# CASE STUDY

## Brüel & Kjær Sound and Vibration Measurement A/S
## "A Lifetime of Quality"
## Transducers – Design, Testing and Quality Assurance

Denmark

Transducers

*As many of you will know, in the world of physics an accelerometer is a device that converts mechanical vibrations into an electrical signal that allows for further signal processing and analysis. Transducers are used extensively in R&D and testing applications – for instance, to develop quieter, safer cars, to ensure that an aircraft and its engines are totally reliable and environmentally friendly, and that household appliances have low levels of noise and vibration. The list of applications where transducers are used is almost endless!*

*At Brüel & Kjær, transducers are a core part of our business. They always have been, for more than 60 years – almost a lifetime! The quality of our transducers is world renowned. It is the result of our unique experience and knowledge, backed up by meticulous testing and quality control. In this case study, our aim is to give you an insight into the processes and procedures that we use to ensure that Brüel & Kjær transducers provide our customers with a lifetime of quality.*

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### Experience, Knowledge and Innovation

Our experience and knowledge, acquired over more than 60 years, are inseparable – they go arm-in-arm. At Brüel & Kjær, we don't just design and manufacture transducers. We are in the business of innovation and always have been. Many of our employees are world-renowned experts, frequently speaking at conferences, presenting papers at seminars, and advising on new Standards. However, our expertise doesn't only come from within; it also comes from working closely together with our customers and suppliers.

Brüel & Kjær's range of transducers is very wide and includes measurement microphones, hydrophones and accelerometers for a huge range of applications. But technology has no limits – if we and our customers can imagine it, then we can develop it. And this is where our story begins.

Brüel & Kjær has a huge database of transducer design data. Through verification of the FEM with the tested parameters of transducers, the 'quality' of mathematical models constantly increases, and less prototypes are needed.

Bin Liu is a Transducer Development Engineer. Bin has a B.Sc. in Underwater Acoustics, and Master's Degree in Electronic Engineering and a Ph.D. The subject of her dissertation was 'Transducers for Sound and Vibration – Finite Element Method Based Design'

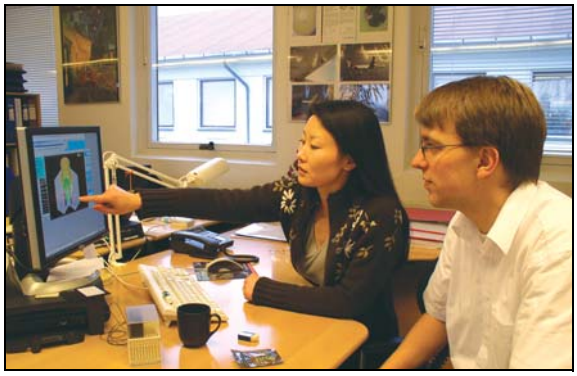


***Fig. 1***
*Bin Liu, Development Engineer, and Jens Ole Gullov, Project Manager, discuss a FEM model*

Bin says, "Based on input from our customers, their requirements, and our own product development plans, we decide upon the parameters of a new transdcuer. Brüel & Kjær probably has the industry's broadest range of transducers, and it's still growing. So, we normally make modifications to an existing type and change dimensions, materials, etc. As an example, our new Miniature Triaxial DeltaTron® Accelerometer Type 4524 is an improvement to the popular OrthoShear®. This makes it more rugged, reliable and ensures even more consistent production quality and adherence to specification".

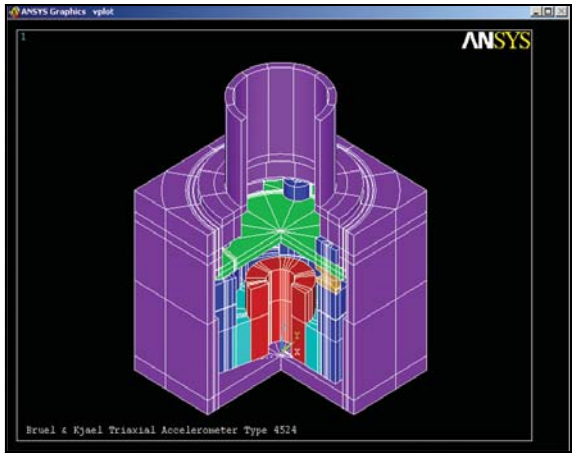



***Fig. 2***
*Finite Element Model of Miniature Triaxial DeltaTron® Accelerometer Type 4524*

Bin continues, "First, we make a finite element model (FEM). This takes between one and three days, depending on its complexity. Using ANSYS software, we can animate the 3D geometry picture of the model. We then make adjustments to the design until it conforms to the requirements, and we define a final predictive specification".

## Customisation

Sometimes a measurement situation requires a solution that cannot be met by existing Brüel & Kjær transducers. To effectively satisfy our customers' needs, we have a procedure for efficiently handling requests for special and customised products.

Minor modifications can be handled rapidly, and at low cost, whereas major or new items which require substantial engineering have to be technically and economically evaluated. Normally, such major projects require a substantial number of units to be ordered to make them feasible, otherwise all non-recurrent engineering would have to be paid as a separate item.

After evaluation, an offer is made, and a contract stating specifications, tests, price and delivery is drafted to ensure that both parties agree.

### *Examples of Customised Accelerometers*

Brief details of typical customised accelerometers are:

- To optimise the dynamic range of the DeltaTron® (IEPE) range of accelerometers, a bias voltage of 12 V has been chosen. This requires a minimum power supply voltage of 18 V. In some cases this is not available, and therefore, on special request, we can offer versions of these accelerometers with bias voltages down to approximately 8 V
- The DeltaTron® range can also be supplied with first-order (6 dB/octave or 20 dB/decade) high-pass and low-pass filters at specified frequencies, and their sensitivity can be varied to within approximately 50% of the nominal value. Other changes, for example, to studs and mounting holes are also available

For further details of the range, availability and price of non-standard transducers, please contact your local Brüel & Kjær representative.

## Prototype Testing and Verification

Jens Ole Gullov is a Project Manager and is responsible for Brüel & Kjær's transducer R&D department. Jens has a M.Sc. in Electrical Engineering – Semiconductor Physics, and has worked at Brüel & Kjær for 10 years.

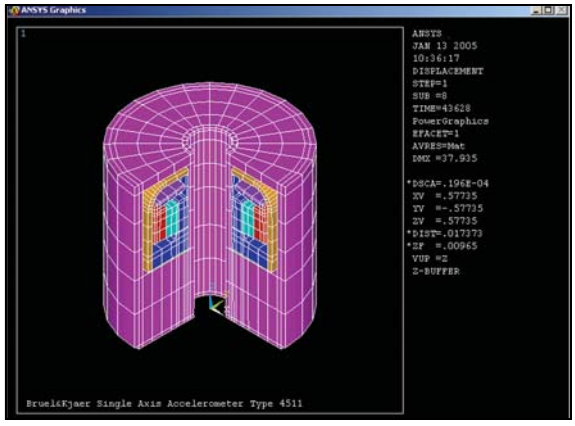



***Fig. 3***
*Finite Element Model of DeltaTron® Accelerometer Type 4511. Some of the predictive parameters are shown*

Jens explains, "Following verification of the mathematical model, the next step in the development of a new transducer is to construct several prototypes. Based on the FEM model, we make between 10 and 20. These are hand made in our production department under the supervision of R&D".

The parameters of each prototype are thoroughly tested and verified against the FEM model and the requirement specification. In addition, further tests are made including:

- Environmental testing – heat, humidity, etc.
- EMC (electromagnetic compatibility)
- Base bending
- Destructive testing – to check the parameters at which it fails to function correctly

### Measurement Accuracy

Jens continues, "There are many external inputs that can create measurement errors in an accelerometer and thus affect its output and the accuracy of the measurement. Therefore, it is extremely important to know how sensitive each type of accelerometer is to these external parameters".

The sensitivity to unwanted external sources can only be accurately determined using advanced testing techniques and at Brüel & Kjær we have developed our own testing equipment using the latest advanced technology.

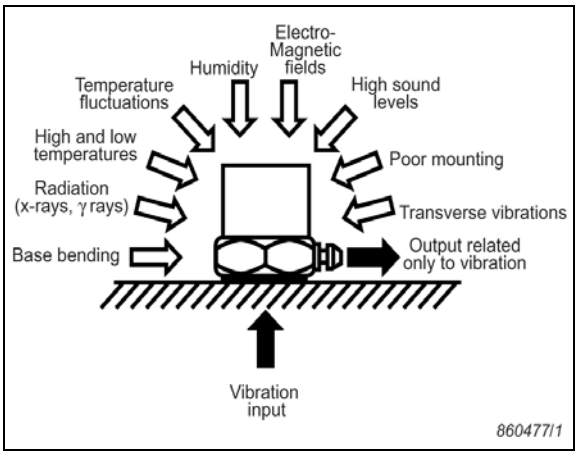
Once known, the effects of these extraneous inputs enable the correct type of accelerometer to be selected for specific testing applications.

For instance, you can select a transducer with low sensitivity in the areas which are of greatest importance.

***Fig. 4***
*Many extraneous inputs can result in non-vibration outputs in a poorly designed vibration transducer*

Alternatively, the measurement results can be corrected to allow for these external factors, but either way, it is crucial to be fully aware of the influence of external influences.

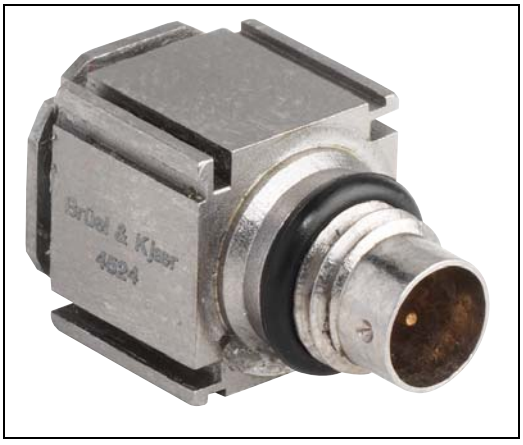
Jens says, “It is much better to find any errors at this stage, rather than later. However, our FEM modelling is now so accurate that, in some case, physical prototypes are not necessary, and of course this saves development time and reduces development costs”.




## Pilot Production

The valuable manufacturing experience gained during manufacture of the prototypes is used in the design of the production tooling. Typical pilot production quantities are from 20 to 50 units.

***Fig. 5***
*The final result*
*Left: Miniature Triaxial DeltaTron® Accelerometer Type 4524*
*Right: DeltaTron® Accelerometer Type 4511*



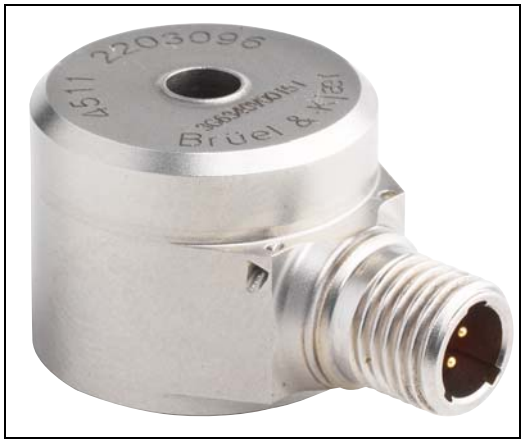




***Fig. 6***
*Training, intense concentration and manual dexterity are required to assemble a precision Brüel & Kjær accelerometer*

Jens says, “The pilot production batch is made without R&D or engineering supervision. This ensures that production takes place in the normal manufacturing routine. At this stage, the accelerometers are tested to their basic calibration parameters. If we experience problems, we investigate the cause, re-engineer, and make a new pilot production quantity”.

Jens admits, “Of course this can result in a delay in bringing a new type to market but quality is always our most important focus”

### Verification of Pilot Production

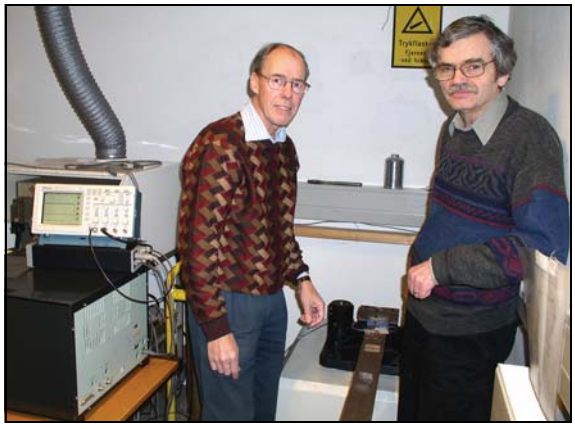


*Fig. 7*
*Knud Styhr Hansen and Lars Munch Kofoed make a base bending (base strain) measurement on a Type 4517 accelerometer*

For a new type of accelerometer to be released for production, it must pass two levels:

- The production department can manufacture the accelerometer without incurring problems
- The pilot production accelerometers fully comply with the complete product specifications

In addition, the pilot production batch is placed in quarantine and subjected to a further series of tests including EMC, climatic testing, base bending, shock, etc.

*Fig. 8*
*Jesper Asgaard, Development Engineer, and Jens Sylvest, Quality Assurance Engineer, set up an EMC test on a seismic accelerometer. A typical EMC test is made from 27 mHz to 1 gHz. The GTEM (gigahertz transverse-electromagnetic) test cell provides high degrees of accuracy and reproducibility*

The results of these tests are placed in a verification report. This is frequently used when advising customers and helping them to determine the correct transducer for a specific testing requirement.

Jens concludes, “We try to prove that what we do is not good enough. But if the pilot production quantity is verified according to our exacting standards, then it’s released for normal production”.

## Production – Test, Test and Test Again!

Klaus Seest Jørgensen is Brüel & Kjær’s Quality Assurance Manager. He has a Master’s degree in Electronics from The Technical University of Denmark, and joined Brüel & Kjær in 1993. Klaus’ initial tasks were to develop and implement a common quality assurance system, and to obtain ISO 9001 accreditation for Brüel & Kjær on a global basis

Klaus says, “Many companies can make transducers but it is our attention to testing and quality control at all stages of the production process that makes the difference. In this ever more technical world, our customers demand transducers that enable them to make precise, and totally accurate measurements. All Brüel & Kjær transducers are thoroughly tested, often in the harshest environmental conditions, and extremely high standards are met in all levels of production quality. This is reflected in our status as an ISO 9001 certified company.

Before the production of a transducer starts, all component parts, whether from sub-suppliers or manufactured within Brüel & Kjær, are subjected to rigorous inspection. This takes the form of physical and dimensional inspection, and conformity to specifications. Using ultrasound, the component parts are cleaned in a demineralised water and soap solution. They are dried using compressed air and placed in an oven to remove any traces of humidity. A special process is used to clean electronic components.

### How Often Do We Do It?

Depending on the type, each transducer is subjected to between five and ten test functions during its manufacture. Here are some examples

***Fig. 9***
*Left: Tiny wires are attached to the centre post or clamp ring using resistance spot welding techniques Right: Close-up view of resistance welding. Visual magnification and a steady hand are essential as securely attaching the wires is vital*

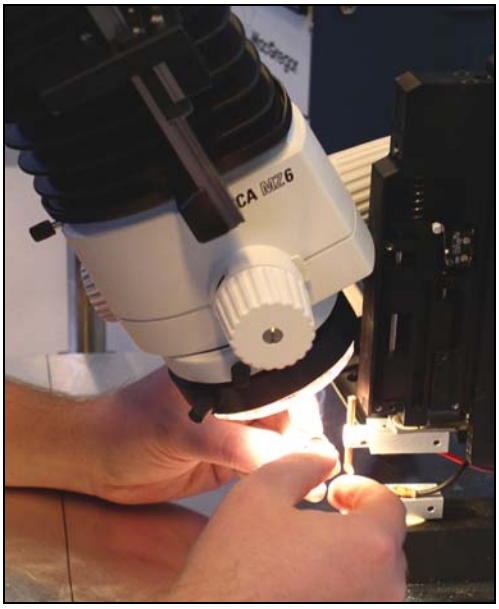
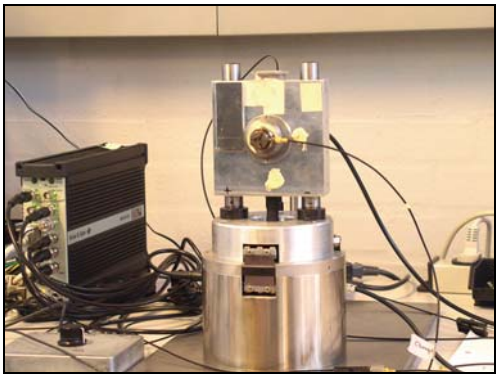
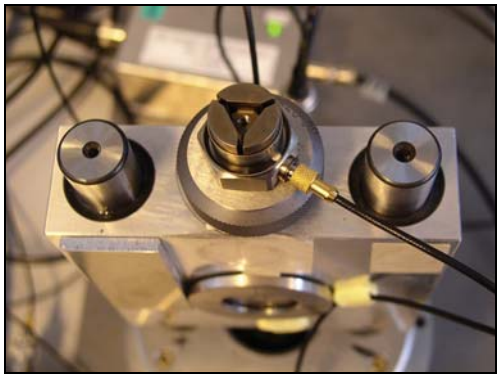



***Fig. 10*** *:*
*Left: Ole John Meier, Support Engineer, uses a 5-channel PULSE data acquisition system and Vibration Exciter Type 4809 to 100% test each accelerometer for transverse sensitivity, sensitivity adjustment and frequency response. The sensitivity can be fine-tuned during the manufacturing process Right: Epoxy compounds are widely used in the manufacture of accelerometers. Here, an operator removes excess material after the epoxy has been applied*


***Fig. 11***
*Left: A second PULSE Type 3560 B system is used to check transverse sensitivity Right: Close-up view of an accelerometer being tested for transverse sensitivity on a second axis*





*Sensitivity and Frequency Response*

The sensitivity of each accelerometer is tested during the manufacturing process. With some accelerometer types, the sensitivity can be adjusted during production. For instance, the sensitivity of charge accelerometers can be varied by adding or removing masses. The sensitivity

of DeltaTron® types can be adjusted by changing capacitance. Again, a 5-channel PULSE Type 3560 B data acquisition system is used, connected to Vibration Exciter Type 4809. The vibration exciter is driven by the PULSE system's built-in generator

### *Transverse Sensitivity*

During the manufacturing process, 100% testing is carried out to check the transverse sensitivity. A compact and rugged 5-channel PULSE Type 3560 B data acquisition system is connected to a shaker which is excited with a 10 Hz sine-wave from the generator in PULSE

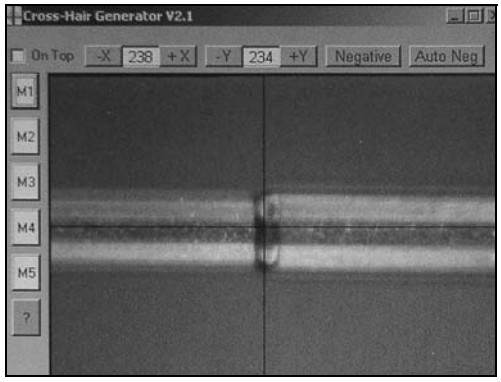



***Fig. 12***
*Left: Metallic components within the accelerometer are manually assembled and then joined using automated laser welding technology Right: A closed -circuit television camera projects an image of the welding process onto the operators PC display*

The same test setup is used to 100% test the frequency response and sensitivity parameters of every accelerometer when the manufacturing process is completed, but before final calibration.

### *Clinically Clean*

Before an accelerometer is finally sealed, the level of cleanliness is checked in a specially developed test setup. Up to 24 accelerometers are screwed into the lid of a container using their connector threads. By exposure to heat and high humidity, a check on the bias voltage will show the presence of any contamination.

### *Structural Integrity*

After closure of the accelerometer housing a special test has been developed to check the integrity of the laser welding process. The test uses water heated to about 90°C. This test is on a sample basis. Normally about 10% of each production quantity is tested in this way.

## Quality

During 2004, the delivered quality of Brüel & Kjær accelerometers was 99.6% or, put another way, in only four instances out of every 1000 deliveries, was something not as it should have been. For instance, there might be an error in functionality or an incorrect number entered on the calibration sheet.

Although this very high quality level is only achieved by our meticulous attention to testing during the development and manufacturing process, we constantly strive for improvement.

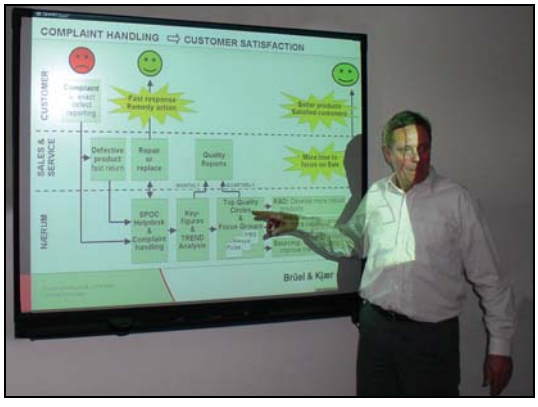



***Fig. 13***
*Klaus Seest Jørgensen, Quality Assurance Manager, explains at a TQC (top quality circle) meeting how feedback statistics are analysed to help us deliver high quality products and services*

## Final Calibration

After the production process is completed, the key parameters of every accelerometer are tested to check that its performance is within the specified parameters. The first tests are carried out in the production area. This is followed by further testing in the calibration laboratory.

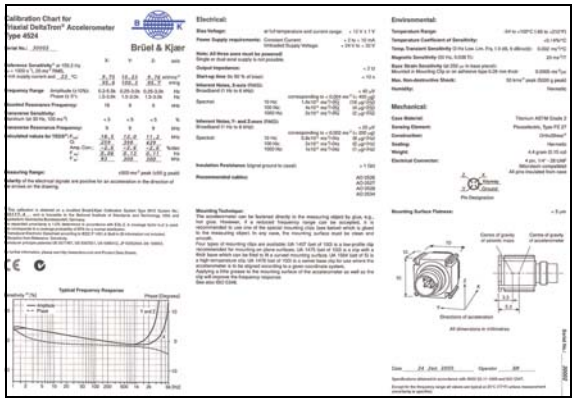


*Fig. 14*
*Typical Calibration Chart of Miniature Triaxial DeltaTron® Accelerometer Type 4524*

Jørgen Moth Monrad is Service Manager and has worked for Brüel & Kjær for 27 years. He is responsible for Service Centre Nærum, including the calibration laboratory.

Jørgen says, "We use a new Vibration Transducer Calibration System Type 3629 for final calibration. An individual calibration chart is issued and, at this stage, if the accelerometer is a TEDS type, the TEDS information is programmed into the built-in chip".


*Fig. 15*
*PULSE-based Vibration Transducer Calibration System Type 3629. Two of these systems are used to 100% test every transducer during final inspection. A third system is used in Service Centre Nærum for special calibration procedure*

If specified at the time of purchase, a new accelerometer can be supplied with Accredited Initial Calibration (CAI).

## Legislation

It is not only our customers' demands that must be satisfied – legislation also sets exacting standards. This often means documented results that are traceable to known sources, such as a national calibration laboratory. Brüel & Kjær's transducer calibration service provides:

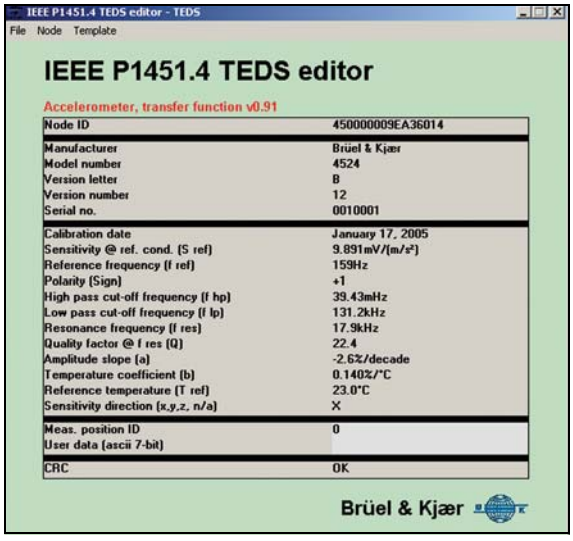



*Fig. 16*
*IEEE P1451.4 TEDS editor display for Miniature Triaxial DeltaTron® Accelerometer Type 4524*

- Calibration of vibration transducers to international standards
- Calibration to meet ISO 9000 requirements
- Calibration according to ISO 5347
- Calibrations are traceable to National Institute of Standards and Technology (NIST), USA and Physikalisch-Technische Bundesanstalt (PTB)
- Certificate of calibration specifying all test and instrument details
- All calibration test procedures fully comply with European Norm EN 45001

## Primary Accredited Calibration

Brüel & Kjær operates The Danish Primary Laboratory of Acoustics (DPLA). It offers primary accredited calibration of vibration transducers which serve as Reference Standards and Working Standards for measurement laboratories and other users within the field of vibration.

Absolute calibrations which are made at DPLA are compared with standards from leading primary laboratories all over the world. This is to ensure present harmony, and to improve future consistency in calibrations made by different laboratories.

## After-sales Service and Customer Support

***Fig. 17***
*Jørgen Moth Monrad is Brüel & Kjær's Service Manager and is responsible for Service Centre Nærum. Here, Jørgen and a colleague inspect a transducer in the calibration laboratory*

Jørgen continues, "With out transducers, we normally provide a service period of five years after production ends – such is their reliability, quality and robustness".

Many customers return transducers to us on a regular basis for calibration. Using Vibration Transducer Calibration System Type 3629, either Accredited Calibration (CAF) or Traceable Calibration (CTF) can be specified. The calibration turnaround time is normally seven working days.

Calibration Exciter Type 4294 is widely used by our customers to ensure that vibration measurement data is completely accurate. It is a small, handy, completely self-contained vibration reference source and is intended for fast calibration and accelerometer checking. This instrument requires annual calibration.

## Key Facts

- An accelerometer is a device that converts mechanical vibrations to an electrical signal that allows for further signal processing and analysis
- Transducers are a core part of Brüel & Kjær's business – they always have been, for more than 60 years
- Brüel & Kjær is accredited to ISO 9001
- The quality of Brüel & Kjær's transducers is world renowned – it is the result of our unique experience and knowledge, backed up by meticulous testing and quality control
- The parameters of prototypes are thoroughly tested and verified against the FEM model and the requirement specification
- Brüel & Kjær continually invests in state-of-the-art transducer production and test equipment
- Each transducer is subjected to between five and ten test functions during its manufacture
- After the production process is completed, the key parameters of every accelerometer are 100% tested to check that it's performance is within specification
- "Many companies can make transducers but it is our attention to testing and quality control at all stages of the production process that makes the difference"

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