Noise induced vibration of a thin projection screen

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Introduction

In the new ambient experience CT (Computer Tomography) scanner, developed at Philips Healthcare, the patients well being is improved by projection screens onto which images are projected during the scanning procedure, see Figure 1 and Figure 2. Unfortunately, the movies pictured on these screens suffered from blurriness. For reasons unknown at that time the projection screens wobbled, leading to blurry images. Since the images are projected onto the screens from above, see Figure 3, the screens have to be transparent and fairly thin. The screens are typically produced in Chlorinated Polyvinyl Chloride material, with a lateral dimension of 1410 x 1820 mm^2 and a thickness of 0.177 mm. Philips Applied Technologies in Eindhoven set out to identify the root cause of the wobbling of the screens, and to suggest possible remedies. The suspicion was that either flow-induced or noise-induced vibrations of the screens led to the image quality problems. Structure-borne transmission paths via the floor and the wall to the ceiling were also considered a possible cause. A series of experiments was set up from which the cause of the problem could be deduced. The measurements and the suggested solutions are described in this paper.

Figure 1: Typical installation of an ambient experience CT scanner, control room view

Figure 2: Typical installation of an ambient experience CT scanner, scanner view

Relevant layout of CT scanner

The hart of the CT scanner consists of the so-called gantry. This is a large circular/cylindrical structure that rotates around the patient tunnel, and bears (amongst others) the rontgen source and receptor. The rotational speed is typical 2-3 Hz, at an outer diameter of 1600 mm. At the top of the gantry housing two large vent holes are present for forced cooling by means of fans. The non-smooth/irregular surface of the gantry may transport the surrounding air in a pulsating air flow that emerges from these vent holes. The airflow variations from the vent holes may excite the projection screens and thus form an airborne transmission path. Alternatively, the rotations of the gantry or any other vibrational phenomenon inside the CT scanner may excite the CT covers. The covers are meant for both protection from the rotating gantry and for acoustic shielding. The vibrating covers in turn radiate acoustic noise that excites the projection screens. This forms the structure-borne transmission path.

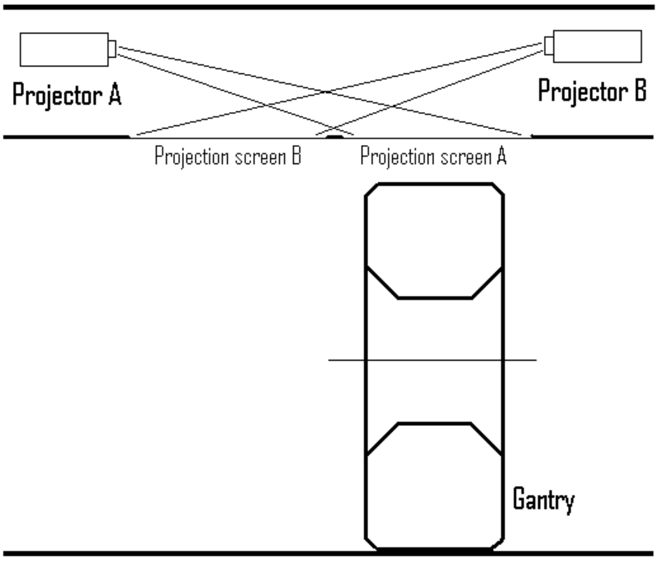

Figure 3: Ambient Experience CT projection method

Experiments

Reference measurements

A series of experiments was carried out to find the root cause of the problem. First reference measurements were conducted. Vibrations of the projection screen were quantified by means of laser doppler vibrometry during operation of the CT scanner, the measurement set-up shown in Figure 4. The measured velocity autospectra at a rotational gantry speed of 2 Hz and 2.375 Hz are shown in Figure 5 and Figure 6, respectively. The distinct peaks in the spectra occur exactly at the fundamental frequency of the rotational speed and its harmonics. Thus a clear correlation exists between the wobbling of the projection screen and the rotational speed of the gantry.

In addition to the laser vibrometry measurements of the projection screen, the acoustic pressure was measured as well, the measurement set-up shown in Figure 8. As expected, the sound pressure spectra also show distinct peaks at the gantry rotational speed and its harmonics, see Figure 7.

Shielding experiments

Next pragmatic shielding experiments were performed blocking the air flow coming out of the gantry, in an effort to asses the importance of this airborne transmission path. A number of shielding experiments were performed. Figure 9 shows a triplex plate standing on four wooden legs. This way of shielding appeared not to influence the vibrations of the projection screen significantly (only 1.7 dB reduction). Adding a 22mm foam layer to it, as shown in Figure 10 gave an additional (minor) 4.7 dB reduction. However, placing the triplex plate with foam on the top gantry, as shown in Figure 11, reduced the vibrations of the projection screen with an additional 10 dB, giving a total reduction of 16.5 dB as compared to the unshielded situation. Figure 12 summarizes the reductions achieved.

In another experiment, we closed the two fan openings

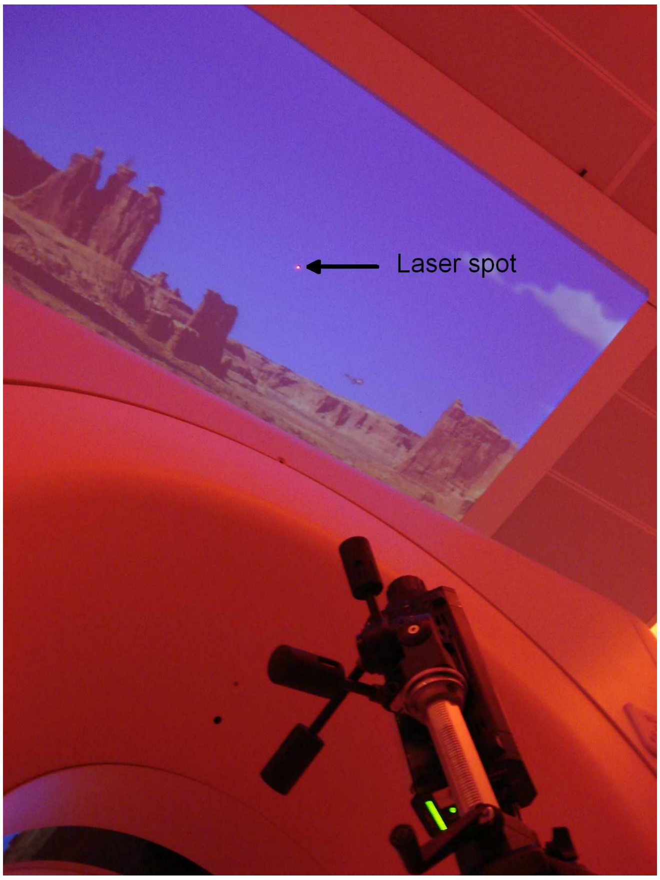

Figure 4: Laser vibrometry set-up to measure the vibration level of the projection screen

at the top of the gantry by means of two wooden "shoeboxes", placed above the two openings. Quite surprisingly, closing the openings did not reduce the vibrations of the projection screen, as shown in Figure 12, last bar item. Whilst putting the triplex plate with foam on top of the grantry reduced the vibration level of the projection screen by more than 15 dB, closing the air outlets by means of the two wooden shoeboxes resulted in a marginally 2 dB reduction. This means that the excitation of the projection screen is not via an airborne path (via the fan openings). What remains is a structure borne transmission path.

Vibration measurements gantry

To investigate the possibility of a structure borne transmission path, in which the gantry as a whole is vibrating and thus radiating acoustic noise, vibration measurements of the gantry were performed, see Figure 13 for the test set-up. The measured acceleration spectra are presented in Figure 14. The vibration level of the plate below the gridplate at 4.75 Hz, the most dominant frequency of vibration, equals -49 dB re 1 ms^{-2} ($3.5{\cdot}10^{-3}$ ms^{-2}), corresponding to a velocity of $1.2{\cdot}10^{-4}$ ms^{-1}. The sound pressure thus radiated by the top part of the gantry can be roughly estimated by assuming a plane wave, which gives an acoustic pressure $p = Z * v = 400 * 1.2 \cdot 10^{-4} = 0.048Pa$, where Z is the acoustic impedance and v is the acoustic particle velocity. This rough estimates gives a sound pressure level of 67 dB

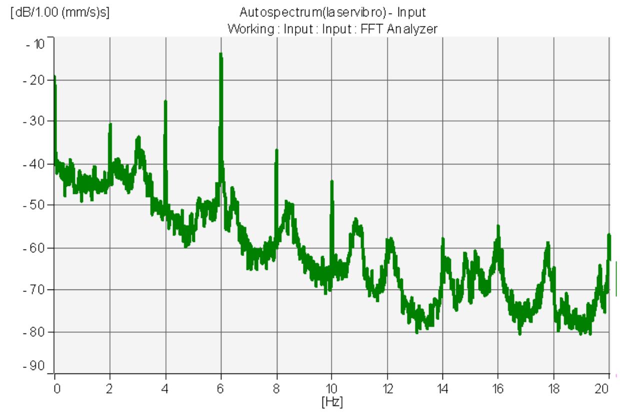

Figure 5: Displacement vibration levels projection screen,rotational speed gantry 2Hz (500 msec)

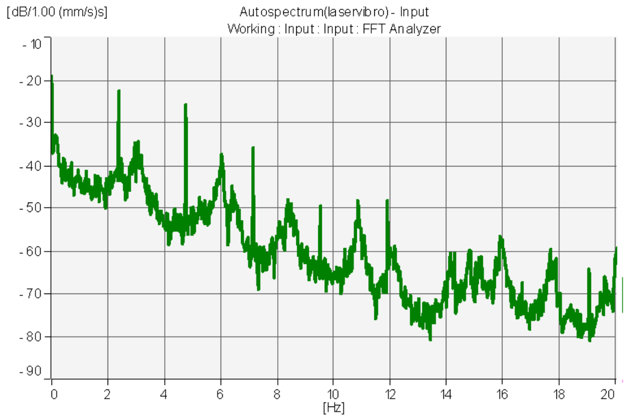

Figure 6: Displacement vibration levels projection screen, rotational speed gantry 2.375Hz (420 msec)

re 20 μPa. Compared to the experimentally obtained sound pressure level (see Figure 7) of 58 dB, this is in reasonable agreement. It confirms that the main transmission path is a structure borne transmission path. The vibrating gantry is radiating acoustic noise which brings the projection screen into vibration.

Conclusions and recommendations

The root cause findings of the waving projection screen can be summarizes as follows:

1. The waving of the screens is correlated to the rotational speed of the gantry.
2. The main transmission path is the structure borne radiation of the gantry.
3. Vibrations of the gantry are most likely caused by a turnplate (rotor) imbalance.

Solutions to the waving projection screen problem can be summarizes as follows:

1. Balancing of turnplate (rotor).
2. Using fairings on the turnplate to reduce flow induced pressure fields.
3. Use a stiffer foundation or fasten the gantry bolts more strongly.
4. Use a thicker projectionscreen (e.g. perpex).

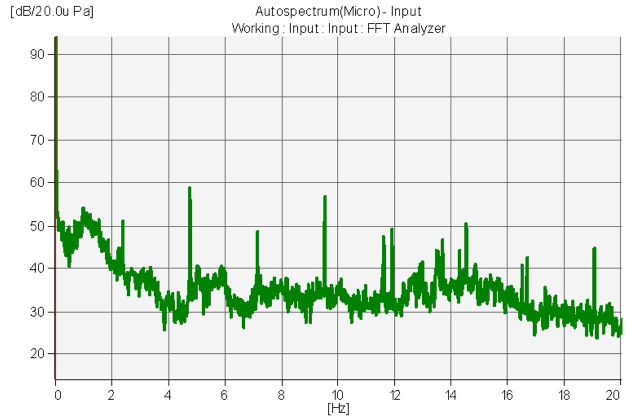

Figure 7: Sound pressure levels near projection screen, rotational speed gantry 2.375Hz (420 msec)

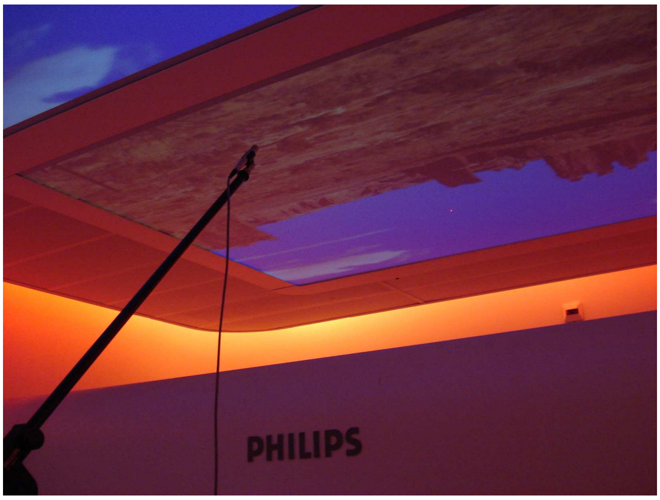

Figure 8: Microphone measuring the sound pressure close to the projection screen

The latter solution was applied in practice to solve the problem on site. Philips is working on the other solution directions to reduce the vibration at the source.

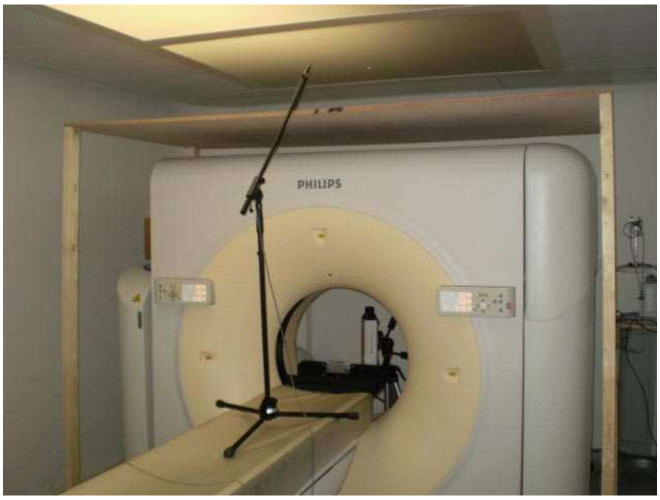

Figure 9: Plywood plate placed between the CT scanner and the projection screens

Figure 10: Plywood plate with absorbing foam placed between the CT scanner and the projection screens

Figure 11: Plywood plate with absorbing foam lying on gantry

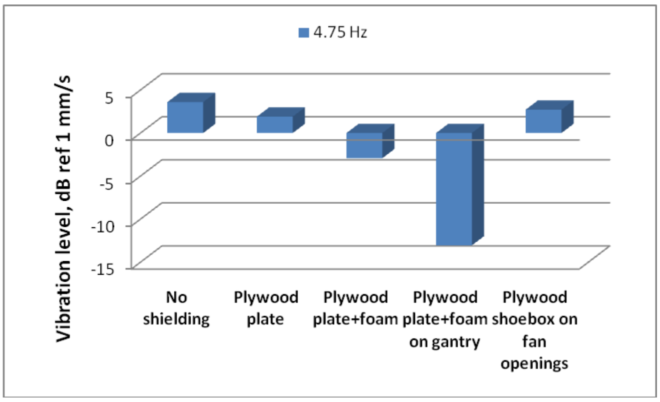

Figure 12: Vibration levels standard projection screen; effect of shielding on most dominant frequency component, rotation speed 2.375 Hz (420 msec).

Figure 13: Accelerometer measurement set-up to determine the vibration levels of the CT gantry

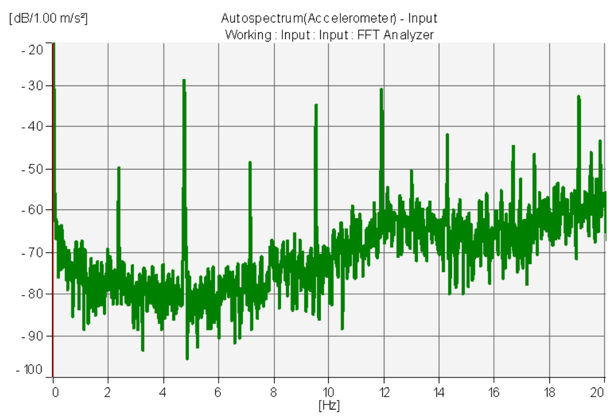

Figure 14: Acceleration levels of the CT gantry