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Mathematical Modelling and Analysis of BLDC Motor for Vibration and Noise Effect Along with Current Variation

Yogesh Singh Barod[1], Alka Thakur[2]
[1]*M.Tech. Scholar, Department of Electrical Engineering, Sri Satya Sai University, Bhopal, India*
[2]*Professor & HoD, Department of Electrical Engineering, Sri Satya Sai University, Bhopal, India*

***Abstract*: It is evident that an induction motor is very reliable, robust and efficient machine used for various industrial applications under various loading conditions. Induction motors are cheaper in cost, rugged in construction and require very little maintenance. Lightweight, compact and inexpensive DC motors are well suited for low cost high production use in industry. Unfortunately, the audible noise emanating from these motors can cause a false negative perception of the motor's quality. The objective of present study is to examine the connection between motor noise and the line current wave for a specific four pole BLDC permanent magnet motor. In Current study we are using Ansys Maxwell for Simulative investigation. BLDC Motor is designed in RMxpert. Simulative results show an excellent stable flow in linear harmonic analysis for various frequency level. It is observed that vibration signals are well in range as per the ISO 7919-2: 2001 guidelines however acoustic noise signals are almost double of higher side of prescribed range as per the IEEE Standard 8i.5-1980. Therefore, it is required to understand and develop the methods to supress the acoustic noise from the BLDC drive.**

***Keywords*: Acoustic noise, brushless direct current (BLDC) motor drives, field-programmable gate arrays (FPGA), pulse width modulation (PWM) and vibration, Ansys Maxwell.**

1. Introduction

A. Background and motivation

It is hard for us to imagine today's world without electric motors. And their use keeps expanding into ever new areas of our lives. At the same time, we are becoming increasingly demanding when it comes to the acoustic quality of these motors. Manufacturers of motors and other equipment increasingly need to have broad competence in dealing with noise. In fact, Success in the competitive marketplace is coming to depend on having such acoustic know-how. Unfortunately, manufacturers often have a hard time finding solutions to their noise problems. It is often extremely difficult even to describe a problem in a qualified manner. Frequently, this is not even attempted. Instead, people come up with vague statements like "We have a noise problem!" Many times engineers and technical people who are not experts in acoustics are assigned the task of solving this noise problem. This study is intended to help them arrive at an efficient and effective procedure for eliminating irritating vibration and acoustic problems with small electric motors. It is based on real-world industrial experience and is not intended to be an academic text, but rather a practical manual. Until now there has not been any literature on possible approaches to the analysis and elimination of vibrations and noises in small motors. The purpose of this study, therefore, is to provide users and manufacturers of small electric motors with the basic understanding needed for dealing with noise. In the first chapter we introduce the vibration and noise behavior of small electric motors and present key terms and the relationships between these terms. We then describe various options for reducing noise. Finally, we address the key principles of mechanical vibrations and acoustics needed to achieve success. The remaining chapters deal in detail with measuring vibrations and noises, with the analysis of these measurements, and with the problems associated with noise testing in large-scale manufacturing. The principal methods are illustrated, together with their advantages and disadvantages. The study concludes with a series of examples from actual industrial practice.

B. Introduction to the topic

When motors of all types and sizes are evaluated, the main concerns involve the quality of the desired functions, service life, and purchase and operating costs. Side effects such as heating, vibrations and noise are generally undesirable, and they play a very important role in the decision to use a specific motor. Small motors are usually installed in tight spaces in equipment, so that the heat they produce can be particularly disadvantageous, even when the actual heat output is small, since the surrounding equipment itself often offers little opportunity for removing heat. Since these motors are usually located close to humans and to their ears and sense of touch , the noise and vibrations that they are permitted to generate are significantly less in relative terms than would be permitted for larger motors. For large electrical machines and motors there are standards that must be used to measure and evaluate noise and vibrations. Considered in isolation, a small motor is barely audible because of its small dimensions. Even the vibrations it produces are generally not found to be objectionable. A small motor does not have a significant impact until it is installed in or on a piece of equipment and then evaluated subjectively, usually only in this installed environment. This subjective evaluation of the noise and vibration characteristics of the motor installed in the equipment must be quantified by means of measurement technology.

C. Basics of vibrations, structure-borne noise, and airborne noise

Noise and vibrations are oscillations, namely changes of states or conditions that occur with periodic regularity. We describe an oscillation by the duration of its period or frequency and by the maximum value of its state over time (amplitude). There are many kinds of oscillations. In the text below we shall only consider those whose states involve periodic movement in space (mechanical vibrations). Such movements can be generated by periodically changing forces, such as those encountered in a crank mechanism (forced excitation). But they can also be produced independently by a spontaneous exchange of energy between various energy stores, such as that which occurs with elasticities (stores for deformation energy) and inertial masses (stores for kinetic energy), if these stores can in some way be energized (for example: a swing, bell, violin string, whistle). An oscillation that is controlled by means of these energy stores is called a natural oscillation. Its frequency (natural frequency) is often determined solely by the properties of the energy stores and not by the energy that is stored in them. Because of the unavoidable damping that causes energy to be "lost" (for example: the energy that is consumed when materials change shape), a natural oscillation cannot be maintained indefinitely unless a source of appropriate energy is applied further to the system. In addition to the supply of energy by means of an appropriate forced excitation, a supplier of power that is constant over time can, as a result of the properties of an oscillatory system, produce self-controlled, i.e. self-generated, natural oscillations (such as friction-caused vibration, whistling noises).

D. Causes of vibrations and noises in small motors

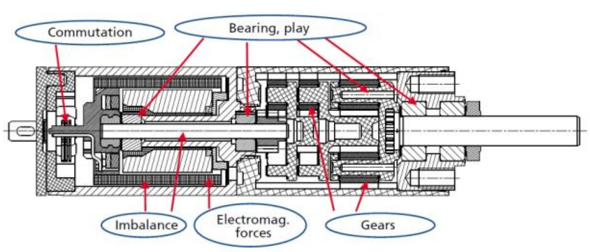

Fig. 1. Sources of vibrations and noises in an electric motor

In each motor undesirable forces, torques, and motions are unavoidably produced in addition to those that are desired. Undesirable fluctuations (oscillating torques) are superimposed on the desired electric motor torques. This results in oscillating rotational movements. Radial forces caused by imbalance and magnetic effects cause radial movements. Friction forces that fluctuate over time occur in bearings and on sliding contacts and cause undesirable movements. When gearboxes are installed in equipment, undesirable rotational oscillations are caused by the gears. All these movements constitute structure-borne noise, and they are transferred as such to the vibrating surfaces of the motor. Fig. 1 shows typical examples of the main locations at which vibrations and noises can be produced in an electric motor.

2. Literature review

A. Motor Noise Research

Motors are used in every facet of modem life. As the public demands a quieter environment, the emitted noise and vibration levels of motors must decrease. Lightweight, compact, and inexpensive DC permanent magnet motors are increasingly being used in industry. In the automotive industry, they are used extensively to drive fans, windshield wipers, antenna lifts, and power windows. In cars, fan rnotor noise can be a nuisance and a quality defect. Active noise suppression, where speakers are used to cancel noise emanating from annoying sources, would be very effective but expensive. Mechanical dampers, such as rubber boots, reflecting enclosures such as used with refrigerator compressors, and adsorptive silencers around the motor, lower the level of transmitted noise. Unfortunately, mechanical dampers aren't always economical or adequate and they are almost always bulky. Signature analysis can be used in determining where motor noise originates. The frequency spectrum is used to identify whether the noise in an induction motor is of magnetic origin or from the wind age. In a vacuum cleaner, signature analysis can pin down whether the noise is due to the airflow, motor or surrounding structure. Laser holography can be utilized to do a modal shape analysis. It has been used to determine the complex mode shapes of an automobile engine. After the vibration analysis is came out, mass can be added to or removed from the motor case in such a way as to eliminate imitating noise frequencies by eliminating the corresponding mode shape. Noise levels are reduced by decreasing vibration, because the noise is related to the level of vibration.

3. Objective of the study

Electric motors play an important role in industry, and the induction motors are the most widely used among them. Any motor failure interrupts the process, causes loss of productivity, and may also damages to other machinery. Therefore, to prevent sudden failure of motor (such as on the large or critical motor) it is essential to have an early fault detection mechanism. The work presented in this paper is concerned with the detection of the mechanical faults in three phased induction motors. Motor current signal analysis (MCSA) is used in identification of artificially induced mechanical faults, and it is also supported with vibration signal analysis. The most common mechanical problems; mechanical unbalance, shaft misalignment, and bearing failures are investigated experimentally. In Present study we will investigate the effect of current variation on noise generation in DC Motor with the help of Simulation. Simulation will be done in Ansys Software and proposed results are noise level and frequency for the system in different current zone.

4. Methodology

Basic steps to perform ANSYS Maxwell

A. Maxwell Designs

1) Adding a design to Maxwell

B. Maxwell Design Types

1) RMxprt

Rotating Machinery Expert is an interactive analytical tool used for designing and analyzing electrical machines.

2) Maxwell 2D

Maxwell 2D uses Finite Element Analysis to simulate and solve 2D electromagnetic fields in XY or RZ planes.

3) Maxwell 3D

Maxwell 3D uses Finite Element Analysis to simulate and solve three dimensional electromagnetic fields.

C. Solvers in Maxwell

1) Setting a Solver Type

Appropriate Maxwell solver can be selected based on the application being solved.

Solver type can be set by selecting the menu item *Maxwell 3D/2D*

Solution Type

For 2D, users can also specify if the problem will be solved in XY or RZ plane

2) Magnetic Solvers

Magnetostatic Solver

Solves Static magnetic fields caused by DC currents and permanent magnets. Can solve both Linear and nonlinear materials.

- Design Based on requirement of BLDC 4 Pole Permanent Magnet
- Circuit Design
- Slot design: - Selection of type of slots and dimension for the slot, conductor cross selection and dimension's.
- Winding Design for Stator: Circuit selection and connection design
- Magnet Design for Rotor: Selection of Material for Magnet and design of 4 pole magnet.
- 3D Model will be created in RMxprt: Defining all the dimension and parameters in RMxprt for 3D modal creation.
- Export Model from RMxprt: Export Model in CAD neutral format
- CAD Model is added to the Ansys Maxwell
- Solution of Problem in Maxwell 3D with Parameters at constant Power
- Post-Processing in Maxwell 3D

5. Results and discussion

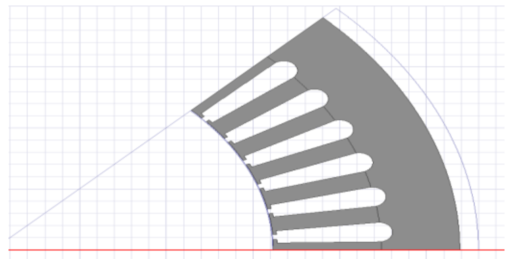

Fig. 2. Section Stator with Slots

Stator with Slots indicated in the figure 2. Material used in the Stator is M19_26G with consist of all magnetic Property as B-H curve.

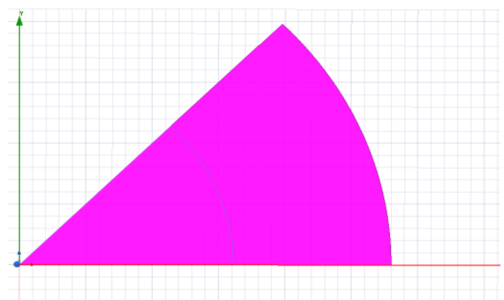

Fig. 3. Vacuum model Stator section

Vacuum is modeled as we need to calculate magnetic field in the specific volume and magnetic flux crossing the domains.

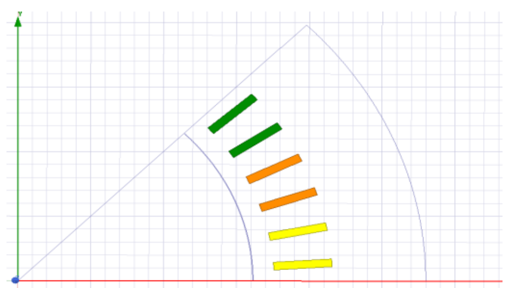

Fig. 4. Rotor section with rectangular coil

In the indicated figure 4 rectangular Coil is shown. Every Coil having 8 Conductor. Conductors are made of Copper material.

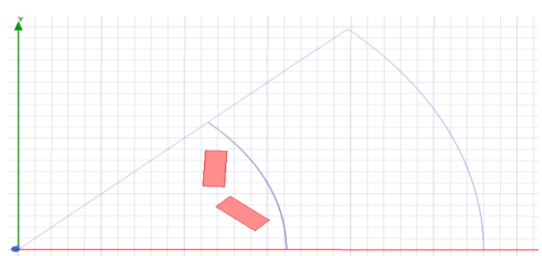

Fig. 5. Rotor section with magnet

In the indicated figure rectangular Sketch are representing Magnet. Material of Magnet is NdFe35.

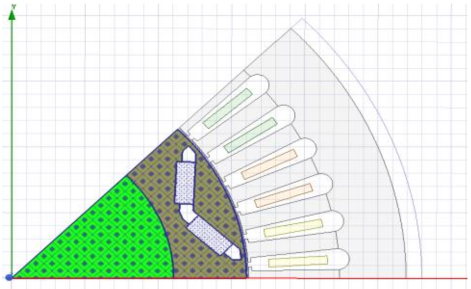
Fig. 6. Complete section model with all component

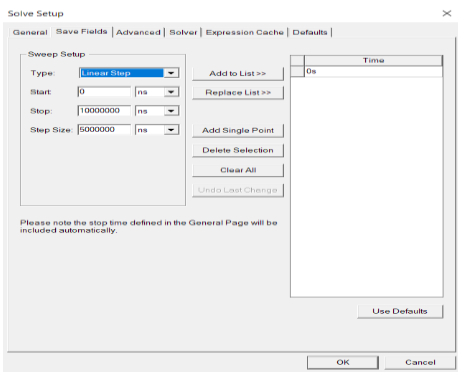

Fig. 7. Solver setup window in Ansys Maxwell

Table 1
Material of component

SR No.	Material	Part Name
1	Coppr	Coils
2	M19_26G	Stator & Rotor
3	NdFe35	Magnet
4	Stainless Steel	Rotor
5	Vacuum	Air

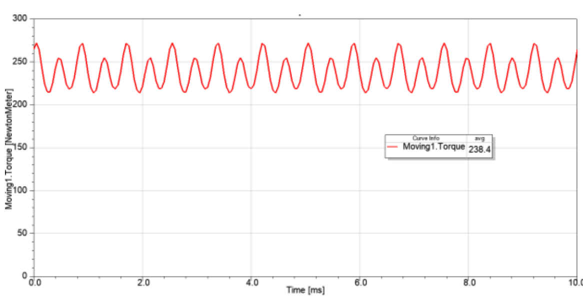

Fig. 8. Torque vs. Time

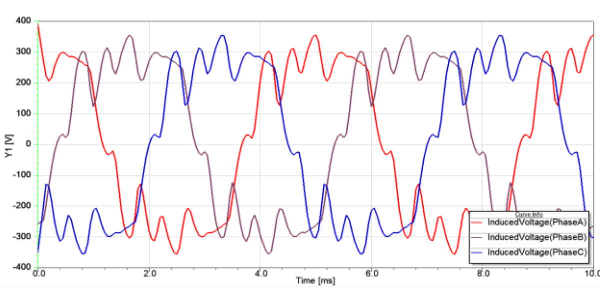

Fig. 9. Induced Voltage in phase A, B & C

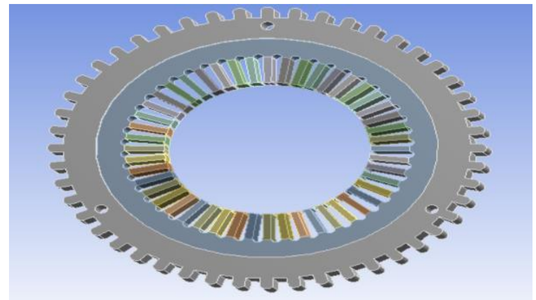
Fig. 10. Complete model

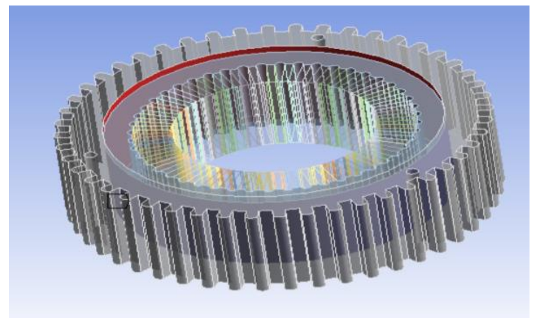
Fig. 11. (a) Magnetic field model

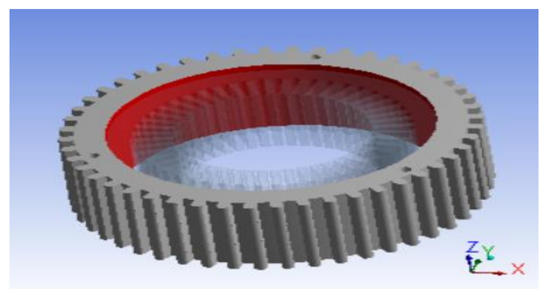
Fig. 11. (b) Magnetic field model

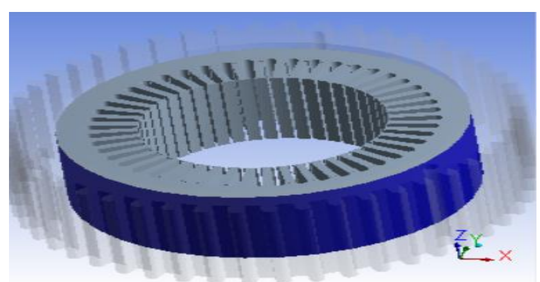
Fig. 11. (c) Magnetic field model

Table 2
Frequency Analysis Inputs

Analysis Method	Description
Frequency spacing	Linear
Range	0-10000 Hz
Solution Intervals	25
Method	Full Harmonic
Damping	None

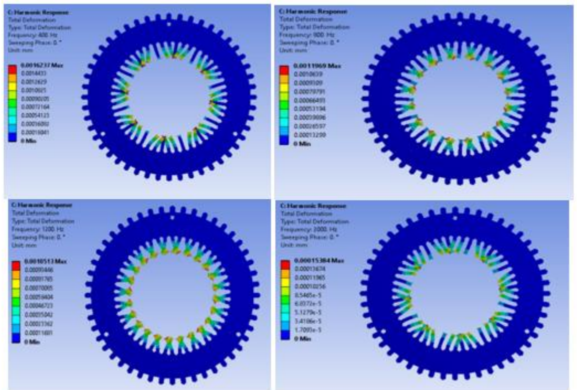

Fig. 12. Frequency response @ 400-1600hz

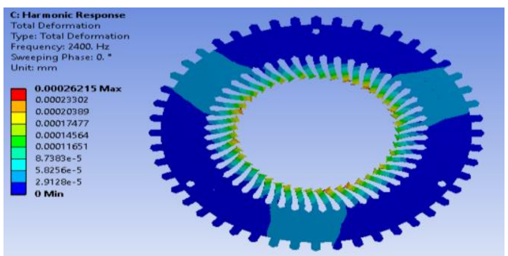

Fig. 13. Frequency response@ 2000 hz

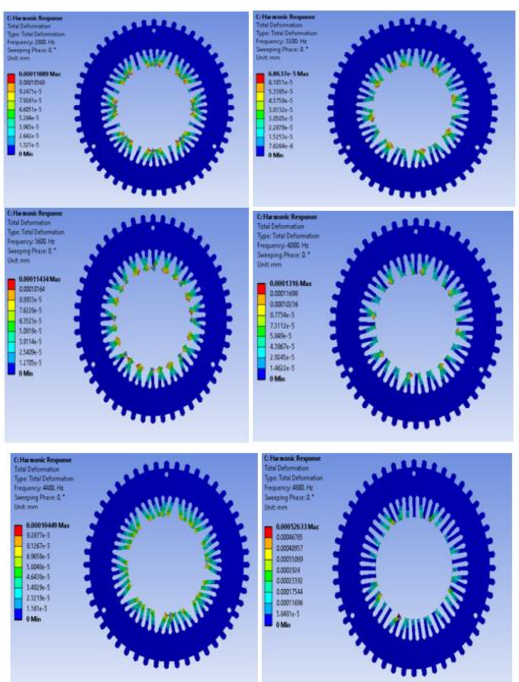

Fig. 14. Frequency response@ 2400-4400 hz

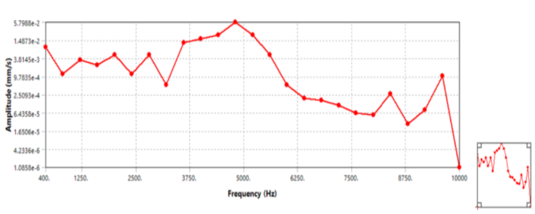

Fig. 15. Frequency (Hz) vs. Amplitude(mm/s)

6. Vibration and noise effect

The vibrations and noises produced by rotating electric motors have three fundamentally different components in their frequency spectra:

1. Components proportional to rotational speed
2. Components independent of rotational speed
3. Resonance increases caused by excitations of component natural frequencies.

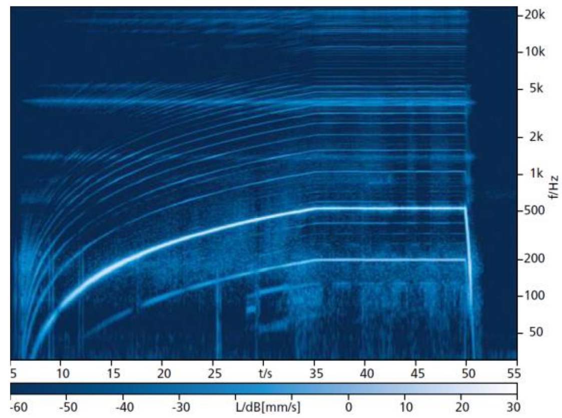

Fig. 16. Frequency spectrum vs. time (run-up)

Measuring a motor under different conditions (such as rotational speed acceleration, changing loads) provides more accurate information on its oscillatory behavior in the actual installed condition because motors are seldom operated at constant rpm, or they must in any event pass through a particular rotational speed range in order to reach their operating speed.

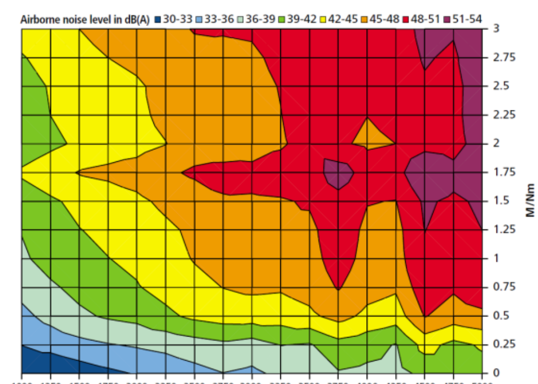

Fig. 17. Airborne noise level over rpm and torque

7. Conclusion

In this paper, ANSYS Maxwell 3D and RMxprt software tools are used to create a BLDC motor design and to analyze it. The motor parameters and characteristics can be precisely calculated and predicted in terms of field computation and analysis results. Also it is seen that by developing the computer technology and increasing computing times, the FEM tools are becoming more beneficial to analyze the motor.

Acoustic noise analyses are useful for evaluating the available machine conditions and diagnosing the fault associated with the operational machine. In this paper a Simulative study has been presented for varying operating conditions of a brushless direct current (BLDC) motor drive and effect of such changes on the acoustic noise and vibration produced by the drive has been measured and analyzed. The electromagnetic forces are the main cause of vibration and acoustic noise for BLDC motor drive, rather than the torque ripple and cogging torque.

Measured vibrational signal and acoustic noise of BLDC motor drive has been analyzed and it is observed that vibration signals are well in range as per the ISO 7919-2: 2001 guidelines however acoustic noise signals are almost double of higher side of prescribed range as per the IEEE Standard 85-1980. Therefore, it is required to understand and develop the methods to suppress the acoustic noise from the BLDC drive.

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