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Behavior Technical Analysis of the Asynchronous Motor

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Abstract: The analysis of the asynchronous motor working regime in presence of some failure constitutes a big interest for the mastery of the risks that the motors incur in a fabrication line in presence of damage. It especially contributes to improve their working safety and to enlighten the making decision for the electric machinery exploitation confronted to some undesirable modes. It is vital to know the consequences of these asynchronous motor failures on the equipment and especially the operating staff in order to forecast the necessary safety measures. In some laborious or specific operating conditions (metallurgy, cement factory), the induction motors are subject to simple or combined electric defects of the stator and rotor coils. This research essentially targets the survey and the analysis of the technical behavior and the faculty to operate of the asynchronous motor confronted to the apparition of these defects confining to the state of stationary working of the asynchronous motors. The length of the transitional processes is considered very minimal and can prove to be insufficient for the appreciation of the limits associated to the defects. Some experimental statements have been done on 2 types of motors. They have been compared to the numeric results and proved to be very conclusive.

Key words: Asynchronous motor, electric faults, electric asymmetry, working safety, constitutes, operating conditions

INTRODUCTION

Most of the time, the machines turn without abnormal risk because in fact defect does not mean obligatorily danger, it all depends on proportioning. Any machine in good health is sick and carries in germ the symptoms of the diseases that researchers want to diagnose. In fact, the major difficulty of the diagnosis in many cases does not consist to detect a possible defect but to evaluate if it presents a risk. The monitoring of the motors must in the first place ensure their protection. This protection is assured if certain limits are not exceeded and by acting on the operating conditions of the motors to put them in safety. Some defects of the asynchronous motors can occur under normal operation.

They are due to electric defects affecting the stator or the rotor. They are very considerable, especially for the electric drives with great inertia. Statistics showed that 60-70% of the breakdowns of the induction motors originate in the operation of the latter on 2 phases. Therefore, it is useful to have references which define the thresholds normally met for the various sizes measured (current, couple, time, speed) and those beyond whose the behavior of the asynchronous motor can be regarded as abnormal. In spite of the existence of many researches completed (Thomson, 1984), in this research area several questions remain posed. This relates to as well their analysis as the methods used for their study. The short circuits between whirls and the phase lack for the ring engines, the ruptures of bars for the squirrel-cage engines many other failures involve the asymmetry of these electric machines.

Like rule in front of such defects, the machine must be stopped then repaired or replaced. Nevertheless, certain priority installations can make the exception of it. A cage engine involving a constant load and consuming 1.75-1.85 times, the rated current can develop 60% of its nominal output without warming up. The operation of the asynchronous motors presenting a failure combined with the stator and the rotor is a relatively rare practical case. But for the annoying consequences of this type of failure, this consideration proves to be necessary at least for the strategic electric actuators and the SDF. This can also be useful like reference for the diagnosis and the methods of early detection of these electric defects and consequently within the context of the experience feedback. However, this asymmetrical mode is very common in the single-phase current engines and takes place even under normal operation for certain special asynchronous motors.

The combination of the electric defects stator and rotor is modelled (Thomson, 1983; Razik, 2003) by equations with periodic coefficient which makes the study more complex and requires the contribution of the data-processing tool.

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MODELING ASYMETRIC MODES IN THE CASE OF RINGS'S MOTORS

The electric balance of the rotor circuit can be disturbed following a variation of the active or inductive resistance of one of its phases (Bonnett and Soukup, 1992). Researchers will consider a rotor asymmetry in case of ring engine by associating a resistance R to 1 of its 3 phases. Let consider the rupture of the phase a stator coiling, the sinusoidal tension U_{bc} is written in vectorial form:

$$ue^{j\gamma r} - u^*e^{-j\gamma r} = j2U_m \sin t \quad (1)$$

Where:

u, u* = Represent the vectors tension and its combined
γ_r = The swing angle of the reference mark

While indicating by:

$$ue^{j\gamma r} = u_\alpha \text{ et } u^*e^{-j\gamma r} = u^*_\alpha$$

The equations of the stator coilings of the symmetrical machine in the fixed reference mark (α, β) are written:

$$u_\alpha = i_\alpha r + \frac{d\psi_\alpha}{dt}$$
$$u^*_\alpha = i^*_\alpha r + \frac{d\psi^*_\alpha}{dt} \quad (2)$$

By substituting in Eq. 2, the vectors flow ψ of the stator coilings of the symmetrical machine by their expressions and after transformation is obtain:

$$jU_m \sin t = i_\alpha r + \frac{d}{dt}\left[x_s i_\alpha + \frac{1}{2}x_m\left(i_{r\alpha} - i^*_{r\alpha}\right)\right] \quad (3)$$

The mathematical model describing the rupture of the phase a and rotor asymmetry with the connection of R in a rotor phase of the ring engine is written according to the axis β as follows:

$$i_\beta r + \frac{dy}{dt}(x_s i_\beta + x_m i_{r\beta}) = U_m \sin t \quad (4)$$

$$i_{r\beta}\left(r_r + \frac{R}{3}\right) - (i_{r\alpha}\sin 2\gamma_r - i_{r\beta}\cos 2\gamma_r)\frac{R}{3} +$$
$$\frac{d}{dt}(x_r i_{r\beta} + x_m i_\beta) - \omega_r x_r i_{r\alpha} = 0 \quad (5)$$

The analysis of the processes is established for a constant speed ω_R. The modeling of the engine in the presence of a combined electric failure, i.e., a rupture of the rolling up of the phase a of the stator accompanied by a rupture on the level of the rotor phase (R = ∞) can be described by the system of equations following:

$$i_{r\alpha} r_r + \frac{d\psi_{r\alpha^*}}{dt} + \omega_r \psi_{r\beta^*} = 0$$
$$i_{r\alpha} r_r + \frac{d\psi_{r\alpha^*}}{dt} + \omega_r \psi_{r\beta^*} = 0 \quad (6)$$
$$i_{r\beta} r_r + \frac{d\psi_{r\beta^*}}{dt} + \omega_r \psi_{r\alpha^*} = 0$$

Avec:

$$\psi_{r\alpha^*} = x_r i_{r\alpha} - x_m i_\beta \sin 2\omega_r t$$
$$\psi_{r\beta^*} = x_r i_{r\beta} + \frac{1}{2}x_m i_\beta(1 + \cos 2\omega_r t)$$

RESULTS ANALYSIS

Calculations were carried out with the average parameters of the ring engines whose power vary from 4.5-40 kw:

$$2p = 4;\ g_n = 3.5\%;\ x'_s = 0.23;\ x_m = 2.40;$$
$$x_s = x_r = 2.52;\ \sigma = 0.093;\ C_{max}{}^* = \pm 13.3$$

The curves of the Fig. 1 shows the instantaneous electromagnetic couple for various values of $K = R/r_R$. For K = 0, the engine work at a normal rate single-phase current. Consequently, direct and opposite fields appear and their interaction with corresponding rotor ones imply variable couples whose superposition gives like resultant a periodic couple with double frequency. For k = 5, the average value of the couple decreases. The vibrations and the sound effects increase. These phenomena are amplified with the growth of rotor electric asymmetry corresponding to the increase of K. The overpressures hardly exceeding 10-15% of the nominal voltage become considerable on the level of the stator phase in rupture (K = ∞). The same driving motor is cut down simultaneously by a stator and rotor phase. Figure 2 shows C(t) for a slip of 3%. It is clear that for such a mode, the engine can not involve loads exceeding the order of

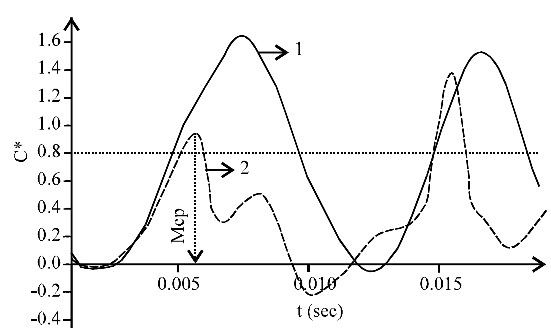

Fig. 1: Electromagnetic couple of the ring engine (1 for k = 0 and 2 for k = 5)

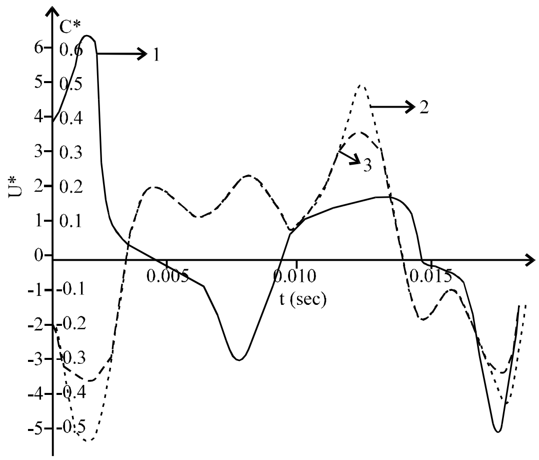

Fig. 2: Electromagnetic couple and tension of the phase during a simultaneous rupture (1: Electromagnetic couple; 2: Terminal voltage of the open phase during the rupture of one rotor phase and 3: Terminal voltage of the open phase during the rupture of one rotor phase with taking into account of saturation

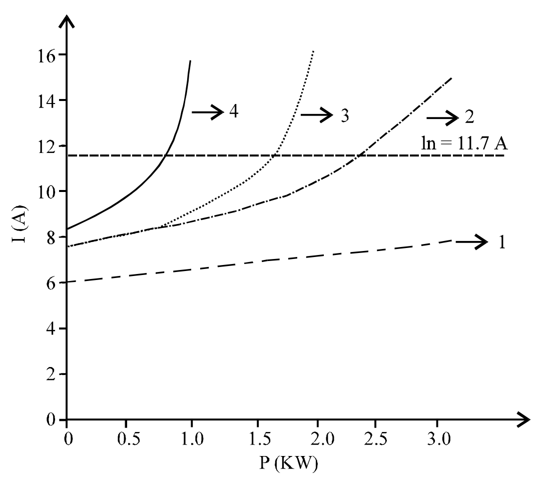

Fig. 3: Stator current according to ring the healthy engine output then affected of various electric failures

the 20%. Beyond this load, the engine rocks quickly and remarkable oscillations of the speed with an accentuated vibration and sound effects are observed. The overpressure effect increases strongly, exceeding even 5 times of the nominal voltage and this without considering the saturation of X_m = const. Nevertheless with the growth of the tension, the saturation of X_m decreases and consequently, a light fall of overpressure is observed (Fig. 2). Quality of operation of the engine deteriorates due to the effect of rotor asymmetry which

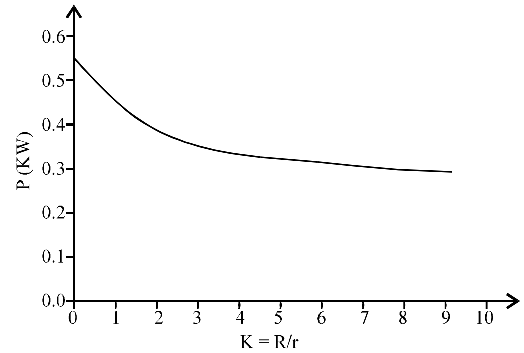

Fig. 4: Dependence of the power in shaft end of the engine according to the degree rotor asymmetry

increases with increasing load. Different experimental tests (Fig. 3) were exerted on the typical wound rotor engine whose stator is coupled out of star:

$$P_N = 5 \text{ kw}; U_N = 380 \text{ V}; N = 1430 \text{ trs mn}^{-1}; I_N = 11.7 \text{ A}$$

Curve 1 shows the normal operation of the engine with the brushes raised. The curves 2 and 3 are obtained during the absence of a stator phase, respectively for k = 0 and k = 5. On the other side, the curve 4 shows the most critical case which consists of the presence of combined electric defects, i.e., the simultaneous rupture of a stator phase and a rotor phase. It results from it that with the evolution of the electric asymmetry of the rotor following the increase in K = R/r, the power developed by the wound rotor engine is in strong regression. Already, with a symmetrical rotor and a rupture of phase to the stator the power in shaft end decreases by 50%. Figure 4 shows P_2 = f (k) of the ring engine, it is constructed without the influence of the contact resistance of rushes. In the presence of the rupture of a rotor phase (R = ∞) despite the absorption of the rated current, the engine just manages to develop a mechanical power of 16%.

MODELING OF THE ASYMMETRIC MODES

In front of an electric failure with the rotor, the behavior of the ring engine differs from that with rotor in short circuit. For this last as an example, the rupture of a rotor phase has a relatively weak impact on the engine operation especially if the machine is multipolar.

However, the analytical calculation of the conditions of asymmetry conditions following the defects of the bars or the rings of short circuitage is more complex than for the wound rotor (Menacer *et al*., 2004; Casimir *et al*., 2003a, b). Let us suppose the break of K bars of the rotor cage:

$$i_A = i_B = i_C = \ldots = i_K = 0 \quad (7)$$

In vectorial form the condition, Eq. 7 is written in the reference mark turning at the speed of the spinning field pattern:

$$\begin{aligned} i_A &= \frac{1}{2}\left[i_r e^{j\beta_r} + i_r^* e^{-j\beta_r}\right] = 0 \\ i_B &= \frac{1}{2}\left[i_r e^{j(\beta_r - \alpha_m)} + i_r^* e^{-j(\beta_r - \alpha_m)}\right] = 0 \\ i_K &= \frac{1}{2}\left\{i_r e^{j[\beta_r - (k-1)\alpha_m} + i_r^* e^{-j[\beta_r - (k-1)\alpha_m}\right\} = 0 \end{aligned} \quad (8)$$

Or:

$$\beta_r = \int_0^t s\,dt$$

$$\alpha_m = \frac{2\pi}{z_2}$$

Where, z_2 is a number of bars rotor. The stator and rotor currents when the engine functions with such or such number of rotor bars in rupture can be obtained by the equations above:

$$\begin{aligned} &U\frac{m_2 - k}{m_2} - U*B = i\frac{m_2 - k}{m_2}(r + jx_s) - iB(r - jx_s) + i_{rr} jx_m \\ &i_{rr}\left[r_r + \frac{jsx_m}{D}\left(\frac{m_2 - k}{m_2}\right)^2 + \frac{jsx_r}{D}BB*\right] - \\ &-i_{rr} * jsx_r \frac{2B\left(\frac{m_2 - k}{m_2}\right)}{D} + jsx_m\left(i\frac{m_2 - k}{m_2} - i*B\right) = 0 \end{aligned} \quad (9)$$

If the defect is combined then the couple will express like:

$$C = x_m^2 \frac{m_2 - k}{m_2} \frac{\frac{r_r}{s}}{\left(\frac{r_r}{s}\right)^2 + x_r^2} i^2 \quad (10)$$

RESULTS ANALYSIS

Calculations as well as a series of experimental studies were conducted on the motor with squirrel-cage P = 3 KW; 2p = 6; U = 220/380 V; I = 12.5/7.2 A; N = 950 trs mn^{-1}; the rotor cage comprises 45 bars.

Relative parameters:

$x_\sigma = x'_{r\sigma} = 0.12$; $x_s = x_r = 1.86$; $x_m = 1.74$; $r = 0.04$; $r_r = 0.06$

Figure 5 shows the curves resulting from calculations and the experimental points expressing the current and the couple of the engine functioning without defect (curve1) then with a rupture of the third of the rotor bars (curve 2). The results for the current as well theoretical as experimental are completely satisfactory. On the other hand, those for the couples diverge slightly. It is obvious that in the presence of rotor defects, the slip and consequently the losses increase. The curves of the Fig. 6 which express C(s) obtained by calculations and raised in experiments have a good coincidence. The divergence of the curves with the increase in slip is allotted to the negligence of the theoretical term B and to the variation of the engine's parameters. Different types of electric failures of the cage (Fig. 7a) combined with a rupture of the stator phase (Fig. 7b) were tried out on the cage engine and this for various modes of service. Table 1 shows the times, raised experimentally at the time of two dynamic modes of the asynchronous rotor motor in short circuit which are respectively the starting and the inversion of the rotation's direction and this for a healthy state of the engine and when it is affected with various failures on level of its rotor cage. It arises from Table 1 that these times increase with the consequently they can

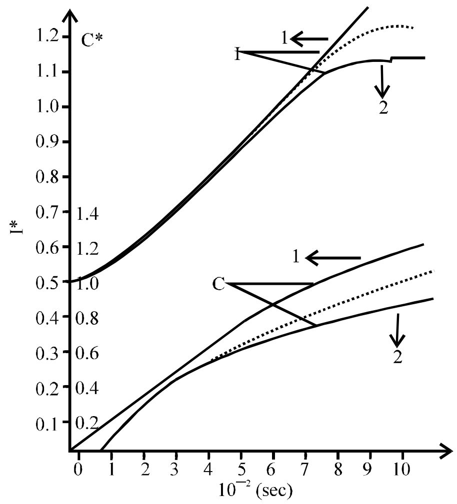

Fig. 5: Running and engine couples with cage p = 3 KW; 1: Engine without defect; 2: Third of the cage at fault; x: Statements tried out X

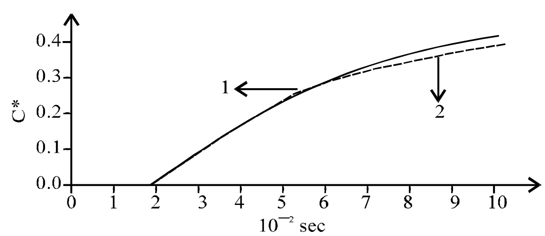

Fig. 6: Mechanical characteristics; 1) calculated and 2) experimental cage engine at the time of a combination of electric failures (rupture of 15 bars to the rotor and a phase with the stator)

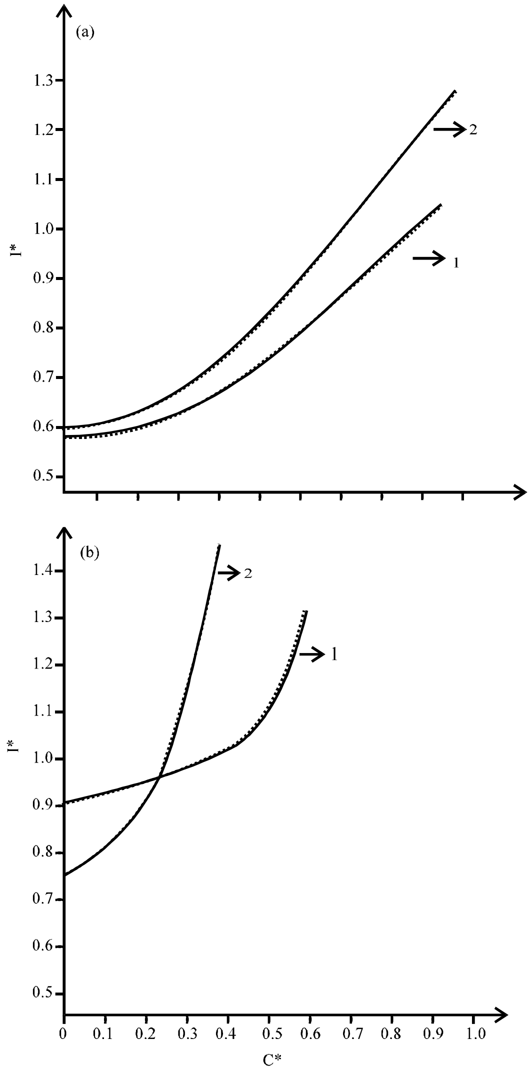

Fig. 7: Experimental curves of the stator current of the cage engine; a) for different electric defects rotor and b) for simultaneous defects with the rotor and the stator; curve 1: operational engine and curve 2: engine with rupture of 15 bars and a crack on the level of the ring of short circuitage

Table 1: Influence failures of rotor rolling up over the time of starting and inversion of feel rotation

Types of failures rotor cage	Time of starting (sec)	Time of inversion (sec)
Operational rotor	1.11	1.97
Rupture of 5 bars	1.16	2.00
Rupture of 10 bars	1.39	2.52
Rupture of 15 bars (1/3 of the cage)	1.45	2.64
Rupture of 15 bars and crack of the ring of short circuitage in only one place	1.51	2.87
Rupture of 15 bars and crack of the ring of short circuitage in only one place	1.56	2.94

evolution of the failure's degree of rotor and be of a great contribution to decide health of the induction's engine.

CONCLUSION

The results of this research can contribute to establish health checks generally reserved for the significant asynchronous motors whose breakdowns are likely to jeopardize the reliability or to involve significant disturbances of the production or high costs of maintenance. Moreover, they can be useful as data bases for the experience feedback. Certain asymmetrical modes which appear in the electric drives are accompanied by very painful conditions of operating. They can contribute to annoying consequences for the electric motors. If the engines are not in priority industrial axes, their stop proves to be obligatory and it y' required to replace them. For the strategic machines and when the process technological does not allow their direct consignment, the analysis carried out previously offers the possibility to the owners of choosing the most rational method to circumvent or to liquidate these types of damages. However, the choice of the asynchronous motors to supervise and the programs of maintenance or control will be carried out by analysis of the type OMF (Optimization of the maintenance based on reliability).

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