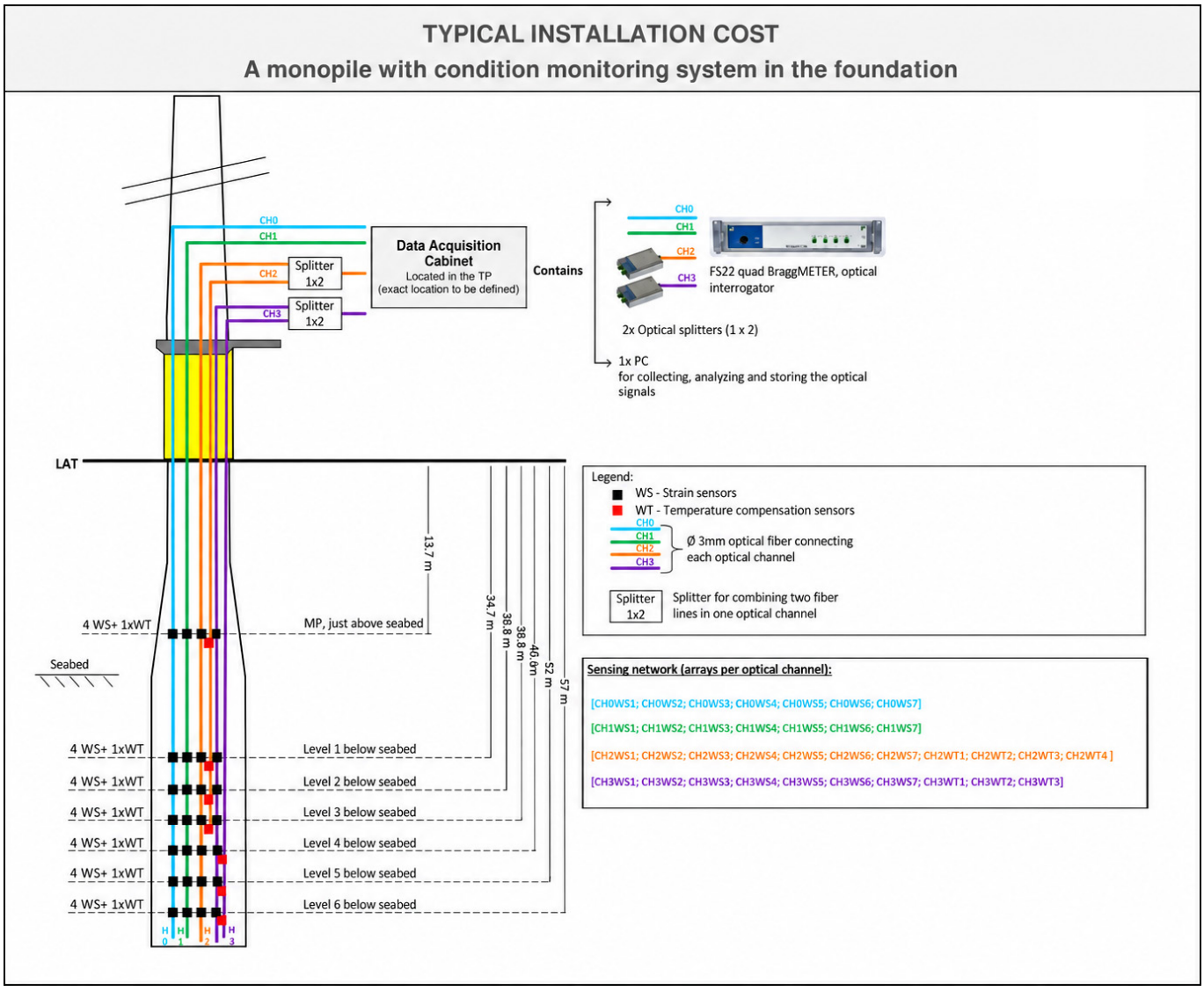
In the graph below, we look at a typical installation: A monopile with a condition monitoring system in the foundation, designed primarily for short-term (a few years) measurement of the critical areas of the foundation. The same system will continue to operate well beyond this and, in any case, the costs are the same regardless of the length of the measurement campaign.

The DAQ hardware cost is, on its own, typically more for fibre-optical gauges than the equivalent channel count DAQ for resistive strain gauges. Fibre-optical technology employs laser technology, for example. Conversely, HBM's fibre optical strain gauges can be spot-welded into place, a technique which (with training) takes roughly half the time to install as a resistive gauge via a gluing method.

Considering the large number of strain gauge positions sometimes required in an offshore wind turbine, the reduced installation cost (through time saved) per position outweighs the comparatively more expensive DAQ hardware required.

There is a tipping point, of course, as the cost benefits of complex hardware are greater in larger systems. Training costs should be considered, too. It could be argued that the skill (and, therefore, employee cost) of spot-welding a strain gauge is lower than that of a glued strain gauge. There is no soldering and less cable handling.

The protective covering over the measurement position needed for strain gauges located in the foundation and, in particular, below the seabed, is the same regardless of strain gauge type. Also, the factory and site acceptance tests and set-up times are broadly the same for both.



	Resistive strain gauge, compared to optical	Optical strain gauge, compared to resistive	Note
DAQ hardware cost	-10%	+10%	
Strain gauge cost	-75%	+75%	Optical strain gauges include cable as part of array. Resistive gauges require extra cable, hence the large cost difference.
DAQ installation cost	Same	Same	
Strain gauge installation cost by qualified engineer	+15%	-15%	
Cabling	3 km	Included in strain gauge cost as part of array	
Total difference in cost for an installed system		c.-10%	

Cost comparison (48-channel strain-gauge system)

In summary

The use of fibre optical technology is not new. Despite this, there has been a relatively slow uptake in its use for the application of offshore wind turbine foundation monitoring.

In an industry requiring a design life of perhaps 25 years, with strain gauges often installed in a position unreachable after installation, there can be no room for experimentation. The technical benefits have been clear for many years, but to be commercially viable this technology must bring considerable cost benefits, too. The asset owner looking to extend operational life will appreciate the benefit of continued accurate measurement after many years, as will engineers looking for reliable data for design validation.

But the benefit of a lower installed cost, at the time of construction, now makes fibre optical technology, when installed correctly, a cost-effective solution for accurate foundation monitoring in offshore wind turbines.

Note: Please contact HBK for the contents of the tests mentioned here, technical datasheets on the products mentioned, or advice on how to ensure longevity in subsea measurement points.