About the Use of High Speed Cameras in Acoustics

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Introduction High speed cameras (HSC) have been used in the automotive industry as a means to observe airbag deployment or car safety (HIB). It is possible to optimally view rapid movements by shooting up to 10,000 pictures per second. So movements can be observed which would be too fast for the human eye otherwise. In contrast to the Laser-Doppler-Vibrometry, dynamical changes can be observed. A reflective coating is not necessary. In this presentation the possibilities and limitations of using this method in acoustics will be discussed.

Setup Fig. 1 shows the setup for a speaker measurement in front of and behind the camera. As the exposure

Fig. 1: Setup in front of and behind the camera.

time is very short an adequate illumination for the taking is necessary. In order to receive optimal results, strong contrasts in the sequence of motion should be available. Another advantage of this method should be mentioned. Measurements in the climate chamber with a temperature range of -30°C to 100°C can also be taken (floodlights in the camber - camera outside). No special optical glass is required, clean glass panels are enough.

Depending on the system, several thousands of pictures in the bitmap-format will be stored on a computer. Animations can be produced with almost every currently available imaging process software. In the imaging software, the time for each single picture of the movie is adjusted. As a standard 0.1 seconds per picture is installed, but the final customers can change this set time with freeware programs. The avi-format is the only movie format giving acceptable results. Other ones like gif are not able to reproduce animations as the picture frequency is too high. Uncompressed pictures can overstrain many computers in companies so that it seems advisable to use an adequate codec. Very good results have been achieved with the MS MPEG-4 Codec V2 or the XviD and DivX-codecs. The customer will also be provided with a freeware program which includes a collection of all the frequently used codecs.

Noise identification An exact localization of the source of noise in a system is often very difficult and time consuming. Marginal deviations of loose parts are often the source of an unwanted noise. In the case illustrated in Fig. 2 a small slackness of the axis is responsible for the disturbance of the ganging. The slackness can be observed at the upper edge of the spindle. In the left picture the distance from the head of the spindle to the edge is 0.2 mm larger than in the right picture which shows the position half a spindle rotation ahead. The result is a low frequency

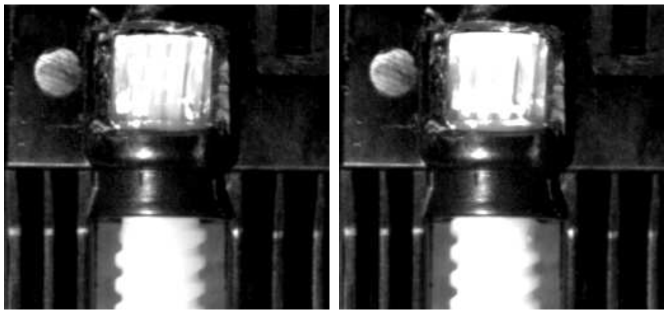

Fig. 2: Slackness of the axis of a drive.

modulated signal ("wow wow"). A sound like this disturbs the overall impression significantly.

Dynamical tests In order to analyze vibration or shock absorbers which promote drop-outs of CD-players or CD/radio combinations in the underlying test runs, a drop-test has been chosen to simulate the characteristics of the problem. In previous tests the minimal height of drop could be determined which would be leading to the equvalent drop-outs of the CD-drive. For reproducibility of results the drop was released by an electromechanical circuit. Based on the actual condition visible in Fig. 4 with a sufficiently accepted result in the suspension, it was the goal to produce a similar drop behavior but without drop-outs and, if possible, less expensive. One reason for the drop-outs can also be seen in the left picture of Fig. 4: The right front corner is clearly heavier and therefore pitches first. The advantage of this method of observation clearly lies in the short time of availability. Visiting test tracks

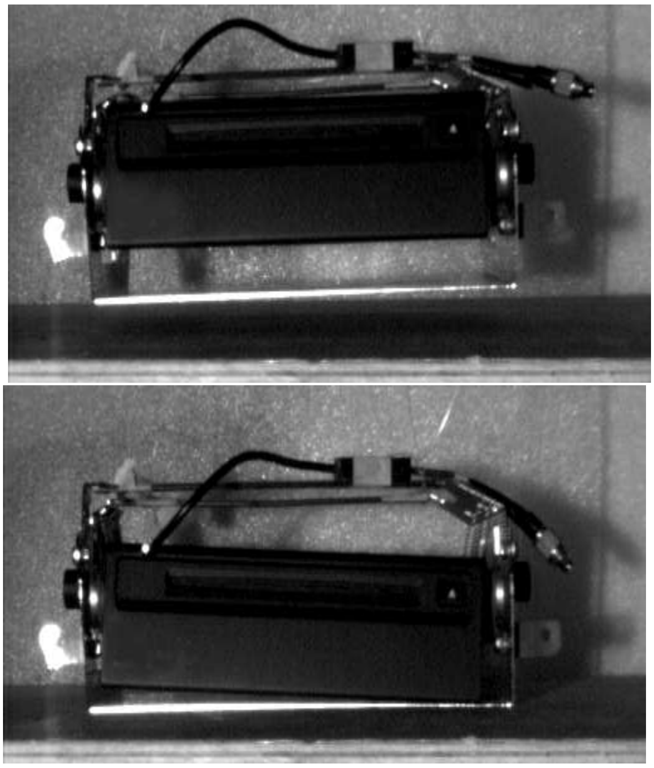

Fig. 3: Drop-test of the present state.

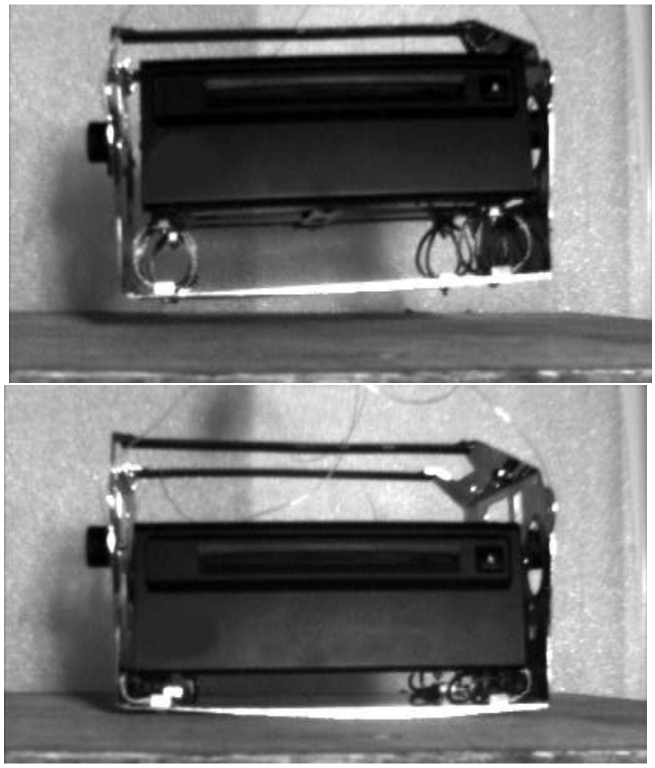

Fig. 4: Drop-test of a modification status.

is by far more time consuming and very expensive, and modifications cannot be put into practice so quickly.

Limits of the procedure One of the limits of the procedure is determined by the sampling theorem. The highest presentable frequency lies at the half the number of pictures per second:

$$f_{max} \leq \frac{Number\ of\ pictures\ per\ second}{2}$$

In order to detect phase deviations a minimum of 4 pictures per frequency should be taken.
The second and decisive limit of the procedure is the amplitude of the object. Measurements with test units that show high contrast have presented a perception of changes of less than 0.2 mm. Using a maximum frequency of 1,000 Hz an unrealistic velocity of 0.22 m/s would be necessary. Realistic frequencies showing a comparable amplitude are up to approx. 75 Hz.
The modulation of a tone / noise with the modulation frequency of 4 Hz is perceived as exceptionally disturbing. Irregularities of rotating parts providing these modulations can be localized very well.
The two directions which are not orthogonally to the point of view, are always the only observable ones.

Further development In the present state it is possible to detect irregularities of rotating parts. From the pictures a quantitative conclusion can be ascertained, with a certain amount of effort. Some image editing programs like the GNU-project GIMP or the commercial Photoshop can be used to determine the differences between two pictures by using the difference mode or the method of subtraction. The differences are especially pronounced when the resulting picture is shown in the negative mode, see Fig. 5.

In the future, an image processing program shall be used e.g. under Matlab®. The dynamical changes in the pictures could be highlighted with colors, and with the insertion of a scale, the dimension can be made visible as well.

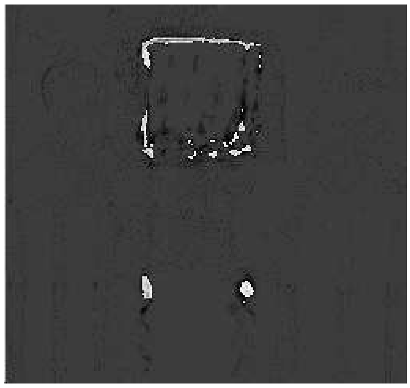

Fig. 5: Differences between the two single pictures from the noise identification of Fig. 2 (negative mode).

It is our intention to evaluate not only single pictures but complete film sequences with up to 10 seconds.

Summary By using high speed cameras it is possible to detect acoustically relevant malfunctions which are not visible to the human eye. This method is an addition to the Laser-Doppler-Vibrometry for detecting dynamic changes and large deflections. It is possible to observe two directions, even in the climate chamber, in contrast to the laser-scanning method. An adequate lighting source is required. Changes with less than 0.2 mm can be identified. This method is not only useful for noise identification, but it is possible to generally inspect the balance of rotating parts. High speed recordings in laboratory tests are less expensive for the optimization of damping / suspension than field tests.

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