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ON THE MAGNETIC NOISE AT ROTARY ELECTRIC MACHINES. PART I

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Abstract. In the paper it is studied the magnetic noise which has its origin in the action of Maxwell forces of traction, which appear in the air gap of rotary electric machines. It is put in evidence the fact that under the action of the alternative forces, which have, in the air gap, a periodic distribution in relation to the space and time, the stator and rotor of rotary electric machines execute forced oscillations of extension and flexion. There are established the oscillation shapes of stators, respectively of rotors of rotary electric machines.

1. INTRODUCTION

The magnetic noise has its origin in the action of Maxwell forces of traction, which appear in the air gap of machine. Under the action of the alternative forces, which have, in the air gap, a periodic distribution in relation to the space and time, the stator and rotor execute forced oscillations of extension and flexion. Practically, the radial efforts are the only ones which produce noise, the other ones being taken into account in special cases, only [2].

2. OSCILLATION SHAPES OF STATOR AND ROTOR

Among the electric machines, the asynchronous motor is the one which has the biggest complexity, from the point of view of the magnetic noise. Because this type of rotary machine is used in the most different technical domains, it is important to be as silent as possible.

The magnetic forces, generated on the surface unit, depend on the square of normal component of induction in the air gap, *b,*

$$f_\delta \sim b^2. \tag{1}$$

The magnetic field in the air gap contains, in addition to the fundamental b_1, a sum of field harmonics, of order *i,* because of different causes *j* (harmonics of the winding and of the slots of stator and rotor, field waves of the polar wheel at idle running),

$$b = b_1 + \sum_i b_i , \tag{2}$$

where

$$b_i = \sum_j b_{ij} . \tag{3}$$

More shortly, the relation (2) can be written

$$b = b_1 + \sum_i \sum_j b_{ij}. \tag{4}$$

By squaring the equation (4), in addition to the squared fundamental, b_1^2, it is obtained a sum of products of field waves, of form $b_{j1i1}b_{j2i2}$.

For the asynchronous machine, it results seven sums, if there are taken into account the field harmonics of the winding, inclusively their slot harmonics and the field harmonics of the slots of the stator, of order $i = \nu$, as well as the same field harmonics of the rotor, with $i = \mu$,

$$b^2 = b_1^2 + 2\Big(\sum_{\nu} b_1 b_\nu + \sum_{\mu} b_1 b_\mu\Big) + \sum_{\nu} b_\nu^2 + \sum_{\mu} b_\mu^2 + 2\Big(\sum_{\nu_1 \prec \nu_2} b_{\nu_1} b_{\nu_2} + \sum_{\mu_1 \prec \mu_2} b_{\mu_1} b_{\mu_2} + \sum_{\nu_\mu} b_\nu b_\mu\Big). \tag{5}$$

For the synchronous machine, the relation (5) is also valid, but instead of the field waves of rotor (index μ), intervene the field waves of the excitation of the polar wheel at idle running, with index η.

The interaction of two rotating field waves, b_{i1} and b_{i2}, designated as product of field waves $b_{i1}b_{i2}$, gives, in accordance to the relation (1), two rotating mechanical waves, whose variation has the form [2],

$$f_{r,i1,i2} \sim \frac{b_{i1}b_{i2}}{B_{i1}B_{i2}} = \frac{1}{2}\cos[(i_1 + i_2)px - (\omega_{i1} + \omega_{i2})t] + \frac{1}{2}\cos[(i_1 - i_2)px - (\omega_{i1} - \omega_{i2})t]. \tag{6}$$

Noting by *r* the order number of the mechanical rotating waves for the free field waves b_{i1} and b_{i2}, it results

$$r = p(i_1 \pm i_2) = p_{i1} \pm p_{i2} = \bar{i}_1 \pm \bar{i}_2, \tag{7}$$

and the frequencies f_r, which give a discontinuous spectrum are

$$f_r = f_{i1} \pm f_{i2}. \tag{8}$$

In relation to *r*, it can be deduced different shapes of oscillations, corresponding to the representations in figure 1.

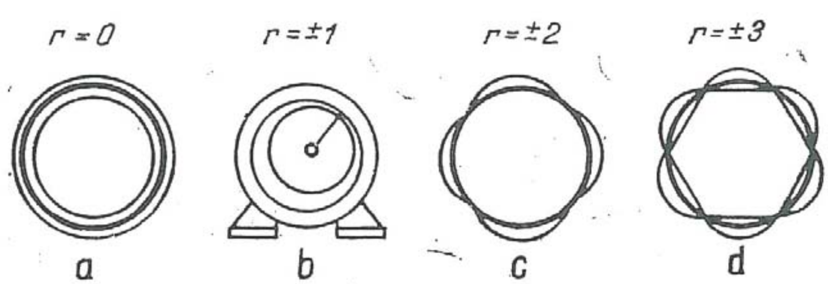

Fig. 1. Oscillation shapes of stator, respectively of rotor

The case in figure 1,*a* ($r = 0$) corresponds to a radial force, uniformly distributed on the periphery of the armature of stack of sheets; the case in figure 1,*b* ($r = \pm 1$) corresponds to an unilateral magnetic force of attraction; the other cases correspond to different shapes of oscillations of the carcass, around the medium line of the collar plate, represented by thick line.

For the maximal value of the static flexion, which characterizes the rigidity, for $r = 0$, it is obtained [2]

$$X_{rstat} = \frac{R}{E\frac{h}{R_{js}}} F_0, \tag{9}$$

and for $r \geq 2$,

$$X_{rstat} = 12 \frac{R}{E(\frac{h}{R_{js}})^3 (r^2 - 1)^2} F_r. \tag{10}$$

In these relations, in addition to the notations in figure 2, there are used the notations as fallows:
- E - modulus of elasticity;
- F_0 and F_r - distributed radial forces of attraction.

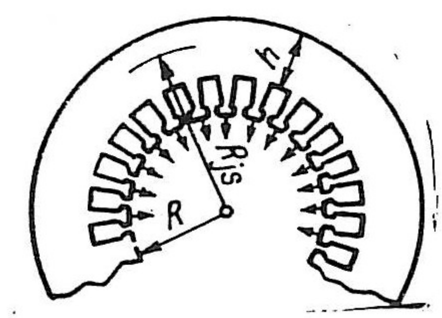

Fig. 2. Signification of notations in formulae (9) and (10)

In the case of the unilateral magnetic forces of attraction, with $r = \pm 1$, it takes place, mainly, a flexion of the shaft of rotor, whereas the deformation of the stack of sheets of the stator is very small.

In the case in figure 1,*b*, the unilateral magnetic forces of attraction are transmitted and they are propagated to the foundation, by the flanges of machine, as a structural noise, whereas the external surface of the stator emits only a weak noise.

In the cases in figure 1,*a*, *c* and *d*, the noise is emitted especially from the external surface of the machine.

In order to find which ones of the products in relation (5) generate dangerous mechanical rotating waves, characterized by *r* and f_r, it must that the order numbers *i* of the field waves from the equation (5), to be introduced in the equation (7), and their frequencies, in the equation (8).

In relation to the order number *r*, it is rational to consider only the mechanical waves with an order number, superiorly limited, and the frequencies f_r must be situated in the domain of the dangerous frequencies.

From the physical point of view, the induction in the air gap, $b(x,t)$, is given by the product between the magnetic tension $V_m(x,t)$ and the permeance $\Delta(x,t)$ of the air gap. If these quantities are analytically represented by Fourier series, it results

$$b(x,t) = [\sum_{\rho=1}^{\infty} V_\rho \cos(\rho px - \omega_\rho t)][\sum_{k=0}^{\infty} \Lambda_k \cos(kpx - \omega_k t)]. \quad (11)$$

The order number of the excitation field wave is indicated by ρ (the special influence of coils in the slots and on the poles), and the order number of the permeance is given by the index k. In this study, the factors of amplitude are neglected so that, from the equation (11), it results

$$b(x,t) = [\sum_{\rho=1}^{\infty} b_\rho(x,t)]_{k=0} + \sum_{\rho=1}^{\infty}\sum_{k=1}^{\infty} b_{\rho k}(x,t), \quad (12)$$

where

$$b_\rho(x,t) \sim \cos(\rho px - \omega_\rho t) \quad (13)$$

and

$$b_{\rho k}(x,t) \sim \cos[(\rho \pm k)px - (\omega_\rho \pm \omega_k)t]. \quad (14)$$

From the analysis of relations above the fallowing aspects appear:

- by b_ρ there are noted the field waves which appear as a consequence of a constant average permeance of the air gap $(k = 0)$; their order number ρ is equal to the order number of the field wave of excitation:
  - $\rho = \nu$ for the field waves of stator;
  - $\rho = \mu$ for the field waves of rotor;
  - $\rho = \eta$ for the field waves of the polar wheel of synchronous machine;
- by $b_{\rho k}$ there are noted the harmonics of denture, which are given by the harmonics of permeance of order k; for the waves of denture with Z slots, it can be written

$$k = \frac{Z}{p} k_N, \quad (15)$$

where $k_N = 1,2,3,...$

In order to study the order number r and the frequency f_r of the mechanical wave, in accordance to the equations (7) and (8), for the order numbers i_1 and i_2, it must be introduced the corresponding order numbers ρ, respectively $(\rho \pm k)$ of the field waves, where the order numbers k are calculated with the relation (15).

The case of fundamental wave b_1 with $i = \nu = 1$, is comprised here, and for the diametral winding and short-pitch winding, the fundamental wave is described by $g_1 = 0$.

The analysis of frequencies gives for all these cases, in virtue of relation (8), the sum frequency *S*, respectively the difference frequency *D* [1]:

$$\begin{aligned} f_{rS} &= f_{i1} + f_{i2} = 2f, \\ f_{rD} &= f_{i1} - f_{i2} = 0. \end{aligned} \tag{16}$$

3. CONCLUSIONS

From the relations above, it results that it is unnecessary to consider the order numbers ν, because there are only the oscillations with the double of frequency of network that appear.

For the machines of high diameter (big synchronous generators, with much poles and short-pitch winding), which present very small proper frequencies f_p, for small order numbers *r*, the order numbers *r* which appear for the affected products of field waves with the fundamental wave b_1, being so big, so that, at the proper frequencies of their stators, no 2*f* resonance phenomena are expected.

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