# CASE STUDY

**Mazda Motor Corporation**
**Operational Modal Analysis**

Japan

Automotive

PULSE, Software, Transducers

*Mazda Motor Corporation, based in Hiroshima, Japan, commenced automobile production in 1931. Today, the name Mazda is synonymous with the manufacture of high quality cars sold throughout the world and in 2003, its production facilities in Japan and overseas, manufactured more than one million passenger cars and commercial vehicles. Mazda's vision is to create high value – to excite and delight its customers by delivering the best automotive products and services. By continually striving for this goal, Mazda is one of the world's most advanced automotive manufacturing companies.*

*In July 2002, Mazda ordered a Brüel & Kjær 220-channel PULSE™-based NVH data acquisition and analysis system. It is mainly used for modal analysis in Mazda's advanced NVH (noise vibration harshness) laboratory to optimise powertrain noise and vibration. This will also enable Mazda to focus on the measurement and analysis of high frequency noise in its vehicles.*

*Photos by courtesy of Mazda Motor Corporation*

## Mazda Motor Corporation

Based in Hiroshima, Japan, Mazda Motor Corporation manufactures a wide range of passenger cars and commercial vehicles and in 2003, it manufactured more than 800 000 cars and trucks at its Hiroshima and Hofu production sites. More than 550 000 vehicles were exported. Mazda is one of the largest employers in western Japan with some 20 000 employees. Mazda cars and trucks are also assembled in 14 other countries throughout the world, and in 2003, more than 240 000 passenger cars and commercial vehicles were manufactured at these facilities.

Founded in 1920, Mazda began automobile production in 1931. At the end of December 2001, cumulative production in Japan reached approximately 35.3 million units.

Mazda carries the unique distinction as the only automotive company manufacturing three types of engines – conventional gasoline piston, diesel, and rotary (Wankel).

## State-of-the-art Production

Mazda's Hiroshima facility is one of the largest single-site automobile manufacturing plants in the world, with an annual production capacity of around 500000 units. Hofu Plant I, opened in September 1982, can produce over 230000 vehicles a year. Hofu Plant II, a state-of-the-art facility opened in February 1992 and has an annual capacity of 163000 units. All of Mazda's production facilities feature 'model mix' production capability. In June 2000, Mazda's overall operations in Japan received ISO 14001 certification, the international standard on Environmental Management Systems. Mazda's overseas production plants are also ISO 14001 certified.

### Commitments to the Environment and Safety

Mazda is furthering its commitment to R&D in environmental areas in order to achieve greater harmony among cars, society, and nature. Focus areas include zero landfill measures, fuel efficiency improvement, and reduction of emissions.

Mazda strives to reflect the highest level of active and passive safety technologies in its products and has developed its own concept – Advanced Safety Vehicle (ASV) utilising the latest advanced technologies. These include a collision-avoidance system that detects the presence of pedestrians and vehicles approaching the vehicle, preventing possible collisions.

## Long NVH Testing Relationship

***Fig. 1***
*Mazda ordered a large 220-channel PULSE system for modal analysis applications – the goal – to further optimise noise and vibration parameters in vehicle powertrains*

Mazda's relationship with Brüel & Kjær goes back over many years and, during this time, Mazda has continually invested in its R&D NVH analysis facilities. In fact, Mazda has a lot of PULSE 'frames' which together provide many channels of NVH testing and analysis capability. Not only does Mazda have the latest NVH data acquisition systems, but it is now planning further expansion in the coming years.

In July of 2002, Mazda placed an order for an unusual PULSE system – a large 220-channel system for modal analysis applications in Mazda's powertrain division. The goal – to further optimise noise and vibration parameters in vehicle powertrains. Mazda's requirement was to pre- and post-validate the data in the frequency and time domains, and to export the time data for use with the Operational Modal Analysis software.

The PULSE system can measure sound and vibration up to 12.8 kHz on all 220 channels simultaneously. The acquired data is transferred to one of the two work stations in Mazda's powertrain division for operational modal analysis (OMA) where a detailed analysis is made. Though at the time the order was placed, PULSE was limited to 128 channels, Mazda preferred Brüel & Kjær's solution to other potential suppliers. The decisive factors were Mazda's long-term relationship with Brüel & Kjær, its satisfaction with the existing PULSE systems, and Mazda's confidence in the powerful algorithms and features in Brüel & Kjær's Operational Modal Analysis Type 7760 software.

## Powertrain Testing

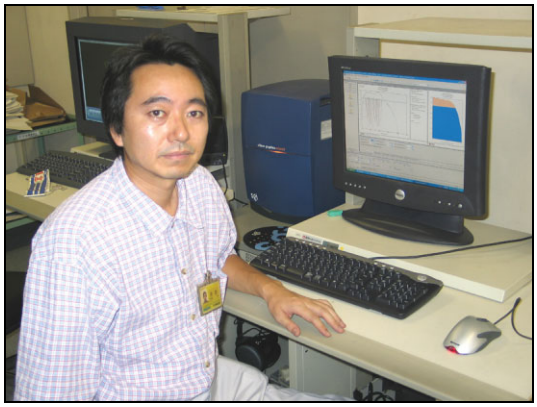

*Fig. 2*
*Mr. Yasunori Kanda is Assistant Manager, AT Testing & Research Group, Drivetrain Development Department*

Mazda Motor Corporation's Powertrain Division includes R&D sections that focus on the development of engines, gearboxes, transmissions and exhaust systems (mufflers). Using Brüel & Kjær PULSE data acquisition systems, each section is highly active in the design, testing and analysis of these units and their components.

Two groups in Mazda's R&D department decided collectively to use OMA. Additionally, a great deal of general NVH testing and evaluation is carried out daily.

Mr. Yasunori Kanda is Assistant Manager, AT Testing & Research Group, Drivetrain Development Department. He says. "In our testing facilities, PULSE is a highly effective test and analysis tool for optimal design and fast product development. For example, several PULSE systems, each of 24 channels, are used daily for NVH bench-testing measurements. In the case of advanced measurement techniques, such as Brüel & Kjær's Non-stationary STSF Software Type 7712 and IBEM (Inverse Boundary Element Method) for advanced noise source location, our 66-channel and 120-channel systems are effective tools for troubleshooting".

In addition, Mazda has several PULSE IDA/IDA$^{e}$ data acquisition systems, each of more than 30 channels, for operating deflection shapes (ODS) and standard experimental modal analysis. These are strongly related to Mazda's CAE software in data communications. They also have Brüel & Kjær's PULSE Sound Quality Software Type 7698. Overall, Mazda has a huge NVH testing capability.

## Results

*Fig. 3*
*The 220-channel PULSE-based OMA system is also used on the chassis dynamometer test bench in order to investigate the vibration characteristics of the powertrain*

To date, using Brüel & Kjær NVH testing solutions, Mazda has achieved good results. By applying test data at the design stage, and by effective troubleshooting, development times have been significantly shortened.

Mr. Kanda continues, "However, high frequency noise will be a problem in the future. Until today, this has been rather neglected while low frequency noise and vibration is well under control".

"Therefore, we made a decision to introduce Operational Modal Analysis based on PULSE. This is a strong and flexible tool for multichannel high- frequency analysis, and enables us to take countermeasures against high-frequency sources. It also provides the Modal Assurance Criteria (MAC) of mode shapes for finite element analysis and operational modal analysis (OMA)."

Mazda's Powertrain Division carries out daily NVH testing. The 220-channel PULSE-based OMA system is also used on the chassis dynamometer test bench in order to investigate the vibration characteristics of the powertrain. A large number of triaxial accelerometers each with TEDS, are mounted around a gearbox and engine assembly.

***Fig. 4***
*A Brüel & Kjær Head and Torso Simulator Type 4128 C (HATS) is placed on the front passenger seat, and measures cabin noise on two channels – additional microphones are located in the cabin*

A Brüel & Kjær Head and Torso Simulator Type 4128 C (HATS) is placed on the front passenger seat, and measures cabin noise on two channels. Several other microphones are located in other cabin and engine compartments. The data from these sensors is simultaneously collected during 90 seconds of run-up testing. All acquired data relates to noise path analysis, operating deflection shapes, sound quality evaluation, and OMA.

This is one of the great benefits of multichannel and multi-analysis measurement – no additional testing is required for a wide range of analysis techniques.

## Operational Modal Analysis Type 7760

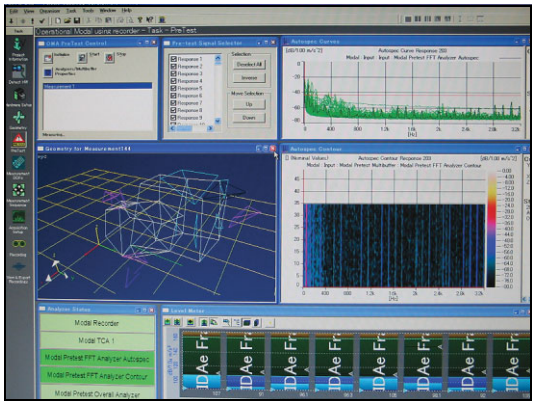

***Fig. 5***
*Operational Modal Analysis Type 7760, together with Modal Test Consultant Type 7753, is a highly effective tool for analysis on structures which are excited by both internal and ambient forces*

Operational Modal Analysis (OMA) enables modal analysis to be made using only the output responses from a structure. This is very different from traditional experimental modal analysis which is based on the frequency response functions between input excitation and output response. This means that the test setup for OMA is relatively simple. It is sufficient to measure response time-data under normal operating conditions, for example during chassis dynamometer testing, or even on the test track!

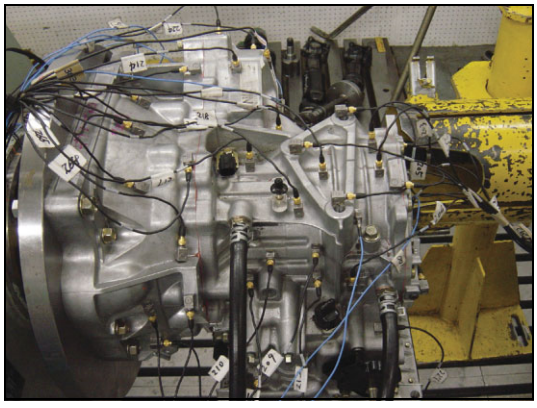

***Fig. 6***
*Mazda's PC-based system enables data from 220-channels up to 12.8 kHz to be acquired simultaneously. The illustration shows 70 Model 66 A12 triaxial accelerometers mounted on a gearbox in one of Mazda's powertrain gear test cells*

OMA was originally developed mainly for civil engineering applications – buildings, bridges, etc., being naturally excited by wind, waves and traffic loads.

As a result of Brüel & Kjær's improvements to the calculation algorithm, and the tremendous increase in the power of PCs, OMA has become a highly effective tool for mechanical applications including automotive, aerospace and operational machinery – structures which are excited by both internal and ambient forces.

From a mechanical engineering perspective, it's a great benefit to identify the modal parameters while the structure is in its operating condition as the obtained modal model represents actual force and vibration levels on true boundary conditions. It also allows a mechanical system to be tested which is difficult to excite artificially and where it is not possible to directly measure the input forces. These benefits are also effective for Mazda's powertrain engineers, resulting in a substantial reduction in testing time while obtaining high-quality data.

## Challenges

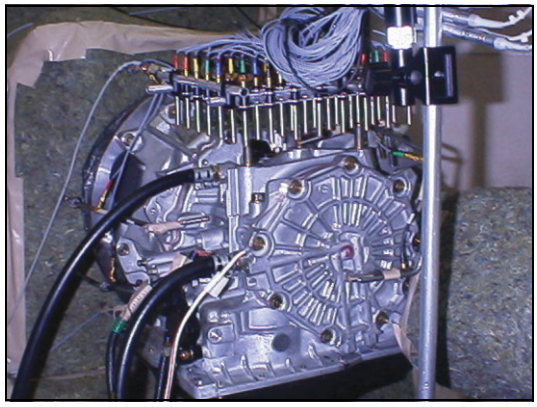

*Fig. 7*
*Mazda's powertrain engineers use Brüel & Kjær Non-stationary STSF Type 7712. The illustration shows a typical test setup to determine sound radiation from a gearbox*

Overcoming the 128-channel limitation was not the only major challenge. Unlike most modal analysis applications, the frequency range was required to be as high as 12.8 kHz, and this required a vast amount of measurement data to be recorded and analysed. And the OMA algorithms in the software had to be significantly improved to handle this huge amount of data in a single data set. These improvements were merged into the standard PULSE software from version 8.0, released in the latter half of 2003.

PULSE provided the right solutions for Mazda. It is based on a fully modular and scalable PC-based system and enables the raw data, evaluation data and analysis data from 220-channels up to 12.8 kHz to be handled in one simultaneous measurement.

### The Right Solution

The 220-channel PULSE test bench solution for Mazda comprises:

- Two very powerful PCs – one PC handles the GUI and the other PC handles the data acquisition
- PULSE software including:
  - PULSE FFT & CPB Analysis Type 7700
  - Data Recorder Type 7701
  - Time File Management Type 7789
  - Modal Test Consultant™ Type 7753
  - Operational Modal Analysis Type 7760
- Eight 3560 D frames – each frame contains front-end modules which together provide 30 channels of data acquisition capability
- 70 × ENDEVCO Model 66 A12 (100 mV/g) Triaxial Accelerometers with TEDS
- Two separate OMA post-processing stations

Post-processing of the OMA data is carried out on high performance PCs in two R&D buildings – each is standard and therefore easy to maintain and upgrade – and they are versatile and portable, enabling them to be used, if required, with other PULSE automotive NVH testing solutions.

## Near Future

Within a year, Mazda's Powertrain Division in Hiroshima will have additional PULSE systems, each of 17-channels, based on the new Type 3038 and Type 7537 front-end modules. This will increase Mazda's capability for simultaneous high frequency measurement using the existing PULSE IDA$^e$ platform for OMA and Non-stationary STSF testing.

Mr. Kanda say, "Using OMA, we find it easy to identify gear noise problems such as the structural resonances of gearboxes and the effect of internal gear resonances, even if there are complicated situations due to the high orders of rotating components, and a lot of resonances of related structures".

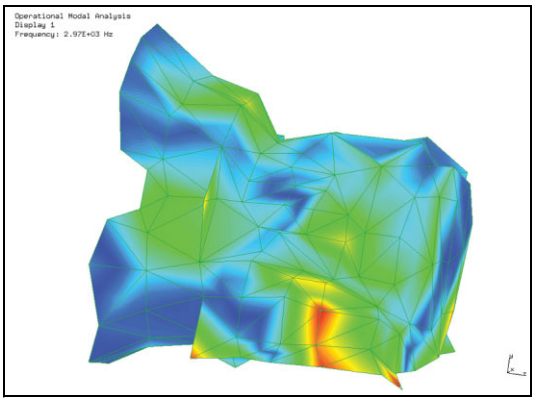


***Fig. 8***
*A typical result from Mazda's PULSE-based 220-channel OMA system. The data acquisition and analysis on a gearbox is output using CAE software and is shared by all relevant departments*

Mazda NVH engineers are very satisfied with the flexibility of the PULSE hardware and software platform. Mazda can use its 220-channel system for data acquisition, post-processing or real-time analysis in Brüel & Kjær other NVH applications, for example, order analysis, ODS, OMA, standard modal analysis, acoustic holography, and source path contribution analysis – all based on one common platform. All NVH data can be smoothly transferred and easily shared by Mazda's CAE tools.

Mr. Kanda concludes, "Brüel & Kjær is highly competitive to other companies providing NVH solutions. We are very pleased with our new OMA system. We have achieved significant testing improvements and we can use it for many different types of tests. We are expecting even stronger cooperation with Brüel & Kjær in the future."

## Key Facts

- Mazda began automobile production in Japan 1931
- Based in Hiroshima, in 2003, Mazda manufactured more than 800 000 cars and trucks
- Mazda is one of the largest employers in western Japan with some 20 000 employees
- Mazda's relationship with Brüel & Kjær goes back over many years and, during this time, Mazda has continually invested in its R&D NVH analysis facilities
- Mazda has several dozen PULSE 'frames' which provide very versatile NVH testing and analysis capabilities
- In July of 2002, Mazda placed an order for a large 220-channel system for modal analysis applications in its advanced NVH laboratory
- The purpose of the OMA system is to further optimise the noise parameters in the powertrain
- The PULSE system can measure sound and vibration up to 12.8 kHz on all 220 channels simultaneously
- The decisive factors in placing the order were Mazda's long-term relationship with Brüel & Kjær, its satisfaction with the existing PULSE systems, and Mazda's confidence in the powerful algorithms and features in Brüel & Kjær's Operational Modal Analysis Type 7760 software
- OMA's great benefits are that it is easy to setup and modal testing can be carried out during typical operating conditions
- By applying test data at the design stage, and by effective troubleshooting, development times have been significantly shortened
- "High frequency noise will be a problem in the future. Therefore, we made a decision to introduce Operational Modal Analysis based on PULSE. This is a strong and flexible tool for multichannel and high-frequency analysis"
- "Using OMA, we find it easy to identify gear noise problems such as the structural resonances of gearboxes and the effect of internal gear resonances, even if there are complicated situations due to the high orders of rotating components, and a lot of resonances of related structures"
- "Brüel & Kjær is highly competitive to other companies providing NVH solutions. We are very pleased with our new OMA system, we have achieved significant testing improvements, and we can use it for many different types of tests. We are expecting even stronger cooperation with Brüel & Kjær in the future"

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**HEADQUARTERS: DK-2850 Nærum · Denmark · Telephone: +45 4580 0500 · Fax: +45 4580 1405 · www.bksv.com · info@bksv.com**
Australia (+61) 2 9889-8888 · Austria (+43) 1 865 74 00 · Brazil (+55) 11 5188-8166 · Canada (+1) 514 695-8225
China (+86) 10 680 29906 · Czech Republic (+420) 2 6702 1100 · Finland (+358) 9-755 950 · France (+33) 1 69 90 71 00
Germany (+49) 421 17 87 0 · Hong Kong (+852) 2548 7486 · Hungary (+36) 1 215 83 05 · Ireland (+353) 1 807 4083
Italy (+39) 0257 68061 · Japan (+81) 3 5715 1612 · Republic of Korea (+82) 2 3473 0605 · Netherlands (+31) 318 55 9290
Norway (+47) 66 77 11 55 · Poland (+48) 22 816 75 56 · Portugal (+351) 21 47 11 4 53 · Singapore (+65) 377 4512
Slovak Republic (+421) 25 443 0701 · Spain (+34) 91 659 0820 · Sweden (+46) 8 449 8600 · Switzerland (+41) 1 880 7035
Taiwan (+886) 2 2502 7255 · United Kingdom (+44) 14 38 739 000 · USA (+1) 800 332 2040
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