On Line Current Monitoring and Application of a Residual Method for Eccentricity Fault Detection

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***Abstract*—This work concerns the monitoring and diagnosis of faults in induction motors. We develop an approach based on residual analysis of stator currents to detect and diagnose faults eccentricity static, dynamic and mixed in three phase induction motor. To simulate the behavior of motor failure, a model is proposed based on the approach of magnetically coupled coils. The simulation results show the importance of the approach applied for the detection and diagnosis of fault in three phase induction motor.**

***Index Terms*— detection, diagnosis, eccentricity, monitoring, residuals.**

I. Introduction

The monitoring and diagnosis of faults in induction motor rally to date many researchers [1]. The induction motor during operation is subject to several constrains causing defects in different parts of the engine [2]. The protection of induction motors does not avoid the occurrence of these defects and their effects on electrical motors. So preventive maintenance has become a major necessity to avoid total failure of electrics motors. Several research studies have been devoted to this new type of maintenance using different diagnosis techniques [3]. This study is devoted to the technique based on the use of residuals of stator currents to detect and diagnose faults of eccentricity from the monitoring of residuals of the phase stator currents.

II. Presentation of Models Studied

Consider a three-phase induction motor, cage rotor consists of N_b bars isolated uniformly distributed aver the surface of rotor is short-circuited by two rings. Under classical simplifying assumptions [4], the mathematical model of induction motor is presented by the system of equation:

$$[V] = \left[R + \frac{dL}{dt} \right][I] + [L]\frac{d}{dt}[I] \tag{1}$$

$$\frac{d}{dt}[I] = -[L]^{-1}\left[R + \frac{dL}{dt} \right][I] + [L]^{-1}[V] \tag{2}$$

where,

$$[V] = [v_a \ v_b \ v_c \ 0 \ 0 ... 0] \tag{3}$$

$$[I] = [i_a \ i_b \ i_c \ i_{r_1} \ i_{r_2} ... i_{N_b} \ \ i_e] \tag{4}$$

The voltage equation is presented by :

$$[V] = [X][I] \tag{5}$$

with,

$$[X] = \begin{bmatrix} [R_s] & \frac{d}{dt}[L_{sr}] \\ \frac{d}{dt}[L_{sr}]^T & [R_r] \end{bmatrix} + \begin{bmatrix} [L_s] & [L_{sr}] \\ [L_{sr}]^T & [L_r] \end{bmatrix} \tag{6}$$

The stator resistance and inductance are of size (3x3):

$$[R_s] = \begin{bmatrix} R_s & 0 & 0 \\ 0 & R_S & 0 \\ 0 & 0 & R_s \end{bmatrix} \tag{7}$$

$$[L_s] = \begin{bmatrix} L_{aa} & L_{ab} & L_{ac} \\ L_{bc} & L_{bb} & L_{bc} \\ L_{ca} & L_{cb} & L_{cc} \end{bmatrix} \tag{8}$$

The rotor resistance and inductance are of dimension $[(N_b+1)x(N_b+1)]$:

$$[R_r] = \begin{bmatrix} R_r & -R_b & 0... & 0 & -R_b & R_e \\ -R_b & R_r & 0... & 0 & 0 & R_e \\ .. & .. & .. & .. & .. & .. \\ -R_b & 0 & 0... & -R_b & R_r & R_e \\ R_e & R_e & R_e... & R_e & R_e & N_b R_e \end{bmatrix} \tag{9}$$

$$[L_r] = \begin{bmatrix} L_{r_1 r_1} & L_{r_1 r_2} .... L_{r_1 r_{N_b}} & L_e \\ L_{r_2 r_1} & L_{r_2 r_2} ...... L_{r_2 r_{N_b}} & L_e \\ .. & .. \quad .. \quad .. & \\ L_{r_{N_b} r_1} & L_{r_{N_b} r_2} .... L_{r_{N_b} r_{N_b}} & L_e \\ L_e & L_e .... L_e & L_e \end{bmatrix} \tag{10}$$

The inductance of the motor is calculated by using the function approach winding [5, 8].

III. Defects Eccentricities

The purpose of this paragraph is to study and then explain the changes observed in the stator phase currents, and residual currents of the supply phases in the case of a defect in the eccentricity induction motor. The eccentricity of the motor is defined as asymmetry in the gap of the gap between the stator and rotor. The eccentricity is divided into two categories: static and dynamic eccentricity. The static eccentricity is characterized by the fact that the center of the rotor is not equal to the stator. The dynamic eccentricity is characterized by the center of the motor rotates around the

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center of the stator [6].

There size of the gap, the presence of air gap eccentricity is modeled by the following equation [7]:

$$e\left(\theta_s,\theta_r\right)=e_0+a_1.\cos\left(\theta_s\right) + a_2.\cos\left(\theta_s-\theta\right) \quad (11)$$

with,

e_0 : is the size of the gap in the absence of default,

$a_1 = es.e_0$: is the amount of static eccentricity,

$a_2 = ed.e_0$: is the amount of dynamic eccentricity,

es and ed : are respectively the orders of static and dynamic eccentricity,

θ_s : is the angular position in a coordinate system relate to the stator,

θ : is the angular position of rotor relative to stator.

1- case of static eccentricity $a_2 = 0$, the expression (11) becomes:

$$e\left(\theta_s\right)=e_0+a_1.\cos(\theta_s) \quad (12)$$

2- case of dynamic eccentricity $a_1 = 0$, the expression (11) becomes:

$$e\left(\theta_s,\theta\right)=e_0+a_1.\cos(\theta_s-\theta) \quad (13)$$

3- case of mixed eccentricity $a_1 \neq 0$ and $a_2 \neq 0$.

In the presence of absence of eccentricity, the gap function is changed, and the main inductance is expressed as [8]:

$$L_{ii}(\theta)=\frac{1}{\mu_0}\int_{-L_{ax}/2}^{L_{ax}/2}\int_0^{2\pi}F_{Bi}^2(\theta,\theta_s,z).P^2(\theta,\theta_s,z).\,r_{moy}(\theta,\theta_s,z).e(\theta,\theta_s,z)d\theta_s.dz \quad (14)$$

And the mutual inductance between windings *i* and *j* that is presented by:

$$L_{ij}(\theta)=\frac{1}{\mu_0}\int_{-L_{ax}/2}^{L_{ax}/2}\int_0^{2\pi}F_{Bi}(\theta,\theta_s,z).F_{Bj}(\theta,\theta_s,z).P^2(\theta,\theta_s,z).\,r_{moy}(\theta,\theta_s,z).e(\theta,\theta_s,z)d\theta_s.dz \quad (15)$$

with,

$F_{BJ}(\theta,\theta_s,z)$: is the magneto-motive force of the winding j,

$p(\theta,\theta_s,z)$: is the permeance of the air-gap,

$r_{moy}(\theta,\theta_s,z)$: is the mean radius of the air-gap.

IV. Use in the Detection and Diagnosis

In this paper we develop a technique for monitoring and fault diagnosis of eccentricity in the induction motor. This approach allows of defects in the first stage, then the diagnosis of the type of defects in a second step. The principle of monitoring and fault diagnosis eccentricity in this paper is based on the analysis of residual currents of the three stator phases and the calculation error between the output of the real machine and that estimated with models reference for the three phases [3, 9]:

$$\begin{aligned} r_A(t) &= y_A(t) - y_{estA}(t) \\ r_B(t) &= y_B(t) - y_{estC}(t) \\ r_C(t) &= y_C(t) - y_{estC}(t) \end{aligned} \quad (16)$$

The method is shown figure 1

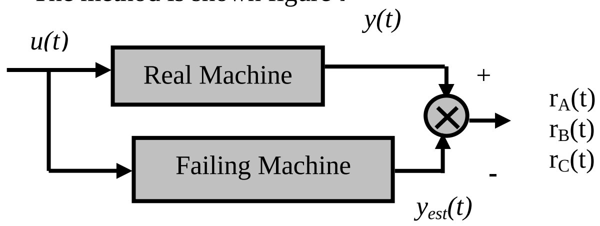

Figure 1 Principle of detection and diagnosis

This method allows the online detection and estimation of the moments of appearance of defects. It also allows the diagnosis of the type defects.

V. Results and Interpretation

This results presented are simulation results obtained with an analytical model of the machine to which was added white noise of magnitude 0.001.

There sequences are performed, in the first, a static default is simulated at t=1(s), in the second, a dynamic fault is simulated at t=1.5(s), in the past, a mixed fault is simulated at t=2(s).

VI. Stage of Detection

The parameters of the simulated induction motor are given in appendix. Using the mathematical model magnetically coupled simulations is performed first for a healthy motor with load torque at time 0.5 seconds, then in the case of defects static, dynamic and mixed. The following figures (5, 6 and 7) illustrate the residual current phase of the stator with default static, dynamic and mixed waste.

The results of identified residuals obtained show that the results from the model to defect faults and eccentricities to estimate with good accuracy the moment of occurrence of the defect t_d, indeed, before the fault occurs, the residual is zero mean with small amplitude variations due to measurement noise.

In the case of a default or default static and mixed amplitude significantly in comparison with the measurement noise, a simple threshold of the residual r_1 can conclude. In the case of default dynamic detection and estimation of t_d can be obtained using a sequential algorithm for change detection (maximum likelihood or cumulative sum). Yields:

t_d(static fault)=1.12 (s),
t_d(dynamic fault)=1.5 (s),
t_d(mixed fault)=2.15 (s),

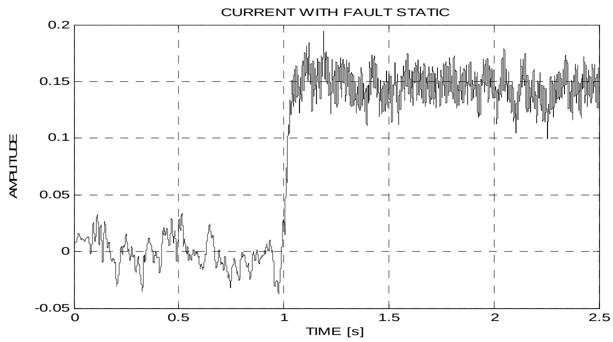

Figure 2. Residual of a phase in the presence of static defects

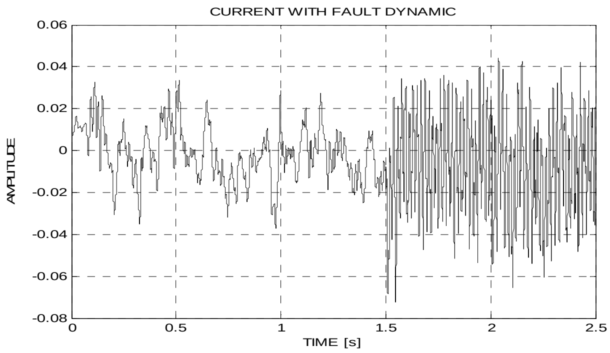

Figure 3. Residual of a phase in the presence of dynamic defects

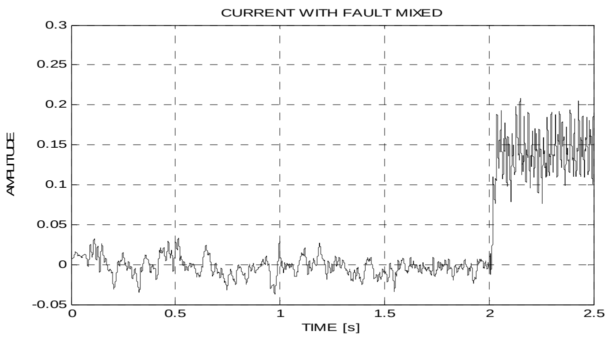

Figure 4. Residual of a phase in the presence of mixed defects

VII. Stage of Diagnosis

The diagnosis is performed offline, based on analysis of residuals for each phase. Figures 8 to 16 show the residuals of identifications of the three phases stator respectively with the presence of static eccentricity faults (5,8 and 11), dynamic (6,9 and 12) and mixed (7,10 and 13).

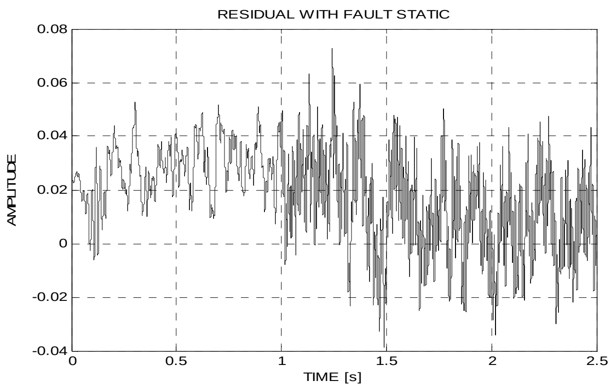

Figure 5. Residual of phase A in the presence of static defect

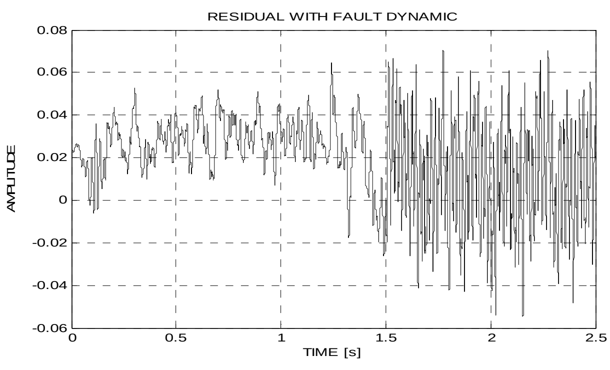

Figure 6. Residual of phase A in the presence of dynamic defects

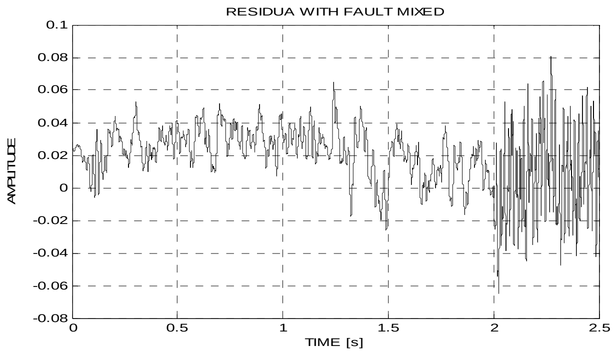

Figure 7. Residual of phase A in the presence of mixed defects

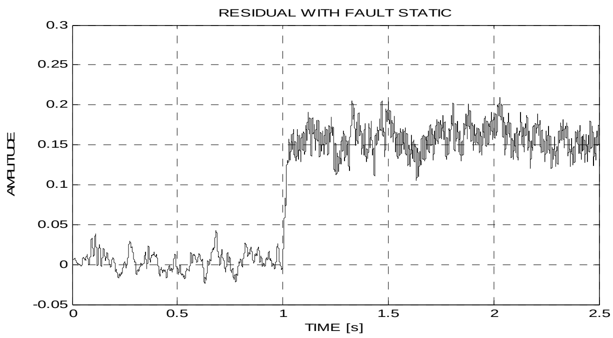

Figure 8 Residual of phase B in the presence static defect

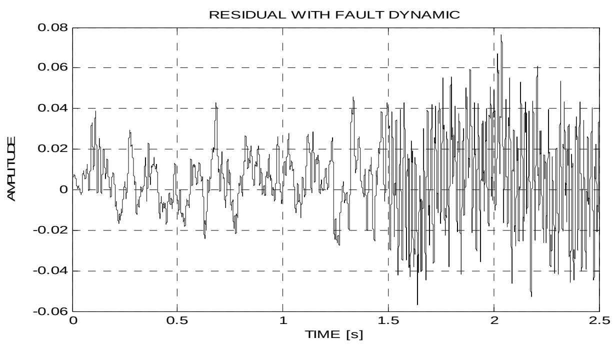

Figure 9. Residual of phase B in the presence dynamic defect

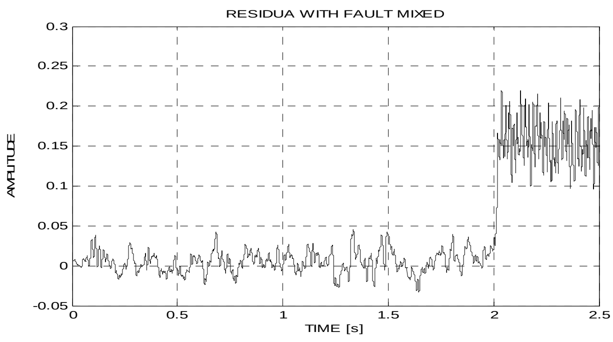

Figure 10. Residual of phase B in the presence mixed defect

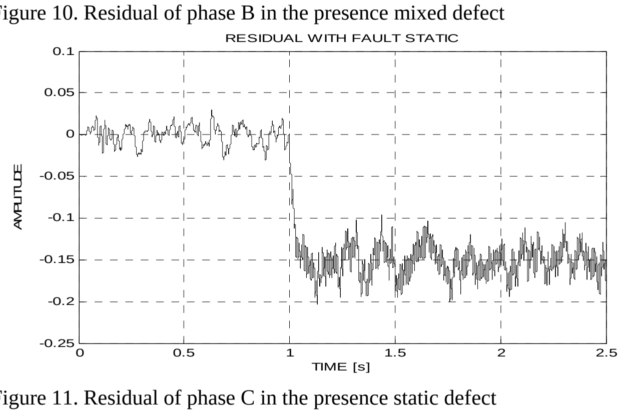

Figure 11. Residual of phase C in the presence static defect

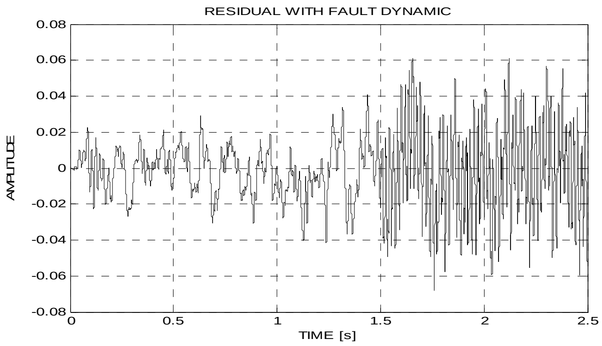

Figure 12. Residual of phase C in the presence dynamic defect

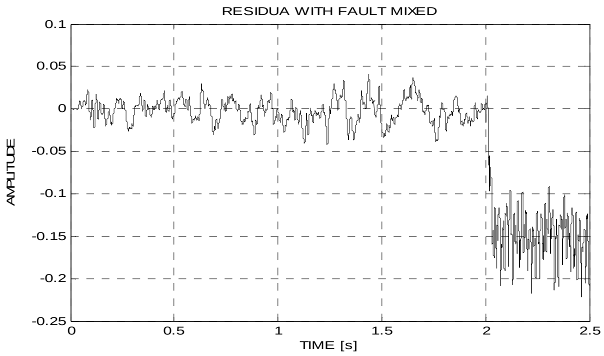

Figure 13. Residual of phase C in the presence mixed defect

The eccentricity faults occur by the appearance of unbalanced supply phases in the case of static eccentricity faults and mixed as shown in figures 5,8 and 11 (static), and 6, 9 and 12 (mixed). By cons in the case of a failure of the current dynamic eccentricity of the three stator phases are balanced in figure 7, 10 and 13.

VIII. Conclusion

The analysis of one of the 3 residuals (derived from any of the three phases) is sufficient to detect defects of eccentricity and estimate the time of occurrence of defects.

The joint analysis of 3 residuals can diagnose the defect complained of by the table below. For a default dynamic residuals are zero on average, while a default static or mixed the average residual deviates from 0 to 2 out of 3 phases

Structuring residuals.

Faults / Residuals	Static	Dynamic	Mixed
$r_A(t)$	0	0	0
$r_B(t)$	+	0	+
$r_C(t)$	_	0	_

The delay in detection of however quite important especially for a mixed defect. Reducing the delay will be our future work.

Appendix

The characteristics of the induction motor are:

Number of rotor bars q=16, stator resistance R_s =9.2Ω, inductance of a bar L_b=0.114.10^{-6}H, resistance of a bar R_b R_b =68*10^{-6} Ω, inductance of a portion of ring L_e=$2*10^{-9}H$, resistance of a protion of ring R_e=43.79*10^{-8}Ω, number of peer pole 1, Moment of inertia j=0.0045, power frequency f=50 Hz, Average radius of the gap r=55.7*10^{-3}m, machine length l=0.1m, number of stator slot N_s=240, air permeability μ_0 =4*10^{-7}, leakage inductance L_f=0.08H, No calculation h=0.001.

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