International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Review on Numerical Investigation of BLDC Motor for Acoustic effect with Current variation

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ABSTRACT

An induction motor is clearly a very reliable, strong, and efficient machine that is employed in a variety of industrial applications under diverse loading circumstances. Induction motors are less expensive, have a more durable structure, and require minimum maintenance. DC motors are ideal for low-cost, high-production applications in industry because they are lightweight, compact, and affordable. Unfortunately, the loud noise produced by these motors can lead to an erroneous poor impression of their quality. The goal of this research is to look into the relationship between motor noise and the line current wave for a four-pole BLDC permanent magnet motor. For the current work, we are using Ansys Maxwell for simulation. In RMxpert, a BLDC motor is designed. For various frequency levels, simulation results show an excellent stable flow in linear harmonic analysis. Vibration signals are well within the ISO 7919-2: 2001 standards, while acoustic noise signals are nearly double the higher side of the prescribed range, according to IEEE Standard 8i.5-1980. As a result, it is necessary to comprehend and develop solutions for reducing BLDC drive acoustic noise.

Key Words— Acoustic noise, brushless direct current (BLDC) motor drives, field-programmable gate arrays, (FPGA), pulse width modulation (PWM) and vibration, Ansys MAXWELL.

1. INTRODUCTION

1.1 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.

1.2 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. Heating, vibrations, and noise are all negative side effects, and they play a big role in deciding whether or not to employ a certain engine. Because small motors are typically located in confined places in equipment, the heat they generate can be particularly harmful, even though the actual heat output is low, because the surrounding equipment frequently provides limited chance for heat removal. Because these motors are typically placed close to humans, their ears, and their sense of touch, the noise and vibrations that they are allowed to produce are substantially lower in comparison to larger motors. There are standards for measuring and evaluating noise and vibrations in large electrical machinery and motors. Because of its modest size, a little motor is barely audible when considered alone. Even the vibrations it generates are often regarded as unobtrusive. A small motor has little effect until it is installed in or on a piece of equipment and then subjectively evaluated, usually only in this installed setting.

This subjective evaluation of the noise and vibration characteristics of the motor installed in the equipment must be quantified by means of measurement technology. From this information, specifications for the vibration and noise limits for the motor alone must be derived and agreed upon and then met when the motor is manufactured. The description and derivation of such limits can be very complex in individual cases; therefore test standards like those used for large motors do not make sense for small motors. Above all, the small motor manufacturer wants to be successful in the marketplace. So he will work to identify the causes of objectionable vibrations and noises in his product and try to eliminate them as much as possible.

In the final analysis the motor is the source of the noise, and the equipment in which it is installed is "merely the loudspeaker." Working together with his customer, the manufacturer must also try to figure out how an anticipated or existing vibration or noise problem can be optimally solved with regard to the entire system in which the motor operates. It may often be easier and more cost-effective to overcome an undesirable vibration or noise along the path from the motor itself to our sense of hearing or touch than it would be to eliminate the problem at the source. Frequently, if certain rules are not followed, the vibrations caused by the motor along its transmission path become "the mouse that roared." This means that the path itself must be analyzed and taken into account.

In the section below we shall first explain some important terms relating to the noises and vibrations produced by small motors. We will then describe the basic principles relating to the transmission paths. This will be followed by a look at the causes of noises and vibrations in small motors, as well as the unique characteristics of such noises and vibrations and the technical options for reducing them. Before any measurements are made, the vibration behavior of the equipment in which a motor is installed must first be considered conceptually. Systematic measurements and testing derived from this conceptual analysis should then follow to support or reject the conceptual model; but efficiency demands that the brainwork comes first. Only if the measurements are carefully planned and systematic will their consequences be clear. Therefore, a detailed description of acoustic and vibration measurement technology, combined with suitable methods, follows. In this way, it is possible to move from subjective judgments to descriptions based on actual measurements in order to obtain limit values that can be used in the development, manufacturing, application, and quality testing of motors.

Noise can be a problem with any piece of electrical equipment. Industry is continually looking for cost-effective ways to reduce emitted acoustic noise and improve the perceived quality of electrical devices, from transformers to DC motors. Noise is produced by electromagnetic interactions in rotating machines and transformers. For a tiny DC motor, this thesis examines the link between current and noise. The relationship between machine parameters and current wave patterns for this motor is next investigated. The topic of noise in electromechanical devices is introduced by discussing transformer noise.

1.3 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).

In addition to its manifestation over time, a natural oscillation also always has a specific spatial distribution of its peaks and valleys (natural waveshape), which can only form if no disruptive forces can act upon the oscillatory systemvia mounting systems. A natural waveshape can simultaneously have identical motion excursions throughout the waveshape; when this occurs, it has the mode $r = 0$. This is the case, for example, when a ring is "breathing," i.e. when it changes its diameter in all directions in the same way over time. If a natural waveshape is characterized by simultaneously having two points of maximum but opposite oscillation excursion amplitudes (oscillation antinodes) and two points at which no motion is present between them (oscillation nodes), it has a mode of $r = 1$. The flexural oscillation of a motor illustrates how mounting systems can hinder the formation of waveshapes: radial vibrations are hindered if not prevented at the bearing points. However, the shaft can vibrate radially. In this case at two opposite points on the circumference of the rotor the radial movement is maximal but is equal to zero at the points offset by 90°. Seen in the circumferential direction, the mode is $r = 1$. But in the axial direction, this is not the case because only a single antinode can be seen between the bearings. The bearings hinder the free formation of $r = 1$, and therefore radial alternating forces (vibratory forces) occur in the bearings. If the rotor were not hindered by the bearings, it would vibrate on both ends in the direction opposite to the vibrations in the middle of the rotor, and two nodes would form between its ends. If the bearings were placed at the nodes and the outer ends of the shaft were allowed to oscillate freely, the free rotor flexural oscillation would not be impeded. In fact, $r = 1$ also establishes itself when hindering bearings are present because the bearing system, with its elasticity and mass, simply needs to be included as part of the oscillatory system. The corresponding flexural natural frequency , of course, is different from that of the rotor without bearings.

The oval deformation of a tubular metal package is characterized by the mode $r = 2$ (two full waves along the circumference, four antinodes, four nodes, etc.). Antinodes and nodes can change location relative to time, but he deformation pattern, in other words the mode. A configuration with more than two possibilities for storing various forms of energy (such as potential and kinetic energy) is capable of having a number of different natural oscillations with various corresponding natural frequencies and wave shapes, i.e. with a number of different antinodes and nodes superimposed on each other in time and space.

In industrial applications, forced excitation and the ability to engage in natural oscillation usually occur in combination. If a forced excitation acts upon a system that is capable of natural oscillation, the system continuously oscillates at the rate of the forced excitation, but also temporarily at its own natural frequencies, provided that the forced oscillation is not applied precisely at the node of the corresponding natural wave shape . If the forced excitation frequency and the natural frequency are identical, the term resonance is used. In this case the corresponding wave shape movements can become very large if damping is small. If the natural frequency is less than the excitation frequency, operation above resonance occurs. In the reverse case operation below resonance occurs. Given that industrial equipment generally has a number of natural frequencies (and natural wave shapes) and given that the Basics of vibrations, structure-borne noise, and airborne noise forced excitation can also contain a number of frequencies, operation above resonance and operation below resonance are often both done. Tuning can greatly alter the effect of forced excitations. The point at which the forced excitation is applied or how the excitation is spatially distributed also plays an important role! If the forced excitation is only applied at a single node of a wave shape , then no resonance occurs (at least not theoretically), even if the natural frequency of this wave shape and the frequency of the forced excitation are the same. In general: For resonance to occur, the frequencies and the modes of the wave shape and the forced excitation distribution must be the same. If forced excitation is applied at specific points outside of the natural wave shape node, it is important to consider that such excitation at specific points is comprised of excitation components that theoretically can have an infinite number of modes, so that a resonance can result with any one of these components. Oscillations from and in solid and liquid materials are referred to as structure- borne noise ; in the case of liquids, they are also referred to as fluid borne noise . We humans experience such structure-borne noise with our sense of touch . Vibrations from and in gases (air) are referred to as airborne noise . We perceive this noise with our sense of hearing and, at very low frequencies and high amplitudes, also with our sense of touch. While structure-borne noise is transferred as a result of the elasticity of solid substances, airborne noise or fluid-borne noise is transferred as a result of the compressibility of gases and liquids; the losses that result from the change in the shape of objects (material damping) and friction in the air weaken the transfer along the transfer path. Our sense of hearing has a large range of perception across approximately six powers of 10 of the amplitude of the vibration between the (lower) threshold of perception (auditory threshold) and the threshold of pain , and it has a large frequency range with highly frequency-dependent sensitivity. In addition, there are also individual evaluations of frequency mixtures (spectrum) and changes in noises over time, as well as the stereo effect that results from hearing with both ears, along with overlapping individual psychological effects.

1.4 Transmission paths

A transmission path is the path over which the oscillation is carried from the generator to our sense of hearing or touch . It extends from the source of the oscillation as structure-borne noise to the surface of the source (in this case the motor) and from there as structure-borne noise across the mounting system into the driven device and from there as structure-borne noise to the outer surface of the device housing. At the same time, airborne noise is produced at the surface of the motor. In the equipment in which the motor is installed, this noise strikes the inside surface of the housing and from there is transferred as additional structure-borne noise through the housing wall to the outer surface of the equipment. If the housing has openings, the "inner" airborne noise also escapes directly to the outside and is added on to the airborne noise that comes from the oscillating housing surface and is radiated inward and outward. With our sense of touch we feel the vibrations on the housing surface and, in some cases, also the vibrations that are transferred from the housing surface into a cover or mounting system. The airborne noise reaches our sense of hearing. The effect of the properties of the structure-borne noise path (distribution of masses and elasticities) to the surface that generates airborne noise is shown by the comparison of the noise produced by a small motor in installed condition (light blue spectrum) and in uninstalled condition (dark blue spectrum)

(Fig. 1.1): An uninstalled motor is almost always significantly quieter because of its smaller surface area and its vibration distribution. Therefore, the airborne noise that it generates is small and is largely short circuited acoustically because its dimensions are small in comparison with the wavelengths of the sound oscillations. The fact that it can often still be heard is due to the large range of sensitivity provided by our sense of hearing. In this case, though, we only hear the high-frequency noise components since these components short-circuit acoustically somewhat less than the low-frequency noise components, to which our sense of hearing is also less sensitive. This is one of the reasons why the sound impressions produced by an uninstalled motor and those produced by an installed motor usually differ significantly. Another reason is that the system used to mount the motor in the equipment only transfers the structure borne oscillations that are present at the mounting point. Therefore, the nature of the mounting system plays a very important role in acoustics and vibration!

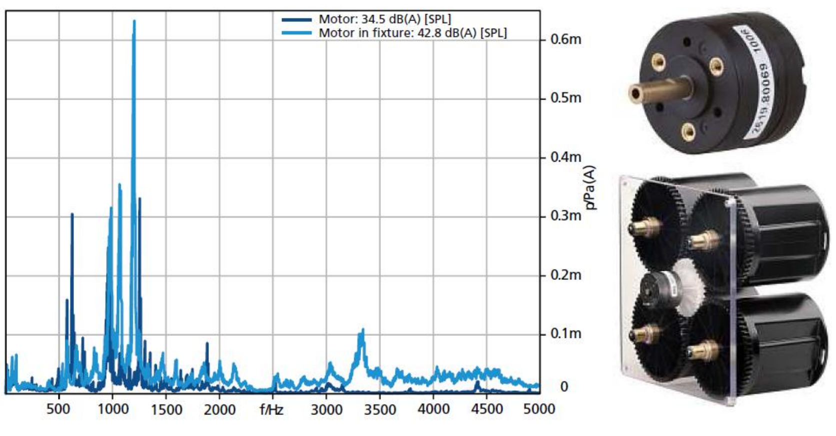

Fig. 1.1: Effect of installation situation on noise radiation characteristics

In the example shown in Figure 1.1, the motor is mounted directly on an acrylic plate without any decoupling . The center of the acrylic plate was chosen as the mounting location – theoretically the worst case. The antinode of the first natural oscillation mode with the corresponding lowest natural frequency of the acrylic plate is located here. Applying a vibration at this point therefore has the maximum effect and will generate the largest conceivable noise radiation which is by no means desirable.

The transmission path to our sense of touch is limited to the transfer of vibrations by means of structure-borne noise to the surface that is touched. Airborne noise and structure-borne noise often work together; an everyday example is an electric shaver whose motor vibrations are felt on our skin and heard with our ears. Measures to reduce undesirable airborne noise are generally the most effective when they are applied to the noise source and/or the path of structure-borne noise, in the latter case in particular at the motor mounting area.

1.5 Causes of vibrations and noises in small motors

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. Figure 1.2 shows typical examples of the main locations at which vibrations and noises can be produced in an electric motor.

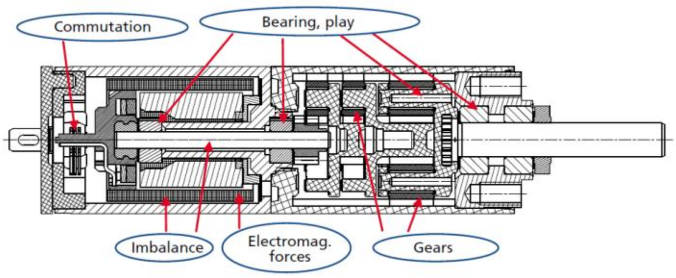

Fig. 1.2: Sources of vibrations and noises in an electric motor

1.6 Electromagnetically induced vibrations

The surface and the shaft of each electrical machine also move in undesirable ways. This is the result of the hetero polar concept that is always used for electrical machines for functional reasons and that has significant advantages over unipolar machines. As a result of this concept, the distribution of the magnetic energy density that is needed to generate the machine’s torque in the air gap between the stator and rotor of an electrical machine must unavoidably fluctuate in time and space. Slotting (the distribution of the magnetic permanence for the magnetic air gap), the design of the permanent magnets, the distribution of the current-carrying winding, the way the current is applied, and the curve of current over time are all factors in these fluctuations. On the peripheral surface of the rotor and on the air gap side of the stator, the fluctuation of the spatial energy density distribution over time causes fluctuating tangential and radial forces that are applied at different locations – so-called force excitations.

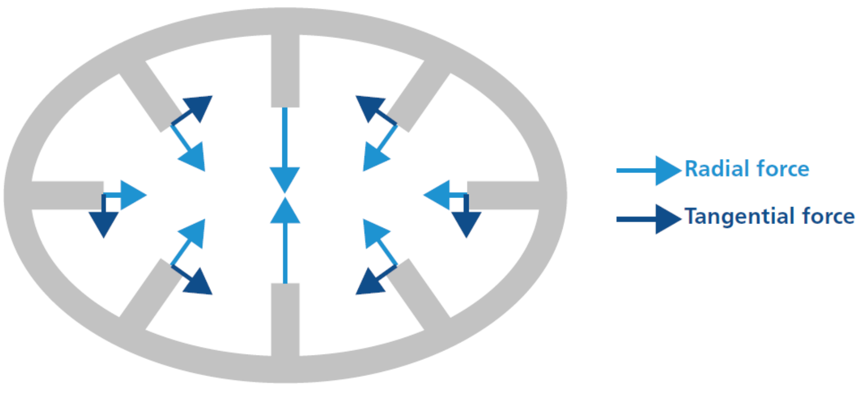

Fig. 1.3 : Force excitations on the stator of an electrical machine

If the motor is suitably designed, the fluctuations in the tangential forces within the torque have very little effect because, when they are added up along the circumference, the large number of local fluctuations offset each other over time. In this way, oscillating torques can be kept low. This also applies to the cogging torques of motors equipped with permanent magnets. Locally caused tangential force fluctuations, however, cause tangential flexural deformation oscillations – for example, on the teeth of the metal packages of the stator and rotor (if teeth are present). The distribution of the radially oriented magnetic tensile forces causes radial movements and deformations of the stator and the rotor. Depending on the nature of the spatial distribution of these forces, this can be a resting or circumferential shift or a vibratory movement. In the stator and rotor, these shifts in movements are out of phase, and the overall center of gravity is maintained.

1.7 Effect of electronic commutation

In electronically commutated motors, the currents applied to the individual motor phases are turned off and on by electronic circuitry. Depending on the pattern of these phase currents over time, radial and tangential forces act upon the stator teeth, and forces act upon the electrical conductors in the motor phases. The latter case occurs in particular with unslotted motors with air gap windings. In the case of rectangular current patterns over time, local rectangularly shaped forces are also produced over time, causing abrupt oscillatory excitations at the stator. This excites oscillations at the switching frequency (fundamental oscillation) of the current phases, as well as their harmonics. With ideally rectangular currents and ideally symmetrical motors, the torque remains constant over time. However, if in reality there are geometric asymmetries, differences in the phase inductances and resistances as well as differences in the electronic circuitry, then current time gaps or overlaps will result in the individual phases. These will cause torque fluctuations and additional vibratory excitations at the stator. The resulting noises are often called "commutation noise ," and their importance must not be underestimated! The use of electronic control circuitry that works with sinusoidal current patterns results in poorer motor efficiency, but it does eliminate or at least greatly reduce this type of noise.

1.8 Mechanically induced causes of vibrations in small motors

1.8.1 Vibrations in bearings

Vibrations like these occur in simple bearings due to intermittent mechanical contact between the shaft and the bearing surface. There is no such contact or noise when a lubricant film transmits the load between the shaft and bearing around the entire circle. When the radial forces on the bearing are excessive (belt drive, gear, air gap field), when the shaft and/or bearing sleeve are not round or crooked, if the sintered bearing surfaces are not porous enough, if the shaft running surface is too smooth, or if there is not enough lubricant in the bearing, contact does occur (mixed friction). The result is vibrations at various frequencies (frequency band in spectrum) in the audible range at the roughness peaks of the bearing surfaces, which are depending on the elasticity of the shaft or bearing. The frequency of rotation and its multiples are especially noticeable. The amplitudes of higher frequency vibrations are frequently simply adjusted, making friction noises particularly irritating. Mechanical contacts grow when the shortage of lubricant worsens, resulting in mechanical friction and increased wear. This causes natural bearing vibrations (due to the self-induced addition of energy from bearing friction), which is heard as a squeaking or squealing noise. The deformations in plain bearings are primary, while the deformation forces that arise are secondary (displacement excitation).

Rolling elements – commonly ball bearings in small motors – roll in inner and outer rings, usually with mechanical contact, in roller bearings. They are encased in a thin layer of lubricant, which provides some cushioning and enlarges the contact area. Only a broad frequency band (spectrum) of oscillations results if the rolling elements and ring raceways are sufficiently round and undamaged, as a result of circumferential elastic deformations at the contact points caused by compression forces (force excitation) and as a result of lubricant movements (displacement excitation). Vibrations are dampened by the lubrication. Because the pressures at the contact sites increase if there is not enough lubricant or the viscosity of the lubricant is improper, vibration will increase ("metallic, hard-sounding" noise). Material weariness is on the rise. Damage to the raceways, particularly axial overloading of the bearings, accelerates material fatigue.

Because of how they're made and how they work, radial ball bearings feature radial bearing play. The bearing balls cannot transfer the radial forces optimally if the radial play is "compressed to zero" as a result of an inappropriate elastic axial preload on the outer or inner ring. In this scenario, the bearing's installation fit as well as the assembly quality are critical. The balls actually run in sync instead of in a circular, wavy route at certain rotational rates. As a result, the bearing bracket experiences self-induced axial vibrations, which are audible as howling noises. Thus, we mostly encounter motions in bearings that generate elastic forces, which cause vibrations, as well as forces that cause oscillating motions. This means that both displacement and force excitation exist, and that both must be considered when analysing the individual instance in theoretical terms.

1.9 Options for reducing and optimizing noises

The motion vibrations that occur in motors are transmitted from the motor surface as airborne noise and at the shaft and motor mount as structure borne noise . From here they are transmitted further into the environment as structure-borne noise and to some extent also as airborne noise. To reduce noise, the general approach is to interrupt the noise chain from source to transmission path to ear, or better still, to reduce the generation of noise directly at the source. If this is not possible, one can at least try to make the noise more pleasant and less objectionable. This activity is referred to as "noise optimization ," even though such a systematic effort to alter the noise being produced is not an optimization in the true sense. In the individual case, the measures that are taken must always take economic considerations into account.

1.9 .1 Insulation and deadening

Sound barriers can be achieved by means of acoustic and vibration insulation . Insulation must be clearly distinguished from damping , in which vibrational energy is converted to frictional heat. In solid bodies, such frictional heat is caused by the movement of molecules or relatively large particles against each other inside the body, but also in material that is installed outside of the equipment (such as foam, nonwoven materials, elastomers) and that exhibits substantial internal friction. In order for such material also to have a damping effect, it must be attached at vibration antinodes on the surfaces, in other words at those locations where the vibrations cause the greatest deformations in the material. Such material is often called insulating material, even if it does not insulate but rather dampens. With liquids, viscosity has a damping effect, but only in combination with compressibility or a significant deformation of the liquid "body" in its container. The damping ability of water is very low because of its low internal friction and because it is nearly incompressible. Oil also is nearly incompressible. Its significantly higher viscosity only has a damping effect when it is forced through narrow openings, in other words changes shape, such as is the case in shock absorbers. Gases are compressible, but because of the large distances between their particles, they have very low internal friction and therefore are low in damping ability. However, if gas flows through barriers such as narrow screens, filters, foam, or if the gas particles oscillate within such barriers, then the friction, sound pressure, and sound particle velocity increase , so that the sound volume decreases and the sound energy is “rubbed” into heat. Thus, screens, filters and similar devices are sound dampers. In general, insulation and damping measures must be considered separately. They often are mutually exclusive. However, in many cases insulation and damping measures make sense, provided that they are carried out at the right location.

1.9.2 Reducing sound radiation

The radiation of airborne noise to the outside can be significantly reduced by encapsulating the entire motor. In this way the propagation of the airborne noise is limited and is “dammed in”; in this case we speak of sound insulation. Resonances that are caused by the encapsulation itself, as well as cavity resonances, must be taken into account. Frequently, the entire motor cannot be completely encapsulated because of the connection to the unit being driven or to the environment. In the case of openings, attention must be given to achieving a desirable mismatch of the (sound) wave resistances that are involved in the transmission of the sound, and to avoiding objectionable reflection. Covering the capsule with sound insulating material helps to prevent cavity resonances and helps to dampen the vibrations of the capsule itself. In the case of sound dampening in contrast to sound insulation – sound energy is “destroyed” (converted to friction). In the case of small motors, covering the capsule with insulating material often is not possible for space-related reasons, or it is not done for cost reasons. Surfaces that radiate noise can be quieted by providing them with openings. This reduces the size of the radiating surface (compare this with a loudspeaker diaphragm!) and also fundamentally changes the vibrational behavior of the surface. In this way, natural frequencies can be shifted and objectionable vibration modes together with their nodes and antinodes can be rendered harmless. Additional reinforcements or bracing can have an effect similar to that of openings.

1.9.3 Reducing sound and vibration transfer

In theory, the measures referred to for reducing sound radiation also apply to preventing motor vibrations from being transferred across the shaft and the motor mounting system in the equipment (or in the environment). However, there are some general “recipes for success”: Mounting should always be done as close as possible to the node sites of the most objectionable vibratory motion. As a rule, the most important nodes are found near the bearings. The vibratory motions that are still present there should transfer the lowest possible force oscillations. In other words, the mounting system in the direction of vibration should be as flexible as possible and have as little damping as is possible with the given motor application and other conditions (such as transport shocks). If the force oscillations are small, then they only result in small vibratory motion in the attached parts, even with small masses (lightweight equipment). More equipment mass, in particular in the area where the motor is mounted, is often advantageous. Of course, the oscillating mass of the motor, the elasticity of the mounting system, and the mass of the equipment in the vicinity of the motor mount must be matched to each other so that no resonance with the objectionable motion frequency results. The system must be tuned so that the resonance is below the operating point.

1.9.4 Reducing sound and vibration excitation

Ideally, noise and vibrations are best reduced where they are created: at the source. However, in electric motors, forces and torques are needed, and they often unavoidably include undesirable components (oscillating torques, cogging torques, etc.), which cannot be completely avoided. The wide variety of motor concepts that is currently encountered with their varying operating principles also leads to various noise excitations. Asynchronous motors behave differently than synchronous motors (including electronically commutated motors and stepper motors !), and DC machines behave differently than the piezo motors. Noise and vibration excitation therefore can often only be minimized by very carefully selecting a suitable motor and a suitable motor size.

The noise level of a small electric motor naturally increases with its operating speed. Therefore, reducing the motor’s operating speed is one way to successfully reduce the noise level it causes. As a rule, drive motors – in contrast, for example, to blowers – are not operated continuously at a fixed speed, but rather are used for positioning tasks. During a positioning cycle, the motor passes through all speeds from zero up to the maximum operating speed relatively quickly. Resonances can be produced in the process. In particular, very objectionable noise levels can result when operating speeds that are close to resonant frequencies are present for a relatively long time. A slight change in the motor’s rotational speed may be helpful here if the task that the motor is performing and the positioning velocity permit. However, caution should be observed in making rpm changes: With small motors, rotational speed variations are much greater than with larger motors because friction and component tolerances have a much more pronounced effect in relative terms. Thus, a slight change in the rotational speed of a small motor may be helpful with one motor, but harmful in the next motor of the same model from a different production lot.

1.10 Typical BLDC motor applications

BLDC motors are used in almost every market category. Appliances, industrial control, automation, and aircraft are just a few examples. We may divide BLDC motor control into three major categories:

• Continual load
• Differential loads
• Applications for positioning

1.10.1 Applications with Constant Loads

These are the kinds of applications where having a variable speed is more critical than maintaining a set speed's accuracy. The load is directly linked to the motor shaft in these applications. Fans, pumps, and blowers are examples of these types of applications. These applications necessitate low-cost controllers that are essentially open-loop.

1.10.2 Applications with Varying

These are the applications in which the motor's load varies throughout a speed range. These applications may necessitate high-speed control accuracy and responsiveness. Washers, dryers, and compressors are examples of home appliances. Fuel pump control, electronic steering control, engine control, and electric vehicle control are all instances of this in the automotive industry. There are a variety of applications in aerospace, such as centrifuges, pumps, robotic arm controls, gyroscope controls, and so on. These applications may make use of speed feedback devices and operate in either a semi-closed loop or a completely closed loop. These applications use advanced control algorithms, thus complicating the controller. Also, this increases the price of the complete system.

1.10.3. Positioning Applications

This category includes the majority of industrial and automation applications. This category includes applications with some form of power transmission, such as mechanical gears, timer belts, or a basic belt-driven system. The dynamic reactivity of speed and torque is critical in these applications. These applications may also experience frequent rotational direction reversals. An acceleration phase, a constant speed phase, and a deceleration and positioning phase are all part of a normal cycle. During all of these phases, the load on the motor may change, making the controller complex. The majority of these systems work in a closed loop. Three control loops might be active at the same time: Torque Control Loop, Speed Control Loop, and Position Control Loop. The real speed of the motor is measured using an optical encoder or synchronous resolves. The same sensors are sometimes utilised to provide relative position data. Separate position sensors can be utilised to obtain absolute positions if necessary. CNC (Computer Numeric Controlled) machines are an excellent example.

1.11 A comparison of BLDC motors vs traditional DC motors

Brushes create mechanical contact with a series of electrical contacts on the rotor (called the commutator) in a traditional (brushed) DC-motor, forming an electrical circuit between the DC electrical source and the armature coil-windings. The stationary brushes come into contact with different areas of the revolving commutator as the armature spins on its axis. The commutator and brush system combine to generate a series of electrical switches that fire in order, ensuring that electrical current is always directed to the armature coil closest to the stationary stator (permanent magnet).

The electromagnets of a BLDC motor do not move; instead, the permanent magnets do. This solves the issue of transferring current to a moving armature. The commutator assembly is replaced with an intelligent electronic controller to do this. The controller uses a solid-state circuit instead of a commutator to provide the same power distribution as a brushed DC motor. BLDC motors have a number of benefits over DC motors. Here are a few examples:

- High dynamic response
- High efficiency
- Long operating life
- Noiseless operation
- Higher speed ranges

The biggest downside of BLDC is its increased cost, which stems from two difficulties. To begin with, BLDC motors require sophisticated electronic speed controllers to operate. A comparably simple variable resistor (potentiometer or rheostat) can be used to regulate brushed DC motors, which is inefficient yet acceptable for cost-sensitive applications.

2. LITERATURE REVIEW

2.1 Motor Noise Research

Every aspect of modern life involves the usage of motors. Motors must reduce their produced noise and vibration levels since the public demands a quieter environment. DC permanent magnet motors are becoming increasingly used in industry due to their light weight, compact size, and low cost. They are widely used in the automotive sector to power fans, windshield wipers, antenna lifts, and power windows. Fan rnotor noise in automobiles can be both an annoyance and a quality problem. Active noise suppression, in which speakers are utilised to silence noise from bothersome sources, would be incredibly effective but costly. Mechanical dampers, such as rubber boots, reflecting enclosures, such as those used with refrigerator compressors, and adsorptive silencers around the motor, all help to reduce the amount of noise transmitted. Mechanical dampers, on the other hand, aren't always cost-effective or appropriate, and they're usually always big. Signature analysis can be used to figure out where motor noise comes from**.**

The frequency spectrum is used to determine whether noise in an induction motor is caused by magnetic fields or by the passage of time. Signature analysis in a vacuum cleaner can determine whether the noise is caused by the airflow, the motor, or the surrounding structure. A modal shape analysis can be performed using laser holography. It's been used to figure out how an automotive engine's complex mode shapes work. Following the completion of the vibration analysis, mass can be added or removed from the motor casing in order to minimise imitation noise frequencies by removing the appropriate mode shape. Because noise is proportional to vibration, it is possible to reduce noise levels by lowering vibration. Vibrations and noise can be caused by current discontinuities that result in an overabundance of harmonic frequencies. The papers describe various power electronics-based strategies for reducing noise from both AC and DC machines by influencing non-fundamental current harmonics in the audible frequency range. By isolating or dampening the noise transmission line or source of noise, mechanical noise transmissions can be decreased. The stiffness or damping of the transmission path can be changed to reduce noise transmission. Using low noise bearings and lubricants is one technique to modify the noise transmission path. Low-noise ball bearings feature less stiffness changes during bearing rotation than ordinary bearings, resulting in fewer system oscillations and reduced instability, which can cause to vibration and noise. Standard lubricants have less damping than low noise lubricants. Fluoro ester-based oils are particularly effective. Vibrations in TIC machines can be actively controlled by adding extra coils to give magnetic fields equal to and opposite to those produced by the machine.However this technique is too expensive to be feasible when dealing with low cost, high volume, compact DC motors. Review of Modeling Techniques any authors have contributed to the modeling and analysis of DC motor devices and motors with permanent magnets. Much of the published research on DC permanent magnet motors is devoted to the shape of the magnetic field and its influence upon the voltage, torque and current of the motor. Research devoted to the critical aspect of the motor brush design is very important, but generally proprietary. Inrushes for DC motors are generally made out of a carbon graphite compound. For very small DC micro motors the brushes are usually carbon steel springs, to maintain strength in very small size. Carbon brushes are generally compounded with various alloys to increase current flow, decrease frictional coefficients, strengthen the brush, lengthen the life of the brush and decrease the amount of commutator arcing. For example, copper and graphite are both used to increase the current carrying capacity of a brush. Graphite reduces the frictional coefficient between the brush and the comrnutator bars, but graphite reduces the brush life span. Copper in real life of the brush and strengthens it, but also increases the frictional coefficient between the brush and the commutator bars.

2.2 Review on brushless dc motor modeling

According to recent research [1]-[2], permanent magnet motor drives, such as the permanent magnet synchronous motor (PMSM) and the brushless dc motor (BDCM), could become serious competitors for servo applications. To produce constant torque, the PMSM has a sinusoidal back emf and requires sinusoidal stator currents, whereas the BDCM has a trapezoidal back emf and requires rectangular stator currents. There is some uncertainty about which models should be employed in which cases, both in the industry and in the university research environment. The PMSM is extremely similar to a typical wound rotor synchronous machine, with the exception that it lacks damper windings and relies on a permanent magnet for excitation rather than a field winding.

As a result, the PMSM's d, q model may be derived from the well-known [4] synchronous machine model by removing the equations for damper windings and field current dynamics. All sinusoidal changing inductances in the abc frame become constant in the d, q frame when the synchronous machine equations are transformed from the abc phase variables to the d, q variables, as is well known. Because the back emf in the BDCM motor is not sinusoidal, the inductances do not vary sinusoidally in the abc frame, and transforming the equations to the d, q frame does not appear to be helpful because the inductances will not be constant after transformation. As a result, the abc phase variables model for the BDCM is proposed. Furthermore, this kind of BDCM modelling allows for a complete evaluation of the machine's torque behaviour, which would not be possible if any simplifying assumptions were used. The transient behaviour of a high performance vector controlled PMSM servo drive was studied using the PMSM's d, q model [5]. The abc phase variable model has also been used to investigate the behaviour of a BDCM speed servo drive [6]. [7] describes the application features of both devices. The goal of this research is to compare the two models and demonstrate that the d, q model is sufficient for studying the PMSM in depth, whereas the abc model should be utilised to investigate the BDCM.

3. BACKGROUND AND OBJECTIVE

Electric motors play a significant part in industry, with induction motors being the most extensively utilised. Any motor failure disrupts the process, reduces output, and puts other machinery at risk. As a result, having an early defect detection method is vital to preventing sudden motor failure (such as on big or critical motors). The research reported in this paper focuses on detecting mechanical flaws in three-phased induction motors. MCSA (motor current signal analysis) is a technique for detecting intentionally produced mechanical problems that is aided by vibration signal analysis. Experiments are conducted on the most prevalent mechanical issues, such as mechanical unbalance, shaft misalignment, and bearing failures.

With the use of simulation, we will analyse the influence of current variation on noise generation in DC Motors in this study. The simulation will be carried out in Ansys Software, with the intended outputs being the noise level and frequency for the system in various current zones.

3.1 Statement of the Issue

Dual Stator IM DriveA conventional die cast squirrel cage rotor and a stator with two independent windings wound for a different number of poles (4/12) make up the potential induction machine. Any dissimilar pole number sequence can be employed, however to optimise the magnetic material and minimise local saturation and increased stator losses,, it has been observed that the most beneficial arrangement should have a pole ratio 1:3.

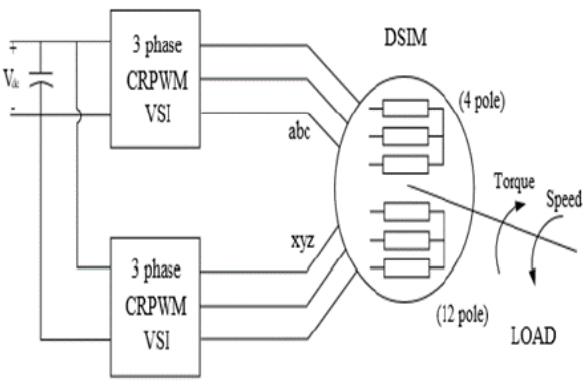

Figure 3.1: Dual Stator Induction Motor

To avoid deep saturation, the maximum magnetic loading caused by the combined aftermath of the two stator mfs should be comparable to a single stator winding configuration. The peak air gap flux must be maintained to maintain the saturation level in the stator teeth. In order to keep the stator yoke loaded, the peak flux density per pole in both the dual stator and single stator configurations should be interchangeable. This will be completed by culling, excluding space harmonics.

$B_{g4} = 0.819B_0$

$B_{g12} = 0.543B_0$

The highest air gap flux densities achieved by a proportional single stator, the 4-pole and 12-pole stator windings, are represented by B0, Bg4, and Bg12. The rotor of the DSIM is a conventional squirrel cage, which ensures that both stator current distributions will couple with the rotor flux at the same time to produce the desired torque. The DSIM functions as two autonomous induction machines physically coupled using shaft due to the decoupling response constructed by windings with differing number of poles. General assumptions have been considered for our machine, which are as follows:

• Trivial saturation

• Homogeneous air gap

• Stator windings sinusoidally dispersed

• No electrical linkage among stators

• Trivial inter-bar current

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