Dr. ETTEMEYER Application Report
No. 01-98

3D-ESPI for Vibration Analysis on Catalytic Converters

Oliver Erne *, Christian Guist #, Hans Bode #, Andreas Ettemeyer *

* Dr. Ettemeyer GmbH & Co.
Heinz-Rühmann-Str. 207
D-89231 Neu-Ulm, Germany
Tel.: +49/731/98 58 3-0
Fax: +49/731/98 58 3-70
E-mail: sales@ettemeyer.de
Internet: http://www.ettemeyer.de

Bergische Universität
Gesamthochschule Wuppertal
Fachbereich 12, Maschinentechnik
D-42097 Wuppertal, Germany
Tel: +49/202/439-2037
Fax: +49/202/439-2032

ETTEMEYER

3D-ESPI for Vibration Analysis on Catalytic Converters

Oliver Erne *, Christian Guist #, Hans Bode #, Andreas Ettemeyer *
* Dr. Ettemeyer GmbH & Co.
Heinz-Rühmann-Str. 207
D-89231 Neu-Ulm, Germany
BUGH- Wuppertal
Maschinentechnik
D-42097 Wuppertal, Germany

Introduction: In 1995 the BMW Alpina B12 became the first series vehicle to be introduced in the European and Japanese markets with an electrically heated catalytic converter (EHC), [1]. During the development of this type of converter, besides others, natural vibration frequencies were analyzed by the use of speckle interferometry.

Problem of vibration analysis: A special problem for the analysis of catalytic converters is their internal set-up, fig. 1. The matrix of the converter is built of flat and corrugated metal sheets. The outer cylinder of the converter and the matrix show different stiffness and vibration modes. Therefore, the knowledge of their vibration behaviour is important to optimize the lifetime of such components. The experimental analysis of such components is quite difficult, since the thin metal sheets of the matrix do not allow measurement with mechanical contact. Optical access is difficult due to the very thin cross section of the material. Furthermore, the tangential and radial vibration of the matrix and cylinder is required. The complex structure of the matrix additionally requires full field measurement. Therefore electronic-speckle interferometry (ESPI) was found to be the optimal measuring solution for this task.

3D-ESPI: A 3D-ESPI system was used to carry out the vibration measurements. It consists of a miniaturized electro-optical sensor head, a glass fibre coupled frequency doubled NdYAG laser and a ruggedized industrial control and analysis electronic system. The sensor head contains a high resolution CCD-camera and a total of four full field laser illumination systems. The four illumination systems are combined to produce two in-plane and one out-of-plane measuring direction, fig. 2. So, the 3 deformation components of an object can be measured. The sensitivity can be adjusted and typically is less than 0,1 micrometer deformation amplitude. The principle of the ESPI technique is described in [1].

Vibration analysis: In a test set-up, the conveter is bedded at almost zero force. With the aid of a shaker, attached to the mantle, the converters are then caused to oscillate, fig. 3. The oscillation frequency is continuously applied between 1.000 and 6.000 Hz. The light of a frequency doubled NdYAG laser is chopped by an acousto optical modulator to produce stroboscopic illumination. The illumination pulse frequency and phase are adjusted according to the vibration excitation of the shaker to record the upper amplitude level of the vibration, fig. 4. Then the illumination phase is changed to record the lower amplitude level. The subtraction of both images directly shows the vibration amplitude. By these means, the vibration modes of the object can continuously be followed on the monitor when the vibration frequency is changed. A force transducer at the excitation point is used to calibrate the vibration amplitudes.

Quantitative analysis: The observed images are quantitatively analysed with an easy to use Windows 95-software. The system provides a measuring sensitivity between 30 nm and 100 nm, depending on its configuration. The measuring results can be presented in different plots, such as color graphic, 3D-representation, profiles, etc. Interfaces to standard software packages make postprocessing easy and allow combination of different calculation and testing results.

Problem of catalyst surface: The principle of ESPI uses the laser light which is diffusely reflected from the object´s surface. As mentioned earlier, the inner matrix of the catalytic converters are made from thin metal sheets, which are wrapped in different ways.

Fig. 5 shows the standard design of an electrically heated converter (EHC). Obviously, the measuring surface consists mostly of "holes" and only very little light is reflected to the ESPI camera. Therefore, a relatively powerful laser was used for illumination and the camera was slightly defocused on the surface. This enabled, to receive enough reflected laser light with the camera and to analyse the images with good quality.

Display of vibration modes: The vibration is recorded in the directions of the camera coordinate system. Fig. 6, (left) shows the measuring result for the x-direction, respectively the horizontal direction of the vibration separately. The green color indicates low vibration amplitudes blue and red show the maximum amplitude with positive and negative phase. Similarily, fig. 6 (right) shows the vertical component of the vibration (y-direction) in the same color presentation. The blue color indicates amplitude going up and red going down.

Data analysis of EHC: The combined presentation of the x- and y-dircetion makes it easier to understand the deformation in parts of the matrix oscillating at their natural frequency. The 2D-representation shows that the maximum deformation always occures as a radial bending between two supporting points, fig. 7. With ESPI all natural frequencies could be determined in the range from 400 Hz to 6000 Hz. Analysing the data for maximum displacement in opposite directions gives a peak value for each frequency. To compare different results it is neccessary to normalize the peak value by a suitable factor. For this application the induced force was chosen.

Results: The first vibration mode of the described form of an EHC was found to be below 1500 Hz. This was determined to be critical. Therefore, a design change was carried out to increase the frequency for the first occurence of a natural mode, fig. 8. With ESPI it was possible to confirm that the design change lead to a significant frequency shift for the first vibration mode close to 2000 Hz. At the same time the amplitudes in the range from 2000 Hz to 4000 Hz were decreased by about 85 %.

Resumé: ESPI techniques offer high potential to investigate and optimize complicated structures like electrically heated catalytic converters. The combination of non contact and full field measurement on very difficult surfaces and multi dimensional measuring directions enable the quick and effective development of solutions for vibration problems with technical products.

References:

[1] F.J. Hanel, E. Otto, R. Brück. T. Nagel, N. Bergau, Practical Experience with the EHC System in the BMW ALPINA B12, 1997 SAE International Congress, Detroit, Michigan, Febr. 24.-28. 1998

[2] R. Jones and C. Wykes, Holographic and speckle interferometry, 2^{nd} edition, Cambridge University Press, Cambridge 1989

Fig. 1: Electrically heated catalytic converter

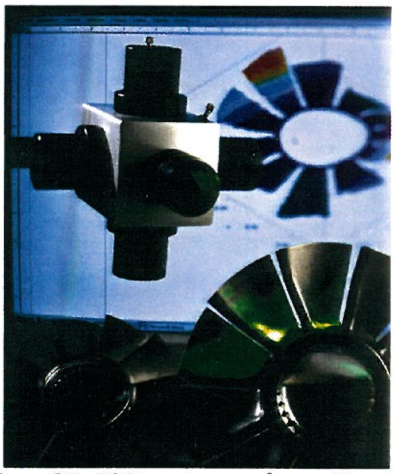

Fig. 2: 3D-ESPI-system for 3D-vibration analysis.

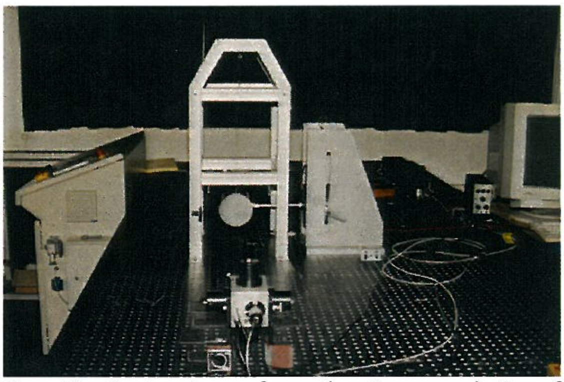

Fig. 3: Test set-up for vibration analysis of catalytic converters. The vibration is induced with the shaker on the right hand.

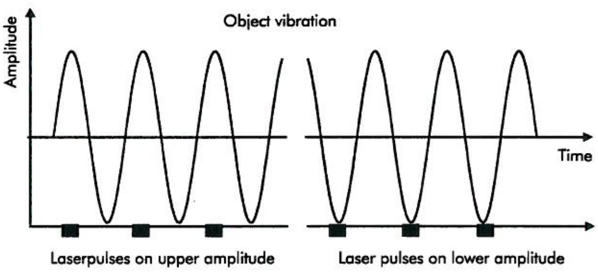

Fig. 4: Vibration amplitude measurement by ESPI with stroboscopic illumination

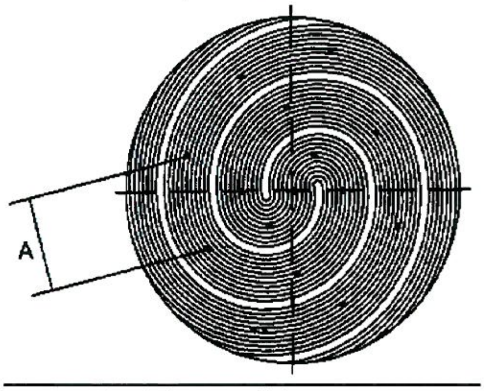

Fig. 5: Standard design of the EHC

Fig. 6: Vibration mode of catalytic converter at 2364 Hz: the colors indicate direction and amplitude of the vibration in horizontal (left) and vertical direction (right)

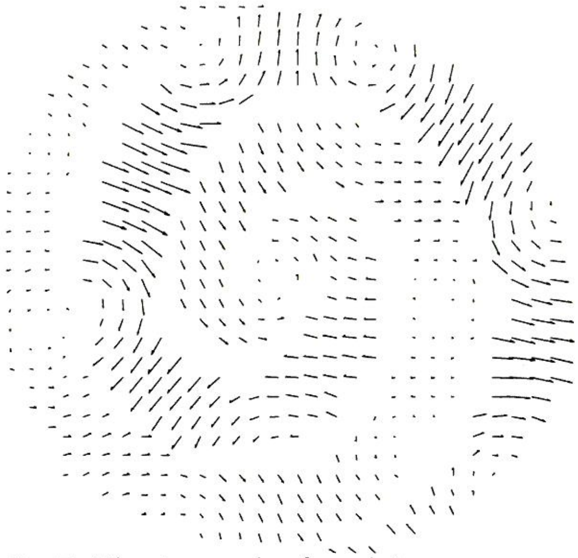

Fig. 7: Vibration mode of catalytic converter at 2364 Hz: 2D-presentation. The image is produced by a combination of fig. 6 left and right.

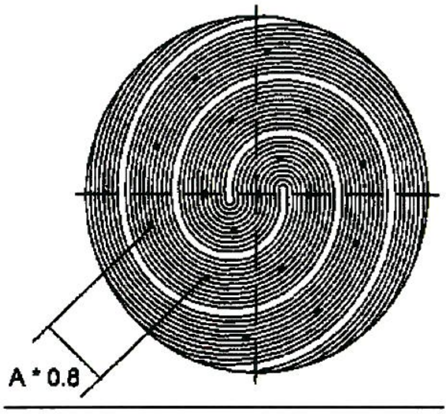

Fig. 8: Modified design of the EHC (BMW ALPINA B12)

Published in proceedings of SEM Spring Conference, June 1-3, 1998, Houston/Texas