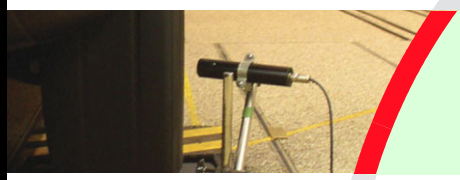

CASE STUDY

Pirelli Reifenwerke

Germany

Automotive

Acoustic and Vibration Analysis of Tyres

PULSE™, Transducers, Software

Over one hundred years experience of tyre technology has enabled Pirelli to combine maximum levels of security, durability and comfort in its products. With today's enhanced technology, and an enthusiasm for driving, Pirelli engineers have been able to make vast steps forward. Each Pirelli tyre provides not only performance but also a 'feel for the road' and communication with the driver, allowing a better understanding of the vehicle's performance.

Pirelli Reifenwerke uses a PULSE data acquisition and analysis system to record and analyse tyre noise and vibration from controlled coast-down tests made in a semi-anechoic test cell. The test data is extensively used in the development of new, quieter tyres.

Pictures by kind permission of Pirelli

A World Market Leader

Within the automotive industry, the name Pirelli is synonymous with the manufacture of high-performance, safe, durable, high-quality tyres for cars, trucks and motorcycles. Its a world market leader and supplies tyres as OEM equipment to such companies as Mercedes, BMW, Volkswagen, Audi and Porsche. The Pirelli Reifenwerke factory at Höchst, 70 km south-east of Frankfurt, Germany has about 3000 employees and manufactures more than 20000 tyres every day, seven days per week – some eight million tyres each year.

Fig. 1
Aerial view of the Pirelli Reifenwerke factory at Höchst, 70 km south-east of Frankfurt. This facility manufactures more than 20 000 tyres each day

Pirelli's headquarters and main research centre is in Milan, Italy. Car tyres are produced at Höchst and at other sites, including Turin, Italy. Truck tyres are mainly manufactured in Turkey. Some years ago, Pirelli acquired Metzeler – renowned for the manufacture of motorcycle tyres.

About 30% of Pirelli's tyres are sold directly to automotive manufacturers. This high percentage is very important to Pirelli. The balance of 70% is distributed as replacements through tyre distributors throughout the world.

In Search of Quieter Tyres

Fig. 2
Bernd Sattler is an acoustics expert. He has worked at Pirelli for more than 20 years and heads the company's NVH test department

Bernd Sattler heads Pirelli's noise and vibration test and development department at Höchst. He has a degree in mechanical engineering and has worked with acoustics at Pirelli for more than 20 years. He is also integrated in the development of the test system and testing methodology used at Pirelli's Milan research facility. Mr. Sattler is a member of the ISO 10844 Standard working group (ISO/TC 43/SC 1/WG 42 TT – development of a vehicle test more representative of urban driving).

Mr. Sattler says, "Tyre noise is an ever-increasingly important issue. Our aim is to produce quieter tyres, but without sacrificing durability or safety. For instance, wet tyres are generally more noisy than dry tyres so we aim to achieve the best possible roadholding while reducing noise to a level that does not compromise safety – and safety is always our first concern. We test both car and motorcycle tyres. The testing of motorcycle tyres is greatly increasing".

He continues, "The noise and vibration test data is mainly used in the development of new, quieter tyre designs but we also benchmark test the tyres of our competitors".

State-of-the-art Test Facility

Fig. 3
The semi-anechoic room has a cut-off frequency of 170 Hz. The floor has reflecting characteristics similar to road surfaces

In the late 1980s, Mr. Sattler was closely involved with the design and construction of the test laboratory building, the semi-anechoic room, test instrumentation and methodology – it was the subject of his degree thesis.

Mr. Sattler explains, "Today, we use an 8-channel PULSE data acquisition and analysis system to record data from controlled coast-down tests made in our 10×7 metre semi-anechoic room. The room has a cut-off frequency of 170 Hz and the floor has reflecting characteristics similar to road surfaces".

Fig. 4
The acoustic test cell control room. The test is monitored using closed-circuit television

"By means of heating built into the floor and good thermal insulation, a temperature of 23°C is maintained within the semi-anechoic room. We aim for a temperature of 20°C on the 'safety walk' surface of the dynamometer drum. Our research shows that the noise varies by 0.3 dB for each 10°C above 20°C, and by 0.6 dB for each 10°C below 20°C. Therefore, before each test, we allow the tyre to warm up by running it at 80 kilometres per hour for ten minutes."

The electrically driven drum of the dynamometer has a diameter of two metres and is 40 cm wide. The motor is located remotely and sound insulated to ensure that it has no effect on the accuracy of the test data.

Testing

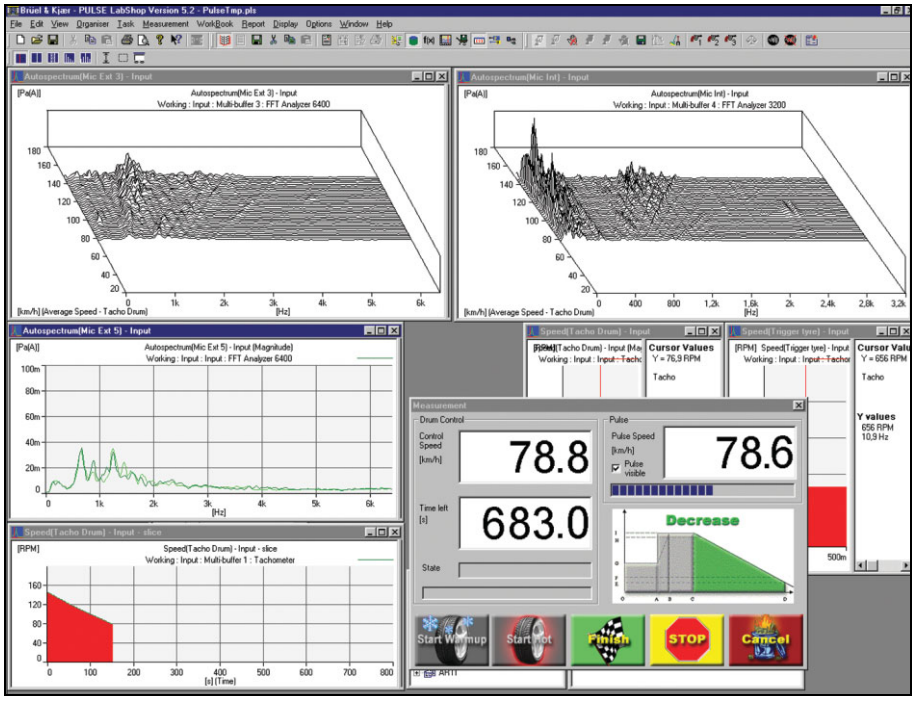

Fig. 5
Typical display during a measurement on a tyre. The waterfall plots are scaled in Pascal instead of dB – this makes them easier to read.
Top left to bottom right:
– waterfall plot from external microphone
– waterfall plot from internal microphone
– external frequency spectra
– speed vs. time
– control window (drum speed (km/h) and tyre speed (rpm)

In the acoustic test cell, the noise and vibration from a tyre is recorded in relation to speed. Coast-down tests are made over an accurately controlled speed range from 180 to 20 km/hour over a twelve minute period. A-weighted overall level, FFT spectra and order analyses are made on each channel.

Fig. 6
During a test, one microphone is placed inside the vehicle, two microphones outside the vehicle in the far-field

During a test, one microphone is placed inside the vehicle, two microphones outside the vehicle in the far-field (Brüel & Kjær Type 4190). A Tri-axial Accelerometer Type 4321 is mounted on the vehicle, as close as possible to the tyre being tested. Two 4-channel NEXUS™ Conditioning Amplifiers Type 2692 provide the interface between the transducers and PULSE.

The following parameters can be measured in a single measurement:

- Overall level vs. speed
- Overall level calculated from a specific frequency range vs. speed
- Order vs. speed
- FFT vs. speed

The analyses made are:

- FFT analysis as a waterfall diagram
- Order analysis as a waterfall diagram
- FFT analysis as a contour plot
- Order analysis as a contour plot

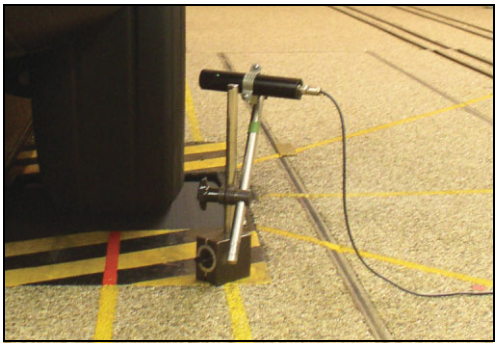

Fig. 7
Photoelectric Probe MM 0024 provides the rpm of the tyre when order analysis is carried out

Two tachometer signals are provided by Photoelectric Probes MM 0024. One probe provides the rpm of the tyre when order analysis is carried out. The other photoelectric probe gives the speed in km/hour of the dynamometer road surface drum.

In Germany, the internal microphone is placed on the driver's seat so that the tyre noise is measured at this location. In Italy, the microphone is placed centrally within the vehicle and the measured noise is representative of the whole passenger cabin.

Testing is always carried out on the non-driven axle (for example, the front axle of a BMW, the rear axle of an Audi). To test the tyre on the other axle, the propshaft/differential are disconnected.

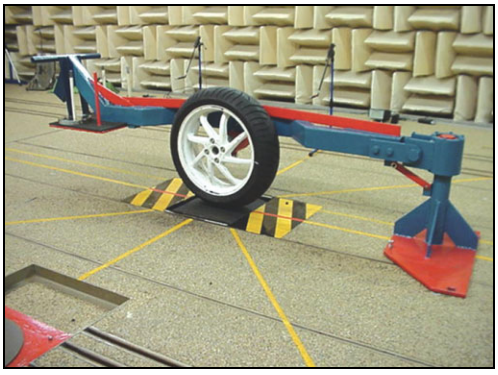

Fig. 8
About 50% of NVH testing is made on motorcycle tyres. A specially designed fixture is used

With external tyre noise, the main frequencies of interest are around 1 kHz. For tyre noise measured in the vehicle, lower frequencies are more relevant.

Mr. Sattler continues, "During a typical test, overall levels, FFT spectra and order analysis will be carried out for each channel in relation to tyre speed. We measure the SPL every one kilometre per hour and therefore take 160 measurements. We make FFT and order analysis measurements every two kilometres per hour and therefore have 80 values. On the external and internal microphones, we measure over a frequency range from 0 – 6.4 kHz."

Three different FFT frequency ranges are set up with the internal microphone:

- 0 – 800 Hz
- 0 – 3.2 kHz
- 0 – 6.4 kHz

Typical tests on one car, including setup time, normally take about a day. A standard test involves between five and eight sets of tyres. One set of tyres is from a competitor and one is an existing Pirelli type which is used as the base specification for a new tyre design.

PULSE

Fig. 9
Pirelli uses an 8-channel PULSE data acquisition and analysis system to record data from controlled coast-down tests. Tests are monitored using closed-circuit television

Mr. Sattler says, "We have used Brüel & Kjær analyzers, sound level meters, transducers and calibrators for nearly twenty years. They have a reputation as the world market leader in the field of sound and vibration measurement".

He continues, "PULSE is known to be an easy-to-use and accurate measurement platform. It was an advantage to be able to see PULSE in use, and to obtain everything from one source. This ensures that all the component parts fit together and function correctly. These are the reasons that we chose to buy PULSE".

Akustec – ARTI Software

Five years ago, Bernd Sattler, in cooperation with his colleagues at Pirelli in Milan, worked with Brüel & Kjær and the German company Akustec, to develop a customised user interface for use with their PULSE data acquisition platforms.

Mr. Sattler explains, "The PULSE software automatically runs in the background and is controlled by Akustec's ARTI (Anechoic Room Tyre test International) software. This also controls the drum speed, makes the measurements, displays the results, and stores and retrieves the data to and from an Oracle database. After the system is started, all parameters of the test are controlled completely automatically. A new test template can easily be defined inside the ARTI program."

Fig. 10
The customised ARTI software controls the complete test. It was developed by Akustec, based near Munster, Germany

The overall specification for the complete noise measurement system includes:

- Calibration of acoustic channels
- Management of setup parameters and data headers
- Configuration of channels and analysis
- Configuration of start and update trigger conditions
- Output set speed points to the test stand to perform the assumed speed profile
- Visualisation of data during the coast-down travel
- Data transfer from PULSE
- Storage and management of data in the database
- Management of the use of time data recording tracks of the PULSE system
- Display of the test data in graphical form for viewing, editing and comparison of measurements
- Report generation using a selectable range of data
- Export of data as ASCII files

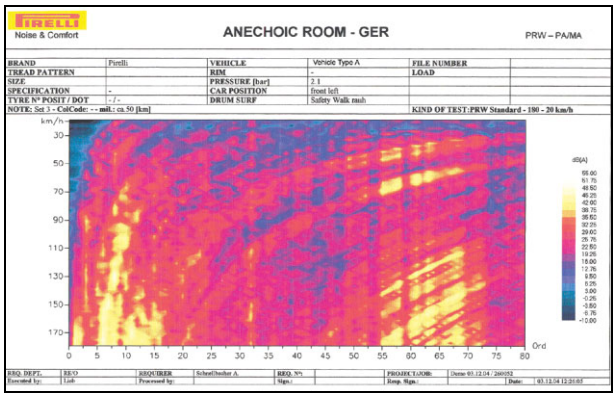

Fig. 11
One page from a typical report made using Microsoft® Word. This example is a contour plot showing orders vs. speed

Mr. Sattler adds, "It is very important for us to be able to instantly compare the noise from different tyre designs. The facilities in the Akustec ARTI software have recently been updated and now enable us to easily and quickly store, retrieve and compare test data.

"We can take saved test data from up to five different tyre designs and superimpose these on each other in a display. We can select a wide range of test parameters, for example, speed and SPL in dB(A) – the selected graph is indicated by a thicker line and the cursor reading shows the values. General parameters that apply to all tested tyres are shown at the top of the display while variable information is shown below. It is very easy to use and a super tool."

"The complete noise and vibration data acquisition system is reliable, stable and easy to use. And we get excellent back-up and technical support from both Brüel & Kjær and Akustec. I am very happy with it."

Subjective Testing

Pirelli has a small, highly experienced team that carries out subjective testing on the local roads around Höchst. This gives Mr. Sattler and his colleagues a good overview and helps to achieve a good correlation between road noise under real conditions, and the noise measured in the test laboratory.

Pass-by Testing

For pass-by testing, Pirelli uses an ISO standard approved track at a small airfield about 20 km from Höchst. The test surface is paved with ISO asphalt and it is 600 metres long and 15 metres wide.

A Brüel & Kjær Pass-by Noise Measurement System Type 3558 with a 2-channel Order Tracking Analyzer Type 2145 is installed in a van that has been converted for use as a mobile noise laboratory. Radar Unit ZZ 0231 provides the speed signals.

The tests are made using two special, acoustically insulated, 'silent' cars (a Toyota and a BMW) The noise data is acquired during a coast-down in the speed range from 90 – 40 kilometres/hour. The speed is more or less constant in the test area. Regression analysis techniques are used to calculate the noise values.

The ISO test track is also used in the certification of pass-by noise with new vehicles. The ISO standard in Europe specifies a maximum noise level of 74 dB(A) and this figure is determined by using the maximum value of the noise data measured at full acceleration in second and third gear after approaching the test area with a constant speed of 50 kilometres per hour.

Data Management and Reporting

Pirelli's main research centre in Milan has an identical PULSE system that is used for the acquisition of test data. This also uses the ARTI customised software developed by Akustec.

Mr. Sattler explains, "We have a permanently leased communications line that links us with our colleagues in Milan. As the data acquisition systems are the same, we can easily and

quickly exchange data with each other. We also send copies of our final reports to Milan. The test systems runs under Windows® NT®.

Fig. 12
Example of a test report showing the plots of SPL vs. speed for one internal and two external microphones

The test data results are exported as ASCII files. Printed reports are instantly and automatically generated using Microsoft® Word as soon as the test is completed.

There is also a facility to archive and retrieve the data using a tape streamer, if required. The reports are sent to the research and development departments in Milan and Höchst.

In addition, the ARTI software and test data are immediately available on the PCs used by the research and development departments.

Mr. Sattler adds, "It is fully 'interactive' and, using stored data to compare tyre designs, enables us to accurately predict the noise of a new tyre design before it is actually produced. This greatly shortens the development time of a new design and considerably reduces development costs as far fewer prototypes are needed".

The Future

Mr. Sattler concludes, "We are currently considering investing in a new PULSE system. We want a portable data acquisition system for troubleshooting and general noise investigations at our OEM customer's facilities. This will use a number of microphones inside the cabin and allow us to compare noise levels of different tyre types with data previously saved from tests in our test cell".

Key Facts

- The Pirelli name is synonymous with high-performance, safe, durable, quality tyres
- Pirelli supplies tyres as original equipment (OEM) to major automotive manufacturers
- Pirelli's Reifenwerke factory manufactures some eight million tyres each year
- Tyre/road noise is an ever increasingly important issue
- Pirelli's aim is to produce quieter tyres without sacrificing durability or safety
- Pirelli has used Brüel & Kjær products for more than twenty years
- An 8-channel PULSE data acquisition and analysis systems to record and analyse tyre noise and vibration
- "Brüel & Kjær has a reputation as the world market leader in sound and vibration"
- Akustec developed the special ARTI user interface – tests are controlled automatically
- "The total noise acquisition system is reliable, stable and easy-to-use, and we get good back up and technical support from both Brüel & Kjær and Akustec"
- "It is fully 'interactive' and enables us to predict the noise of a new tyre design before it is actually produced. This greatly shortens the development time of a new design and and considerably reduces development costs as far fewer prototypes are needed"

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