CASE STUDY

United States of America

Automotive

PULSE

Purdue University
Unique Technology for the Study of Tire/Road Noise

Purdue University has developed a unique test apparatus to further the understanding of noise generation created by tire/road interaction. The data is used in the research and development of practical road surfaces, road construction techniques, and tire designs.

A 14-channel PULSE™ Multi-analyzer, with full wireless data transmission capability, was selected to perform the noise and vibration test and analysis function for the new equipment.

Graduate Research Facility

Established in the 1950s, the Ray W. Herrick Laboratories is an acoustics and noise control graduate research facility affiliated with the School of Mechanical Engineering at Purdue University, West Lafayette, Indiana, USA. The acoustics laboratory covers some 17 600 square feet (1635 m^2) and comprises workshop and engineering facilities, and reverberation, anechoic, hemi-anechoic and audiometric rooms. A wide range of state-of-the-art sound and vibration analysis equipment is available including transducers, real-time analyzers, a scanning laser vibrometer, high speed digital video, and PC-based data acquisition and control systems.

Faculty

Fig. 1
Professor Robert J. Bernhard is Director of the Ray. W. Herrick Laboratories, and Professor of Mechanical Engineering at Purdue University

Professor Bernhard earned his Bachelor's Degree in Mechanical Engineering from Iowa State University in 1973. From 1973 until 1977 he worked for Westinghouse where he specialised in modal analysis and finite element modelling techniques. He earned a Master's Degree at the University of Maryland in 1976, and his Doctorate (finite element acoustics) was awarded by Iowa State University in 1982.

In that year, Professor Bernhard joined Purdue University as an assistant professor, becoming professor in 1991 and Director of the Herrick Laboratories in 1994.

Professor Bernhard says, "Professors are attracted to the Herrick Laboratories according to the needs dictated by their research programs. Professors are usually associated with the School of Mechanical Engineering, since most of the research is based on mechanical engineering disciplines. All professors participate in the teaching programs of their respective departments, providing interaction which enhances the teaching and research objectives of Purdue University". He continues, "Both research and education are equally important. Our test facilities are used primarily for research. Much of this research is contract, proprietary research for companies. We offer our test facilities to external companies on a limited basis for consultancy. Much of my own work involves research, including "hands-on" testing, using the latest technology."

The selection of students for Ph.D and Master's degree research programs is based on merit. About 50% of students are from the U.S. and 50% from a variety of other countries.

Automotive Technology

Purdue University has been at the cutting edge of automotive, tire and road surface research for more than 25 years. It is one of a small number of research centers around the world that work within this area and it's the major facility within the U.S.

Professor Bernhard explains, "Working together with some of the world's major tire manufacturers, our research was originally focused on tire durability. About ten years ago we started a number of programs researching interior vehicle noise. All automotive manufacturers want their cars to be as quiet as possible. It's a key sales factor as low noise equates to high quality. In 1998 we received funding to start investigating automotive related environmental noise issues, including pass-by noise testing".

Noise and vibration research programs are not limited to passenger cars. The university has also worked with aircraft, home appliances, motorcycle and heavy truck manufacturers. Significant effort is applied to acoustical materials, sound quality, and aero-acoustics research for automotive and other applications. Purdue University receives funding for its work from a number of sources, including those companies that commission specific research programs. This is not limited to tire companies but includes many of the world's major automotive manufacturers. As an example, one prominent U.S.-based vehicle manufacturer was the instigator of research to ensure that noise data from its tire suppliers was uniform and comparable.

Test Facilities

Fig. 2
Professor Bernhard explains the principles of tire noise and vibration measurement techniques

Specialised test facilities for tire/road noise investigations are available including a 67 inch (1.7 m) two-wheel chassis dynamometer for automotive noise and vibration studies at simulated speeds of up to 70 mph (113 kilometres/hour). A quiet wind tunnel enables aeroacoustic measurements to be made at up 120 mph (54 m/s). The laboratories have three electro-hydraulic shakers and two large electro-magnetic shakers for automotive vibration testing.

Tests on tires are also made in a hemi-anechoic room using a PULSE system and five microphones.

Practical Example

A single point laser doppler vibrometer using a fibre-optic probe is placed six inches (152 mm) away from the tire surface. The tire is excited with a small shaker. Vibration data and near-field sound radiation from the tire's circumference are recorded. Measurements are made at frequencies from 200 Hz to 2 kHz. Initially, the tire revolves freely and is not in contact with a sample of road surface. In the second setup, the tire is in contact with a roller and the tire vibration data are collected on a moving tire. Analysis of the data shows that, above 500 Hz, the waves created at the contact patch do not propagate completely around the tyre to set up normal modes.

Fig. 3
Material testing (TL measurement) using a Brüel & Kjær Type 7758 PULSE Material Testing System

Professor Bernhard explains, "In addition to testing that relates to tire and road noise, we use a very wide range of equipment to carry out other noise and vibration research programs. For example, material testing is carried out using PULSE and Brüel & Kjær's impedance tube measurement system. One of my colleagues, Professor J. Stuart Bolton, is extensively engaged in acoustical materials research and in research using three-dimensional acoustical holography and beamforming technology, and these techniques will be increasingly used in the future for source identification".

Institute for Safe, Quiet, and Durable Highways

Under the direction of Professors Bernhard (Mechanical Engineering) and Vincent P. Drnevich (Civil Engineering), the Institute for Safe, Quiet, and Durable Highways (SQDH) was established at Purdue University in 1998. The Institute is funded by the U.S. Department of Transportation, the Indiana Department of Transportation, many of the world's major tire manufacturers, and by organisations representing companies that manufacture road surface materials. The research goals of the SQDH Institute are:

- to develop an understanding of the fundamental noise generation mechanisms created by tire/road noise interaction
- to develop practical road surface materials, tire designs, and road construction techniques that reduce tire and road noise while maintaining durability and safety

Professor Bernhard says, "Our research programs are interdisciplinary and there is extensive cooperation between the mechanical and civil engineering departments of the university".

Tire Pavement Test Apparatus

Fig. 4
The tire is in contact with a smooth Portland Cement Concrete (PCC) surface. Screw jacks enable the loading of the tire on the surface to be adjusted at up to 1000 pounds (454 kg)

To further the SQDH Institute's research capabilities, the new Tire Pavement Test Apparatus (TPTA) has been developed. Professor Bernhard says, "There are a few test facilities available globally where the road surface can be placed on the inside or outside of a ring that rotates while the tire is stationary. But the pavement surface is not in a normal state of stress and therefore it is not possible to perform tests where the pavement is under real conditions". Professor Bernhard continues, "We have overcome this with our new TPTA system. Here, the ring remains stationary and the tire itself rotates over the pavement surface. The surface has to be as flat as possible and therefore the ring must have a large diameter".

This concept is unique – and the dimensions of the TPTA are impressive! The ring has a diameter of 12 feet (3.66 m) and the total surface is made up of six sections that can be up to 16 inches (406 mm) thick. Testing can be carried out with different surfaces installed on the six sections. This enables different types of surface to be constructed, installed and tested quickly and easily. The rotating structure (painted yellow, as shown in the figures) is driven by a 60 hp DC motor and gearbox at safe speeds of up to 30 mph (48 kilometres/hour). The data can be extrapolated to give accurate predictions at higher speeds.

The acoustic room where TPTA is installed is a 40 × 25 × 20 feet (12 × 7.6 × 6.1 m) hemi-anechoic chamber and has a cut-off frequency of 100 Hz. The frequencies of interest are between 200 Hz and 2 kHz. The loading of the tire on the road surface can be adjusted at up to 1000 pounds (4.54 kN) by means of screw jacks on the two arms. Professor Bernhard says, "Even at maximum speed, the background noise is very low, in fact lower than the wind noise of a microphone with a wind screen. Therefore, the signal-to-noise ratio is excellent. In the future we will add a wheel suspension system to TPTA. We think this is important and influences the noise radiation at frequencies below about 500 Hz".

The microphones, normally five, are positioned in accordance with the draft ISO Standard for Close Proximity Method (CPX) measurements. The ISO working group has developed two standardised methods to measure the effect of a road surface on the noise emission of traffic:

- The Statistical Pass-by Method (SPB) – ISO 11819-1
- The Close Proximity Method (CPX) – ISO/CD 11819-2

Professor Bernhard says, "We believe our experience with the TPTA will advance CPX measurement techniques".

PULSE

Professor Bernhard says, "We required the data acquisition system itself to rotate but didn't want to use a slip-ring, so transmission of the test data had to be wireless. We also needed to have real-time on-board monitoring capability. We also wanted to be able to do some real-time data reduction in the control room during testing".

"Brüel & Kjær was the only company able to offer us a current solution that fit our needs. There were some companies that offered to develop a specialty product for us or promised a future product. In fact, we have used a wide variety of Brüel & Kjær products for many years and have always had first-class service and support, and so it was an easy decision."

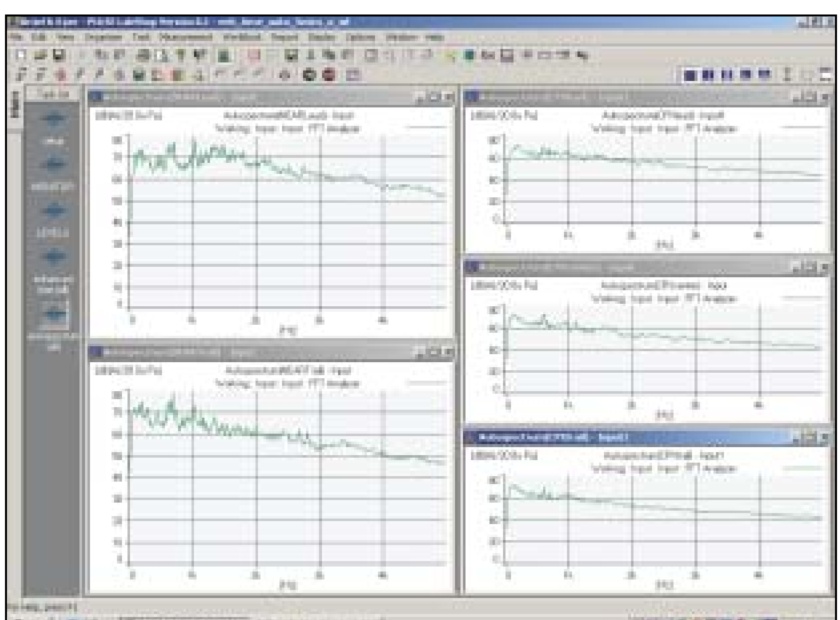

Fig. 5 *Typical PULSE display showing FFT analysis data from the TPTA*

The SQDH Institute selected a PULSE Multi-analyzer with 14 channels and full wireless capability. A typical test uses five or six microphones, and combinations of accelerometers and pressure transducers. DC channels provide data on other test system parameters such as speed. Both CPB and FFT analysis methods are used. A magnet passing over a sensor triggers the PULSE system to start data collection. Purdue typically runs multiple, simultaneous FFT analysis for different pavement test sections.

The Future

Professor Bernhard concludes, "TPTA gives us the opportunity to look in detail at the interface between tires and realistic pavement surfaces. From this I expect to be able to gain a much better fundamental understanding of tire/road noise interaction which will point us towards major breakthroughs in tire and road noise reduction. For example, our initial investigations have shown that a porous concrete road surface is some six to ten decibels quieter than conventional road surfaces at frequencies above 1200 Hz. Instead of the air within the tread of a tire being trapped, compressed and then "exploding", the porous concrete surface enables the air pressure to be relieved. Additionally the porous surface absorbs some of the tire noise, particularly local to the contact patch. Reduced noise and vibration will benefit us all – the driver, passengers, pedestrians and other road users".

Key Facts

- The Ray W. Herrick Laboratories is an acoustics and noise control graduate research facility in the School of Mechanical Engineering at Purdue University
- Purdue University has been at the cutting edge of automotive, tire and road surface research for more than 25 years
- In 1998, investigations began on automotive related environmental noise issues
- "Automotive manufacturers want their cars to be as quiet as possible – low noise equates to high quality"
- Specialised test facilities for tire/road noise investigations are available
- The Institute for Safe, Quiet, and Durable Highways (SQDH) was established at Purdue University in 1998
- The unique new Tire Pavement Test Apparatus (TPTA) has been developed
- SQDH Institute selected a PULSE Multi-analyzer with full wireless capability
- "We have used a wide variety of Brüel & Kjær products for many years and have always had first-class service and support, and so it was an easy decision"

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