Structure-borne Noise Reduction in Washing Machines: Noise Reduction by Modal Analysis

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Abstract

There was an unlucky coincidence between a washing machine motor generating frequency and the resonant frequency of a certain motor part. For investigation and refinement work, modal analysis was done using both FEA and experimentation. A simplified model was used to save time during the FEA modal analysis. Shifting the resonant frequency and adding isolation provided a noise reduction of 3 dBA in one particular washing cycle.

Introduction

Pleasantness can include a lot of factors, one of which is 'noise' or 'sound'. The domestic washing machine is often a noisy machine at home. This paper shows steps taken to make a washing machine quieter and therefore more pleasant.

There are several ways noise is generated in a washing machine including:

- Unbalance of washing drum
- Washing drum-structure borne
- Washing cavity - acoustic cavity mode
- Cavity between base bowl and chassis - acoustic cavity mode
- Base bowl vibration
- Shaft vibration (mainly bending)
- Motor electro-magnetic noise and vibration
- Noise leakage from underneath
- Noise leakage from gap between lid and body

If there is a particularly "big" noise source, it can be very annoying. The first preference is for a machine which is quieter overall. Another useful approach is to eliminate particularly annoying noises to achieve a well-balanced spectrum for a given noise level.

One method of vibration analysis is modal analysis. It can be fulfilled in two ways, one by Finite Element Analysis (FEA) computer modelling, and the other by experiment.

Having a similar modal analysis result between the two is ideal, but this does not always happen. In general, it is relatively easy for simple parts, but complex parts are much more difficult.

FEA modal analysis provides a general idea of vibration modes. By using a simplified model the calculation time is usually very short. Modifications can be made many times in a short period providing refinement relatively quickly.

Experimental modal analysis provides the real behaviour of vibration modes and exact frequencies.

Since a FEA model contains many assumptions, experimental analysis is generally more reliable than FEA.

During development of a new washing machine at Fisher & Paykel, a 100Hz noise problem was discovered.

This paper shows where the noise came from and methods of investigation and refinement for noise reduction.

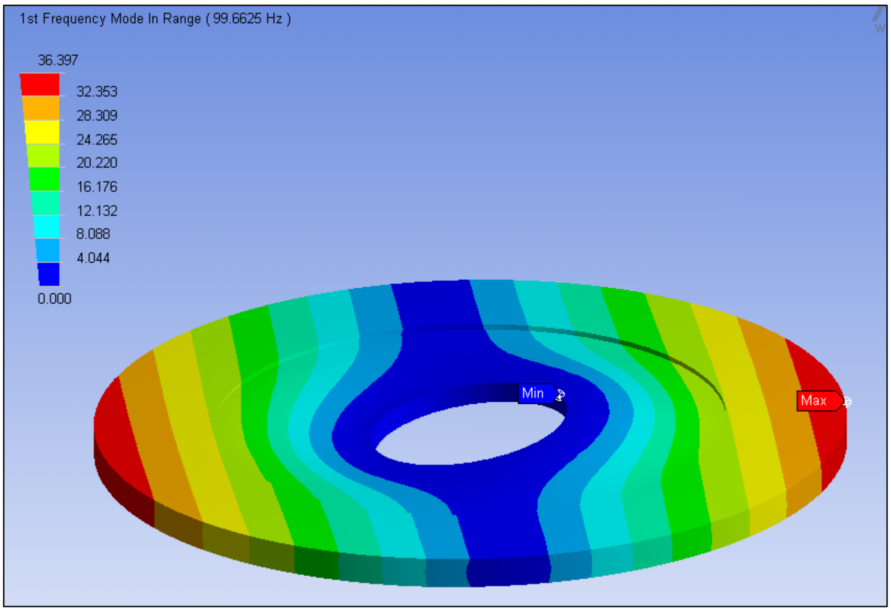

Figure 1 The first mode (99.67Hz) of a motor part of simplified model by Ansys analysis

Noise generating situation

Motor operating speed and the major pulse frequency

When a motor operates there is a major vibration frequency determined by the number of stator poles and rotor slots.

The fundamental vibration frequency, c, is given by:

c = The least common multiple of ‘a’ and ‘b’

Where;

a = Number of stator poles

b = Number of rotor slots

For example: in the case of a stator with 10 poles and 14 slots, c will be 70. If the machine works at 100rpm, then

$$\frac{f \times 60}{c} = 100rpm$$

Hence, f=117Hz.

117Hz is a major exciting frequency.

Washing machine case

There are 5 to 10 different washing cycles and a spinning cycle in the washing machine of interest. One of these wash cycles creates a 100Hz noise. Using the calculation above it has been confirmed that this correlates with the fundamental frequency of the motor operation .

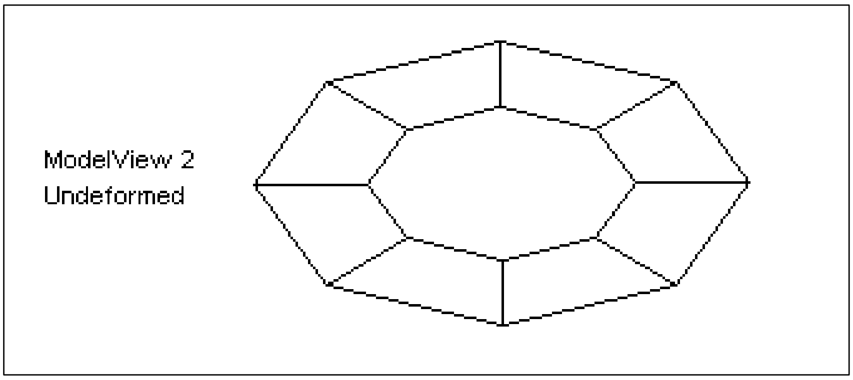

Figure 2 Base model for experimental modal analysis

Solving the problem

Searching noise generation regions

Using simple noise and vibration measurements, it was relatively easy to see that 100Hz was the problem frequency. Further investigation also confirmed quite a few areas and parts had a 100Hz resonant frequency, some of which were significant contributors to 100Hz noise generation in operation.

Noise generating mechanism in a washing machine

After measuring noise and vibration in many positions on the washing machine and some modal analysis, the 100Hz noise generation mechanism has been significantly reduced.

The 100Hz noise generation situation is

- The washing cycle runs at or passes 100Hz.
- The major motor generation noise and vibration is 100Hz
- One of the motor parts resonates at 100Hz.
- Some of the washing parts also resonate at 100Hz.
- Some of the washing parts also have a 100Hz resonant frequency, however not all of them contribute significantly to the overall noise level.
- The base bowl has a lot of vibration modes because it is a relatively big part and has a

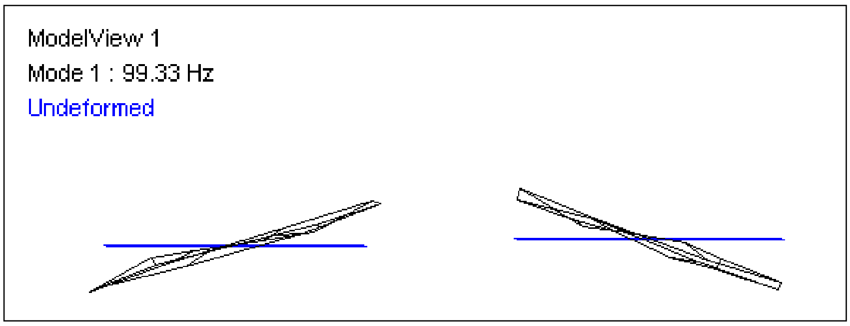

Figure 3 First mode of the motor part – rigid body rolling

complicated structure. It can also transfer vibration to the machine case.

Modal analysis

Modal analysis has been done using both FEA and experimentation for one of the motor parts. Initially a simplified model was used with Ansys (version 9) and the mass and thickness tuned to achieve the right frequency and mode shape. (Fig 1) Experimental modal testing using Star Modal (version 6.3) confirmed the frequency and mode shape. (Fig 2 & 3)

The motor part was treated and calculated as a single degree of freedom spring/mass dynamic model, using the outer part for mass and middle part for spring.

Solutions to the problem

The 100Hz noise and vibration generated by the motor can be magnified by resonances in other parts of the washing machine.

In order to be away from the resonant frequency, it was necessary to shift the frequency lower or higher. Shifting to a lower frequency was chosen. Holes were added to the spring function area, thereby reducing part stiffness. Before making a modified prototype part an Ansys analysis was done. (Fig 4)

The vibration mode shape for the modified part is still the same roll mode, however the frequency has shifted significantly. Rather than making a lot of holes, the frequency shift was prototyped by reducing part wall thickness. Shifted roll mode frequency is 80Hz.

The other major solution was isolation between motor and base bowl.

Results

Noise and vibration data for both original and modified conditions is shown in figures 5 & 6. Noise reduction in the 100Hz area is by frequency shift of the motor part and isolation.

Other frequencies are by isolation alone.

Fig 6 shows vibration data from the underside of the base bowl.

Conclusions

- Modal testing was useful to provide detailed information

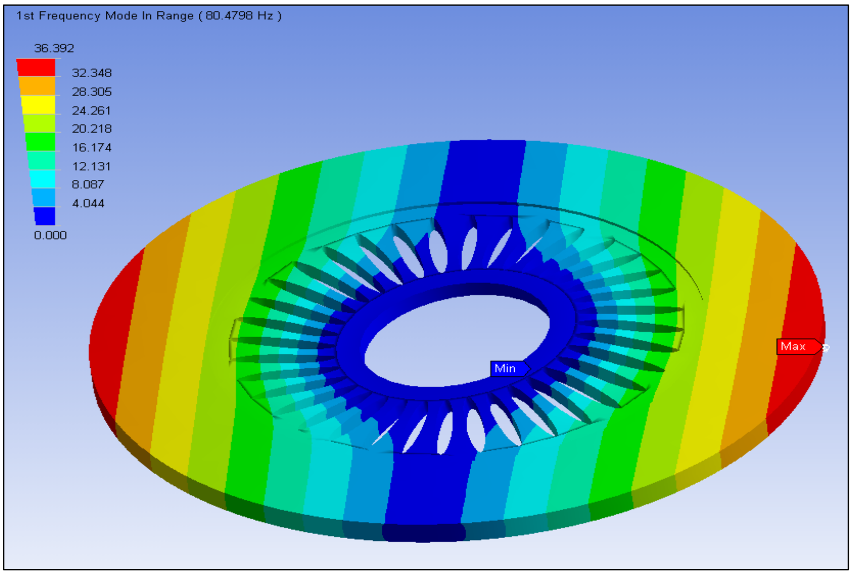

Figure 4 Changed first mode frequency (80.48Hz)

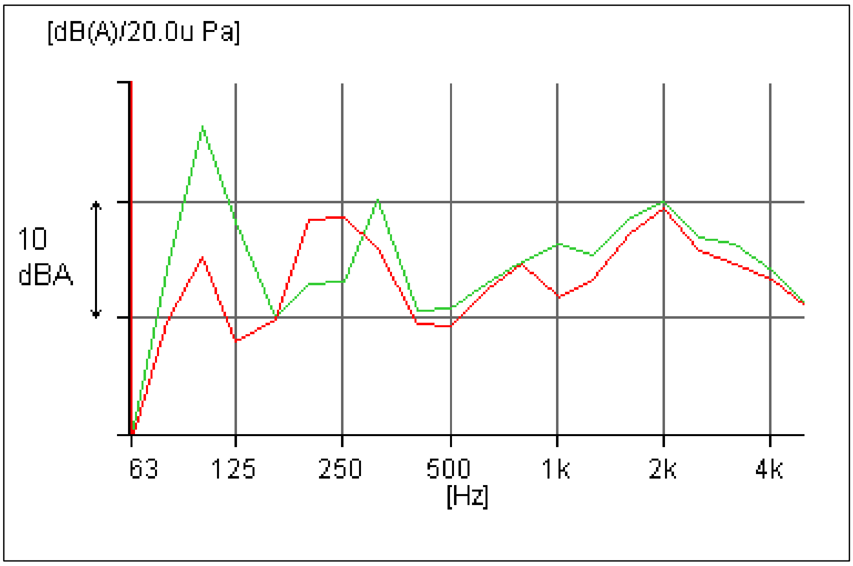

Figure 5 1/3 Octave noise (Pale: original, Dark: modified)

and an understanding of vibration phenomena.

- A simplified model provided a fast way to calculate modes for various modified models without making real test samples.
- The stiffness of a motor part with 100Hz resonance was reduced to shift the driving frequency away from the resonant frequency of other components.
- Vibration isolation proved to be a very useful noise and vibration solution.
- The washing machine sound pressure level was reduced by 3 dBA for the problem cycle. The noise profile in 1/3 octave bands is now well balanced in all frequencies and therefore far more pleasant than prior to treatment.

Acknowledgments

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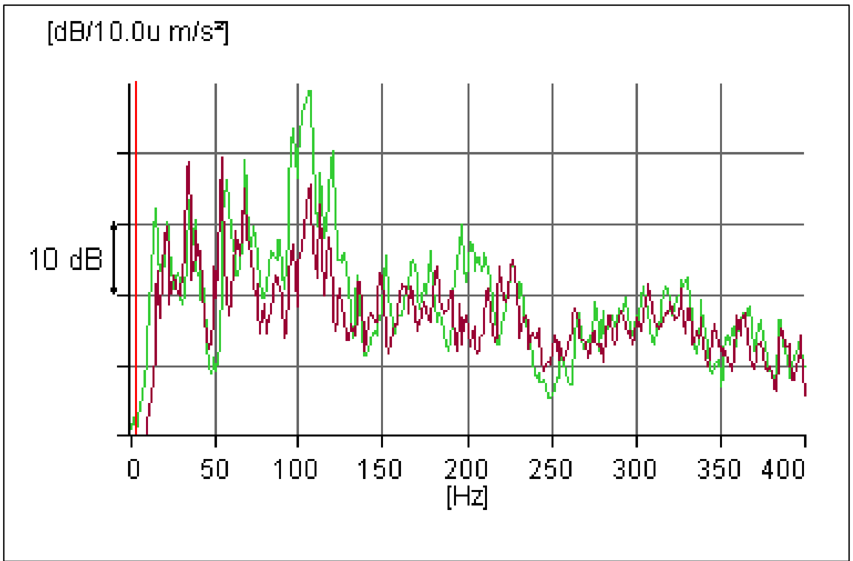

Figure 6 Base bowl vibration (Pale: original, Dark: modified)