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Holographic Vibration Analysis of Loudspeaker Membranes.

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Our optical group was started in 1966 and have been mostly concerned with research on holography and its application. Other institutions have worked on vibration analysis, for example turbine blades, sonar transducers in air and in water. We are now going to use holographic techniques for the analysis of movements in the human ear. The project on loudspeakers has been carried on in co-operation with the Department of Acoustics and a Norwegian manufacturer of loudspeakers.

Problems associated with the holographic analysis of loudspeakers.

Stability. Loudspeakers are extremely unstable objects and very sensitive to external vibrations and sudden small changes in air pressure. Another problem is that the heat from even a medium power laser may cause a cone to move during the exposure.

Some signal generator outputs contain a small amount of 50 or 100 Hz in addition to the desired frequency. This ripple causes an extra uniform movement of the loudspeaker resulting in dark reconstructions.

Reflectivity. Most membranes are made of black paper which reflects very little light. Spraying with silverspray can increase the reflected light up to 10 times, while the mass of the membrane increases approximately by 2 per cent. This added mass has not resulted in any noticable change in the vibration pattern or the sound pressure. This is not the case with high frequency cones however, where even the slightest spraying changes the sound pressure.

Complexity. Loudspeakers vibrate in very complex manners and to obtain the correct vibration pattern both amplitude and phase information is essential. Methods which show only the amplitude distribution might give misleading results as the phase is not necessarily constant along a contour of constant vibration amplitude.

Methods used in the holographic analysis.

Real-time interferometry. In a conventional holographic set-up the filmplate (hologram) is exposed by the light reflected from the loudspeaker (objectwave) and the reference wave. The plate is developed and replaced exactly in its.....

original position. If nothing has changed in the set-up two identical objectwaves will emerge from the hologram- the real objectwave and the reconstructed wave caused by diffraction of the reference wave in the hologram. When the loudspeaker is vibrating the objectwave coming from the real object changes with the vibrations and interference fringes moves over the object. If the vibration frequency is high enough (> 30 Hz) a stable interference pattern is observed due to the averaging effect. This interference pattern will have low contrast due to the high bias level of light and more then two fringe orders are hard to detect on loudspeakers.

To make the observations easier the loudspeaker is usually rotated a small angle resulting in straight high contrast fringes covering the surface. When the loudspeaker is vibrating fringes with full contrast will be observed in the nodes while the fringe contrast will be reduced with increasing amplitude.

This method is very useful when resonance frequencies and interesting vibrations patterns are searched for. Only one hologram is needed while the frequency (and amplitude) can be varied over the whole range of interest. The method is also always used for testing a new set-up as instabilities and unwanted vibrations can readily be detected as random movement of the fringes.

In connection with this method it has been useful to image the object on to a photodetector. If the effective area of the photodetector is small then the signal out of the detector will indicate the fringe movement on a small area (typical 1 mm^2) on the object. If this signal is compared on a double-beam oscilloscope with the signal driving the loudspeaker, the vibrational amplitude and phase can be measured. As this is a point measurement a complete measurement of the loudspeaker's vibration pattern would be very time consuming. But it might sometimes be of interest to measure how the amplitude and phase on a certain point changes over a great frequency range. In such a case this method is much faster than other holographic methods.

Time-average method. In this method the loudspeaker is vibrating with a constant frequency while the hologramplate is exposed. When the exposed plate is developed and reconstructed, the reconstructed image of the loudspeaker will be covered with fringes indicating the vibration amplitude.

The nodes where the amplitude is zero will reconstruct as very bright fringes while the fringes representing constant amplitudes are reconstructed with decreasing brightness. The fringe pattern is like a map where the sealevel is shown very light and the hills are shown as heightcontours which gets darker with incresing height. Therefore the fringe pattern is easily converted into the corresponding amplitudes.

In this (and the former) method there is no practical limit to the frequency which can be used as long as the vibration amplitudes doesn't get too big or too small. Upwards 20 fringes are readily resolved which corresponds to a vibration amplitude of appr. $3 \cdot 10^{-3}$ mm with the He-Ne laser. The lower limit is about 10^{-4} mm, but if necessary amplitudes down to $3 \cdot 10^{-6}$ mm have been measured by introducing controlled phase-shift into the reference beam. By using the same phase-shift it is also possible to measure the vibration phase of the loudspeaker speaker but the procedure is rather cumbersome.

The big disadvantage of this method is that one hologram recording is needed for each change in frequency or amplitude. But if 35 mm holographic film is used the recording of 30-40 vibration pattern is done in half an hour for a reasonable cost.

The stroboscopic method. A hologram is recorded of the loudspeaker in its restposition. The developed hologram is put exactly back in place in the set-up. When the loudspeaker is vibrating, the wavefront from the real loudspeaker is changing because the surface is deformed by the vibrations. As the reference wave will reconstruct the loudspeaker in its restposition the real and the reconstructed wavefronts will interfere according to the instant deformation. To stop the movement of the fringepattern, a fast shutter is placed in the laserbeam. This shutter is syncronized with the frequency of the drive signal and is opened appr. 1/20 of the vibration period. A stable interference pattern will therefore be observed which indicates the amplitude at the particular stage of vibration that the shutter is opened. If the phase between the opening of the shutter and the drive signal is changed the vibration can be studied through the whole cycle. It the light pulse frequency is different from the drive signal the vibration is shown in slow motion. The method works like ordinary stroboscopy only here the object is seen covered with fringes showing the contours of constant amplitude.

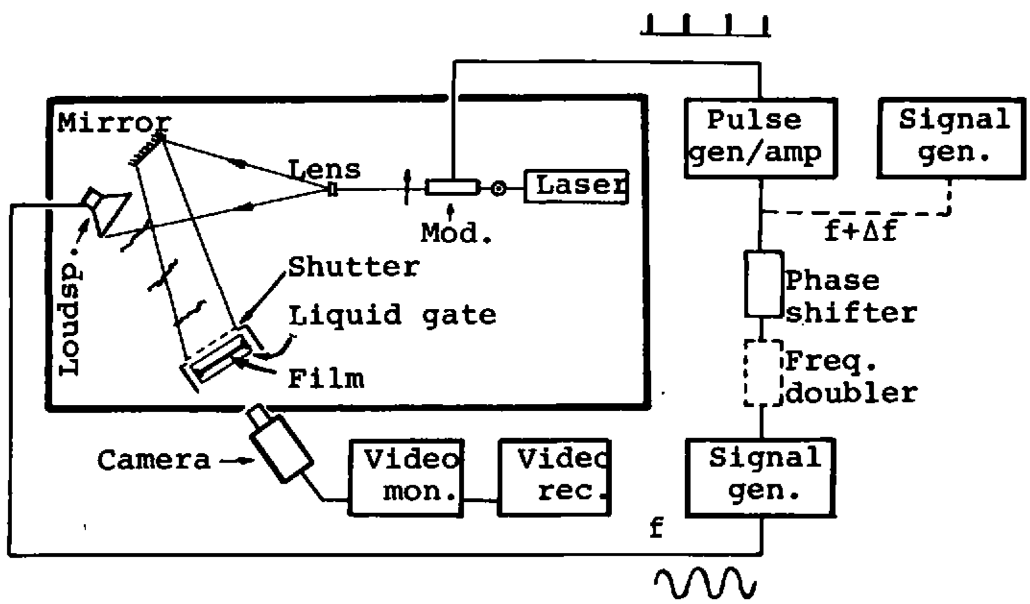

Fig.1. The stroboscopical set-up.

The equipment presently used is shown on fig.1. where the optical part is very simplified. The set-up is placed upon a granite table (weight, appr. 1000 kg) resting upon 4 inner tubes in order to isolate from vibration in the floor.

The strobing shutter consists of an electro-optical modulator placed between crossed polarizers. When an electrical pulse is applied to the modulator the plane of polarization of the light is rotated 90° and a light pulse is let through the second polarizer. The on-off ratio for the He-Ne laser modulator has been up to 1:200 while the Argon laser modulator reaches 1:80 at its very best.

The pulsegenerator/amplifier combination is in no way optimal, but acceptable strobing has been achieved over 20 kHz. The generator is triggered by a signal from the signalgenerator driving the loudspeaker. This trig-signal might be phase-shifted 0 to 180° or frequency-doubled (and phase-shifted) if two pulses during the cycle is desired. If the vibrations are to be observed in slow motion the trig-signal is taken from a second signalgenerator which is regulated to a frequency shifted appr. 0,5 Hz from the drive-signal.

The filmplate is placed in a liquid gate (containing Agfa G 144 b monobath developer) 5 seconds before the exposure. The filmplate is fully developed and fixed after 3 minutes but in practise observation might start after 1 to 1½ minutes without noticeable extra density on the film. The light is pulsed also during the exposure to avoid changes in light intensity on the loudspeaker which might give thermal creep and unwanted fringes. In addition a light-tight box is placed over the liquid gate so the loudspeaker can be continuously illuminated. A home made slit shutter is built into the front of the box as a conventional shutter is too noisy.

The fringe pattern is shown on a 8''-monitor using a television camera. Interesting vibration patterns are recorded on a video tape-recorder.

The whole set-up is giving acceptable results, but as the Argon laser is not very convenient to use due to high power consumption and (noisy) watercooling, the sensitivity of the TV-system will be increased so that a He-Ne laser can be used.

Experimental results.

Recently 5 identical and 2 somewhat different 4'' loudspeakers were analyzed by the different methods. Even rather big variations in the sound pressure could not be correlated to a corresponding change in vibration pattern and vice versa. A general tendency in the vibration pattern change with frequency could be found. This is the conclusion for the timeaverage methods. The analyses by the stroboscopical method are not finished yet, but it is obvious that no loudspeakers behave according to the simple theories that exists to-day. The exact analysis of vibration pattern will be very time consuming and it is very desireable to find means to get the information directly into a computor. Because of the rather depressing vibration pattern shown, the work in the Department of Acoustics are now concentrating on new materials for making loudspeaker. This material should be more uniform than paper.