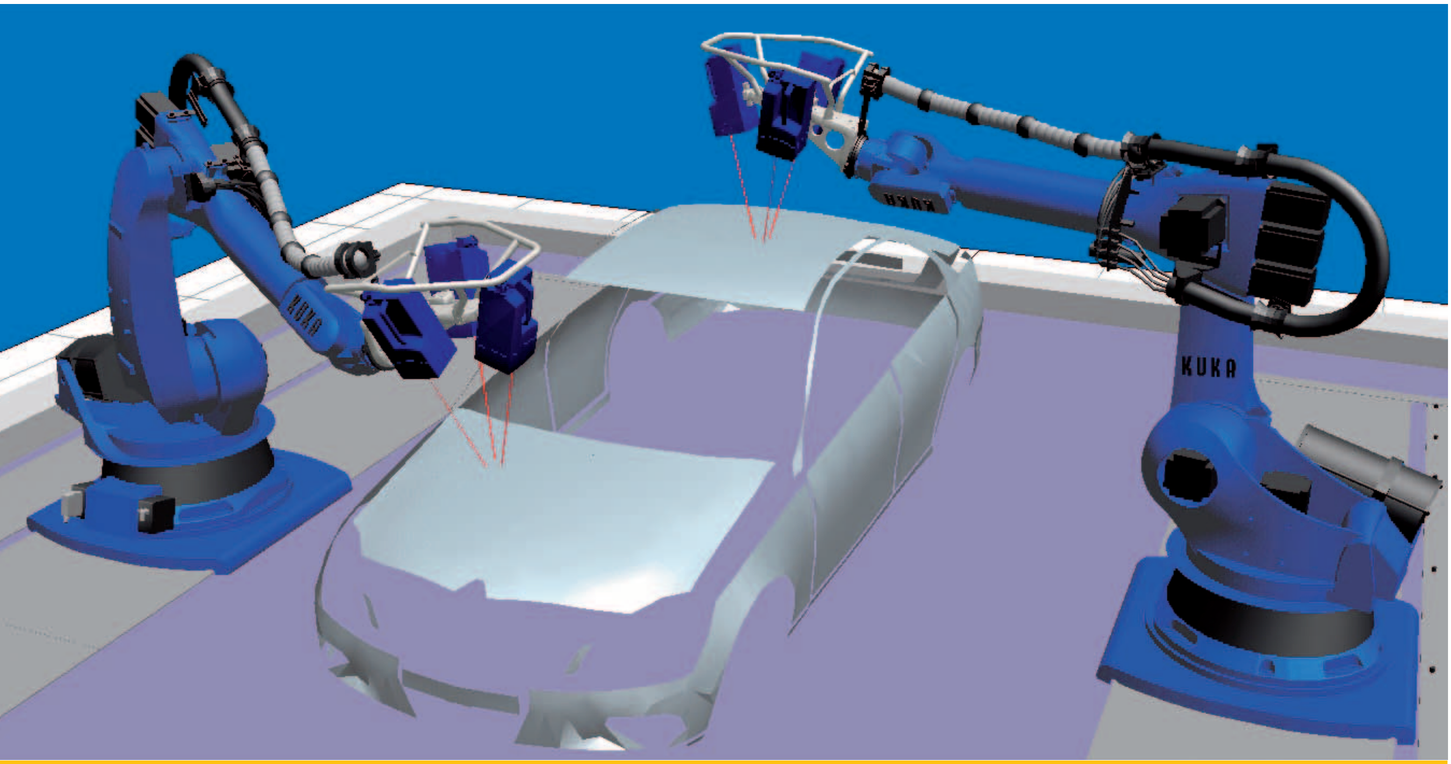
Closing the Data Gap

Improved FE Model Validation by Automated Modal Testing with RoboVib®



A new approach was presented during the ANSYS Conference & 28th CADFEM User's Meeting held in 2010 in Aachen, Germany, which facilitates the integration of experimental modal analysis test into the CAE data chain. This approach combines the properties of the PSV-3D Scanning Vibrometer with robotics and makes it possible to use CAE data for defining the test. The core benefit for the model updating process is the ability to work with imported FE geometries and coordinate systems, and to acquire data automatically at all of the nodal points.

Optical vs. Conventional Testing Approach

A case study compared the automated optical approach to conventional modal testing with accelerometers (Fig. 1). A cast alloy motorcycle gearbox cover was probed with both methods. The focus was not so much on comparing the efficiency of the methods but on the benefits for the FE (finite elements) model update. The FE model was a tetrahedral mesh type with 69019 elements and 19994 nodes.

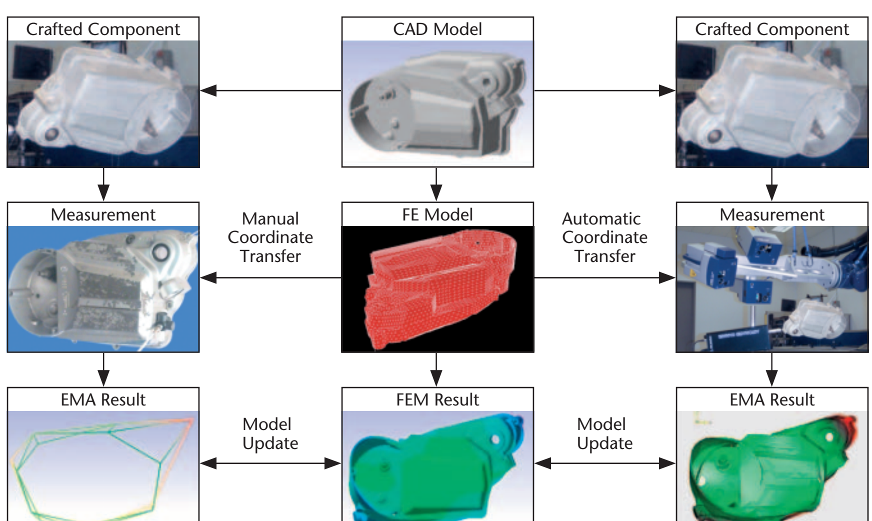


Fig. 1: Comparison of two approaches to the FE model updating process. Center: FE model generation; left: accelerometer modal test; right: RoboVib® modal test.

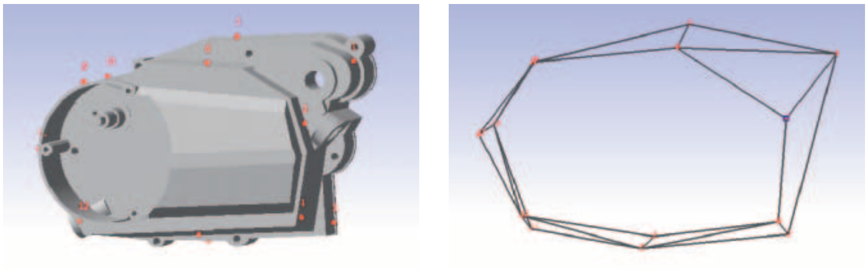


Fig. 2: CAD model with measurement locations. Wire frame model resulting from measurement points.

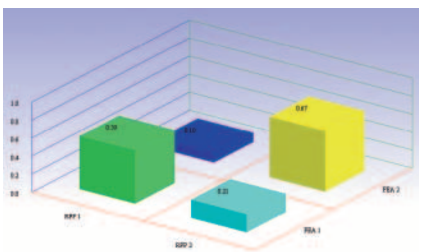


Fig. 5: MAC comparing FE simulation and tri-axial accelerometer measurements.

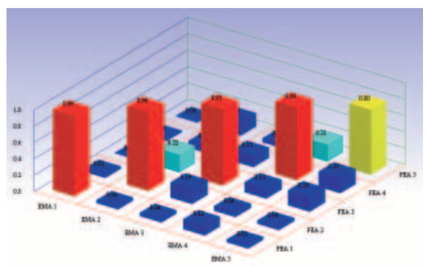


Fig. 6: MAC comparing FE simulation and RoboVib® measurements.

■ Accelerometer Test

When testing with accelerometers, an impulse hammer was used to excite the gearbox cover. Measurements were acquired at 14 measurement points as shown in Fig. 2. The locations were defined manually from the FE modal analysis results.

■ Test with RoboVib®

Optical methods are able to use measurement grids that are derived from existing FE models of an object under test. Being free from the constraints of physically mounted and cabled sensors, two major shortfalls of conventional testing methods are overcome: the limited spatial density of measurement nodes; and mass loading. By overcoming these constraints, the Modal Assurance Criterion (MAC) values between measurement and simulation are considerably improved, which allows for a much better FE validation quality. The imported grid was coarsened by a factor of roughly 10, which still gives 100x more data points than the accelerometer test.

In order to optically scan the complete cover, the robot was taught positions so that all sides of the cover could be measured. After preparing the measurement during the daytime, the measurement was left to run overnight (Fig. 3). Data from 1630 nodes were acquired automatically and results from all robot positions were automatically stitched together into a single seamless file for analysis. Post-processing was performed in the VMAP Modal Analysis package. The results of the first two modes for the different measurement techniques are displayed in Fig. 4, as well as the first two modes from FEA as a reference.

MAC Analysis

One major application of RoboVib® is to be able to compare and update finite element models (FEM). In this case study the VMAP modal analysis program from TechPassion was used to extract the modal parameters. It offers a native import of Polytec's binary file format. The mode shapes and Eigen frequencies can be compared to the values calculated from the simulation and the modal damping added to the FEM. The FEM can now be tuned to the real structure and an improved model can be derived using VMAP FE model updating tools.

■ Accelerometer Test

The modal analysis from the conventional accelerometer test was limited to the first 2 modes at 592 Hz and 933 Hz. The MAC values between the same modes from measurement and simulation are 0.67 and 0.59 (Fig. 5). These values lead to the conclusion that some parameters of the test, e. g. accelerometer masses and the location and orientation of the sensors, have a lowering influence on the quality of the measurement.

■ RoboVib® Test

Using a 100x higher point resolution allows higher modes of the gear box cover to be extracted. The MAC values between the same modes from measurement and simulation are close to 1, showing a much better match compared to the accelerometer test. Fig. 6 shows the MAC matrix for the first five modes, the diagonal values are close to 1 and the off-diagonal values are close to zero. This allows precise matching of the measured modes with the simulated modes.

1st Mode
592.1 Hz

2nd Mode
932.5 Hz

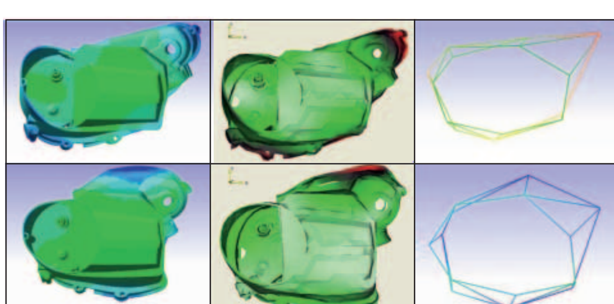


Fig. 4: Comparison of mode shapes from FE analysis (left) with RoboVib® (center) and conventional measurements (right).

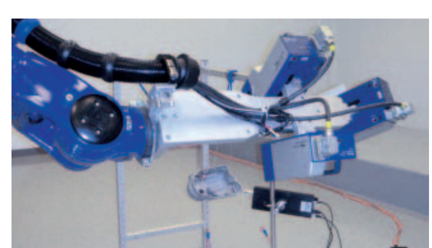


Fig. 3: Measurement of the gearbox cover with RoboVib®.

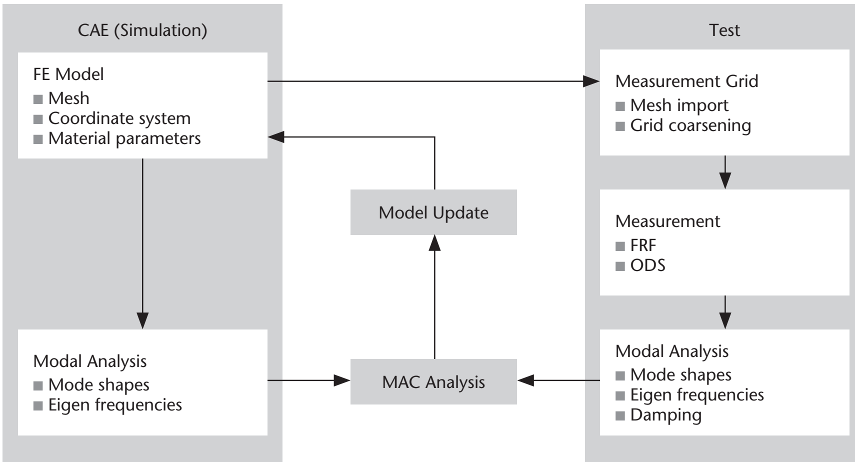


Fig. 7: CAE-Test Workflow.

Improving the Incompleteness Ratio

An FE mesh is generated to ideally represent the later prototype. The FE model should be able to predict the dynamic and durability parameters of these components for a defined operating condition. The results of the modal analysis, Eigen modes and Eigen frequencies are then validated by the resulting mode shapes and damping values from the experimental modal test (Fig. 7). FE models typically contain at least several thousand nodes. In practice a measurement for validating the FE model contains only a subset of the FE nodes. In other words: the measurement is incomplete. This incompleteness is described by the term "incompleteness ratio":

$$i_r = \frac{n}{N} \quad \text{(eq. 1)}$$

where n is the number of measured nodes and N the number of nodes in the FE model. Other authors have shown that the quality of an FE model update strongly depends on the incompleteness ratio. E.g. Grafe states: "The real challenge of updating large FE models is not so much the size of the models, as these can be solved by ever more powerful computers, but rather small incompleteness ratios" (Model Updating of Large Structural Dynamics Models Using Measured Response Functions, Doctoral thesis, University of London, 1998). In other words: the number of measurement nodes must be sufficiently high to ensure a correct update of the FE model.

The significant reduction of the incompleteness by means of the automatic approach with RoboVib® thus opens the path to an optimized model updating.

Authors · Contact
Dipl.-Ing. Jörg Sauer[a],
Dhanushkodi Mariappan[b],
Dipl.-Ing. (FH) Matthias Schüssler[a],
Dipl.-Ing. (FH) Arend von der Lieth[c],
Michael Stone[c]
oms@polytec.de
[a] Polytec GmbH; [b] TechPassion Technologies Pvt. Limited, Chennai, India;
[c] Polytec Inc., Dexter, MI, USA

This article is based on the same-titled paper presented at the ANSYS Conference & 28th CADFEM Users' Meeting, Nov. 3-5, 2010, Aachen, Germany.
The full paper is available at:
www.polytec.com/fe-test-correlation