RECENT TRENDS IN THE NOISE AND VIBRATION INVESTIGATIONS OF ASYNCHRONOUS MOTORS

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Summary

In semiconductor drives controlled by thyristors, a voltage rich in time harmonics gets to the terminals of the asynchronous motor, and under certain circumstances this leads to a considerable increase of noise and vibration. It became necessary to elaborate the theory of the noise and vibration changes arising in the transient operation of asynchronous motors, as well as to develop transient measurements, as the users do not accept the increase of noise during the transient as a law of nature. Present article deals with this problems and demonstrates the physical phenomenon causing increase in noise and vibration.

Introduction

Specialists took note of the noise produced by asynchronous motors already six and a half decades ago. The ventilation noise was insignificant because of the generous dimensioning, the noise of ball bearings was a well-known phenomenon from the operation of other machines, so the interest turned to the electromagnetic noise.

In the first 15 years, rotors with different slot-numbers placed in the same stator showed the existence of advantageous and disadvantageous Z_1/Z_2 combinations of slot-numbers. In the thirties it had been observed that slot-number combinations found earlier to be good or wrong might show even opposite characteristics in the case of a different machine size. So the interest turned to the effect of mechanical construction of motors, on noise production.

In papers of that time, engineering common sense had arrived empirically at practically correct statements. For about two decades after the '40s numerous analytical works hawe been dealt with the steadystate space analysis of asynchronous motors, and with the influence of small technical changes.

It seemed as if by the time the noise behaviour of asynchronous motors became the marketability criterion all over the world, the specialists were prepared for the challenge of the market. All questions in connection with the electromagnetic noise arising in steady state of the asynchronous motors were meant to be solved and interests were turned to noises produced by the ventilation and the ball-bearings still theoretically unclear.

Till the mid sixties Hungarian publications reflected little interest on the part of engineers in the noise problem. Ervin Kovács was the first to publish a paper in review "Elektrotechnika" in 1965 on the noise problem and its international literature, by the occasion, of the visit of Prof. Heinz Jordan a world famous noise specialist, in Budapest and his lecture in the Hungarian Association of Electrotechnicians. Noise problems during arisen to then in electrical machine factories, were solved by endowed engineers of the given factories as individual problems. By the late sixtes, the Department of Electrical Machines Technical University, of Budapest started an intensive work to make up the lag behind the international standard. But by the mid-seventies the technical development raised another aspect of this problem concerning the recent, increasingly applied electric drives containing controllable semiconductors. While earlier only spatial upper harmonics of the field curve had taken part in noise production in steady state of the asynchronous motors, now also upper harmonics in time production new noise components.

Thereupon the hitherto silent motors have become noisy. Another new problem was the transitory noise increase in the transient work of asynchronous motors. Intensive research made at the Department of Electrical Machines reported in 1975 at an international scientific conference first in international literature helped to clear the noise and vibration increase caused by the antiductor feeding of slip-ring asynchronous motors. In the following, these questions will be comprehensively examined.

The noise and vibration increase caused by semiconductor feeding

Oscillations of the magnetic conductivity due foremost to the practical realization of energy transformation making use of the electromagnetic field: to the stepped distribution of excitation along the periphery of the stator boring: to the slotting, to the air-gap eccentricity and the saturation are functions periodical along the circumference. Fourier series expansion of the field curve produces an infinite set of induction harmonics.

The instantaneous value of the fundamental harmonic of induction wave is:

$$b_1(x, t) = B_{1m} \cos(px - \omega_1 t - \varphi_1)\,. \tag{1}$$

The instantaneous value of an arbitrary element of the so-called stator induction spatial upper harmonics arising upon exciting the stator is:

$$b_\mu(x, t) = B_{\mu m} \cos(\mu px - \omega_1 t - \varphi_\mu)\,. \tag{2}$$

The instantaneous value of an arbitrary term of the induction spatial upper harmonics due to the excited state of the rotor in a coordinate system fitted to the stator is:

$$b_\lambda(x, t) = B_{\lambda m} \cos(\lambda p x - \omega_2 t - \varphi_\lambda) \tag{3}$$

where

$$\omega_\lambda = \omega_1 \left[(\lambda - 1)(1 - s) + 1\right]. \tag{3a}$$

Ordinal numbers of spatial upper harmonics according to their origin, have been compiled in Table 1.

Table 1

	Ordinal number of			
	Excitation	Slotting	Excentricity	Saturation
μ	$2mg_1+1$	$6g_1q_1+1$	$1 \pm \frac{1}{p}$	3
λ (for a squirrel cage machine)	$\frac{g_2Z_2}{p}+1$	$\frac{g_2Z_2}{p}+1$	$\frac{g_2Z_2}{p}+1 \pm \frac{1}{p}$	$\frac{g_2Z_2}{p}+3$
λ (for a slip ring machine)	$2mg_2+1$	$6g_2q_2+1$	...	...

The vibration of asynchronous motor its noise of electromagnetic origin is caused by a multiplicity of radially acting force waves of sinusoidal distribution along the circumference to be computed as:

$$p(x, t) = \frac{b^2(x, t)}{2\mu_0} = \frac{(b_1 + \Sigma b_\mu + \Sigma b_\lambda)^2}{2\mu_0} \tag{4}$$

the instantaneous value of an arbitrary term of the force waves is:

$$P_R(x, t) = P_R \cos(Rpx - \omega_R t - \varphi_R) \tag{5}$$

where

$$R = \mu \pm \lambda$$
$$\omega_R = \omega_1 \pm \omega_\lambda$$
$$\varphi_R = \varphi_\mu + \varphi_\lambda$$

Since

- the electric machine — as a system able to mechanical vibration — is very stiff against exciting forces of high ordinal number:
- the amplitude of induction upper harmonics rapidly decreases with the increase of the ordinal number,
- the frequency range of interest for vibration and noise (perceptibility) is limited from below and from above:

Only a few from the infinity of terms in the right-hand side of Equ. (4) have to be taken into account. b_1^2 is responsible for 100 Hz vibration, while among mixed products $b_\mu \cdot b_\lambda$, that resulting in exciting force of ordinal number $R \leq 10$ may be important from the point of view of noise. If it is really important depends on the mechanical vibration ability and by the sound emittivity of the machine.

The effective value of the vibration speed in the case of a given force wave of ordinal number R is:

$$V_R = \frac{\omega_R}{\sqrt{2}} \sum_j H_j P_R \tag{6}$$

where H_j is the mechanical system characteristic factor of the machine for mode j. The emitted sound power is:

$$N_R = \rho c V_R^2 S_r \cdot \sigma_R \tag{7}$$

Vibration and noise are very strong if the frequency of electromagnetic exciting force is equal or near to mechanical natural frequencies given as a function system characteristic factor H_j in Equ. (6). Machine constructors could already avoid it, boasting that the problem of electromagnetic noise did not exist any longer. And this was the time of advent of semiconductor drives. In the case of an asynchronous motor, the unit containing controllable semiconductors is mostly built in between the machine and the network. This supplies variable mains voltage of fundamental harmonic f_1 to the terminals of the machine (as e.g. in the case of antiductor drive of slip-ring motors) or variable feed of frequency f_1 (as e.g. the drives with voltage inverter) to controll the revolution number of the motor. Each of the controllable semiconductor drives can be told to supply the terminals of the asynchronous motor besides of the desired three-phase voltage system of frequency f_1 also timely upper harmonic voltage systems — typical of semiconductor solutions of ordinal number ν, angular frequency $\nu\omega_1$ and each of them acts on the machine as an independent feed of a different frequency. Neglecting the saturation their influences can be superinposed. Namely besides of the spatial and timely fundamental induction wave b_1 not only the fundamental wave of frequency f_1 but each timely upper harmonic will have spatial upper harmonics. So the instantaneous value of induction upper harmonics of the stator is:

$$b_{\nu\mu}(x, t) = B_{\nu\mu m} \cos(\mu p x - \nu\omega_1 t - \varphi_\mu) \tag{8}$$

circular frequency ω_λ of the induction upper waves of the rotor will increase by ν:

$$\omega_\lambda = \omega_1 \left[(\lambda - 1)(1 - s) + \nu\right] \tag{9}$$

Reconsidering all over outlined vibration and noise process the timely upper harmonics are seen not to create new force ordinal numbers, that is, the set of R not to extend.

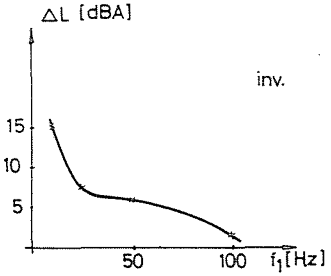

Fig. 1

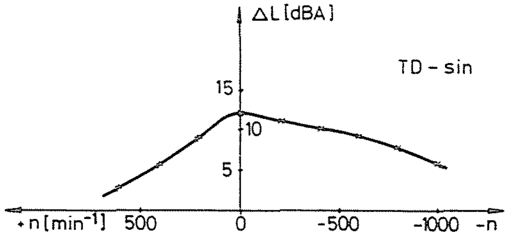

Fig. 2

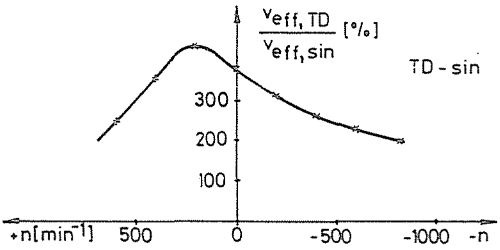

Fig. 3

The quadratic term in (4), however also involves timely upper harmonics with frequencies inexistent before. So new force components are introduced to the range dangerous from the point of view of vibration and noise namely terms b_ν^2 and $b_1 b_\nu$ much increasing the probability of strong vibration and noise of electromagnetic origin due to the coincidence of the exciting force frequency and the mechanical natural frequency. Figures 1, 2 and 3 show the vibration and noise increase not to be a theoretical possibility alone but a reality. Any of these figures shows the variation of vibration and noise of an asynchronous motor due to semiconductor feeding rich in timely upper harmonics compared to uniwave feeding producing the same mechanical parameters. The decrease of noise and vibration increase for higher revolution numbers is partly due to the more favourable operation of semiconductor units, somewhat reducing the relative importance of the timely upper harmonics and partly the other components raised by ball bearings and ventilation increase quickly at increasing revolution numbers to repress the vibration and noise of electromagnetic origin. So, of course, their contribution to the whole vibration and noise is less manifest. The abrupt development of semiconductor technics develops more and more new controlled drives for three-phase asynchronous motors not only with symmetrical, but also with asymmetrical connections, further extending the sphere of noise and vibration cases to be examined, enhancing the difficulty of the problem to the machine constructor expected to create a silent machine.

Noise and vibration problems in the transient work of the asynchronous motor

Generalization of controlled individual drives and automation using separate machines for each drive of timely varying intensity have made transient work so to say the rule.

The transient work of motors throw light on the noise problem, beside numerous stability and control problems. The relative position of the frequencies of electromagnetic exciting forces and of the mechanical natural frequencies of the motor seen to be decisive for the arising vibration and noise has to be examined its dynamics. Equ (3a) and (5) shown the frequency of the exciting force to depend on the slip, that is, on the revolution number. The amplitude of the exciting forces with the motor current as factor depends on the load and the work state. Thus on the excitation side, all important parameters change in transient work. Omitting determination of the amplitude of exciting forces in transient work — a very difficult task in itself because of the simultaneity of mechanical and electromagnetical transient processes — considering only the exciting force frequency variations three typical transient work can be distinguished: starting-rising, turn reversal and, for multi-polar motors (e.g. elevator-motors) generator brake operation at pole number change. At start the frequencies of electromagnetic exciting forces will increase according to Fig. 4, starting with 0 or 100 Hz intercept. Each force component has its straight. The slopes of the straights depend on the origin of the force

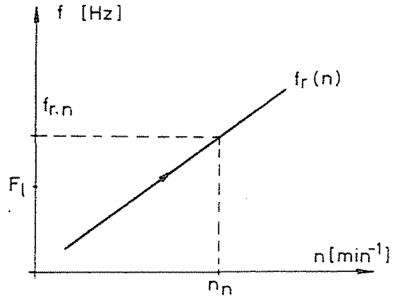

Fig. 4

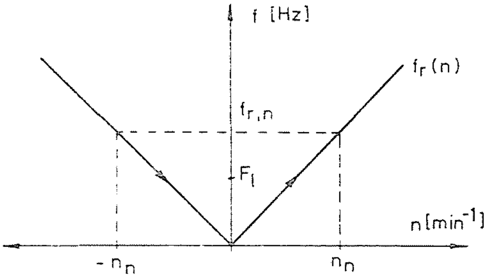

Fig. 5

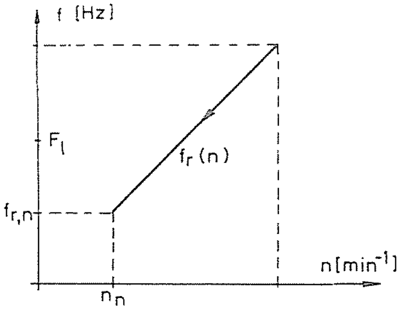

Fig. 6

wave (induction waves from excitation, slotting, eccentricity or saturation; and the respective upper harmonic). Though, in the frequency range passed while the motor accelerates to its rated revolution number one or more mechanical natural frequencies F_l may be found with the risk of transient resonance. Practically the frequency of exciting force remains in the same frequency range also in the case of turn reversal as seen in Fig. 5. A more exciting problem is that of the generator braking work of pole change motors. Upon pole change in a machine of low pole number, high r.p.m. operation the motor can get into an operating condition of very high negative slip (-3, -4 or more), to slow down with generator braking to the rated revolution number conform to the high pole number. As it can be seen in Fig. 6 another frequency range is entered, with another possibility of resonance. The degree of resonance evolution depends, of course, on the dynamics of the revolution number change and also on the mechanical damping of the system.

To avoid all kinds of resonance is so to say an impossibility. All that can be done to achieve a silent machine is to examine which component of the exciting force, on what frequency causes the transient noise, and to zero or nearly this force component by some constructional or technological trick (skewing the rotor slots, pitch shortening of stator winding, mixed winding, etc.). If the machine designer is a lucky fellow, then the noise was caused by this force component also in steady state. Else the problem gets complicated because each constructional change offsets a single upper harmonic.

The examination of transient noises is a difficult problem not only in the theory of electromagnetic noises, but also from the aspect of metrology. The transient noise phenomena of asynchronous motors pass very quickly, maybe a few 10 ms. The traditional analog-system devices of noise measurement do not suit transient noises. For the one-figure examine the transient noise phenomenon (e.g. maximal A-sound pressure level), the pulse-noise level meter will do. But the researcher is also interested in the spectral conditions and timely variation of the transient noise phenomenon, yielding much information of importance for noise decrease. To this aim, continuous research work is done at this Department to develop a hybrid analog-digital measuring system. The obtained results are rather promising, with interesting achievements, including transient measuring technique for the exact experimental determination of mechanical natural frequencies.

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