HBK
HOTTINGER BRÜEL & KJÆR

STRUCTURAL HEALTH MONITORING

Tunnel vision: HBK fibre optic sensors for tunnel monitoring

How HBK's advanced fibre optic sensing technology enabled real-time strain and temperature insights at the Kühtai 2 hydropower station.

THE KÜHTAI 2 HYDROPOWER PLANT PROJECT: A TALE OF TWO RESERVOIRS

In mountainous areas, hydropower plays a crucial role in energy security – storing and releasing electricity on demand to keep grids stable and communities powered.

One ambitious example is the Kühtai 2 hydropower plant, engineered by Tiroler Wasserkraft AG (TIWAG) deep within an underground rock cavern in the Austrian Alps.

At the heart of this pumped-storage facility lies a 4.6-metre diameter underground pressure tunnel, linking the newly constructed Kühtai reservoir with the existing Finstertal reservoir. Driven by two reversible pump turbines, up to 90 m³/s of water flows between the two reservoirs, feeding electricity directly into the grid.

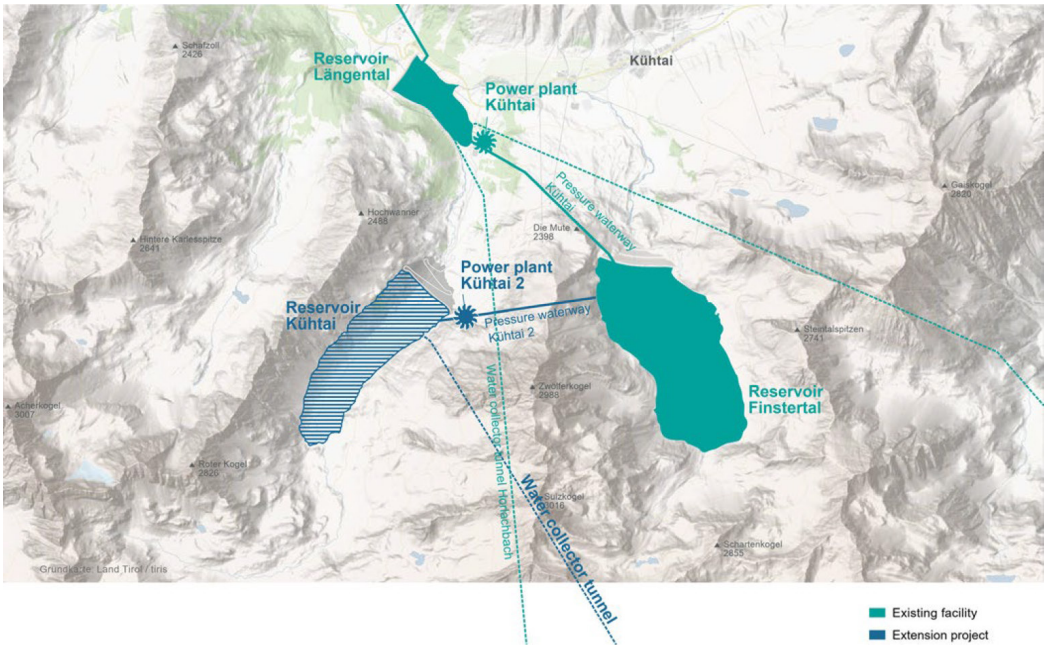

Figure 1 – Project overview of the hydropower plant Kühtai 2 (translated and modified from "www.erneuerbareplus.at").

Lining up the options – and obstacles

Constructing the tunnel in such a volatile environment meant using a variety of linings – including prestressed and unreinforced concrete (with and without waterproof sealing membranes), as well as thick-walled steel – each selected to match site-specific geology, internal pressures, and stress profiles.

During construction and pre-commissioning, each tunnel section faced complex mechanical loads. Cracking was a key concern, especially in unreinforced concrete. Steel segments needed additional reinforcement to avoid buckling. Every lining material responded differently under strain – and each required its own monitoring strategy to provide long-term structural safety. TIWAG needed a solution that could capture precise, long-distance, real-time data – without signal degradation, interfering with tunnel function, or opening the floodgates to structural risk.

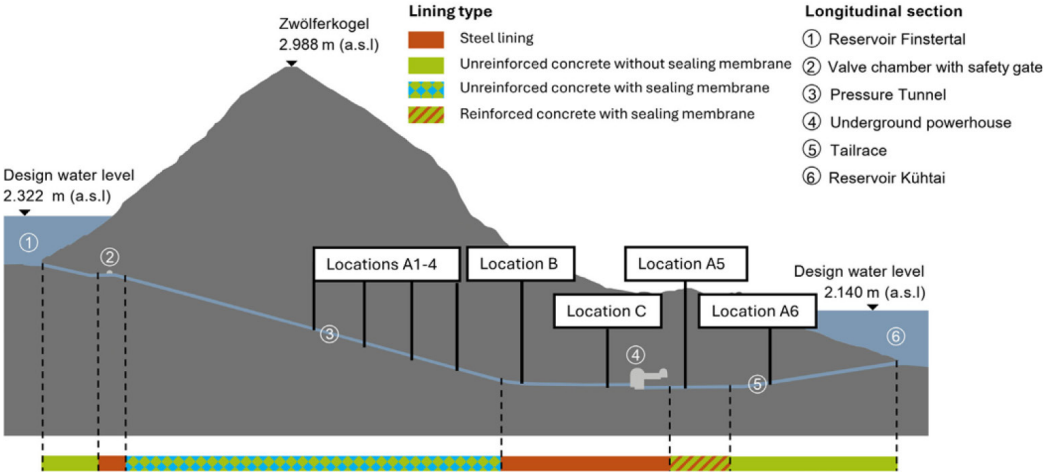

Figure 2 – Longitudinal section of the connection between the new Kühtai reservoir and the existing Finstertal reservoir with the individual measuring sections (translated and modified from "www.erneuerbareplus.at").

Sensing the pressure

TIWAG's ambition did not stop at structural innovation. They wanted to integrate high-resolution sensors directly into the tunnel linings, including prestressed concrete – still a relatively unexplored frontier in hydropower engineering, especially where sensors must survive active loading and pressure cycles.

Three key technical issues stood in their way:

1. In tunnel sections with waterproof sealing membranes, mechanically anchoring or fastening sensors was strictly off-limits – any breach would compromise the tunnel's impermeability and integrity.
2. In bare concrete segments, any sensors would need secure but non-intrusive mounting to maintain signal clarity without disrupting the waterway tunnel's performance.
3. Steel linings also added further complexity. Here, sensors had to be welded onto the outer shell and aligned to track longitudinal strain – without weakening the steel pipe and sacrificing durability.

All sensors needed to operate in a high-pressure environment which faced extreme temperature variations, humidity, vibration, and constant hydrostatic pressure. Crucially, they also needed to be immune to electromagnetic interference, which could distort readings in an electrically active installation.

TIWAG needed a distributed monitoring system that could survive long-term underground deployment, transmit accurate data over kilometres, and help them turn valuable data into confident decisions, from installation to operation. And they needed it fast – before tunnel completion closed the window for embedded instrumentation.

That's where HBK's advanced fibre optic sensing technology came in. This offered TIWAG the flexibility, resilience, and precision needed to make structural health monitoring possible – even in the most inaccessible reaches of the tunnel.

WHY CHOOSE HBK: PIONEERS IN STRUCTURAL HEALTH MONITORING TECHNOLOGY

Tunnels form a vital part of infrastructure all over the world – but their stability can be difficult to guarantee. Even minor deformations or stress points during construction, pressurisation, or long-term operation can escalate into serious safety risks.

Knowing how a tunnel behaves under stress is not just important – it's vital. That's why TIWAG turned to HBK. As a recognised leader in structural health monitoring, HBK delivers sensor solutions specifically designed for demanding civil engineering environments – including tunnels, bridges, and dams – where real-time data and long-term reliability are crucial.

HBK's monitoring solutions include:

- Instrumented tubbing – or tunnel lining – segments
- Deformation and convergence tracking
- Fibre optic inclinometers
- Tailored monitoring solutions for inaccessible linings and ceilings

HBK's monitoring solutions include:

- Zero signal drift over time
- Resistance to humidity, corrosion, and vibration
- Immunity to electromagnetic interference
- Reliable performance in high-pressure, sealed, and hard-to-access areas

When accuracy, resilience, and flexibility were non-negotiable, TIWAG chose HBK. With deep domain expertise and proven fibre optic sensing systems, HBK has the knowledge and technology to meet any civil project's demands – head-on and below ground.

A SMARTER SENSING SYSTEM, BUILT FROM THE GROUND UP

Monitoring a waterway tunnel, this complex demanded more than off-the-shelf sensors. HBK's sensors are engineered to integrate seamlessly across a range of mounting strategies – perfect for precise, reliable measurements along the Kühtai 2 tunnel's various linings.

However, applying the sensors was not a one-size-fits-all task. Each section of the Kühtai 2's underground tunnel required a tailored approach:

- Unreinforced concrete with sealing membrane – as penetrating the waterproof barrier was not an option, we designed a friction-locked sensor cage made from thin glass fibre mat. Not only was this lightweight and corrosion-resistant, it was also engineered to behave like concrete under mechanical stress, preventing distortion to ensure accurate, reliable strain measurements.

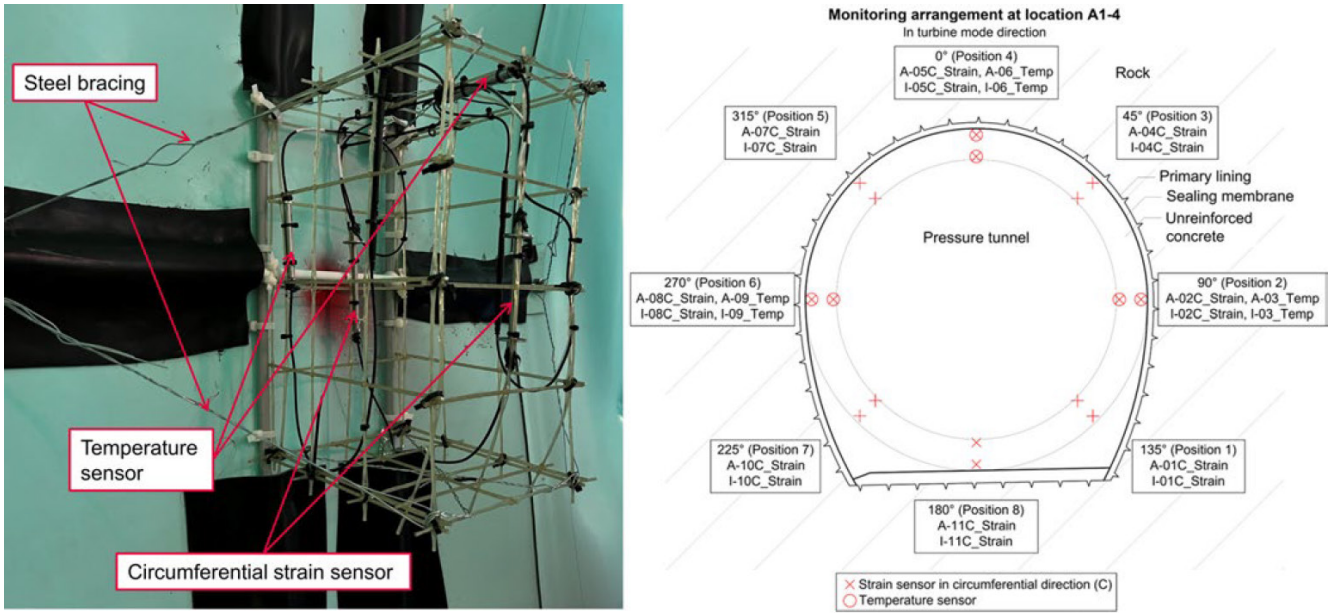

Figure 3 – Sensor application on unreinforced concrete lining; Right: Schematic view of the sensor alignment in turbine mode direction.

- Unreinforced concrete without membrane – here, measuring boxes were mounted on steel rods anchored to the outer lining. Foam covers were added to the rods to minimise mechanical interference and protect signal clarity.

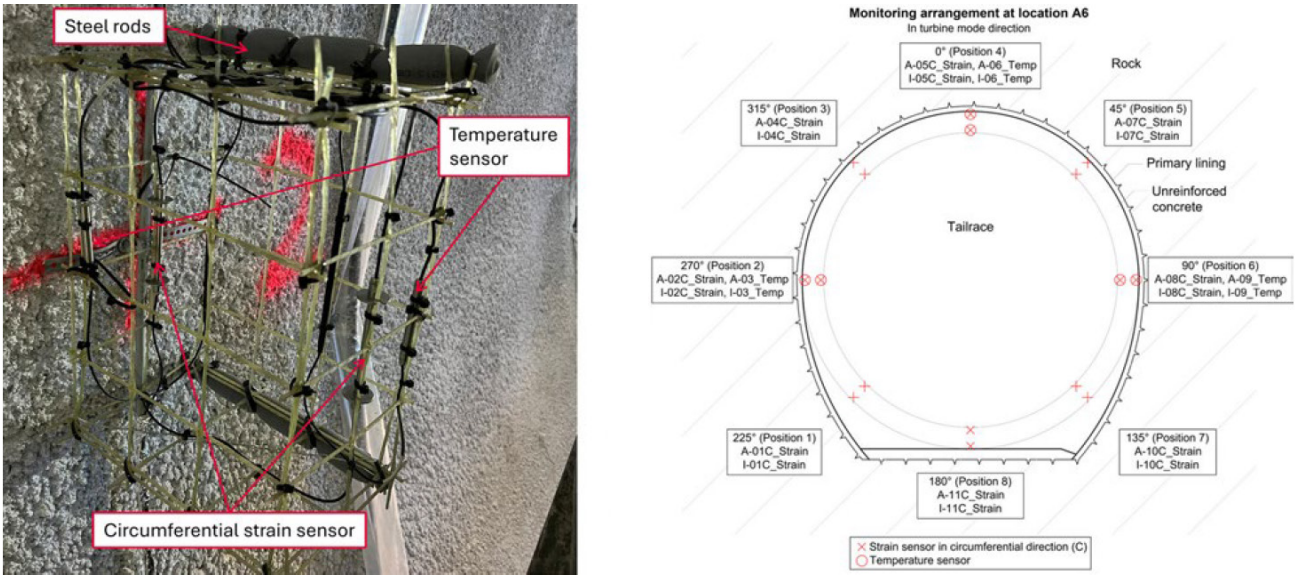

Figure 4 – Sensor application on unreinforced concrete lining without sealing membrane; Right: Schematic view of the sensor alignment in turbine mode direction.

- Steel lining – we welded sensors into place on the outer surface of the steel pipes. Unlike the concrete shell, strain sensors were also arranged in the longitudinal direction.

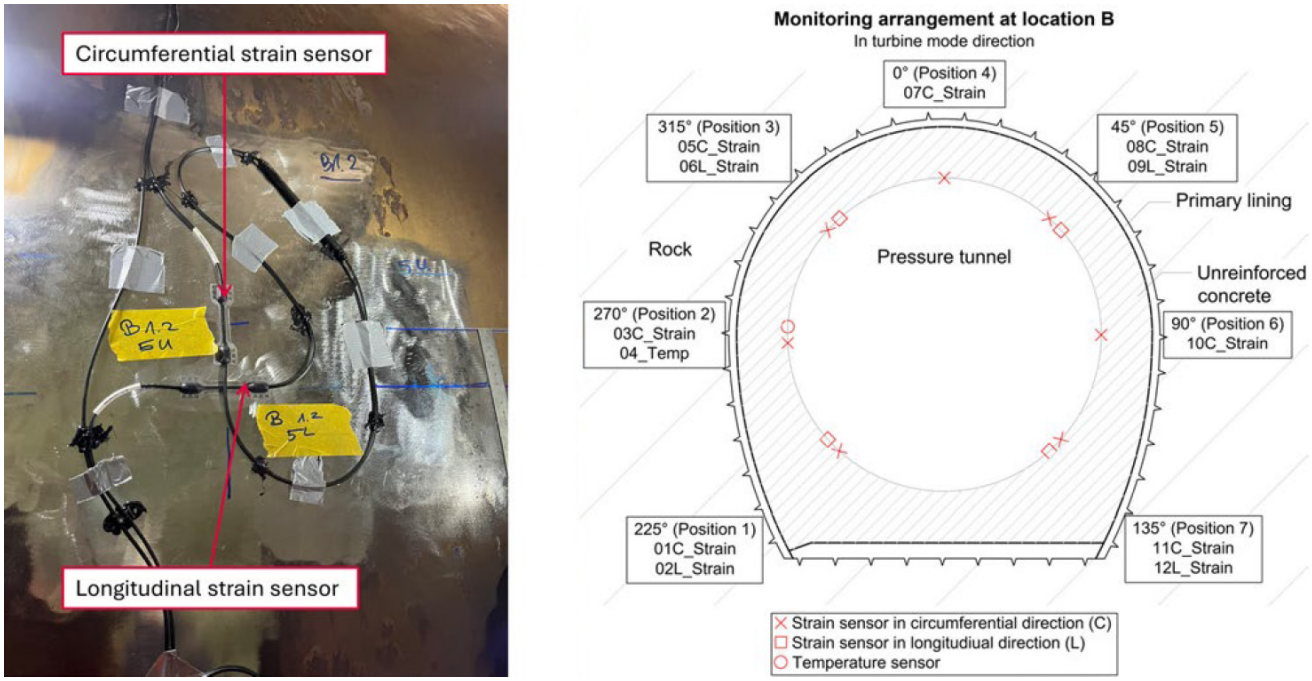

Figure 5 – Left: Sensor application on steel lining; Right: Schematic view of the sensor alignment in turbine mode direction.

These solutions enabled real-time monitoring across multiple phases – including concreting, grouting, and pressurisation – without compromising the tunnel's structural integrity.

FIBRE OPTICS FOR RAPID MEASUREMENTS IN ROUGH ENVIRONMENTS

At the core of the system was our optical sensing platform, built on Fibre Bragg Grating (FBG) sensors – a cutting-edge technology that uses light, not electricity, to measure strain and temperature with extraordinary precision. These compact sensors offer high-resolution measurements of strain, temperature, and pressure.

How do FBG sensors work?

Each sensor contains a microscopic grating pattern inside an optical fibre. As the fibre deforms under load or heat, the grating reflects light at different wavelengths. These shifts can be measured with extreme precision – without signal drift, electromagnetic interference (EMI), or degradation over time.

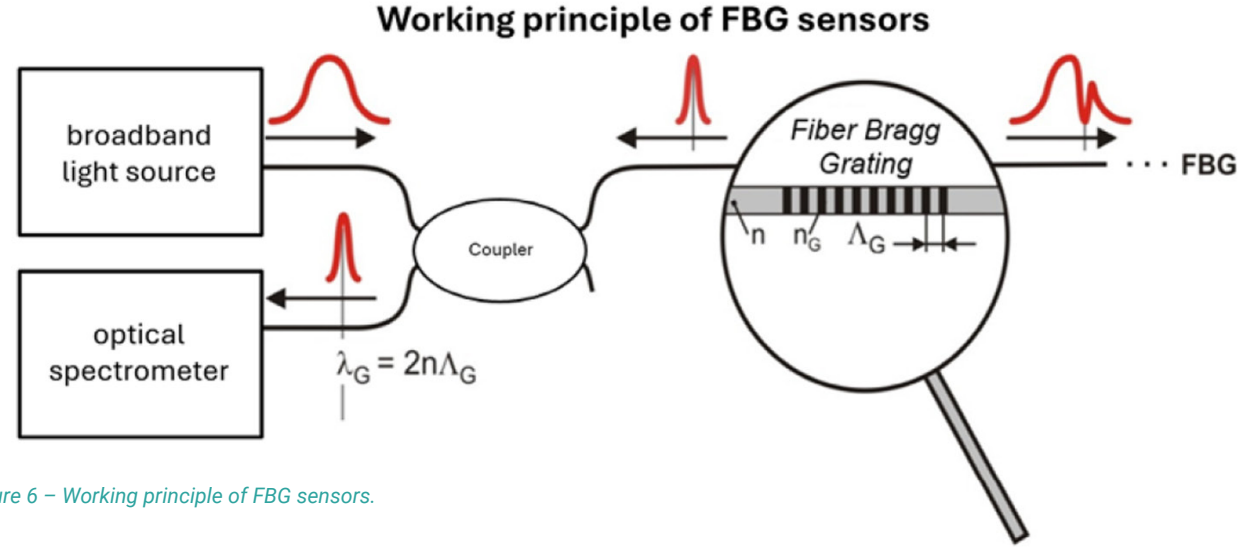

Figure 6 – Working principle of FBG sensors.

How do HBK's FBG sensors make all the difference?

HBK's FBG-based measurement solutions deliver:

- Strain accuracy better than 1µm/m, even under dynamic loading
- Zero signal drift, ideal for long-term tunnel deployments
- Resistant to EMI, humidity, corrosion, and vibration
- Multipoint capability, with several gratings on a single fibre
- Compact, low-profile form, suitable for both embedded and surface applications

Because FBG sensors do not rely on electrical signals, they are immune to many of the challenges that affect conventional monitoring systems – making them a reliable choice for tunnels exposed to harsh environmental and mechanical conditions.

Together with tailored installation methods, HBK's sensing technology gave TIWAG a powerful tool to monitor structural behaviour through construction, testing, and operation – layer by layer, and in real time.

SMARTER TUNNELS, SAFER INFRASTRUCTURE

HBK's fibre optic sensing systems provided TIWAG with more than just measurements – we delivered deep insights into the tunnel's real-world behaviour under load, in real time, and under extreme conditions.

As prestress and contact grouting progressed, the system recorded clear strain and temperature responses across internal and external sensors. These readings allowed engineers to validate structural assumptions and confirm the effectiveness of key construction techniques.

For example, differences in sensor positioning revealed how injected materials affected local strain behaviour – insights that would have been impossible to detect with conventional methods.

Temperature measurements also confirmed predictable heat rises during grouting, with external sensors registering greater increases due to proximity to injected materials. This level of resolution allows operators to distinguish between environmental influences and genuine structural stress.

HBK's monitoring solutions include:

- Real-time data to support live decision-making during construction phases
- High-frequency, high-accuracy monitoring that outperforms conventional electrical strain gauges
- Long-term stability, enabling use through both commissioning and full operation
- Validation of pressure tunnel design assumptions, improving confidence in prestressing and grouting strategies
- Non-invasive monitoring of sealed and inaccessible segments, without compromising tunnel integrity

How do HBK's FBG sensors make all the difference?

Beyond Kühtai 2, HBK's fibre optics measurement solution demonstrates how fibre optic technology is reshaping structural health monitoring – one tunnel at a time.

As infrastructure ages and climate pressures rise, the ability to embed smart, non-intrusive monitoring from day one will be critical – not just for safety, but for resilience, performance, and lifecycle management.

SETTING A NEW BENCHMARK FOR TUNNEL INTELLIGENCE

The Kühtai 2 hydropower project set a high bar for engineering complexity. But with HBK's fibre optic sensing solutions in place, TIWAG gained something more than data – they gained visibility into the tunnel's structural behaviour from the inside out.

Successfully integrating FBG sensors into concrete and steel linings – including unsealed, unreinforced sections – demonstrated the true potential of smart sensing in high-pressure underground environments.

HBK's FBG sensors delivered high-resolution, real-time measurements of strain and temperature across multiple construction stages, from prestressing to full commissioning.

The approach not only validated structural design assumptions – it also provided engineers with actionable insights into how the tunnel materials respond to dynamic loads over time. The system's stability and precision made it a robust tool for construction monitoring and long-term structural health.

As hydropower infrastructure grows and operational demands increase, the ability to embed intelligent, non-intrusive monitoring technologies will become essential to safe, sustainable civil works.

HBK's sensor technology – and its adaptability to challenging environments – shows what's possible when engineering innovation meets real-world conditions. Kühtai 2 now stands as a key benchmark for modern tunnel design, construction, and maintenance.

About HBK

Hottinger Brüel & Kjaer (HBK)'s testing and measurement solutions give engineers around the world the accurate, up-to-date data they need to bring higher-quality products to market faster.

HBK bridges the physical and virtual worlds with robust, flexible hardware and precise, powerful analytics software. Giving design, test, and measurement engineers complete confidence in every reading and every data-driven decision – across the entire product development lifecycle.

Backed by decades of experience and deep expertise, HBK's sensors and software transform testing and measurement in a huge range of use cases, from building more aerodynamic aircraft to testing the safety of automotive vehicles.

We provide exceptional sensing and insights to create solutions for a cleaner, healthier and more productive world

CONTACT US

Ready to take the next step? Speak to an HBK expert to explore how our fibre optic sensors can support your next infrastructure project.

SERVICES

HBK provides comprehensive support for customised and dedicated solutions, specifically tailored to meet our customers' unique needs.

Our commitment extends to customer training, whether conducted remotely, at our facilities, or on-site. We ensure that customers become proficient in deploying and utilising our cutting-edge technology.

Additionally, our specialised engineering team manages installation and project coordination for bespoke projects, drawing upon extensive experience and relevant certifications for offshore or elevated works.

Hottinger Brüel & Kjaer Austria GmbH
Lemböckgasse 63/2, 1230 Wien, Österreich
www.hbkworld.com
info@hbkworld.com