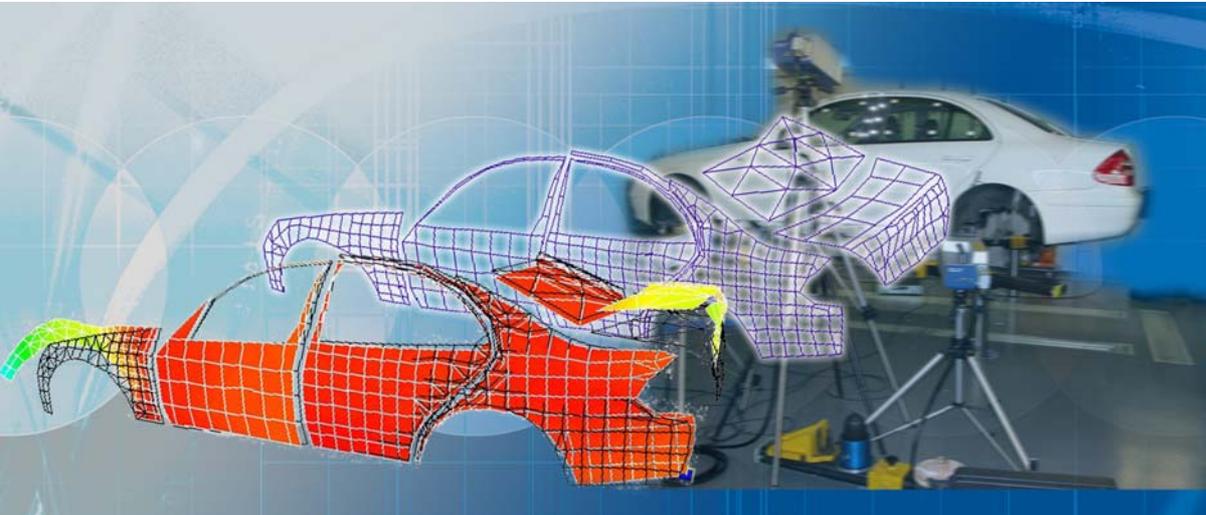


# Application Note *VIB-C-01*



## FIELD OF APPLICATION

- A Aerospace
- B Audio & Acoustics
- C Automotive**
- D Data Storage
- G General Vibrometry
- M Microstructures & -systems
- P Production Testing
- S Scientific & Medical
- T Structural Testing
- U Ultrasonics

## The PSV-400-3D for Car Body Structural Dynamics Testing: a Real-World Test

*DaimlerChrysler studied the suitability of the PSV-400-3D Three Dimensional Scanning Vibrometer for data acquisition in car body modal testing at their facility in Sindelfingen, Germany. The result of their real-world test was very good news for auto body designers around the world. Essentially, the PSV-400-3D can make the same measurements as accelerometers but quicker and more accurately, cutting modal testing costs substantially. Furthermore, it adds all the advantages of laser scanning vibrometry such as high spatial resolution, non-contact measurements, rapid setup and ease of use. This application note summarizes DaimlerChrysler's technique and measurement results.*

### Introduction

High spatial resolution structural dynamics testing on car bodies is a time-consuming and cumbersome task if performed with accelerometers. Accelerometers must be carefully mounted, connected to the data acquisition front-end and their angular orientation has to be determined. Furthermore, for high spatial resolution tests, a very large number of accelerometers has to be employed. This is practically impossible in a single setup as the front end has only a limited number of channels.

Therefore, only a subset of all measurement points is taken in an initial run, with dummy masses on the unmeasured points. In the next run, the accelerometers are moved to the next segment, swapping places with the

dummy masses. This process continues until the entire measurement grid is covered. It is time consuming and often damages the accelerometers with the multiple mounting and removal operations. Furthermore, when using so many accelerometers, the process becomes quite tedious with repetitive tasks like cabling, labeling and error checking. A final drawback is the mass loading of the measurement object by the mounted accelerometers and dummy masses.

The PSV-400-3D uses laser light rather than a contact sensor and has the potential to considerably simplify the setup, greatly up the test and make high spatial resolution measurements without altering the mass or stiffness of the measured object.

Polytec GmbH  
Laser Measurement  
Systems  
Application Note  
VIB-C-01

January 2005

## Test Site

To study the performance and possible limitations of the PSV-400-3D as a data acquisition system for modal analysis, DaimlerChrysler AG initiated a modal analysis project on a car body.

## Structural Dynamics Test Setup

A complete Mercedes E-Class car body, without engine, drivetrain and axles, was tested with the PSV-400-3D (see Figure 1). The body was painted white. No additional surface treatment was necessary to obtain the results required for structural dynamics testing. The test object was excited by one shaker in vertical direction, coupled to the main chassis beam. The car body was mounted on air suspensions for decoupling

from the fixture. A lift system was used to conveniently select the best height for the test. This lift system also enables tests on the underbody of the car. Measurement points on the top of the car were accessed by a crane. Extensive testing has been performed under and on top of a car body but is not reported here.

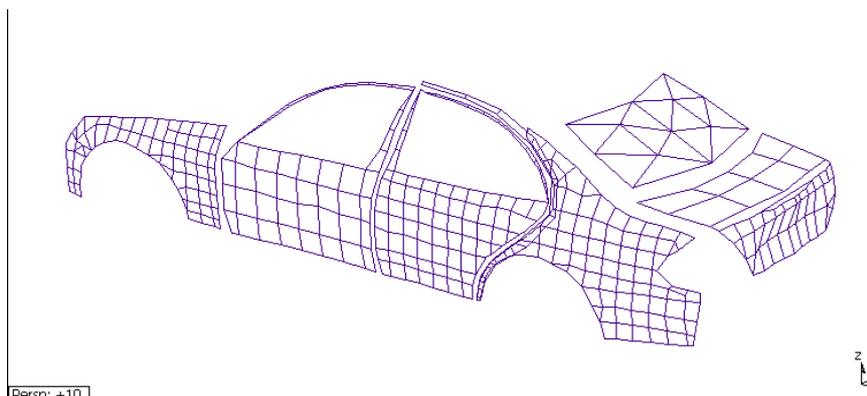
During this benchmark test, measurements were performed on the entire left and back part of the body (Figure 2). The measurement was divided into 5 sections:

- Front left fender
- Front left door part
- Rear left door part
- Rear left fender
- Back

**Figure 1: View of the setup to measure the left rear side body segment.**



**Figure 2: Measurement grid totaling 472 scan points.**



The measurements for each of the individual segments have been stitched (combined) into one global result. The current software version (PSV 8.2) does not support stitching. Instead, a macro must be used for this purpose. Stitching will be available into the next version of the PSV software. During additional testing, it turned out that a division into 3 sections (front part, rear part and back) would have been sufficient.

In between the measurements of the individual segments, the scanning heads were moved to their new positions to scan the next segment. In order to be able to stitch the individual measurements together into one global model, a consistent global coordinate system for all measurements is needed. We used the standard coordinate system of DaimlerChrysler, with the origin in the middle of the front axle, x in opposition to the driver's direction, y pointing from the middle of the car out to the right (view from drivers perspective) and z vertically upwards.

Overall, 472 scan points were measured, each one with its x, y, z vibration components, hence a total of 1416 degrees of freedom. This is sufficient for experimental modal tests on the selected surfaces and for frequencies up to 200 Hz.

## Settings

To cover the frequencies of interest, a 500 Hz bandwidth was selected with a frequency resolution of 0.625 Hz (Table 1).

As the resulting surface speeds are very low, the high resolution digital decoder VD-07 in its most sensitive range 1mm/s/V (10 mm/s peak) was used. This range has the best noise performance for this measurement task.

In a pre-study, different excitation signals were tested. As the behavior of the structure is reasonably linear, pseudo-random excitation was selected. Pseudo-random and periodic chirp have the advantage that amplitude correction files can be applied in the Polytec software to tune the excitation signal to flatten resonances in the applied force. Furthermore, these signals are better suited to measurements with relatively few averages (about 10, see below). Pseudo-random has finally been preferred to periodic chirp as higher excitation forces could be

applied to the structure without breaking the glue of the force transducer.

In order to minimize the measurement time, standard daytime measurements were limited to 10 averages; while overnight measurements were limited to 30 averages. It takes about 30 minutes to accurately measure a segment at 100 points and average each point 10 times.

Used decoder and range	VD-07, 1mm/s/V
Frequency range	0 – 500 Hz
Frequency resolution	0.625 Hz (800 FFT lines)
Excitation signal	Pseudo random
Excitation force at 150 Hz	500 mN
No. of averages	10 during day time, 30 during night

## Workflow

In order to provide insight into measurements with the PSV-400-3D, the typical workflow is outlined below.

1. **Set up** the heads on their tripods to cover the desired scan area. Several considerations should be made:
  - The maximum  $\pm 20^\circ$  scan angle must not be exceeded for ALL heads.
  - Distance from the object being studied should be as small as possible to maximize the signal-to-noise ratio. This depends also on the scattering properties of the surface and the vibration level. As a general rule-of-thumb, the maximum useful distance from a white surface is between 3 and 5 meters.
  - Sufficient angular separation of the optical axes of the scan heads (ideal position is an equilateral triangle). Typically, the orientation of each scan head axis is between  $10^\circ$  and  $20^\circ$  to the surface normal, depending on the scattering properties of the surface.

2. **2-D alignment** to establish the connection between position on the video image and scan angles
3. **3-D alignment**
  - Definition of the coordinate system by pointing the sensor head with the Geometry Scan Unit to 3 known points on the car
  - Alignment of left and right heads using 4 - 7 points whose coordinates can be measured with the Geometry Scan Unit
4. **Measurement grid definition** (alternatively import of geometry file in universal file format, then skip point 5)
5. **Geometry scan** to get the 3D coordinates of the measurement points (alternatively manually set the distances)
6. **Focus setting**
7. **A/D settings** of the measurement system (frequency range and resolution, excitation signal, window, number of averages etc.)
8. **Perform measurement** at defined points as they are automatically scanned
9. **Data visualization** in the PSV software to check deflection shapes
10. **Data export** into customer's modal analysis software package

## Results

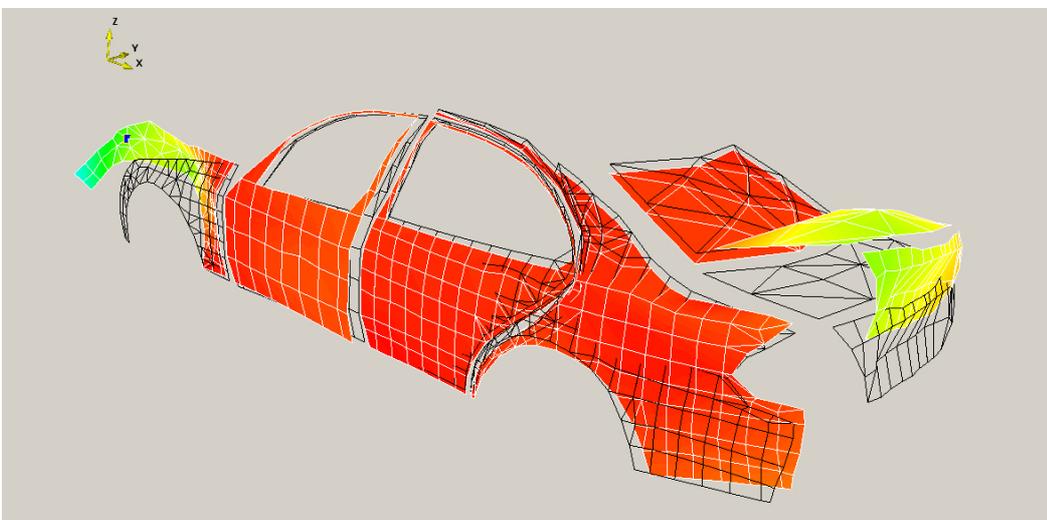
In the following paragraphs, some of the results obtained during the test at DaimlerChrysler are presented.

### Stitching of the individual segments

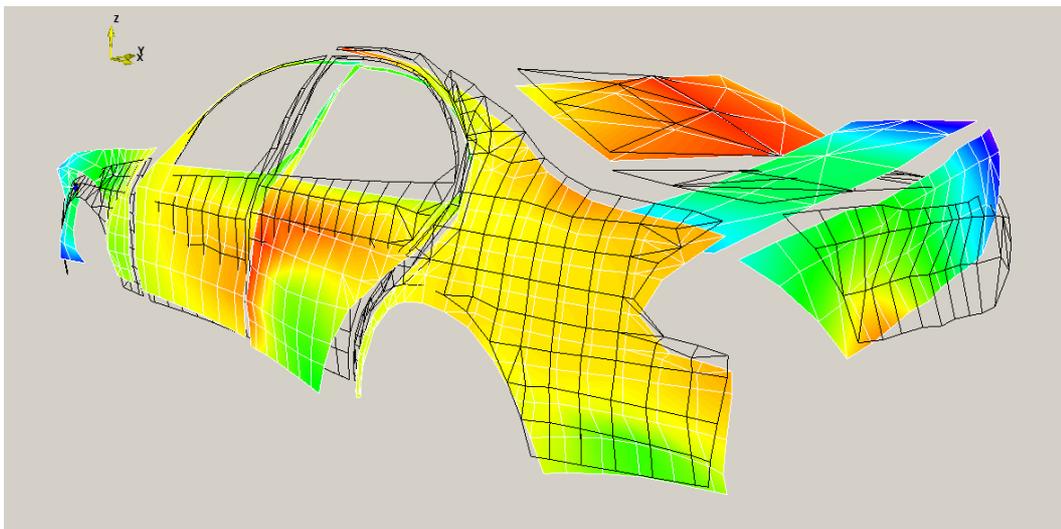
A pre-release version of a software feature that can stitch together measurements was used to combine all individual segments into one combined PSV file. Global deflection shapes can easily be visualized in this way. In Figures 3 - 5, the global deflection shapes are shown.

The different segments fit together well, both in terms of pure geometry as well as in terms of the observed deflection shapes, which often extend over more than one segment. An excellent spatial resolution for the frequencies of interest has been achieved without any disturbance to the vibration characteristics of the structure.

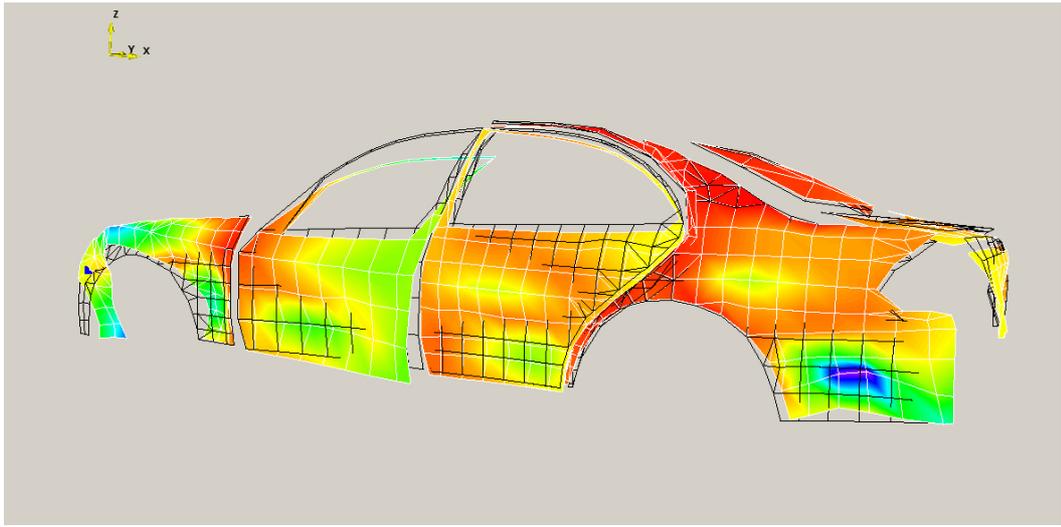
The spatial resolution can be increased very easily (a subsequent test used 5000 points on an entire car surface) so that even higher frequency vibration patterns can be spatially resolved in detail. This point is perhaps even more important in acoustics studies than in modal tests as acoustics tests usually extend up to higher frequencies.



**Figure 3: Deflection shape #1. Front fender and trunk opening.**



**Figure 4: Deflection shape #2. Doors and twist of trunk.**



**Figure 5: Deflection shape #3. Front door, front and rear fender.**

**Measurement time**

The required time for the entire test was 6 to 7 hours and covers the initial setup time as well as the setup and measurement time for each segment, see Table 2.

Table 2: Measurement Time	
Initial setup	1 h
Setup for each segment	30 – 40 min
Measurement of each segment	30 min

The measurement time for each segment depended on the measurement parameters which were

- 100 Measurement points, defined on the video image
- 10 averages, frequency resolution: 0.6 Hz

A prerequisite is that for each segment three points with known coordinates are marked on the structure. If such marked points are not available, one additional hour is required for their definition with the help of the Geometry Scan Unit.

The total time depends of course on the selected measurement segment. If the surface is easily accessible, has a "simple" geometric shape and good backscattering properties, the total setup time will be shorter than for hidden, complicated surfaces with poor backscattering properties. The estimation above is valid for a typical measurement segment on the side, rear or back of a car body.

The time saving as compared to accelerometers is considerable. It gets even more important as soon as the number of simultaneously measurable accelerometers is increased beyond the number of input channels, as in this case accelerometers and dummy masses would have to be displaced during the measurement process.

For higher density grids, the time saving also increases since only the PSV-400-3D measurement time increases while the setup time remains nearly constant.

## Advantages for FEM – Test Correlation

FEM calculations can take advantage of the high quality measurement data delivered from the PSV-400-3D: no accelerometer and dummy masses have to be taken into account in the modeling process. The validation of the FE-model is drastically enhanced by the high spatial resolution of the measurement data. This is especially important if simulations at higher frequencies have to be performed in the structural FE-model.

Furthermore, the PSV-400-3D system can import the FEM surface geometry model in universal file format. This allows for a measurement at all surface nodes of the FE-model. With this, the geometrical correlation between the nodes in the test and FE-model is obsolete.

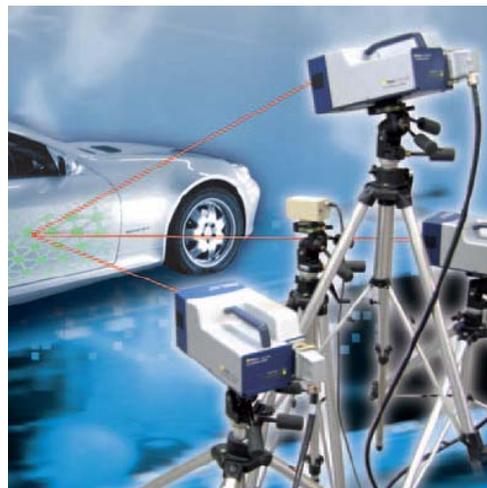
We wish to thank DaimlerChrysler AG for the cooperation and for allowing us to print and to distribute this information.

**For more information about applications of the PSV-400 family of products please contact your local Polytec sales engineer or visit our website [www.polytec.com](http://www.polytec.com)**

## Summary

The PSV-400-3D proves to be very well suited for data acquisition for structural dynamics tests on car bodies. The main advantages as compared to conventional accelerometers are

- Significant decrease of test time
- Higher point density allows more precise results
- Measurements exactly at coordinates of FE-model possible by geometry import
- No alteration of structure (no change of mass or stiffness) and therefore easier and better FEM-correlation
- Ease of setup (no cabling or labeling)
- No error checking of cabling
- No moving of accelerometers and dummy masses
- Software easy to learn and system easy to use
- Lower maintenance costs - only one transducer to recalibrate



### Polytec GmbH

Polytec-Platz 1-7  
76337 Waldbronn

### Germany

Tel. + 49 (0) 7243 604-0  
Fax + 49 (0) 7243 69944  
info@polytec.de

### Polytec-PI, S.A. (France)

32 rue Délizy  
93694 Pantin  
Tel. + 33 (0) 1 48 10 39 34  
Fax + 33 (0) 1 48 10 09 66  
info@polytec-pi.fr

### Lambda Photometrics Ltd. (Great Britain)

Lambda House, Batford Mill  
Harpenden, Herts AL5 5BZ  
Tel. + 44 (0) 1582 764334  
Fax + 44 (0) 1582 712084  
info@lambdaphoto.co.uk

### Polytec KK (Japan)

Hakusan High Tech Park  
1-18-2 Hakusan, Midori-ku  
Yokohama-shi, 226-0006  
Kanagawa-ken  
Tel. +81 (0) 45 938-4960  
Fax +81 (0) 45 938-4961  
info@polytec.co.jp

### Polytec, Inc. (USA)

North American Headquarters  
1342 Bell Avenue, Suite 3-A  
Tustin, CA 92780  
Tel. +1 714 850 1835  
Fax +1 714 850 1831  
info@polytec.com

### Midwest Office

3915 Research Park Dr.,  
#A12  
Ann Arbor, MI 48108  
Tel. +1 734 662 4900  
Fax +1 734 662 4451

### East Coast Office

25 South Street, Suite A  
Hopkinton, MA 01748  
Tel. +1 508 544 1224  
Fax +1 508 544 1225