HBK
HOTTINGER BRÜEL & KJÆR



STRUCTURAL DYNAMICS

Structural dynamics solutions for aerospace, space and defence

Comprehensive HBK solutions for structural characterisation, optimising product safety, performance, comfort, and cost-efficiency, all while minimising environmental impact.

THE IMPORTANCE OF STRUCTURAL DYNAMICS TESTING

Structural dynamics testing is crucial for understanding and optimising the actual behaviour and inherent dynamic properties of structures. This leads to lighter, stronger, and safer constructions with enhanced performance, reduced environmental impact, and improved comfort. Additionally, it lowers development, manufacturing, and maintenance costs.

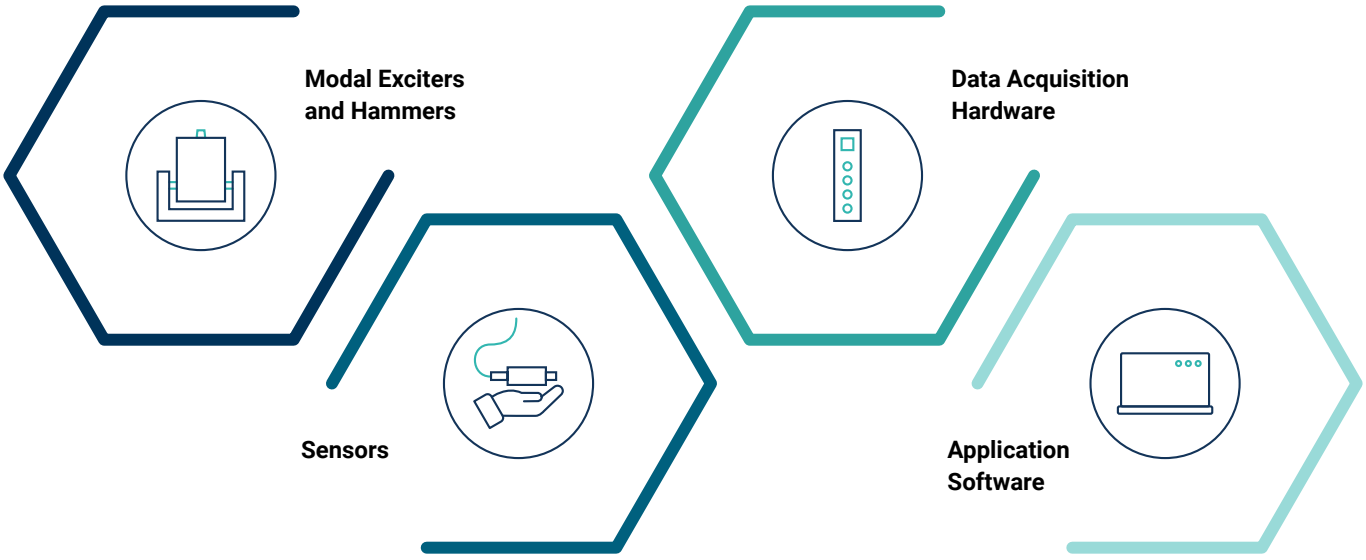
With the increase in use of new designs and materials, the shift towards electrification, shorter development cycles, and the demand for larger and more refined simulation models that require advanced test validation, the requirements for test preparation, setup, execution, and analysis have never been greater. Consequently, systems for structural dynamics testing must efficiently and accurately identify the root causes of structural weaknesses, and provide powerful tools to find optimal solutions for design, material selection, manufacturing and maintenance.

An overview of our solutions

HBK provides a comprehensive range of innovative, stand-alone products and complete, modular, scalable solutions to meet your structural dynamics testing needs, both now and in the future, whether you are a novice or an experienced user.

Our unique, feature rich, and user-friendly structural dynamics testing solutions are developed in close collaboration with leading companies and academics worldwide. They cover operational tests, controlled excitation tests, and Test-Finite Element Analysis (FEA) integration. We provide the complete measurement and analysis chain – from seamlessly integrated modal exciters, impact hammers, sensors and data acquisition hardware, to a wide variety of application software. This enables you to significantly shorten your test campaigns, achieve high-quality results, and minimise the risk of errors.

Whether you need a 2-channel impact testing system for component resonance testing or troubleshooting, or a more comprehensive system with multiple modal exciters, hundreds of accelerometers, and advanced measurement and analysis techniques for large-scale modal surveys for design validation, or Ground Vibration Tests (GVT), HBK offers a complete suite of solutions, services, and training to meet your needs.



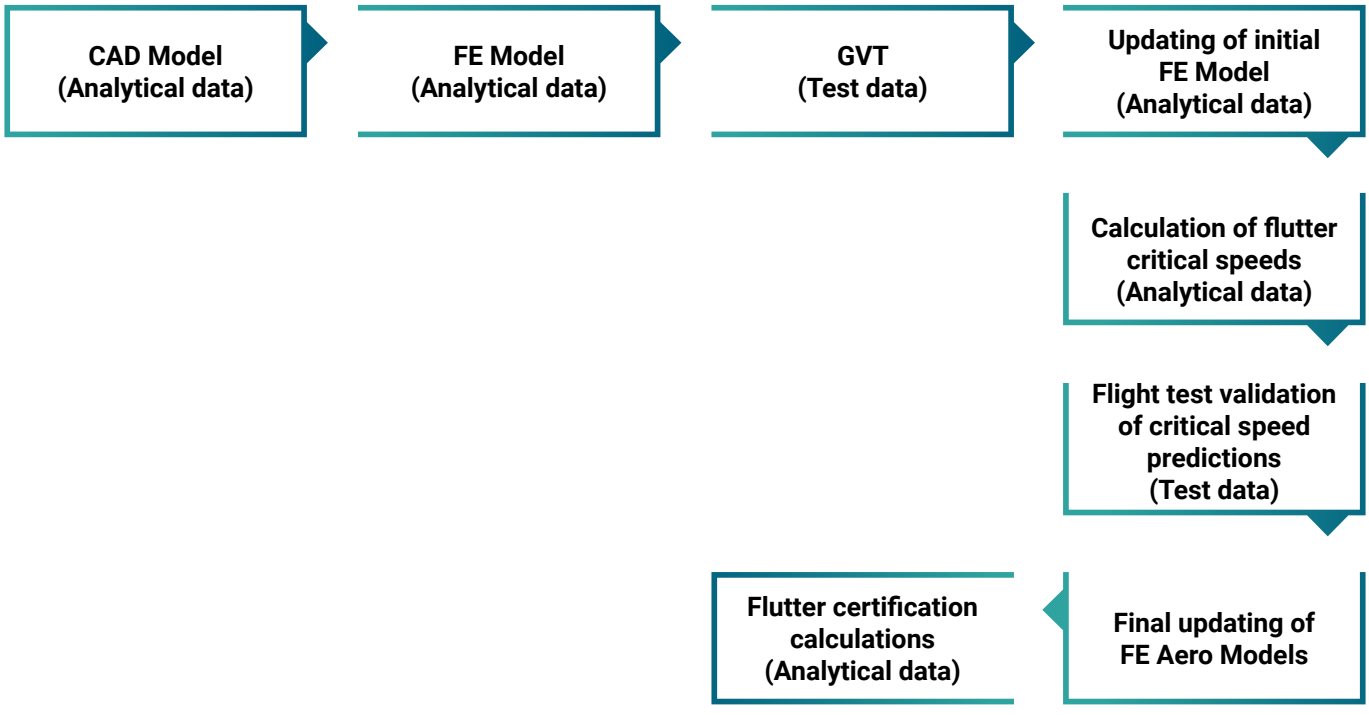
The HBK structural dynamics measurement and analysis chain – from modal exciters and impact hammers to application software.

AIRCRAFT CERTIFICATION

Regulations from airworthiness authorities such as the FAA, EASA, JCAB and CAAC require that aircraft certification should be obtained for new or re-designed aircraft types before they enter into service to ensure aircraft safety, reliability and airworthiness. This includes evaluating the material properties of components and determining the life expectancy of the entire aircraft through full-scale fatigue testing. The certification process includes various dynamic simulation and testing techniques such as CAE-based simulations, GVTs, and flight tests, which assess the aircraft's performance and handling characteristics under a range of operational conditions. A key result of these tests is the establishment of flutter boundaries. Measuring static and dynamic aircraft behaviour under typical and extreme load conditions using various aircraft configurations is both costly and time-consuming, and requires thorough preparation and execution.

Operational tests are performed under actual operating conditions to evaluate the entire aircraft and its systems and components. Controlled excitation tests involve applying known forces to the aircraft structure to study its dynamic properties, and Test-FEA integration compares test results with predictions from finite element analysis to refine and validate the simulation models. These techniques are also widely used to other airborne vehicles, ships, submarines, and various ground vehicles.

Advanced technology, dedicated testing solutions, and highly reliable equipment are essential for performing these complex and expensive tests within a short time frame. HBK understands these challenges and our integrated solutions not only help you utilise testing time and resources efficiently but also meet aviation testing requirements, providing accurate and reliable results to support a 'first-time-right' approach.



Aircraft certification flowchart for structural dynamics.

APPLICATION SOFTWARE

HBK's primary sound and vibration software platform, BK Connect®, is an integrated solution designed to eliminate the tedious and error-prone data transfers between multiple systems. With its simple and intuitive user interface, BK Connect allows for easy navigation between tasks, while its flexible setup can be tailored to meet your specific needs and workflow. This ensures a high level of efficiency, enabling you to complete tasks swiftly, whether you are a specialist performing advanced diagnostic analysis, or an operator conducting standard repetitive testing.

BK Connect's exceptional data management delivers accurate, organised, and well-documented data, including metadata, to ensure confident decision-making. Compatible with data from third-party systems, BK Connect also offers an open programming API that supports third-party applications and integration.



Pre-test Analysis **Setup** **Measurement** **Analysis** **Correlation**

The BK Connect software platform allows you to observe, analyse and document the dynamic behaviour and properties of structures – from pre-test analysis to model correlation.

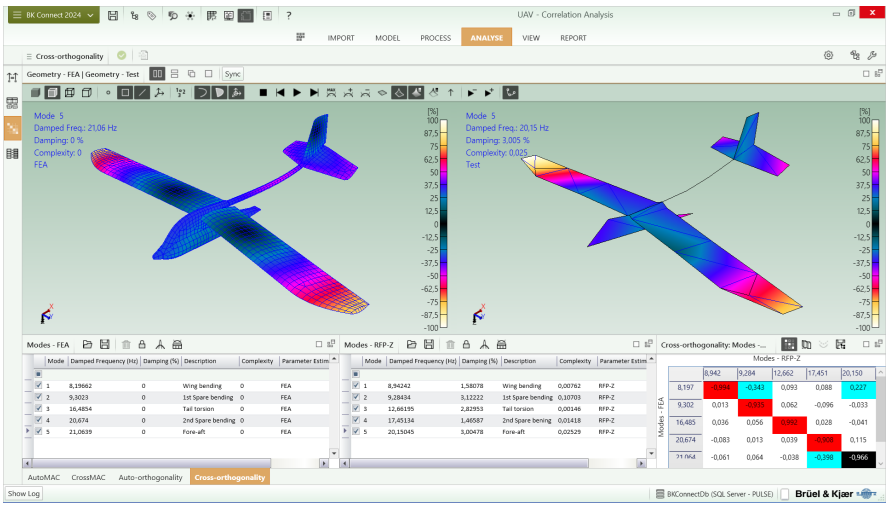
PRE-TEST ANALYSIS AND MODEL CORRELATION

Integrating testing with FEA helps reduce development costs, minimise the number of physical prototypes, and shorten the time from concept to production.

BK Connect provides powerful tools that enhance confidence in both test and simulation results, improving essential engineering judgement skills for test engineers, analysts, and management. By using baseline FE models, you can optimise structural tests early in a project and subsequently refine the FE models using the enhanced test results. FEA results can be imported into BK Connect from leading FEA programs such as Nastran® (MSC, NX, NEi), ANSYS®, and ABAQUS®, or as UFF files, enabling pre-test analysis and model correlation.

During pre-test analysis, simulation predictions are used to optimise the number, position and orientation of test excitation and response DOFs, while an accurate test geometry decimated from the FE model is easily created. After completing the structural test, the results can be correlated with the simulation predictions through model correlation.

BK Connect Correlation Analysis allows you to perform a complete visual and numerical model correlation, identifying short-comings in modal tests and areas of insufficient modelling quality in FE models. This powerful tool helps in designing optimal test conditions and evaluating different modelling strategies. Techniques include geometry alignment, DOF mapping, MAC and orthogonality calculations, and mode pairing.

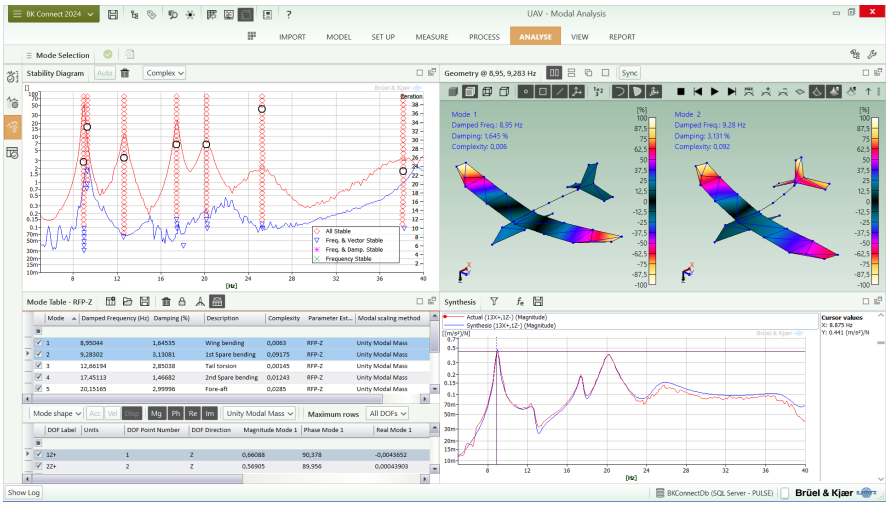


Model correlation of an unmanned aerial vehicle (UAV) using BK Connect Correlation Analysis. The fore-aft mode pair (FEA, Test) selected in the cross-orthogonality table is shown animated.

EXPERIMENTAL AND OPERATIONAL MODAL ANALYSIS

In **experimental modal analysis (EMA)**, also known as classical modal analysis, a model of a structure's inherent dynamic properties is obtained by exciting the structure with measurable forces and determining the response to excitation ratio. Our hammer and (multi-)shaker testing systems are utilised in various types of tests, including ground vibration tests, design validation and optimisation, troubleshooting and diagnostics, benchmarking, and simulation studies. Even in the most demanding scenarios, our systems deliver accurate and reliable results using a targeted set of best-in-class modal parameter estimators (MPEs), and measurement and analysis validation tools.

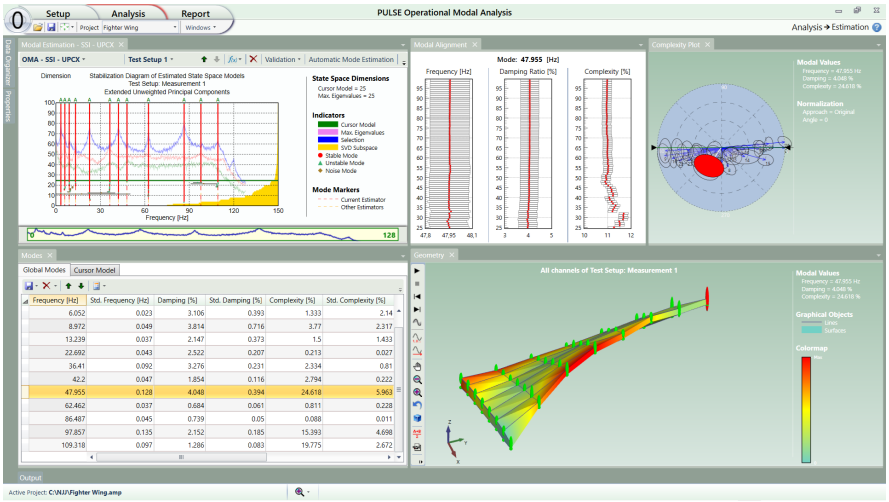
A wide range of excitation signals and analysis techniques are available to perform linearity studies and optimise test execution. This includes random (burst, continuous, pseudo and periodic), sine (single, swept and stepped) and user-defined excitation signals.



Powerful MPEs ensure clean stability diagrams and easy extraction of closely-coupled modes using BK Connect Modal Analysis.

In **operational modal analysis (OMA)**, only the output responses are measured while natural ambient and operating forces serve as unmeasured inputs. OMA is often preferred over experimental modal analysis for accurate modal identification under actual operating conditions, such as during aircraft flight, ship or submarine sailing, vehicle driving, or rocket launches. It is also ideal for scenarios where controlling artificial excitation of the structure is difficult or impossible, such as with large structures like aircraft and ships.

Our OMA systems use state-of-the-art technology to provide automatic suppression of harmonic components, crystal-clear stability diagrams, unbiased modal parameter estimation, automated mode estimation, and uncertainty estimates for the natural frequencies, damping estimates and mode shape complexities. Quantifying uncertainties not only provides insight into the quality of the estimated modal parameters, but is also used to improve them.



OMA on an aircraft wing tip. Uncertainties are shown as confidence bounds for the modal parameters as a function of the model order for a selected mode – in mode tables as standard deviations for each modal parameter, and as ellipsoid for a selected DOF in complexity plots and during animation.

NORMAL MODE TUNING

In Normal Mode Tuning (NMT), a structure is forced to respond in its normal (real) modes – one mode at a time – by applying multi-point sinusoidal modal exciter inputs with a unique level and phase relationship. NMT is the only testing technique that produces normal modes, making it indispensable for design validation tests and non-linearity studies requiring extreme accuracy.

NMT is primarily used to determine flutter-critical modes during ground vibration tests of aircraft and aerospace structures, where other modes of interest are typically assessed using faster sine testing techniques like stepped sine excitation or broadband testing techniques such as burst random excitation. As structures become increasingly non-linear and heavily damped, for example, due to the increasing use of composite materials, the use of NMT and stepped sine testing is growing.

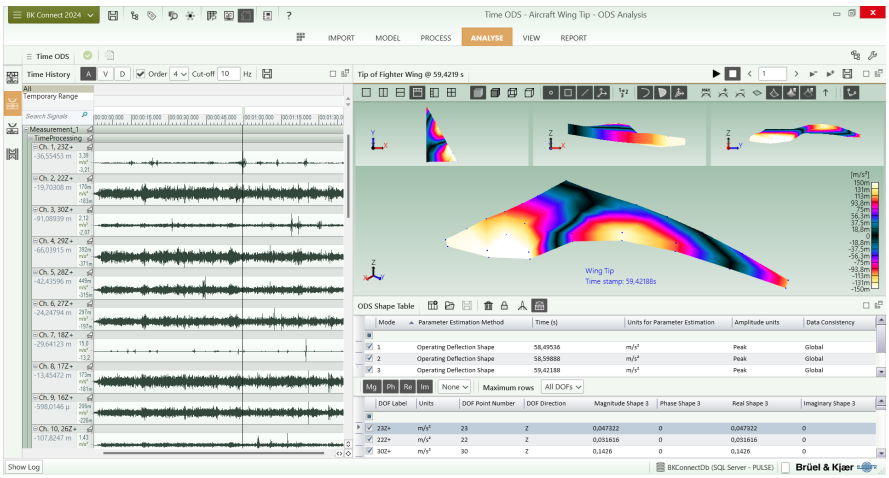
Our NMT solution includes mode tuning by visual reference to Lissajous figures or peak amplitudes, and damping calculations based on decaying sinusoidal transients.

OPERATING DEFLECTION SHAPES ANALYSIS

In operating deflection shapes (ODS) analysis, the vibration pattern of a structure is measured and visualised typically under actual operating, boundary and environmental conditions. ODS analysis is useful for observing the overall vibration pattern of a structure as well as to separate forced vibrations from structural phenomena. As such, ODS analysis is widely used as both a design validation and a troubleshooting tool.

Unlike modal analysis (EMA and OMA), no modal model is created and there are no assumptions about the characteristics of the input forces. The input forces can be stationary, quasi-stationary, or transient, influenced by factors such as engine speed, pressure, temperature, flow, or ambient forces. ODS analysis can, therefore, be used in situations where modal analysis is not possible.

Our solutions support all types of ODS analysis, including time ODS, spectral (frequency or order-based) ODS, and non-stationary (run-up/down) ODS.



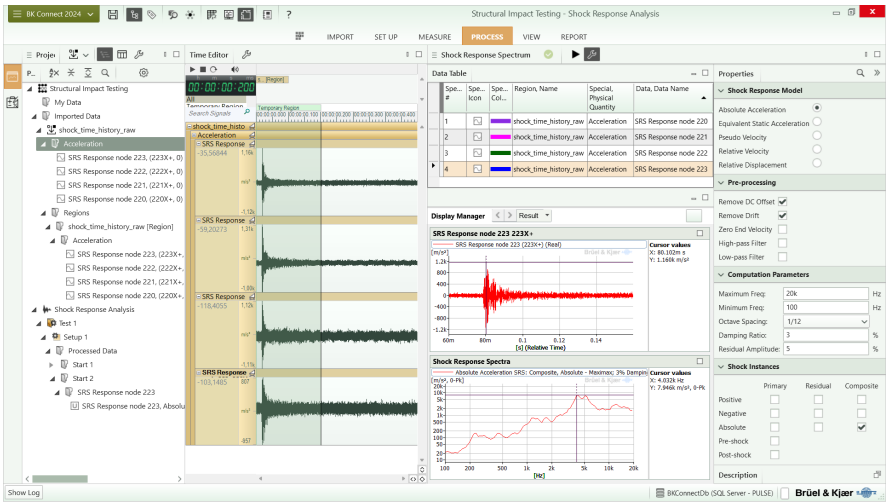
Time ODS on an aircraft wing tip using BK Connect ODS Analysis. Results can be shown as acceleration, velocity or displacement in SI or imperial units.

SHOCK RESPONSE ANALYSIS

The Shock Response Spectrum (SRS) is used to determine the damage potential of components and systems when subjected to transient events like pyroshocks and structural impacts, ensuring their survival in known environments.

SRS analysis is a key application in rocket, space shuttle and satellite testing, ensuring that components can survive the rigours of launch and deployment.

All five SRS models mentioned in ISO 1843-4:2007 are implemented. With these five SRS models and nine standard criteria for amplitude calculation, you can configure up to 45 different response types for full flexibility to match your needs.



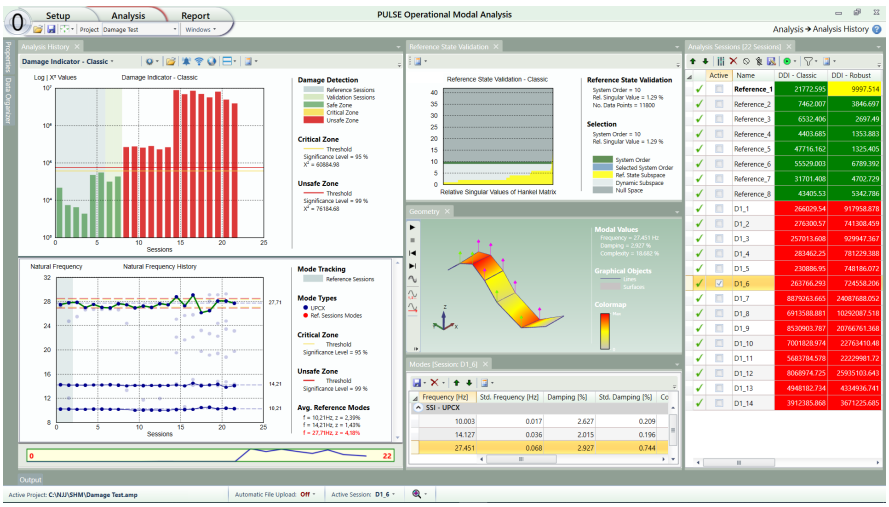
The BK Connect Shock Response Analysis application with its simple and intuitive user interface.

STRUCTURAL HEALTH MONITORING

Structural health monitoring (SHM) systems have for years been used in aircraft, ships, and submarines, but are now also increasingly in demand for space structures. By performing long-term continuous SHM it is possible to monitor and track a structure's health condition and carry out condition-based maintenance to ensure structural integrity and safety.

Our SHM solutions cover the complete measurement and analysis chain. They include automatic data upload and processing, mode tracking, and damage detection. You can configure notification (alert) services via visual, auditory, email, and web platforms.

Notably, our damage detection algorithms operate in the physical domain using state-space models. This approach ensures more robust and reliable damage detection with unparalleled accuracy.



Vibration-based damage detection using the Classic and Robust damage indicators and compared to mode tracking. The latter provides very useful information but cannot stand alone as a damage indicator.

LAN-XI DATA ACQUISITION PLATFORM

HBK's LAN-XI modular data acquisition platform is highly popular among professionals working in structural dynamics, especially in the aerospace, space and defence industries, due to its exceptional performance, flexibility and robustness. This versatile platform can deliver over 1000 channels in a compact DAQ system. It integrates unique technologies that reduce setup and measurement time and ensure accurate measurement results on the first attempt.

All LAN-XI modules are Plug & Play and can function stand-alone or in frames that each hold up to either 5 or 11 modules. Modules and frames can also be used within a distributed system, and in separate systems using GPS synchronisation between the frames. LAN-XI hardware can be used in the field with a battery module connected to a single module or mounted in a frame. Additionally, it can utilise a DC power supply or function as part of a distributed system with Power over Ethernet (PoE) using standard LAN cables.

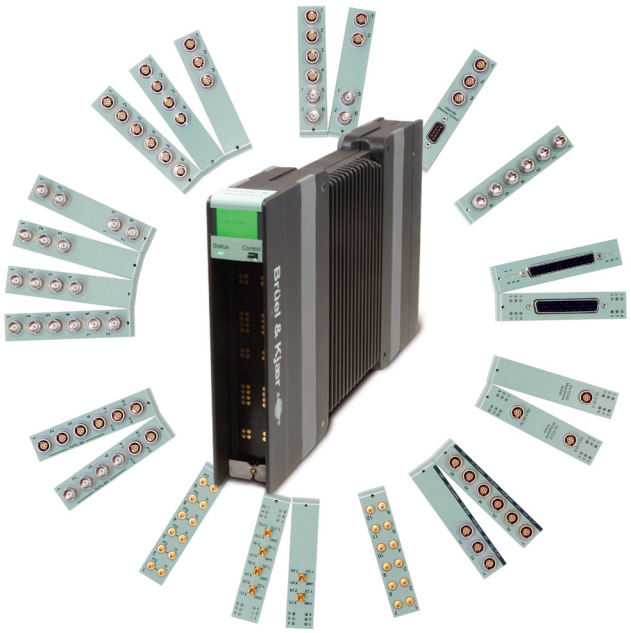
The same LAN cables are used for synchronous sampling between modules using the Precision Time Protocol (PTP). This one-cable operation approach significantly reduces the number of cables needed, lowering costs, minimising downtime, simplifying maintenance, and enhancing installation flexibility.

Other key features include Dyn-X single input range up to 160 dB, frequency range up to 204.8 kHz, and support for IEEE 1451.4-capable TEDS sensors. Additionally, each module can be easily reconfigured with different connectors using interchangeable front panels.

LAN-XI also supports a programmer's interface, the LAN-XI Open API (application protocol interface), which is included with all modules.



From 2 to over 1000 channels using the versatile LAN-XI data acquisition platform.



About 30 interchangeable front panels are available to support different sensors and applications.

MODAL EXCITATION SYSTEMS

Modal excitation systems are typically used for advanced modal testing, where focus is on flexibility and accuracy. By using different excitation signals and techniques, critical measurement parameters such as dynamic range, signal-to-noise ratio, crest factor, linearity, and leakage can be optimised.

The simultaneous deployment of multiple modal exciters (MIMO analysis), enables the extraction of closely-coupled modes and repeated roots, while also distributing forces across the structure to mitigate excitation of non-linearities. This approach is particularly suitable for fixed, large setups.

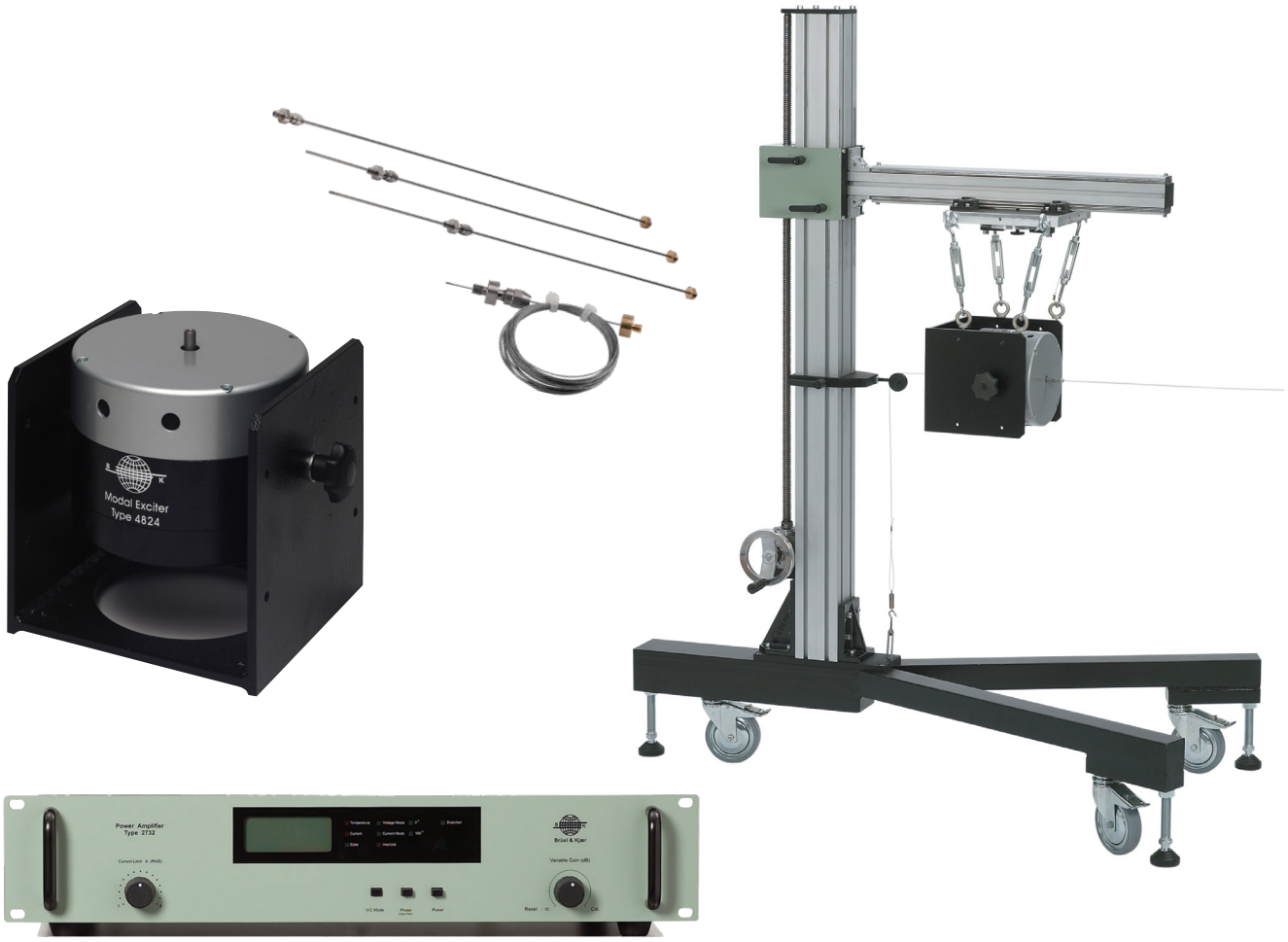
Our modal excitation systems are supplied with matching power amplifiers and accessories, offering an uncompromising balance between modal test performance, user-friendliness, and reliable, long-lasting operation. With force ratings up to 1 kN (225 lbf) sine peak and 2-inch peak-to-peak displacement, they excel in low-frequency excitation. Operating from DC to 5 kHz, they cover a wide frequency range.

The modal exciters feature small physical dimensions relative to the force rating along with low total weight and a low-mass, high-rigidity, spring-suspended armature. The low armature weight helps to ensure high-quality force measurements by minimising force drop-offs at the test specimen's resonance frequencies.

Each exciter features a 'hole-through' design that significantly eases setup and makes it possible to use tension wires or traditional push/pull stingers with ease.

Optional accessories include robust lateral modal exciter stands, traditional push/pull stingers, tension wires, cables, chuck nut assemblies, and an array of adaptors to suit diverse testing needs.

We also offer a range of compact, high-quality permanent magnet vibration exciters with frequency range up to 20 kHz.



Examples of a power amplifier, a modal exciter, a modal exciter stand, push/pull stingers and a tension wire.

IMPACT HAMMERS

Hammer impact testing is well-suited for field work, initial investigations, troubleshooting and measurements in general where focus is on ease-of-use. Extraction of closely-coupled modes and repeated roots are done using multiple reference sensors (roving hammer testing) or excitation in multiple DOFs (fixed hammer testing).

We offer a broad range of high-quality and robust impact hammers from HBK and Dytran to suit even the most demanding tests. They range from ultra miniature hammers with a head mass of 2 g (0.07 oz) to large sledge hammers with head mass up to 5.44 kg (12 lb). They have the ability to excite various structures, from small turbine blades to large structures like vehicles, ships and airframes.

The impact hammers come with interchangeable impact tips of varying hardness, allowing for the selection of the optimal combination of pulse width and frequency content for the structure being tested. Other features include ergonomic handles, carrying cases and, depending on model type, built-in TEDS.



Examples of impact hammers and tips.

SENSORS

Recognising that high-quality, time- and cost-efficient testing is critical to meeting programme milestones, HBK addresses today's engineering needs by providing quality sensor solutions. Whether turnkey solutions or dual-use application needs, HBK provides the aerospace, space and defence sectors with sensors that comply with common industry standards such as ISO or MIL-STD.

Sensors are a vital first link in the measurement chain, supplying the raw data essential for accurate analysis. Therefore, it is crucial that they are reliable, accurate and easy-to-use. Our extensive range of vibration sensors for structural dynamics includes accelerometers, force transducers, impedance heads, tachometer probes, vibration calibrators, cables, and accessories.

In combination with Dytran's piezoelectric sensors for vibration, force, and pressure, as well as an advanced sensing line that includes 6DoF sensors, MEMS accelerometers, and digitally enabled smart sensors, HBK stands as a centre of excellence in accelerometers and other piezo-/MEMS-based sensors. With global reach and exceptional technical expertise in both traditional and cutting-edge technologies, we are equipped to meet diverse and evolving engineering challenges.

ACCELEROMETERS

Uniaxial and triaxial piezoelectric charge and piezoelectric CCLD/IEPE accelerometers, and uniaxial piezoresistive accelerometers are available to cover a broad range of requirements. These include TEDS support, high temperature use, hermetic sealing, low susceptibility to electromagnetic radiation, robustness, low impedance output, and frequency measurements down to DC. Our accelerometers range from miniature tear-drop to seismic accelerometers.

Additionally, our accelerometers are designed to have the lowest possible weight to limit mass loading, a broad frequency range, high dynamic range, low noise, wide range of sensitivities, and feature clear marking for orientation and easy 3D mounting possibilities.

The physical mounting of accelerometers on a test structure is critical. Errors at this stage will corrupt the measurement and cannot be corrected later. Our patented Accelerometer Mounting Check (AMC) algorithm, implemented in our BK Connect software, provides an easy, fast and safe way to ensure that accelerometers are correctly mounted throughout the entire test, replacing lengthy visual and manual inspections.



Examples of accelerometers, a tachometer probe, and a force transducer for structural dynamics testing.

HBK COMPANION APP

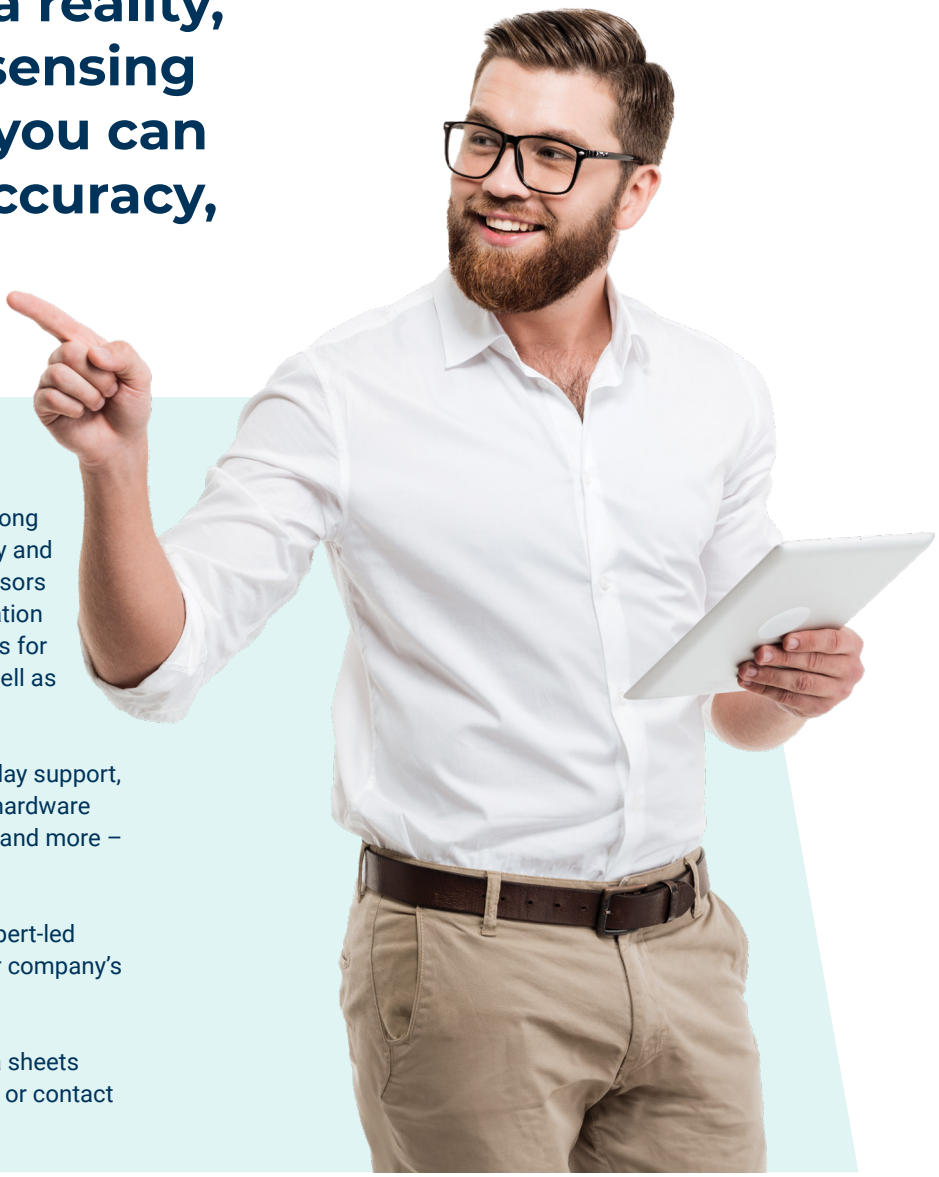
The HBK COMPANION® app enables you to digitalise the test setup by using the camera on an Android device to scan sensors mounted on the test structure. This allows for quick and easy reading of sensor data, position and orientation. If needed, you can also access sensor specifications instantly and document your test setup with pictures. The test setup can be transferred to supported HBK data acquisition software, such as BK Connect, through a simple file export.

This digitalisation process dramatically reduces setup time and minimises potential mounting errors, especially when working with accelerometers mounted with oblique angles.



Accelerometers with a laser-engraved data matrix code are easily scanned.
Accelerometers without a data matrix code and strain gauges are also supported.

Our mission is to help make your vision a reality, with exceptional sensing and insights that you can rely on for ease, accuracy, and efficiency.



SERVICE AND SUPPORT

Our portfolio of structural dynamic solutions, along with HBK nCode and ReliaSoft fatigue, durability and reliability software, HBK DAQ hardware and sensors for static structural testing, as well as LDS vibration test systems, form a complete suite of solutions for both dynamic and static structural testing, as well as advanced vibration testing.

We strive to optimise your business via day-to-day support, access to application engineers, software and hardware maintenance, product calibration, staff training and more – serving as your one-stop-shop for all needs.

Furthermore, through the HBK academy, our expert-led training, courses, and webinars, help boost your company's capabilities with valuable knowledge.

For more detailed information, our product data sheets are readily available online www.hbkworld.com, or contact your local sales representative.

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