Noise Reduction of an Electrical Motor by Using a Numerical Model

Ahmet Ali Uslu
Arcelik A.S. R&D Department, Vibration & Acoustic Technologies Laboratory, Istanbul, Turkey.

Summary
Electrical motor is one of the most important noise sources for washing machine. The aim of this study is to create the vibration model of an electrical motor, which is used to excite a washing machine. By using this model, it is possible to determine the vibration attitudes of the motor. It is also possible to see the effects of the modifications before producing prototypes.
First, the finite element models of the motor components are created in a FEM software. After the experimental verification of the numerical models of motor components, elastic models of components are exported to a multi-body dynamics software and whole motor model is created. After that, numerical analyses are done and natural frequencies and mode shapes of the entire motor model are determined. After the experimental verification of natural frequencies which are extracted from numerical model, some modifications are done on numerical model. The effects of these modifications on the vibration attitude of the motor are inspected. For the final step, some prototyping studies are carried out and effects of these modifications on washing machine noise are observed. According to the final measurements, 3 dBA decrease on sound power level has been achieved.

PACS no. 43.40.+s, 43.50.+y, 43.58.+z

1. Introduction

The electric motor is used to drive an automatic washing machine. It is one of the most important noise sources in the washing machine. When it is excited at its natural frequencies, it generates high vibration and noise because of resonance. In order to discover the modal attitude of the motor, it would be a big advantage to have a verified numerical model.
For the numerical modeling of electrical motors relating to noise and vibration problems; Liang, Li and Wang [1] analyzed the mechanism of motor vibration by using a software and a data acquisition system. Yan, Feng, Zhu and Yang [2] used the finite element analysis to study on the stator modal shapes and natural frequencies of the induction motor. They also calculated the electromagnetic force by using the finite element method and got the spectrum distribution of the radial electromagnetic force. Lennström [3] investigated the methods for motor noise evaluation and control in electric vehicles. McCloskey, Arrasate, Hernandez and Salgado [4] simulated the vibroacoustic performance of an electric motor by using finite element software. The electromagnetic forces were also applied to the whole machine model in order to obtain the vibration response. Eis [5] discussed electric motor vibration from the viewpoint of its causes and cures. The study also covered the important considerations in establishing purchase specifications consistent with final installation requirements. Hallal, Pellerey, Marion, Druesne and Lanfranchi [6] used a multi-physics numerical model in order to predict mechanical vibration caused by magnetic pressure in a wound rotor synchronous machine.
In this study, an electrical motor is modeled numerically and used to understand the vibration characteristics of the motor. In order to get a full motor model, firstly components should be modeled one by one in a FEM software, NX. After the validation of FEM models with the numerical measurements, these components are joined to each other in an industrial software, ADAMS. In ADAMS environment, modal shapes and resonance frequencies of the entire motor model are calculated. With this numerical model, the most critical natural frequencies are determined. Designing new components and adding them into the motor model give an idea about how the modifications affect the vibration

characteristics of the motor. In the last step, physical prototypes are produced and experimented. The electrical motor used in the studies is shown in Figure 1.

Figure 1. Electric Motor of an Automatic Washing Machine

1.1. Effect of The Electrical Motor on Washing Machine Sound Power Level

Electrical motor has an essential effect on the total sound power level value of the washing machine. Sound power level spectrums of a 8 kg capacity washing machine with 1400 rpm spin speed are shown on Figure 2. Spectrums show that different measurement results are obtained with different motors. According to the Figure 2, changes on the sound power levels of the washing machine could be up to 3 dBA with the change of motors. It also can be seen that the biggest change in the spectrums occurs on the 630 Hz value. In order to investigate the effect of the electrical motor on the washing machine total sound power level, a numerical model is built and utilized.

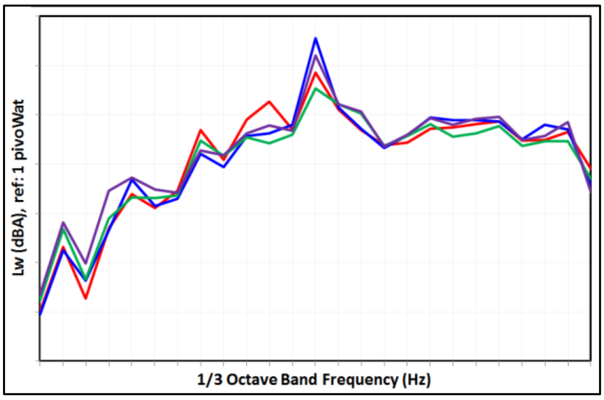

Figure 2. Sound Power Spectrums of Washing Machine

1.2. Free Vibration Models of The Motor Components

A geometric model describes the shape of an object by means of geometric concepts. Both 2D and 3D geometric models are extensively used in computer graphics. In this study, the 3D motor cover models are created in a modeling software, I-DEAS. Since Shell (2D) mesh will be used in the finite element model of the covers, midsurface operations were done. First, midplanes of the covers are extracted and then they are joined to each other to complete the midsurface generation. By using a finite elements software, NX, mesh operations are completed and finite element models of motor covers are created. In this phase, no boundary conditions are defined for the model. The solution is done with free free conditions. This is because the experimental studies, which will be compared to numerical results, are done with the same conditions, free free conditions.

The finite element method is an approximate technique. The differential equations are solved by discretizing the domain of the solution into a mesh consisting of a number of finite elements connected at nodal points. The solution within each element is usually assumed to be a fairly simple polynomial form, such that a piecewise continuous solution is obtained over the entire domain. The direct solution of the unknown variables is obtained at the nodal points. Because this is only an approximation of the real problem, it must be ensured that these approximations are appropriate.

Shell (2D) mesh could be used if property changes may be neglected through the thickness. 2D mesh is used for the FEM model in this study. The assumption of taking the properties constant through the thickness could lead us to some errors, but the computing time is much shorter in the case of using shell elements because the number of elements decreases. The finite element models of the motor covers are shown in Figure 3.

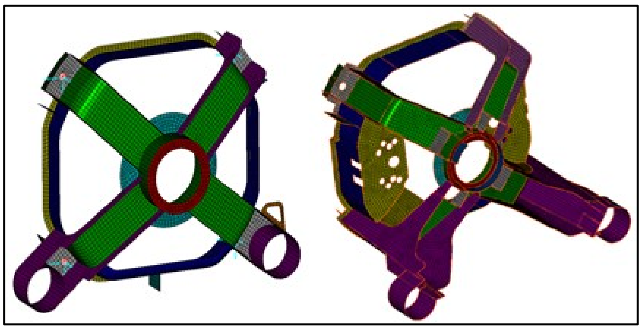

Figure 3. Finite Element Models of Front and Back Motor Covers

The models should be validated by using an experimental measurement. Therefore numerical frequency response functions are calculated from the finite element models. Then these frequency response function results are compared with the experimental results. The compared frequency response functions of the front and back motor covers are shown in Figure 4 and 5.

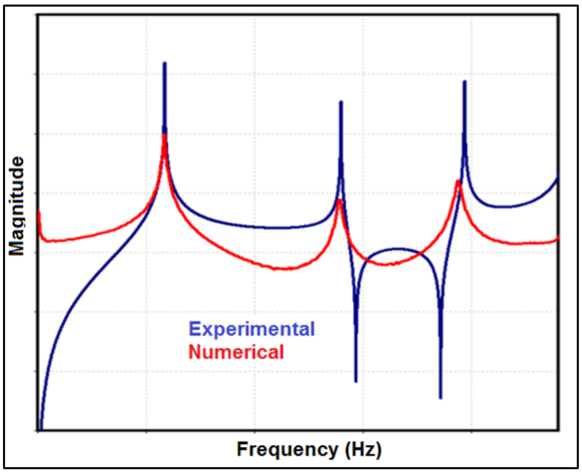

Figure 4. Comparison of Numerical and Experimental FRFs for Front Motor Cover

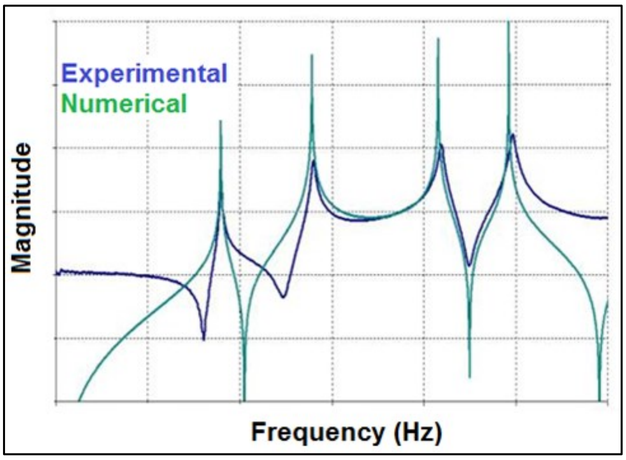

Figure 5. Comparison of Numerical and Experimental FRFs for Back Motor Cover

According to the Figure 4 and 5, there are considerable consistence between the numerical results and experimental results. So, modeling phase can be continued for the other components.
The axle and rotor are modeled as a group together by using both 1D (beam – for axle) and 3D (solid – for rotor) elements. The finite element model for axle rotor group is shown in Figure 6. The comparison between the numerical and experimental FRFs are shown in Figure 7.

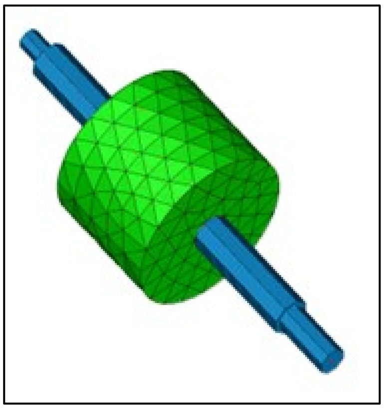

Figure 6. Finite Element Model of Axle-Rotor Group

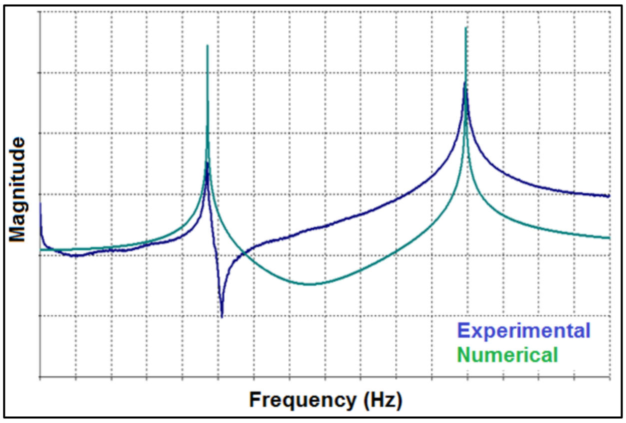

Figure 7. Comparison of Numerical and Experimental FRFs for Axle-Rotor Group

The stator, which is located on the center of the motor assembly, is assumed as rigid; and added to the numerical model as a rigid part.

1.3. Creating the Numerical Model of the Motor Assembly

After creating and verifying the finite element models for the components of the motor assembly, the files are exported to a multibody dynamic software environment. In this study, ADAMS is used in order to create the complete motor model. Since the standard module of ADAMS, which is called ADAMS View, only lets users to study with rigid parts, ADAMS Flex module is used in this study. In addition to the parts that were mentioned in the previous section, stator, connector and pulley are joined to the model as rigid parts. After creating the boundary conditions, the final model of electrical motor is shown in Figure 8. The ball bearings are modeled by using the connection elements called bushing. Bushings are the elements that possess three directional and three rotational stiffness values.

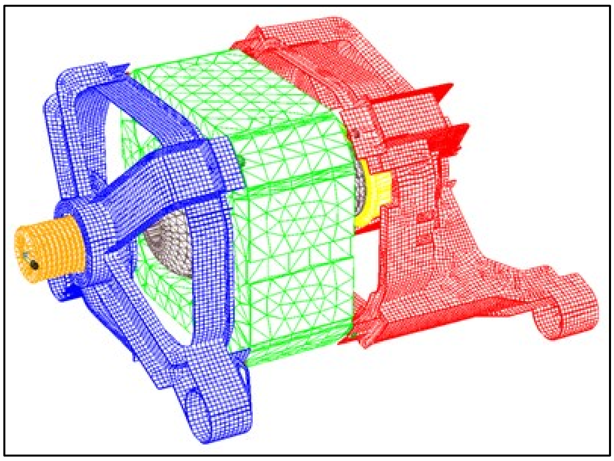

Figure 8. Numerical Model of Electric Motor

By using the Vibration module of the ADAMS software, numerical vibration analyses are completed and free vibration modes of entire motor model are obtained. The natural frequencies and the mode shapes of the motor model around 630 Hz can be seen in Figure 9.

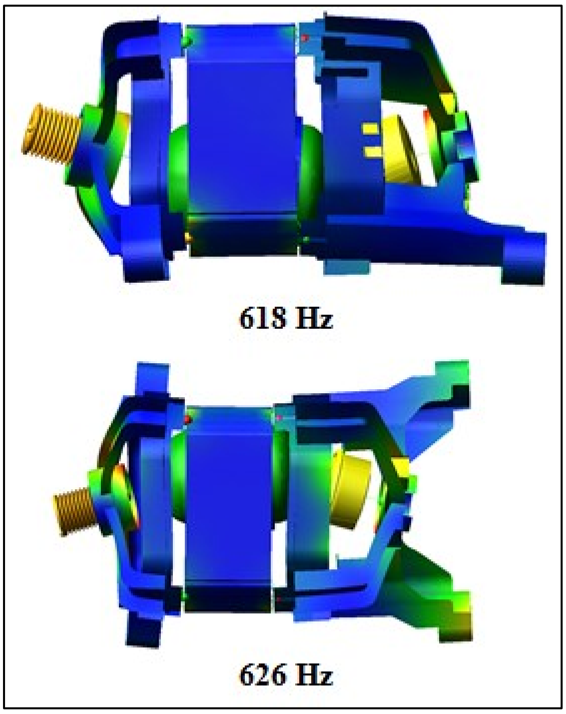

Figure 9. Natural Frequencies and Mode Shapes of the Electric Motor Around 630 Hz

The FRF verification of the numerical model should be done before it can be used as a useful tool for prototyping process. For this reason, a numerical frequency response function is calculated from the numerical model and it is compared to the experimental result obtained directly from the motor itself. The excitation and measurement points used for calculating or measuring the FRFs are shown in Figure 10. The comparison between numerical and experimental FRFs is shown in Figure 11.

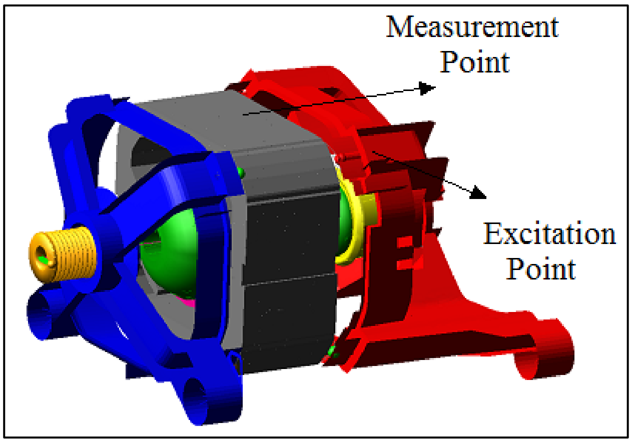

Figure 10. Excitation and Measurement Points for FRF Calculation

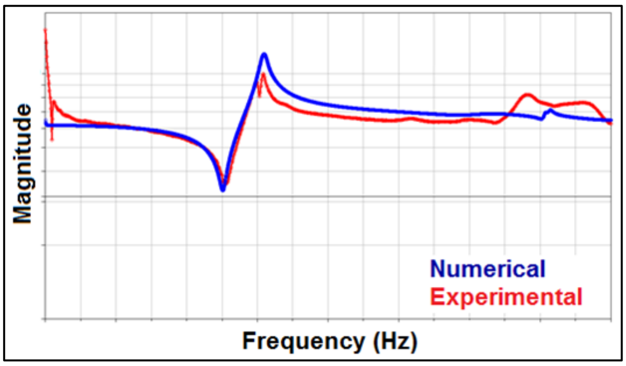

Figure 11. Comparison Between Numerical and Experimental FRFs

Figure 11 shows that the numerical model represents the vibration behavior of electrical model quite accurately. Since it is learned from the numerical model that the mode at 630 Hz is originated from the bending of the axle, it can be said that the noise problem of motor and the washing machine is occurred because of the bending mode of the motor axle. In order to overcome this high noise problem at 630 Hz, new axle prototypes are created and used in the numerical environment.

1.4. Modification on the Numerical Model

In this section, the effects of the modifications of numerical models by changing the axle design are inspected. For a 1400 rpm (~23.3 Hz) spinning phase of washing machine, the electric motor roughly operates at 295 Hz since the rotation ratio between the motor and drum equals to 12.6. Thus, the second harmonic of the excitation frequency excite the natural frequency of the bending mode of the motor axle at 620 Hz and causes resonance. Thus, in order to prevent this problem, bending mode of the axle is tried to be shifted to higher frequency values. One of the easiest and most applicable ways to do it is shortening the axle length. The length of the motor axle (i.e. the distance between two ball bearings) is reduced to 160 mm from 172 mm. The effect of this modification on the frequency response function of the motor model is shown in Figure 12.

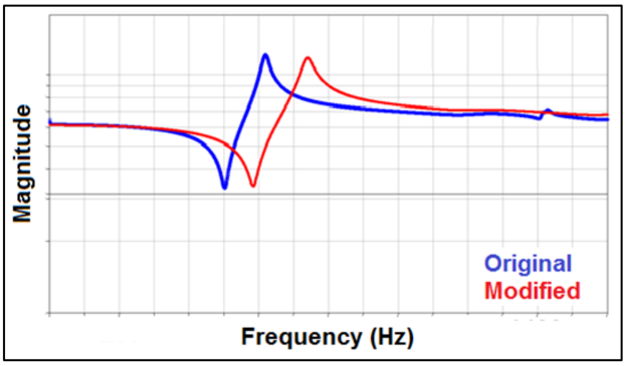

Figure 12. FRF Change with the Modification of Motor Axle

As it can be seen on the Figure 12, shortening the axle length by 12 mm carries the natural frequency to 710 Hz from 620 Hz. It would probably ensure that natural frequency of the motor is safely distant from the second harmonic of the excitation frequency. Considering that it would solve the high noise problem of washing machine, the prototype of the new axle design was manufactured and assembled with the electric motor.

1.5. Results

After the installation of the new axle prototype to the electric motor, a frequency response function of the motor is measured with an impact testing. As expected, the natural frequency of the electric motor is shifted to above 700 Hz. This result proves the accuracy of the numerical motor model one more time. The comparisons between the numerical and experimental results are shown in Figure 13.

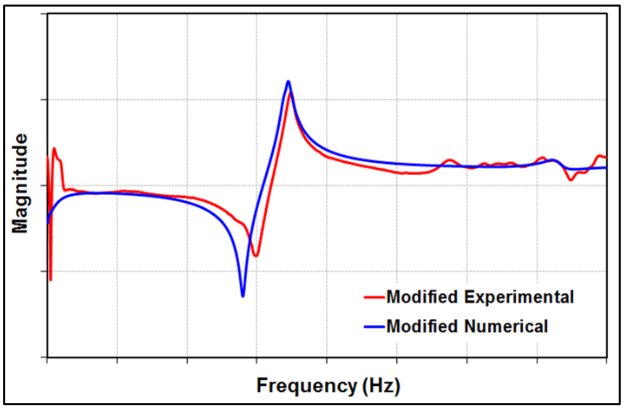

Figure 13. Comparison Between Numerical and Experimental FRFs

For the final step, the modified electric motor prototype is installed to the washing machine and repetitive sound power level measurements are performed. Average sound power level of the washing machine with the new electric motor prototype is shown in Figure 14 with the comparison of the original sound power level of the washing machine. Figure 14 shows that there is a very critical reduction at the 630 Hz and it provides an average of 3 dBA noise reduction in total sound power level.

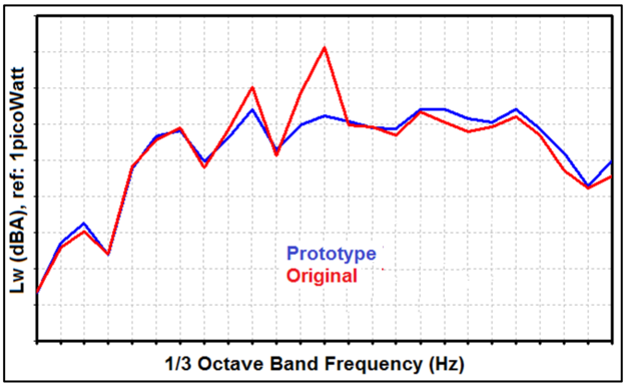

Figure 14. Decrease on Sound Power Level

2. Conclusions

This paper presents a study to create the free vibration model of an electric motor, which is used for driving the washing machine. By using this model it could be possible to determine the vibration characteristics of the motor. First, the validation of the model has been done by comparing numerical results with experimental measurements. Then it could be possible to use the model in order to inspect the effects of some modifications before the prototyping process. The measurement results showed that the numerical model represented the vibration attitude of electric motor quite accurately. A new axle design was used in order to shift the bending mode of the electric motor to higher frequencies. According to the final measurements, 2 dBA decrease on sound power level has been achieved.

As a general rule, the bending natural frequencies of the electric motors should be as far as possible from the excitation frequency or multiples of the excitation frequency. It provides the motor operates at “safer” frequencies, and helps sound power level decrease. Easiest and most applicable methods for shifting the bending mode of the motor are shortening or thickening the motor axle. Changing the profile of axial section could be another option as well.

References

[1] Y. C. Liang, Y. C. Li, J. Q. Wang: Study on the Motor Vibration Based on LabVIEW and FFT. Applied Mechanics and Materials, 06/2014.

[2] R. G. Yan, X. Feng, L. H. Zhu, Q. X. Yang: Vibration Analysis of Motor Stator. Advanced Materials Research, 02/2014.

[3] D. Lennström: Methods for Motor Noise Evaluation and Control in Electric Vehicles. Licentiate Thesis. Lulea University of Technology, Lulea, Sweden, 2013.

[4] A. McCloskey, X. Arrasate, X. Hernandez, O. Salgado: Measurement and Simulation of the Vibroacoustic Performance of an Electric Motor. Vibration Engineering and Technology of Machinery, Mechanisms and Machine Science, 01/2015.

[5] R.O. Eis: Electric Motor Vibration-Cause, Prevention, and Cure. IEEE Transactions on Industry Applications (Impact Factor: 2.05). Large Motor and Generator Department, General Electric Company, Schenectady 06/1975.

[6] J. Hallal, P. Pellerey, F. Marion, F. Druesne, V. Lanfranchi: Harmonic pressure optimization on numerical electric motor model. COMPUMAG2013, Budapest, Hungary, 2013.