Model Structures Used in Rotor Defect Identification of a Squirrel Cage Induction Machine

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Abstract

In this paper a method of detection of broken bars in squirrel cage induction machine is presented. This method is based on the determination of discrete parameters of the transfer functions of the induction machine by model structures such as ARMAX, ARX, IV and OE model structures.

Keywords: *Model structures, diagnosis, identification, squirrel cage induction machine*

1. Introduction

The problem of the rupture of bars in the motors of the stations of " offshore " pumping were at the origin of the first research tasks on the diagnosis itself of the induction machines [1].

Many works [2-4] followed in the same direction, or was initiated in the diagnosis of the other defects of the machine, like the misalignment between the machine and the load, the eccentricity of the rotor, the short circuits of the stator windings or the wear of the bearings.

The defects were often studied within the framework of the industrial applications at constant speed and or by analysis of the stator currents. Generally founded on the analysis of Fourier, the majority of the methods suggested are not adapted any more to the applications at variable speed, the signals being then strongly no stationary. New tools are necessary. Other ways were explored, as the approach of the parameter identification [5]. In this paper, the identification based on the analysis of discrete parameters of the transfer functions of the induction machine, by model structures is presented. Theses model structures are ARMAX (Auto Regressive Moving Average with eXternal Input), ARX (Auto Regressive with eXternal Input), IV (Instrumental Variable) and OE (Output Error). Matlab tools are used for this application of structural and parameter identification

2. The induction machine model

The physical model of an induction machine is based on the park's model. The system which composes the squirrel cage induction machine is represented by linear electric equations with constant coefficients.

The electric equations of the induction machine are presented by:

$$\begin{cases} V_s = R_s I_s + \dfrac{d\phi_s}{dt} + j\omega_s \phi_s \\ 0 = R_r I_r + \dfrac{d\phi_r}{dt} + j\omega_r \phi_r \end{cases} \qquad (1)$$

and,

$$\begin{cases} \phi_r = L_r I_r + M I_s \\ \phi_s = L_s I_s + M I_r \end{cases} \qquad (2)$$

The currents are linked to the flux linkages by:

$$\begin{cases} I_s = \dfrac{1}{\sigma L_s}\phi_s - \dfrac{1-\sigma}{\sigma M}\phi_r \\ I_r = \dfrac{1}{\sigma L_s}\phi_r - \dfrac{1-\sigma}{\sigma M}\phi_s \end{cases} \qquad (3)$$

With s is the leakage coefficient. Using complex electric variables written as:

$$\begin{cases} V_s = V_{sd} + jV_{sq} \\ \phi_s = \phi_{sd} + j\phi_{sq} \\ \phi_r = \phi_{rd} + j\phi_{rq} \\ I_s = I_{sd} + jI_{sq} \\ I_r = I_{rd} + jI_{rq} \end{cases} \qquad (4)$$

From these equations the state system can be written as:

$$\begin{cases} \dfrac{d\phi_s}{dt} = -\dfrac{R_s L_r}{\sigma}\phi_s + \dfrac{R_s M}{\sigma}\phi_r + V_s \\ \dfrac{d\phi_r}{dt} = \dfrac{R_r M}{\sigma}\phi_r - (\dfrac{R_r L_s}{\sigma} - j\omega_r)\phi_s \end{cases} \qquad (5)$$

From this linear-time invariant system, we obtain the transfer function using the s Laplace operator:

$$G(s)=\frac{\frac{R_r}{\sigma}\left[T_r s+(1-j\omega_r T_r)\right]}{s^2+\frac{1}{T}\left(\frac{L_s L_r}{\sigma}-j\omega_r T_s\right)s+\frac{R_s R_r}{\sigma}(1-j\omega_r T_r)} \qquad (6)$$

Where: $T_s=L_s/R,\quad T_r=L_r/R_r \quad and \quad T=1/T_s+1/T_r$.

This transfer function represents the model of linear regression of the induction machine.
The discrete model corresponding is done by:

$$H(Z)=\frac{I_S(Z)}{V_S(Z)}\frac{B_1 Z+B_0}{Z^2+A_1 Z+A_0} \qquad (7)$$

The equations with differences are done by:

$$I_S(k)+A_1 I_S(k-1)+A_0 I_S(k-2)=B_0 V_S(k)+B_1 V_S(k-1) \qquad (8)$$

This can be written as $Y(k)=C(k)\theta(k)$, where

$$\begin{cases} Y(k)=Is(k) \\ C(k)=[-I_s(k-1)\ \ -I_s(k-2)\ \ V_s(k)\ \ V_s(k-1)] \\ \theta(k)=[A_1\ \ A_0\ \ B_1\ \ B_0] \end{cases} \qquad (9)$$

3. Parameter identificatio n by using the model structures

The difference between a linear model and a non linear model is based on the dynamic behavior, i.e., the relation between the dependent time variables and the independent ones. The choice is influenced by the character of the identification problem such as: the theory in which the results of the identification of linear systems. Linear systems represent the most extensively developed area in the field of system identification. We describe some model structures [6]

3.1. ARX model structure

This structure is based on the equation error and is expressed by:

$$y(t)=-a_1 y(t-1)-\ldots-a_n y(t-n)+b_1 u(t-1)+\ldots+b_m u(t-m)+e(t) \qquad (10)$$

The parameter vector can be estimated such as e(t) will a white noise, where

$$A(q)=1+a_1 q^{-1}+\cdots+a_n q^{-n};\ B(q)=b_1 q^{-1}+\cdots+b_m q^{-m}$$
$$G(q)=\frac{B(q)}{A(q)};\ H(q)=\frac{1}{A(q)}$$

e(t) is white noise process with zero mean and variances^2
This model structure is characterized in fig.1.

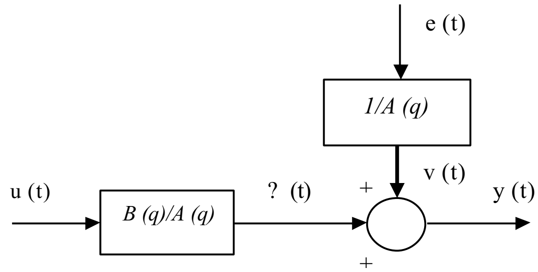

Fig.1: ARX model structure

3.2. ARMAX model structure

The disadvantage of ARX structure is to not still any free for the term to the perturbation. One description giving the most greatly flexibility consists to consider the equation error as the realisation of moving average. It was expressed by:

$$A(q)y(t)=B(q)u(t-nk)+C(q)e(t) \qquad (11)$$

Where $C(q)=1+c_1 q^{-1}+\cdots+c_p q^{-p}$

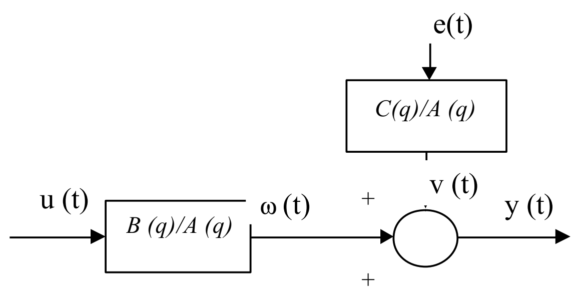

Fig.2: ARMAX model structure.

3.3. Output Error model structure

In the approaches based on the equation error, the transfer functions G and H have a common denominator constituted by the polynomial A. one physical approach consists to compose the independent transfer functions G and H. we consider the perturbation as white noise e(t): y(t) =w(t) +e(t). The unperturbed output ? (t) is modelled by:

$$y(t)=\frac{B(q)}{F(q)}u(t-nk)+e(t) \qquad (12)$$

This model structure is schematized in fig.3.

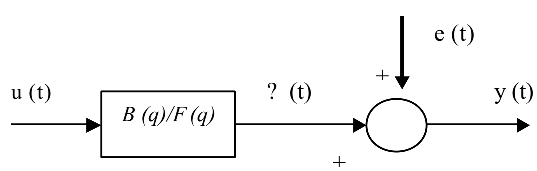

Fig.3: Output Error model structure

3.4. Instrumental variable model structure

A block diagram of the basis IV estimation algorithm is typical of IV mechanizations: x the source of the IV's is formed by passing the input signal assumed statistically independent of the noise e(t) through an adaptive " auxiliary model" of system so that it becomes highly correlated with x, as required, provided convergence is achieved.

$$[x^T.s] = [x^T.x] ? \quad (13)$$

4. Experimental Tests

4.1. Data acquisition

The recording of the experimental numerical signals input-output: $(\{v_S(k)\},\{I_S(k)\})$, $(k=1...,N)$, is carried out using a chart of acquisition GS2020 which transforms the data (signals) analogical worms of the data sampled with a sampling rate of $1kHz$ then these data are transferred towards a computer for the exploitation and the treatment.

To note experimentation, we used induction machines of 4 kW (See Appendix). The machines to be identified are manufactured for the needs of the diagnosis of defects to the rotor:

- healthy induction machine (no defect) for the use of heir parameters like values of reference to detect the defects,
- Induction machine with one rotor broken bar,
- Induction machine with two broken adjacent rotor bars,
- Induction machine with rupture of an end-ring portion.

4.1. Data filtering

The significant specification relates to the filtering of the signals input-outputs. In the absence of filtering, the algorithm of least squares tends to optimize the approximation of the model of the process in the high frequencies. We will use a band pass filter in order to provide to the estimate of information relating to only the necessary frequency band. This numerical filter is of type 2nd order TCHEBYSCHEFF. It has many advantages such as the flexibility of working, the precision and the stiffest cut of all the polynomial filters of the same order [7].

5. Identification results

5.1. Validation of the model structures

The transfer functions identified by using ARX, ARMAX and OE model structures respectively are showed in table1.

Table1: Discrete transfer functions obtained by ARX,ARMAX and IV model structures respectively

Identified machine	Transfer functions for ARX model	Transfer functions for ARMAX model	Transfer function for IV model
Healthy machine	$H(z)=\frac{-0.0012637z+0.0015100}{z^2-1.8952z+0.95926}$	$H(z)=\frac{-0.00087589z+0.0012255}{z^2-1.9243z+0.98832}$	$H(z)=\frac{-0.0013170z+0.0017906}{z^2-1.9262z+0.97811}$
Machine with one broken bar	$H(z)=\frac{-0.0025512z+0.0024708}{z^2-1.8095z+0.87296}$	$H(z)=\frac{-0.0013224z+0.0015974}{z^2-1.9013+0.96407}$	$H(z)=\frac{-0.0015126z+0.0016432}{z^2-1.8742+0.94120}$
Machine with two broken bars	$H(z)=\frac{-0.00084933z+0.00088496}{z^2-1.8827z+0.96275}$	$H(z)=\frac{-0.00052412z+0.00064107}{z^2-1.9058z+0.98628}$	$H(z)=\frac{-0.00041830z+0.00046648}{z^2-1.8997z+0.98488}$
Machine with rupture of end ring portion	$H(z)=\frac{-0.0013847z+0.0011780}{z^2-1.8226z+0.90888}$	$H(z)=\frac{-0.00048732z+0.00052439}{z^2-1.8925z+0.97781}$	$H(z)=\frac{-0.00059946z+0.00063133}{z^2-1.8874z+0.97147}$

5.2. Validation of model structure OE

Also, the transfer functions obtained from OE model structure are presented in table2.

Table2: Discrete transfer functions obtained by OE model structure

Identifiedmachine	Transfer functions for OE model
Healthy machine	$H(z)=\frac{-0.00098337z+0.0013080}{z^2-1.9178z+0.98204}$
Machine with one broken bar.	$H(z)=\frac{-0.0016510z+0.0018895}{z^2-1.8848+0.94493}$
Machine with two broken bars.	$H(z)=\frac{-0.00042465z+0.00037956}{z^2-1.8863z+0.97580}$
Machine with rupture of portion of end-ring.	$H(z)=\frac{-0.00056920z+0.00058253}{z^2-1.8855z+0.97102}$

5.3. Comparison between the measured output and the simulated output

The comparison between the measured output and the simulated ones are presented for the four model structures in Figs. (1, 2, 3, and 4). A close agreement is showed in these figures indicating that the obtained discrete transfer functions correspond to the induction machine models .

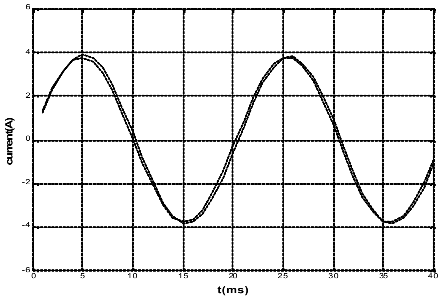

Fig. 1.a

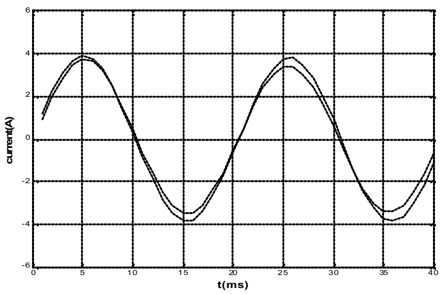

Fig. 1.b

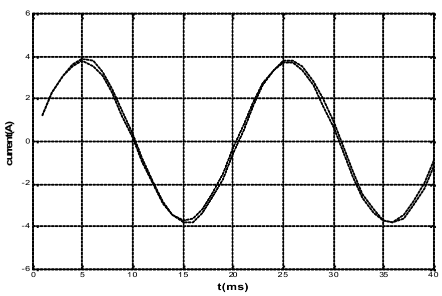

Fig. 1.c

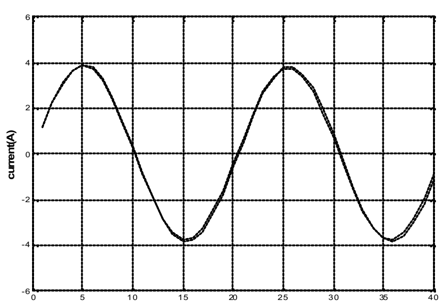

Fig. 1.d

Fig. 1: measured (-) and simulated (….) output by using ARX model structure applied to the four machines.

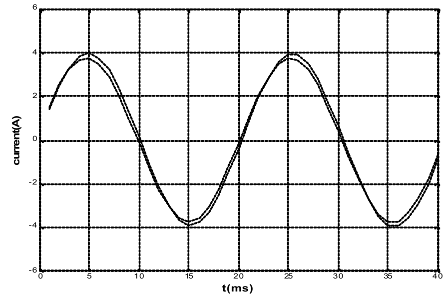

Fig. 2.a

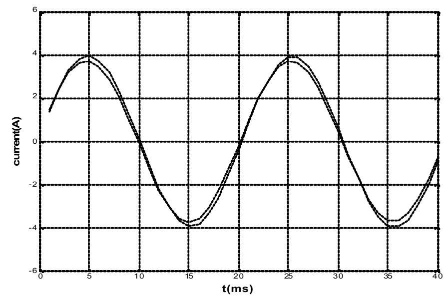

Fig. 2.b

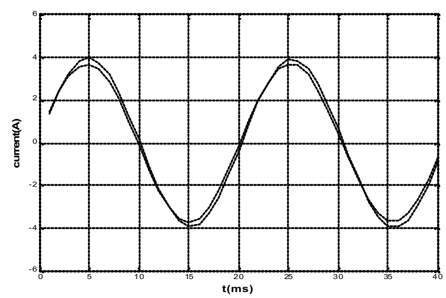

Fig. 2.c

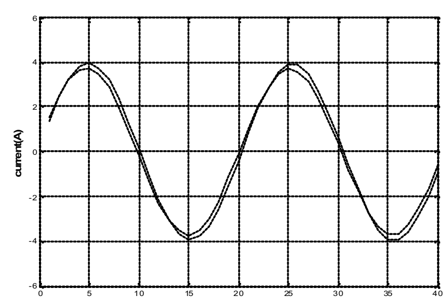

Fig. 2.d

Fig. 2: measured (-) and simulated (….) output by using ARMAX model structure applied to the four machines.

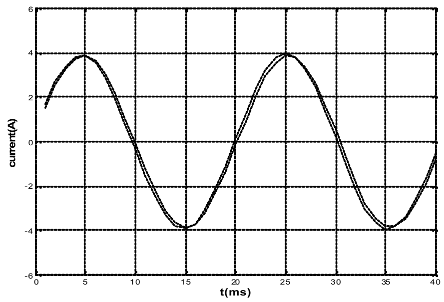

Fig.3.a

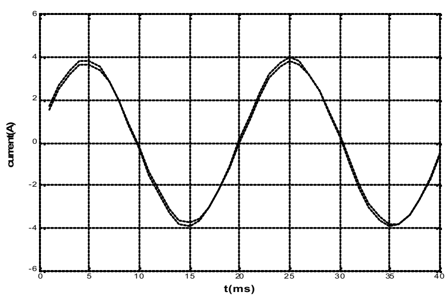

Fig.3.b

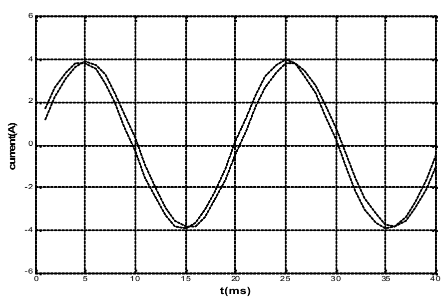

Fig.3.c

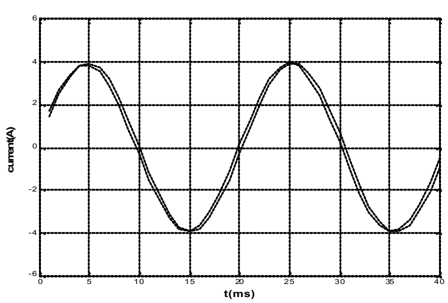

Fig.3.d

Fig.3: measured (-) and simulated (….) output by using IV model structure applied to the four machines.

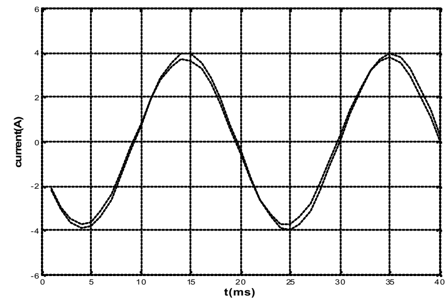

Fig.4.a

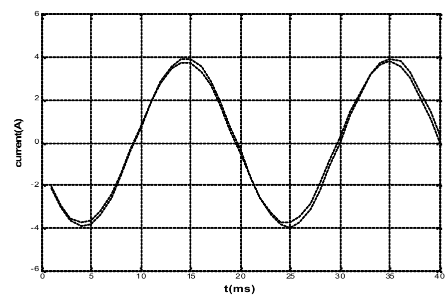

Fig.4.b

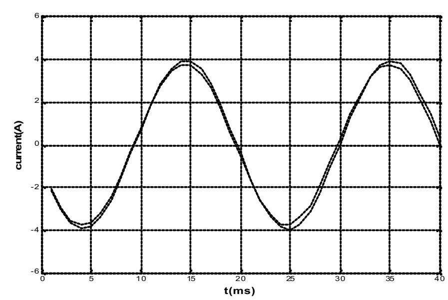

Fig.4.c

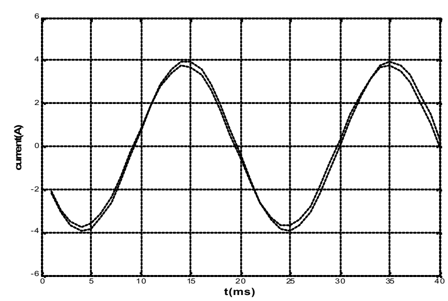

Fig.4.d

Fig.4: measured (-) and simulated (….) output by using OE model structure applied to the four machines.

APPENDIX

The name plate data of a squirrel cage induction machine are [8]:
Pn = 4kW, In = 15,2 /8,8 A, Vn=220/380V, P=2, Power factor $\cos\Phi_n = 0{,}83$

6. Conclusion

A conversational program has been validated under the Software Matlab permitted us to get some results for every model structure. After the determination of the discreet parameters of the model structures one conducts validation. The parameters of the discreet transfer function are direct pictures of the parameters of the continuous transfer function (real parameters of the machine i.e., inductance and resistance); they can inform us on the defect and no on the nature of the defects. The quality of the results gotten is valued by the coefficients of Akaïke that are very small (in our case: FPE Akaïke's $<10^{-5}$).

The results gotten in discreet mode confirmed the objective that remains the detection of the defects at the time of these apparitions. What comes back to say that identification gives a picture realistic of the rotor defect in the machine.

Our identification is organized on a rigid procedure, i.e., Data acquisition, choice of the sampling period, model of knowledge, filtering, model structures.

It is trivial to determine the physical parameters of the machine from the continuous transfer functions obtained by a bilinear transformation discrete to continuous. However it is not our objective, since the goal of work only concerns the determination of the rotor defects obtained only from the transfer functions gotten by the model structures.

Acknowledgements

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