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OPTIMIZATION OF SOUND INSULATION IN THE NEW GENERATION OF WASHING MACHINES

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Abstract

One of the most significant parameters of quality and functionality of washing machines is their noise level. Insulation is certainly the most important method for noise reduction and this is why most research has been dedicated to it. We also took into account the fact that cost limitations were necessary for achieving our target value with the cheapest insulation possible. Consequently, this is a presentation of experimental method of defining sound power and the procedure for the reduction of washing machine noise by the use of muffling materials. The noise level at various development stages was characterized by total sound power level dB, sound intensity, sound pressure level frequency spectra, and sound intensity vector analysis. By measuring sound intensity along all five radiation surfaces the places of the highest radiation were localised and insulation was created according to this. The noise at critical points was reduced and we achieved the recommended values for sound power level.

1. INTRODUCTION

Washing machines are considered to be multiple sources of noise (unwanted sound). To be able to efficiently achieve noise reduction it is necessary to construct the acoustic mechanism model for generating noise (Fig. 1), [1].

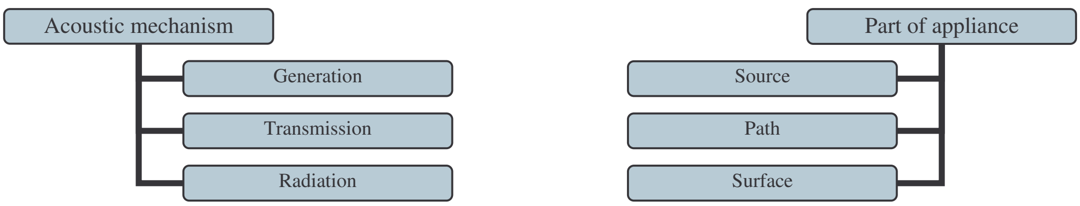

Fig.1. Acoustic mechanism and cause-effect noise generation phenomenon

The sound transfer process in broader sense is carried out in three stages: generation, transfer of sound to the housing of an appliance, and finally acoustic emission into the ambience. In addition, there is also direct transfer of sound by means of sound wave diffraction through the appliance housing openings (Fig. 2).

From the acoustic aspect, parts of appliance are divided into active and passive noise generation components, [2].

Active components are those generating the noise. In broader sense these components convert electrical, mechanical, and magnetic energy, hydraulic pressure, internal forces, and friction into mechanical action. In addition to the above, active noise generation components are also zones of un-stationary flow, as well as contact surfaces of moving components, [1].

Passive components are those transferring the noise resulting from active components. That means that they are not direct noise generators, but only transfer noise into their immediate vicinity. Typical passive noise components are parts of construction and the housing of an appliance, (Fig. 3).

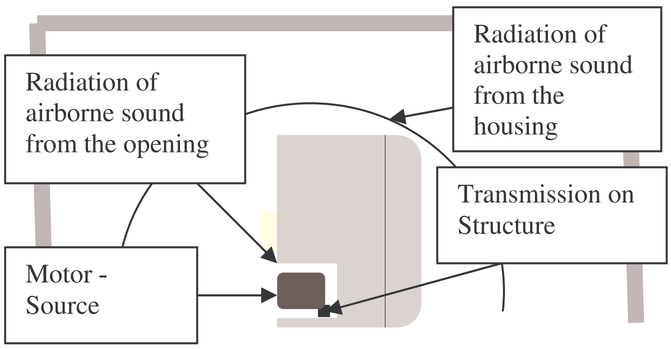

Fig.2. Sound transfer processes from main sources to emission into ambience [3]

The task of appliance designer is to carry out the noise spreading trajectory analysis in accordance with the following «recipe»:

- Divide noise components to active and passive;
- Locate airborne, liquid - borne and structure – borne noise sources;
- Locate noise trajectory transferred through air, liquid, and/or construction;
- Locate the sound radiating surfaces;
- Identify the strongest contributions (sources, transmission paths, radiating surfaces).

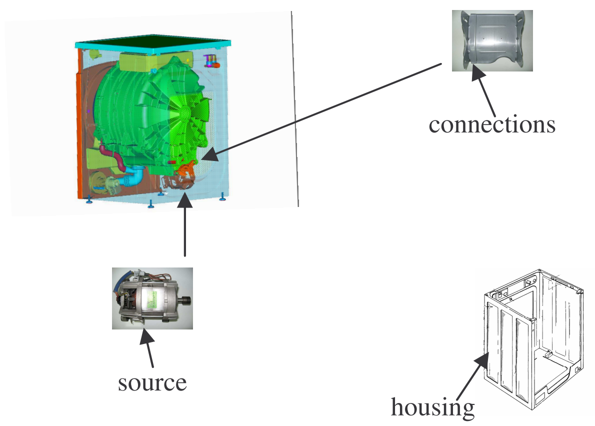

Fig.3. Example of constructional components transferring the sound from the active component to the housing of a washing machine, [3]

2. NOISE REDUCTION IN WASHING MACHINES

Reciprocal relationship between the generation of sound, transfer of sound in the interior of the machine, and radiation of sound in the ambience is formulated by the following equation (equation 1):

$$F = vZ \tag{1}$$

F is a force causing the velocity of vibration v and Z is mechanical impedance. We are talking of course of complex values. F is equivalent to the voltage and v to current in a so called »mechanical Ohm law«, [4].

For the RMS (Root Mean Square) the F and v values are derived from:

$$F_{1,RMS} = v_{1,RMS}|Z_1| \tag{2}$$

where $v_{1,\mathrm{RMS}}$ RMS value of vibration speed in the point of applying the force with the RMS value $F_{1,\mathrm{RMS}}$, and Z_1 is mechanical input impedance of the structure in that position. Values depend on the frequency f of the vibrations. For the propagation of the vibrations through the appliance the following equation is applicable:

$$v_{2,RMS} = Hv_{1,RMS} \tag{3}$$

where H is a real, averaged transfer function of the structure, and $v_{2,RMS}$ is RMS value of vibration velocity, taken on average in time and space on the frame of the appliance.
Power W carried by the sound wave (spreading from the housing through the air in the ambience) is:

$$W = \mathrm{Re}(Z_2)v_{2,RMS}^2 \tag{4}$$

where Z_2 represents mechanical impedance of emitting sound from the appliance housing. Mechanical impedance of emitting sound is defined as complex value between the power and speed relationship.

By combining the equations (2) and (3), and applying the result into the (4) we get the equation for emitted sound power:

$$W = \mathrm{Re}(Z_2)\left(\frac{F_{1,RMS}H}{|Z_1|}\right)^2 \tag{5}$$

In this equation the vibration speed in the structure does not figure anymore. Based on the equation (5) it is possible to draw the conclusion that it is possible to reduce the noise output of an appliance at the place of noise generation. We are talking about the so called primary, direct method of noise reduction, [4].

Equation 5 suggests the following options:

- It is possible to reduce the generating force F_1,
- Increase the mechanical input impedance Z_1 of the structure;

- Prevent propagation of vibration by reducing the transfer function *H*; and
- Reduce the radiation of sound waves by reducing the real part of the mechanical radiation impedance of emission Z_2,[4].

The noise reduction process commences with the analysis of the transfer trajectory of sound generated by major sources. Noise coming from the washing machine depends upon: construction, electric motor, rubber elastic parts for vibration absorption, and finally of passive sound insulation. Each part has its characteristics which may reduce or even increase noise. From the energy and ecology aspect, on the first place are these active sources (electric motor, pump), followed by muffling of sound travelling path (elastic materials, composite metal supports for vibration reduction, and sound insulation on the housing panel interior), which technically seems rather effective. The impact of insulation to the overall sound reduction of noise is relatively rather comprehensive, [2].

Because of limited economical costs in the appliance manufacture, this insulation requires maximum optimization. For the same effects of noise reduction the scope of passive insulation must be reduced to the maximum. Consequently the sound insulation must be applied only on those locations which will bring maximum reduction of the entire noise generated by the washing machine.

Below is the description of the methodology related to noise reduction, and the results achieved from the carried procedure.

3. DESCRIPTION OF METHODOLOGY

To get the comprehensive picture regarding the noise from washing machines, all measurements of various modifications on the machine must be carried out during washing, and on different spinning revs. Further it is necessary to create identical circumstances of washing machine operations to the maximum possible level. This would provide cross-referencing and comparison of results on the same or on different washing machine samples.

In the washing procedure the operating mode was simulated by using test laundry. This could have the impact on the repeated measurements due to small variations of water quantity in the drum. Therefore the results for the sound power are obtained as an average value from 5 consecutive measurements.

For spinning function the same upload conditions were obtained by the application of silicone weights. The drum was loaded with 1.5 + 1.5 + 1.7 kg of weights and additional ex-centre of 0.2 kg affixed always at the same point.

Placing the sound insulation at the optimized location in the machine was provided by the application of the sound intensity method and using the B&K software package called "Noise source location". This procedure discovered places radiating partial sound sources and defining their location and the intensity of sound. This way it was possible to pinpoint the location for installing the insulation barrier to get maximized impact of comprehensive sound power reduction.

It was decided to add the insulation gradually on critical points. Sound power measurements were carried out by the method described in ISO 3745, [5]. Sound power was calculated for each stage of insulation layer.

Measurements had been carried out in the hemi-anechoic chamber of 220 m^3 (7.8 x 6.7 x 4.2 m) free volume. Walls and ceiling were covered with 80 cm long absorption wedges. Between the walls and the wedges there was 5 cm of air space, functioning as the Helmholtz resonator. The lower limit frequency is 100 Hz, basic noise in ideal circumstances is13 dB (A).

All measuring instruments and microphones and cables were in Class 1, which means that they met the IEC 61 672-1 2002 requirements.

3.1 Description of particular sound insulation stages

The sound insulation process was divided into six different levels. Measurements were started with the completely sound non-insulated machine. After that we kept adding insulation plates to each consecutive stage of the experiment. The insulation was always placed on those points where the flux of sound energy was larger. Dimensions of insulation plates differed in different stages. For better orientation Fig. 4 displays the cross-section of the process of adding insulation plates in various stages of noise reduction for the sample washing machine.

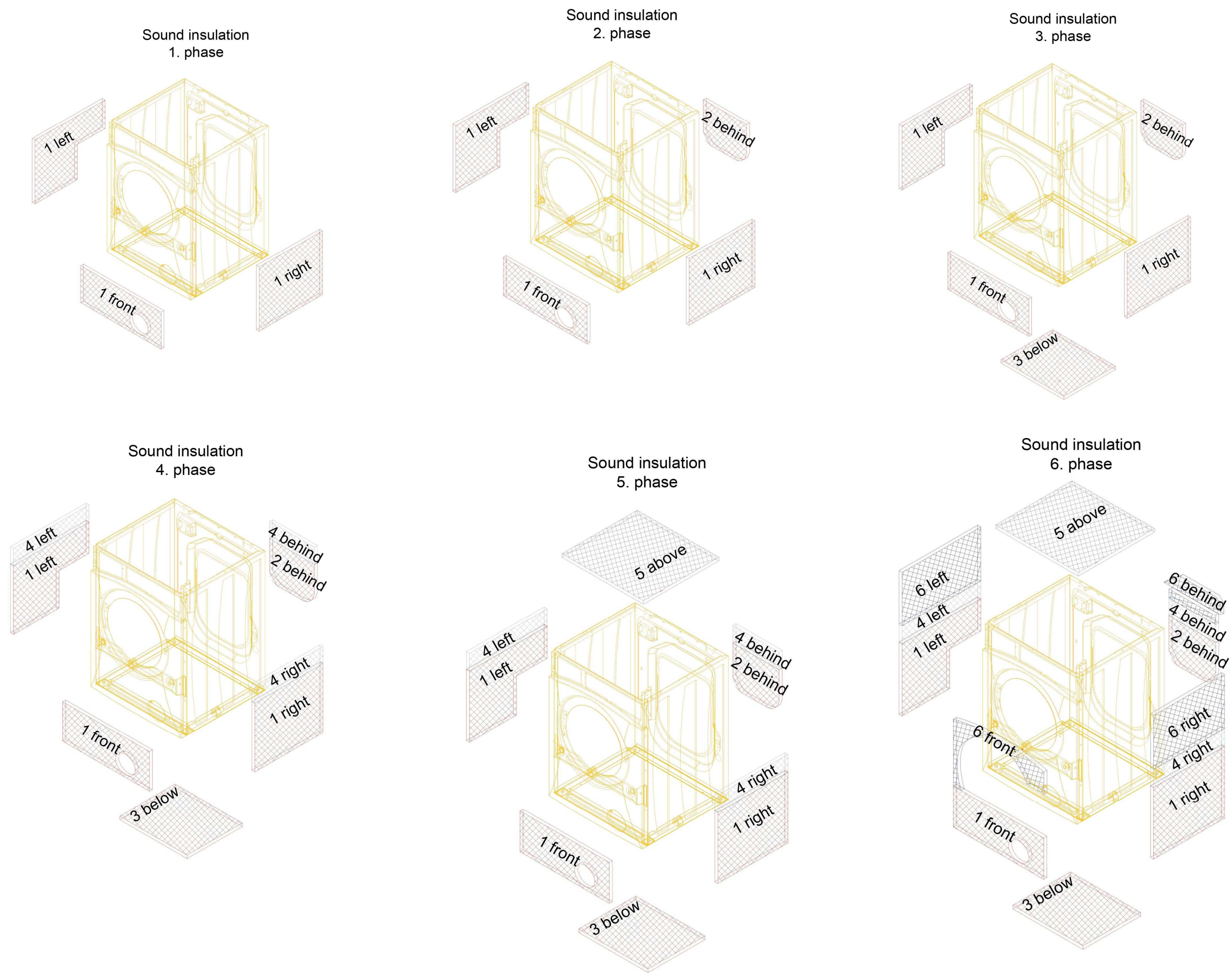

Fig.4. Sound insulation sketches in the washing machine interior from the first to the sixth stage

4. RESULTS

4.1 Sound intensity images

As already described in section three, sound images of washing machines had been recorded in different stages of insulation. Figures 5 through 8 indicate the images of mapping sound intensity for non-insulated machine, stage 1, stage 3, and stage 6. These images provided information for the decisions regarding spots within the interior of the machine that needed sound insulation.

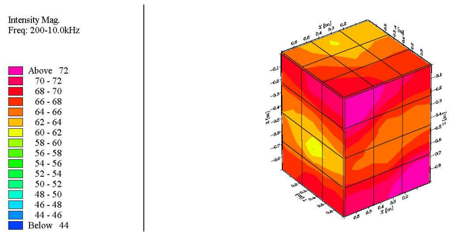

Fig.5. Sound image of the washing machine at 2000 rpm spinning without sound insulation – front left view

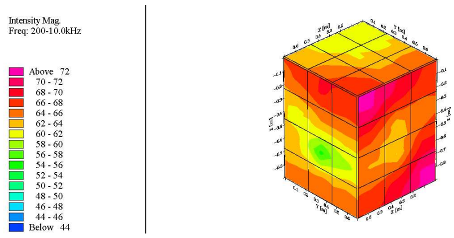

Fig.6. Sound image of the washing machine at 2000 rpm spinning at 1st stage sound insulation – front left view

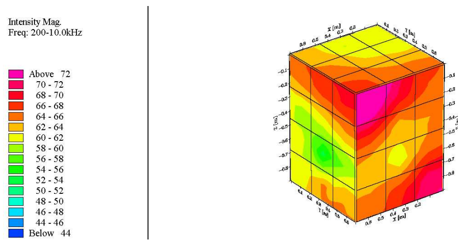

Fig.7. Sound image of the washing machine at 2000 rpm spinning at 3rd stage sound insulation – front left view

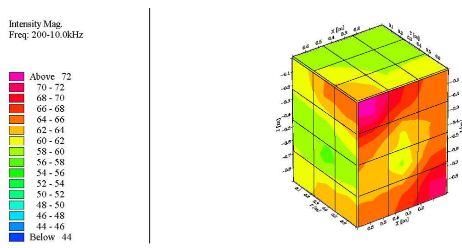

Fig.8. Sound image of the washing machine at 2000 rpm spinning at 6th stage sound insulation – front left view

4.2 Sound-power level in relation to the stage of insulation

Gradual addition of insulation material in different stages was followed by the reduction of sound energy flow at local places resulting in the decrease of the total sound-power level of the washing machine.

Fig. 9 illustrates the dependence of the sound-power level at various spinning revs relevant to the function of various stages of insulation. A–weighted sound-power level of the machine without sound insulation differs from the sound power level in the sixth stage of insulation for 8 dB in almost all spinning frequency (from 1200 rpm to 2000 rpm).

At the commencement of the sound reduction of the machine the largest contribution comes from metallic bottom, immediately followed by the first stage. After that, stage 3 brings an improvement of 1 dB. From stage 3 to stage 6 the sound power reduction level is between 2 and 3 dB.

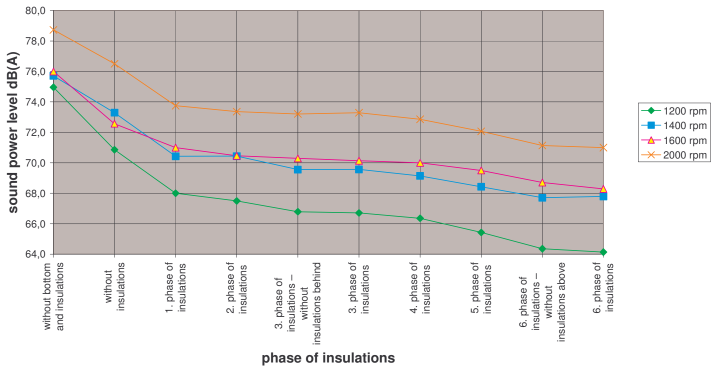

Figure 9. Diagram of sound power level during the spinning in correlation to the insulation stage

Fig. 10 illustrates contribution of each particular stage of insulation in dB to the reduction of total sound power level of the washing machine. Dependence of sound-power level in washing 5.4 kg of laundry in correlation to particular insulation stages is illustrated on Fig. 11. It is possible to conclude that there are similar situations both with the washing cycle and with the spinning cycle. The lowest A–weighted sound-power-level amounts approximately to 47 dB, and in the third insulation stage (which was later accepted as the optimum) the sound power level amounts to 48 dB. We have achieved the target value of the A–weighted total sound-power level in the laundry washing function.

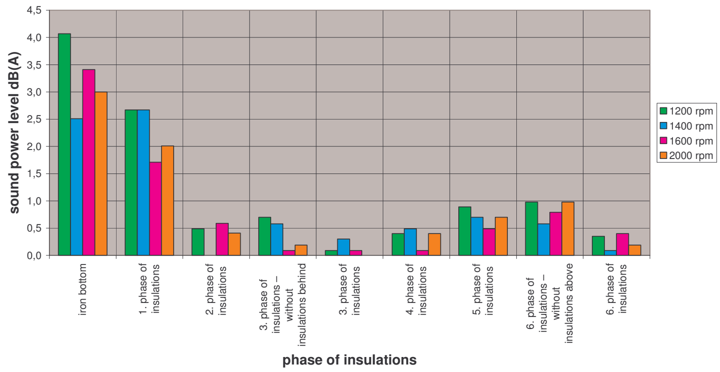

Fig.10. Diagram of sound power level contribution during the spinning in correlation to the insulation stage

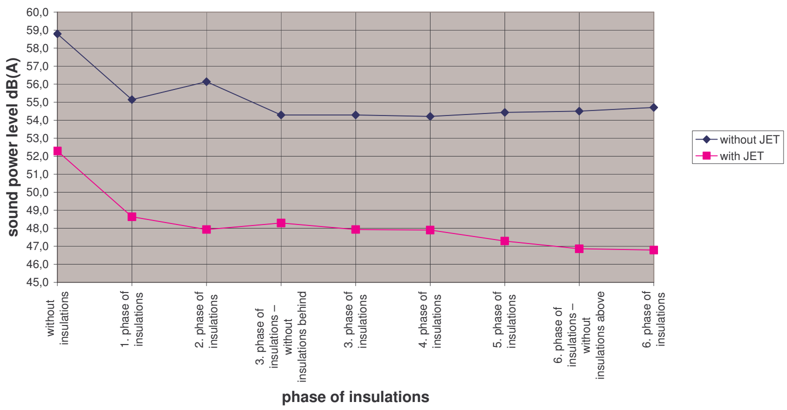

Fig.11. Diagram of sound power level in washing 5.4 kg of laundry in correlation to the insulation stage

During the operation of the JET system (provides circulation of water in the system during the washing cycle – better usage of detergent), the dominant source of sound becomes the JET pump, which fluctuates largely in dependence of different machine variations and models. Fig. 12 illustrates the contribution of sound power level in dB in correlation with the insulation stage.

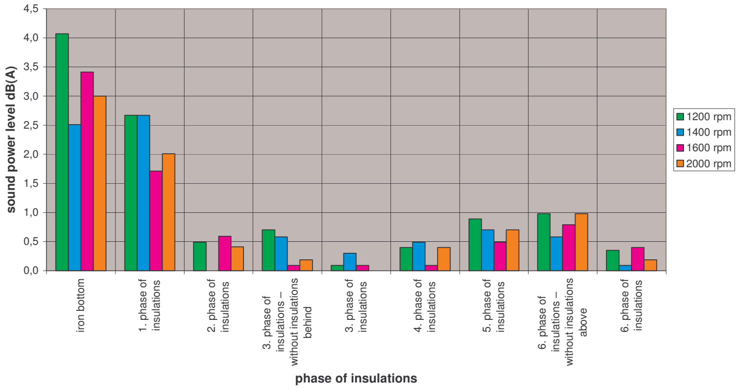

Fig.12. Diagram of the contribution of sound power level in washing 5.4 kg of laundry in correlation to the stage of insulation

6. CONCLUSIONS

Noise of washing machines can not be reduced enough only by the correct selection of active components and reduction of vibrations. The elite market requires the sound power level values which could be achieved only by the application of passive sound insulation. This insulation is placed on the trajectory of sound transfer in the interior of the washing machine.

Alternative procedure of adding passive insulation in the interior of the washing machine which was carried out in six different stages suggested certain conclusions in regard to the optimum quantity of passive insulation. Performed measurements described in this experiment lead to the optimum quantity of insulation for achieving target values of total sound power level. These values enabled the new generation of washing machines to be ranked to the elite A+ class of household appliances at the international market.

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