

# CASE STUDY

Germany

## Continental AG Modal Analysis of Tyres

Automotive

PULSE, Transducers, Laser Vibrometer

*Continental is Europe's second largest tyre manufacturer, and the world's fourth largest. It is also among the ten largest automotive suppliers worldwide. Tyre manufacture is a core part of Continental's business. But, in addition to tyres, Continental has a broad product range and a large number of other automotive components, including brakes, suspension units, electronic control systems, engine mountings, interior trim, hoses, mouldings, seals and other rubber-based components. Continental's markets include manufacturers of cars, trucks, motorcycles, scooters, bicycles, railway rolling stock, agricultural machinery, and industrial products ranging from aviation, protective clothing and footwear to the furniture industry.*

*NVH Engineering at Hannover in northern Germany carries out NVH evaluation on tyres and Continental's other products. Extensive test facilities are available including nine PULSE™ multi-analyzers. Continental has recently commissioned a new Brüel & Kjær system for the modal analysis of tyres using an Ometron VH300+ Laser Doppler Vibrometer Type 8329.*



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## NVH Engineering

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Led by Dr. Ernst-Ulrich Saemann, the Evaluation Group within Continental's NVH Engineering at Hannover has a highly experienced team. NVH testing and analysis is made for the whole Continental group. The state-of-the-art range of facilities is impressive and includes semi-anechoic rooms, dynamometers, sound quality suite, vibration and modal analysis test cells, STSF, Material Testing and Pass-by systems, etc.

Continental make these NVH test facilities, and its testing expertise, available to external companies, including its customers and suppliers, on a consultancy basis.

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## Modal Analysis

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The purpose of making modal analysis on a tyre is to find its natural resonant frequencies. These can be identified below about 400Hz. Vibration from the tyres is transferred by the vehicle's structure into the passenger cabin and to the steering. Knowing the resonant frequency of the tyre makes it possible to minimise the transfer path of the vibration, and to ensure that the vibration does not 'excite' other components with the same resonance. Continental offers this to vehicle manufacturers.

**Fig. 1**  
*Dr. Oliver Schürmann works in Continental's NVH Engineering at Hannover. He designed, installed and commissioned the new modal analysis test facility*



Dr. Oliver Schürmann is a member of Continental's highly experienced team in NVH Engineering at Hannover. He has worked at Continental for eight years and has experience within R&D, truck tyre and car tyre business units. Dr. Schürmann has a Diploma in fluid mechanics and vibration from The University of Göttingen. The dissertation for his Ph.D, also gained at The University of Göttingen, was entitled "Compressible vortex street – airfoil – interaction". Prior to joining Continental, Dr. Schürmann conducted research into helicopter noise at the Max Planck Institute.

Dr. Schürmann explains, "In addition to finding a tyre's natural resonant frequency, the test data acquired during modal analysis is also used to validate finite element models. This verification is obviously very important as it gives us confidence that our finite element models are as accurate as possible and enables us to improve them".

He continues, "Prior to commissioning the new laser-based test facility, we carried out modal analysis using a Brüel & Kjær 2-channel analyzer, either a Type 2032 or Type 3550".

The tyre is either suspended using rubber shock-cord to isolate it as much as possible, and excited by an impact hammer, or alternatively, a Brüel & Kjær Shaker Type 4809 is used to excite the tyre in a rigid test fixture. The tyre can also be loaded to simulate deflection.

**Fig. 2**  
*One method of performing modal analysis on tyres. The tyre, mounted on a rim, is suspended on rubber shock cord. The tyre is excited by an impact hammer and the response is measured by an accelerometer*



The standard test requires about 40 measurements to be made at equal points around the circumference of the tyre, at a single point on the vertical axis. The ideal position for mounting the response accelerometer is on the tyre's centre line but this may not always be possible due to the tyre's tread pattern.

This simple measurement took at least half a day as the accelerometer had to be positioned as accurately as possible, by hand, before a measurement could be made.

For basic studies in technology projects, measurements have to be taken at hundreds of points on a tyre – a process requiring many hours of setup and measurement time.

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## New Laser-based Modal Analysis System

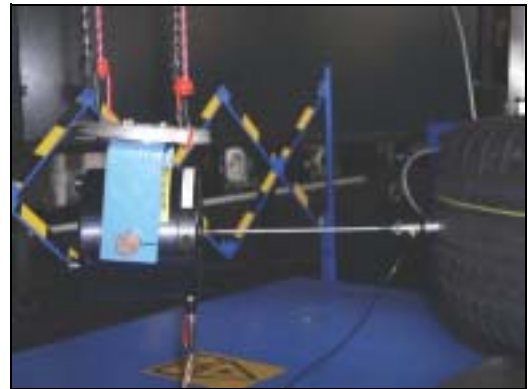
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Dr. Schürmann says, “We started work on the specifications for a new modal analysis system a couple of years ago. We work closely with the vehicle OEMs during the development of new models and there is constantly increasing focus on the NVH characteristics of tyres. This involves a considerable amount of testing during the R&D process. We want to avoid natural resonant frequencies that may interact with other vehicle components. Of course, safety, handling and performance in all driving conditions – is the paramount factor, as is durability, so these factors must be carefully considered when a tyre is designed or modified. Our goal is total performance”.

Continental AG placed an order with Brüel & Kjær for an Ometron VH300 + Laser Doppler Vibrometer Type 8329. The order also included a special laser-positioning robot and customised control software. The fully automated system is used for performing radial vibration scanning of a tyre's tread surface, for both experimental design evaluation and routine laboratory measurements. The new modal analysis system was commissioned in the Spring of 2003.

**Fig. 3**

*Left: The table of the modal analysis test setup is mounted on air springs to isolate it from the floor  
Right: Shaker Type 4809 excites the tyre. The input force is measured via Impedance Head Type 8001*



### Advantages

There were a number of goals for the new test system. These included:

- Quicker development or modification of tyres
- Fewer prototypes
- Saving time and money
- Automatic, unattended testing following initial setup
- Greater accuracy
- Higher quality test data
- Better resolution at higher modes

**Fig. 4**

*Left: The tyre can be loaded via a steel pad and hydraulic cylinder to simulate deflection  
Right: The tyre's vibration is measured by Ometron VH300 + Laser Doppler Vibrometer Type 8329*



### Hardware

Continental designed and manufactured the test table and fixtures. The tyre, mounted on a very heavy solid steel rim, is fixed to the table using a very strong and rigid fixture.

This ensures that the modal parameters of the tyre itself are measured. If required, the natural frequency of a tyre fixed to a specific rim can be measured.

The table is mounted on air springs (manufactured by ContiTech) to isolate it from floor-born vibration. The table was made in Continental's own workshops. If required, the tyre can be loaded by means of a hydraulic cylinder to simulate deflection, and the force applied can be measured. To maximise the excitation, the shaker can be positioned directly opposite to the point on the tyre where the load is applied.

The tyre is excited by a Brüel&Kjær Shaker Type 4809. This is driven, via a power amplifier, with white noise from the PULSE generator module. It is also possible to drive the shaker with a swept sine-wave but this takes longer for each measurement to be made, whereas each measurement using white noise only takes a few seconds. The input force exerted by the shaker is measured by Impedance Head Type 8001 connected to a NEXUS™ Conditioning Amplifier. The input force does not have to be very great – smaller and larger shakers are available if required.

**Fig. 5**

*Left: The test system operating position showing the PULSE system and PC*

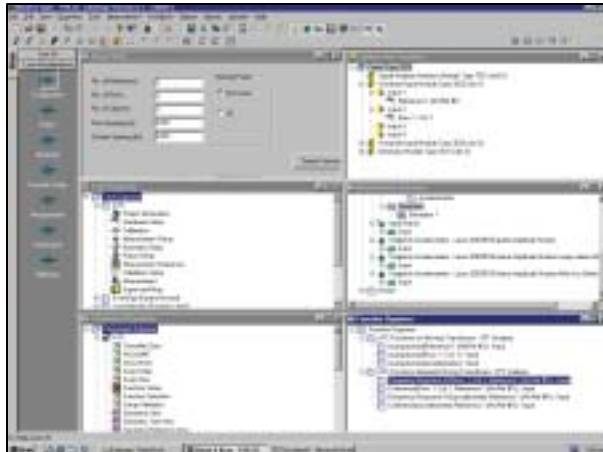
*Right: WB 1477 Motion Controller Unit controls the position of the laser. The other unit is the power amplifier that drives the shaker*



The vibration (normal velocity component) of the tyre is measured by Ometron VH300 + Laser Doppler Vibrometer Type 8329. The laser is positioned by a robot, driven by WB 1477 Motion Controller Unit, that controls its horizontal and vertical axes.

**Fig. 6**

*PULSE display showing setup Array Setup, Task, Component, Configuration Measurement and Function Organisers*



The heart of the system is a PULSE multi-analyzer used for data acquisition. Although the particular model has 8 channels only two are normally used – one to measure the input force and one to measure the response from the laser. The free channels may be used for future MIMO analysis.

### Software

In addition to FFT & CPB Analysis Type 7700, Acoustic Test Consultant Type 7761 and ME'ScopeVES™ Type 7754 are also installed on PULSE.

Acoustic Test Consultant Type 7761 software is normally used as a part of an STSF system. In this case, the software was specially modified by Brüel & Kjær to control the motors of the positioning robot, via the WB 1477 Motion Controller Unit.

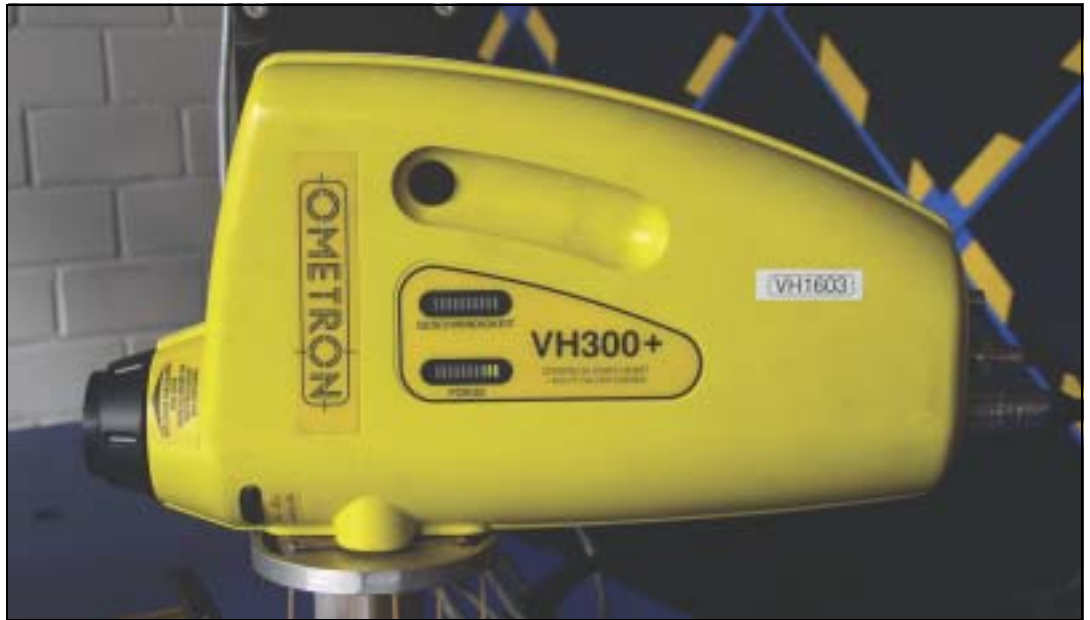
ME'ScopeVES™ Type 7754 is used for post-processing, which includes reduction of the data by extraction of the modal parameters.

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## Laser Doppler Vibrometer — Type 8329

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**Fig. 7**  
Ometron VH300+  
Laser Doppler  
Vibrometer Type  
8329



Ometron VH300 + Laser Doppler Vibrometer Type 8329 is a highly accurate and versatile non-contact vibration transducer for applications where it is impossible or undesirable to mount a vibration transducer onto a vibrating object, and where an accelerometer can be replaced. Ease of use and rugged construction make Type 8329 highly suitable in both laboratory and industrial environments.

Type 8329 specifications have been carefully targeted at R&D applications. The high velocity capability (in excess of 400 mm/s) makes it an extremely versatile laser-based vibration transducer, covering the vast majority of laser vibrometer applications.

Capable of measuring vibration in any direction, Type 8329 features a velocity range up to 425 mm/s, a frequency range from <0.1 Hz to 25 kHz and a dynamic range of 73.5 dB over full bandwidth. Measurements are possible from as close as 0.4 m (16 in) and up to 25 m (82 ft), usually without the need for any surface treatment or retro-reflective tape. For measurements at distances greater than 25 m, retro-reflective tape can be used.

### Optics

Type 8329 is based on a Michelson interferometer in which a laser beam is divided into a reference beam and a signal beam. The signal beam is directed onto a vibrating test structure, and the back-reflected light is recombined with the internal reference beam.

When the test structure moves, the frequency of the signal beam is shifted, resulting in intensity modulation of the recombined beam due to interference between the reference and signal beams. One complete cycle of the intensity modulation corresponds to a surface movement of  $\lambda/2 = 0.316 \mu\text{m}$ , half the wavelength of the helium neon laser source (where  $\lambda$  is the wavelength of the source,  $0.633 \mu\text{m}$ ).

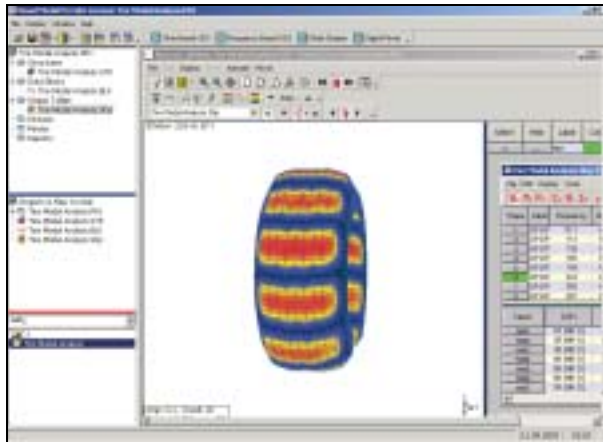
The frequency of this modulation (referred to as the Doppler frequency,  $F_d$ ) is given by  $F_d = 2V/\lambda$ , where  $V$  is the surface velocity. The recombined light is split into two paths, and a quarter-wave plate used so that the two signals are in quadrature (sine and cosine) allowing the direction of motion to be determined. This allows both the speed and direction of motion to be determined. A balanced detection scheme, with two detectors in each channel, is used for low noise and high sensitivity.

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## Data Analysis

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**Fig. 8**  
ME'scopeVES™  
showing 3D view at  
224 Hz. Compared  
to modal analysis  
using an  
accelerometer, the  
resolution is  
particularly good  
at higher mode  
shapes



The test data is initially stored in the PULSE project. It is then exported as a UFF file (universal file format) to ME'ScopeVES™ Type 7754. Dr. Schürmann carries out the post-processing of the data in his office. A precise model is then established and provides the natural frequencies, damping ratios and corresponding mode shapes. The test results are then exported from ME'ScopeVES™ Type 7754 to Microsoft® Office and a printed report is created in either Word or Excel.

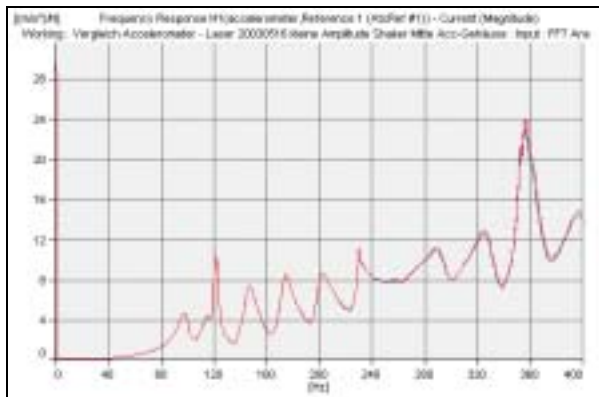
The raw test data, ME'ScopeVES™ animations and tables, and the final test reports are saved on Continental's network and are thus available to engineers throughout Continental's global organisation.

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## Results and Benefits

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**Fig. 9**  
Graph showing  
comparison of FRF  
(frequency  
response function)  
between modal  
analysis made with  
an accelerometer  
(red curve) and  
with Ometron  
VH300+ Laser  
Doppler  
Vibrometer Type  
8329 (blue curve)



Dr. Schürmann says, “During the commissioning phase, we compared the data acquired using an accelerometer to that recorded using the laser system. The results were almost identical and we are extremely pleased with the new system's overall performance and accuracy”.

The advantages of the laser-based system include:

- The system automatically takes measurements at 99 points on each track around the circumference of the tyre compared to 40 points using the original accelerometer-based measurement technique. This gives improved spatial resolution. The intention is to increase the number of measurement points still further
- With the original system, the accelerometer had to be positioned manually and some inaccuracies inevitably occurred. The laser-based system measures on the surface of the tyre to an accuracy that is ten times better – less than one millimetre
- At just one measurement position, the system takes 100 FFT averages
- Once setup, the laser system runs completely automatically and there is no longer a need for constant supervision by a skilled operator or the need to move the accelerometer during the test and start the measurement sequence

Dr. Schürmann adds, “The new system gives us excellent, highly accurate data with much higher spatial resolution. The mode shape is improved and is far smoother especially at higher modes”.

He continues, “For development applications, the new system enables us to take up to 1000 measurement points on two axes. We have developed several test templates for different types of tyres.

“I think that the use of a laser in this type of application is rather unique. The system is always in use. It is designed to measure the parameters of all types of tyres – from motorcycle tyres to truck tyres. Of course, most tests are made on car tyres as this is by far our largest market, and it is also the product where vibration is especially important. So now we have test systems that range from a small, flexible system using PULSE and an impact hammer, up to our advanced laser-based system”.

Dr. Schürmann concludes, “We use a wide range of NVH analysis techniques using a variety of software applications. I am very familiar with PULSE and its capabilities, and it is a great advantage to have just one analyzer platform for all our NVH work”.

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## Key Facts

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- Continental is Europe's second largest tyre manufacturer, and the world's fourth largest
- Tyre manufacture is a core part of Continental's business
- Continental's NVH Engineering at Hannover carries out NVH testing and analysis for the whole Continental group
- Continental make these NVH test facilities, and its testing expertise, available to external companies on a consultancy basis
- Continental placed an order with Brüel & Kjær for an Ometron VH300 + Laser Doppler Vibrometer Type 8329. The order also included a special laser-positioning robot and customised control software
- The fully automated system is used for performing radial vibration scanning of a tyre's tread surface, for both experimental design evaluation and routine laboratory measurements
- “We compared the data acquired using an accelerometer to that recorded using the laser system. The results were almost identical and we are extremely pleased with the new system's overall performance and accuracy”
- “The news system gives us excellent, highly accurate data with much higher spatial resolution”
- “I am very familiar with PULSE and its capabilities, and it is a great advantage to have just one analyzer platform for all our NVH work”