ELECTROMAGNETIC ACOUSTIC NOISE AND VIBRATIONS OF ELECTRICAL MACHINES; THEIR PRODUCTION AND MEANS OF REDUCTION

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1. INTRODUCTION

The increasing applications of electrical machines have resulted in a growing awareness of the problem of noise produced by them. In motors upto 150 kW capacity, lowest cost per unit output has been the principal design criterion. Owing to the increasing economic pressures, modern electrical machine design trends are towards the use of higher currents and flux-densities. To keep the machine size to a minimum and maximize the efficiency, high speed motors are used wherever possible. Such motors are inevitably a source of considerable magnetic, windage and mechanical noise [1].

Mounting criticism of ambient noise levels, even in traditionally noisy environments, has led to increasing attention being focused on the noise emitted by electric motors. Stricter regulations are now being enforced to protect people from a noisy environment. It has, therefore, become necessary for machine manufacturers to specify the noise produced by their products, and try to make them quieter than those of their competitors.

Vibrations and consequently the noise produced by a machine can be reduced to a large extent if the forces produced during their operation are not allowed to excite any resonances of the machine-structure. Accurate determination of the exciting forces and the resonant frequencies are of paramount importance. It is also becoming necessary for a designer to be able to predict the noise produced by a machine from its design data. This is especially significant in the case of large machines where it is not practical to build prototypes and it is expensive to employ external means of noise control.

2. REVIEW OF INVESTIGATIONS

Squirrel-cage induction motors are by far the most commonly used motor for industrial drives. Extensive investigations were conducted to understand the nature and mechanism of production of electromagnetic acoustic noise from squirrel-cage induction motors [2-6]. Detailed theoretical and experimental investigations were conducted to determine the resonant frequencies and the vibrational behaviour of electrical machine stators of different sizes. During the course of the study of resonant frequencies and the nature of the vibration at resonance, the effects of the frame, laminations, dynamics of the teeth and windings were critically examined. Further, investigations were conducted on the electromagnetic excitation forces that induce vibrations in the machine during its operation. These forces produce cyclic deformations of the stator and the rotor, and they generally occur at predictable frequencies. The electromagnetic radial-forces depend on the nature of the magnetic field in the air-gap of a machine. A detailed study was done to examine the effects of various parameters on the magnetic field and the radial-forces [6]. A simple and elegant technique is developed to predict the various frequency components in the audible noise spectrum.

3. RESONANT FREQUENCIES AND VIBRATION BEHAVIOUR OF STATORS

Several analyses have been developed over the years to analytically determine the resonant frequencies and the vibration behaviour of stators. The stator core was treated as a thin shell by many investigators. Such an approximation can be erroneous for stators with thick cores, as in the case of turbogenerators and machines where the core radial-thickness-to-radius ratio may well exceed a value of 0.2. Further, many investigators considered only the lowest resonant frequency of a particular mode to be significant. Although this may be true for small machines, it is certainly not true for large machines where several resonant frequencies for each mode of vibration may lie within the critical frequency range of noise production.

In reference [2], the authors developed an analysis, based on the three dimensional elasticity theory and Flugge's theory of thin shells for the frame, to determine the resonant frequencies and vibration response of stators of encased construction. This analysis while treating the stator core and frame rigorously, treats the teeth and windings as an additional mass. The complex boundary conditions in the presence of both teeth and windings, along with the free end conditions of the stator, posed considerable difficulties in the formulation of the frequency equation. In a revised analysis [3], the general frequency of the stator was derived using the three dimensional theory of elasticity, an energy-method and the principle of Rayleigh-Ritz. By using the energy-method, the problem of satisfying the boundary conditions along the junctions between the various components of the stator was avoided. The assumptions made in the analysis are those related to the homogeneity and linearity of the materials involved. The analysis was further extended in reference [5], to include the more complex configurations of a stator with outside cooling ribs, and a stator core supported by a frame with internal longitudinal ribs. The general frequency equation obtained is equally applicable to all circumferential mode of vibration, including the breathing and the beam-type modes of vibration. It predicts two set of resonant frequencies for circumferential modes, one which is associated with symmetric longitudinal modes and the other with antisymmetric longitudinal modes.

Extensive experimental investigations were conducted on several models to confirm the validity of the analysis. The models were designed to have an increasing degree of complexity in construction such that each model examined the validity of a particular aspect in the analysis. Details of the various models can be found in reference [2-5]. Further experimental investigations were also carried on a 7.5 hp and a 125 hp induction motor stator. The salient findings of this study will be presented by the authors.

4. ELECTROMAGNETIC EXCITATION

The prediction of the vibration behaviour, and the sound radiated from electric machines require accurate determination of the exciting radial-forces. A better understanding of the noise producing radial-forces will definitely help in achieving a good sonic design. A variety of undesirable phenomena such as parasitic torques, stray losses and magnetic noise associated with electrical machines are produced due to the presence of harmonic fluxes in the air-gap. The harmonics in the air-gap field are produced due to the spatial distribution of the current carrying conductors, slotting of the stator and rotor surfaces and magnetic saturation of the iron [6]. Another inadvertent source of harmonic production is the eccentricity of the rotor. The radial forces that act on the stator and rotor are produced by the Maxwell's stresses associated with the magnetic fluxes entering or leaving the iron surfaces. These stresses that act on the stator and rotor surfaces are proportional to the square of the air-gap flux-density.

The significance of a force component depends on the magnitude, frequency and the mode of vibration associated with it. In the event of the exciting force-frequency coinciding with a resonant frequency, even a small exciting force can give rise to appreciable vibrations. At conditions different from that at resonance, the amplitude of the forced response will be determined by the magnitude of the exciting force. Further, it should be emphasised that the flexural rigidity posed by the stator and rotor increases to the forces which induce higher modes of vibration. Consequently, in such a case the dynamic deflections produced will be small. Some results from theoretical and experimental study conducted on squirrel-cage induction machines, will also be presented.

5. MEANS TO REDUCE NOISE

As a first step towards noise reduction, the mechanical structure must be designed in such a way that preferably no exciting force-frequency coincides with a resonant frequency of the machine. Secondly, a stiffer construction may be used to attenuate the vibration response to the various electromagnetic exciting forces.

Most of the secondary phenomena associated with electric motors, such as noise and vibrations, are largely influenced by the winding disposition and the slotting of the stator and rotor surfaces. Since some of the design requirements to diminish these effects are mutually incompatible, design compromises are essential. Magnetic noise is critical with respect to the correct choice of the slot ratio. A prudent slot combination with an appropriate stator winding arrangement will help alleviate the problem by mitigating the effects of some of the important noise producing electromagnetic radial-forces.

6. REFERENCES

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