The Slip Impact on Electromagnetic Shaft (EMSh) : A law or a Particular Case

Fellag.S.A[1], A. Boukadoum[2]

Abstract-**The electrical drive, exploitational and economical, characteristics improving can be achieved by increasing the synchronizing torque that allow the maintain of speed synchronization between motors in their deferent operating regimes, at deferent degree of load carrying. In this paper we study the possibilities of synchronizing torque increasing in electromagnetic shaft system. The results and impact of slip changing ways , calculation that is carried upon 2.8 kW induction machines, have been presented and discussed.**

I. INTRODUCTION

For several multiple motor drives that need speed synchronisation between their motors and, where mechanical connection between them is not preferred or possible, electrical(Esh) and electromagnetic(EMSh) shafts can be used [1,2]. Such systems are capable to deliver enough good as driving as well as synchronising (ST) torques. The laters are a determinant factor to bring motors to tough speed concordance. In this paper we will provide a study of EMSh that use induction rheostat (IR) between motors, in order to show possible ways of increasing synchronising torque.

II. EQUIVALENT EMSH SCHEME :

In fig. A is shown the electrical scheme of EMSh. The equivalent scheme is shown in fig.1 as in [1,2]. Here: r1, x1- active resistance an reactance of stator windings; r2', x2'- active resistance and reactance of rotor windings; rd1,r'd2- additional resistance in stator and rotor circuits consequently; rμ,xμ- resistance and reactance of motor magnetic circuit; r0', x0'-resistance and reactance of IR windings; r'm, x'm-resistance and reactance of IR magnetic circuit .

All rotor's circuit parameters are referred to stator.
On the basis of EMSh equivalent circuit we will develop torque formulae that allow the system to be investigated.

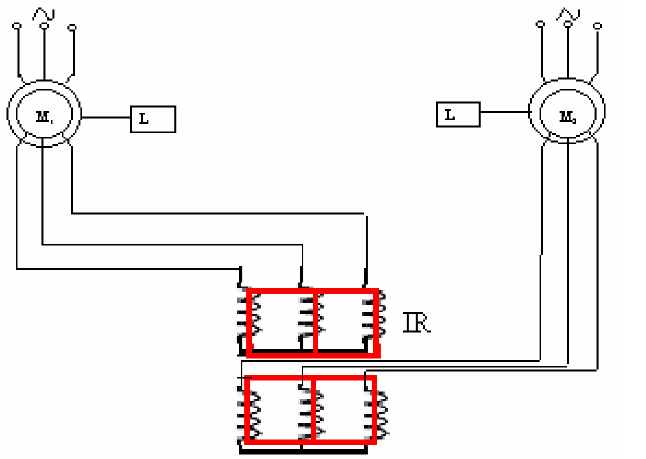

Fig.1 EMSh electrical scheme

Taking $x_k = x_1 + x_2$, and with $\dot{U}_1$, $\dot{U}_2$ -voltage vectors of first and second motors, from the scheme we can write:

$$\dot{U}_1 = \dot{I}_{21}\left[r_1 + \frac{r_2}{s} + \frac{r_0}{s} + \frac{r_m}{\sqrt{s}} + j\left(x_k + x_0 + \frac{x_m}{\sqrt{s}}\right)\right] + \dot{I}_{22}\left[\frac{r_m}{\sqrt{s}} + j\frac{x_m}{\sqrt{s}}\right] \quad \text{..........(1)}$$

$$\dot{U}_2 = \dot{I}_{22}\left[r_1 + \frac{r_2}{s} + \frac{r_0}{s} + \frac{r_m}{\sqrt{s}} + j\left(x_K + x_0 + \frac{x_m}{\sqrt{s}}\right)\right] + \dot{I}_{21}\left[\frac{r_m}{\sqrt{s}} + j\frac{x_m}{\sqrt{s}}\right] \quad \text{..................(2)}$$

[1]Fellag.S.A is with the Université Technologique de Tizi Ouzou- Département d'Electrotechnique- Algérie
E-mail:felags@yahoo.fr
A. Boukadoum is with the Université de Skikda -Département de Génie Electrique , E-mail:boukadoum2003@yahoo.fr

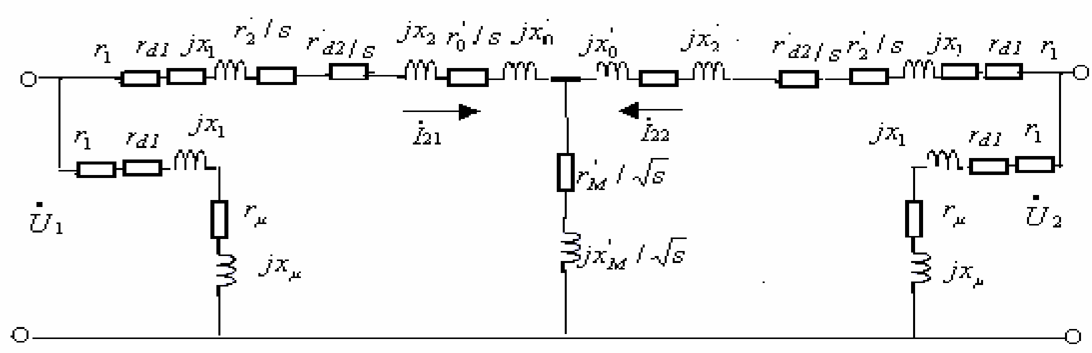

Fig 1.Equivalent scheme of EMSh

After some conversion rotor current vectors can be written as:

$$I_{21}=\frac{1}{2}\left[\frac{U_1+U_2}{Z+2Z_m}+\frac{U_1-U_2}{Z}\right]\ldots\ldots\ldots\ldots..(3)$$

$$I_{22}=\frac{1}{2}\left[\frac{U_1+U_2}{Z+2Z}+\frac{U_2-U_1}{Z}\right]\ldots\ldots\ldots\ldots(4)$$

With :

$$Z=\left[r_1+r_{d1}+\frac{r_2}{s}+\frac{r_{d2}}{s}+\frac{r_0}{s}+j\left(x_K+x_0\right)\right]$$

$$Z_m=\frac{r_m}{\sqrt{s}}+j\frac{x_m}{\sqrt{s}}$$

In the case when both motors carry the same load we have $\dot{U}_1=\dot{U}_2=U$, where U is a source voltage. But in case of deferent load this would yield an angle (α) between their rotors .If this rotors' deference position will be represented by the deference between vector voltages $\dot{U}_1$, $\dot{U}_2$, then we can write:

for the first motor : $\dot{U}_1=U\,.\,e^{-j\alpha}$ …………..(5);

for the second : $\dot{U}_2=,U\,.\,e^{j\alpha}$ ……………….(6);

Torque of induction motor generally for one phase in synchronizing watts can be given as:

$$M=\frac{U}{2}\left(\dot{I}+\overset{*}{I}\right)-\left(\left|I\right|^2R_S\right)\ldots\ldots\ldots\ldots\ldots..(7)$$

where R_S is resistance in stator circuit.
With U -phase voltage;

$\dot{I}$ -rotor current vector; $\overset{*}{I}$ -its conjugate

As it is seen it is composed from two parts ,the second one represent losses in stator circuits . If we ignore those loses the torque for multiphase consideration would gain more simply expression [2,4] :

$$M=\frac{U_f mp}{2\omega_0}\left(\dot{I}+\overset{*}{I}\right)\ldots\ldots\ldots..(8)$$

With U_f -phase voltage; m-number of phase; p-number of pair pole; ω_0 speed of stator magnetic field.

$\dot{I}$ -rotor current vector; $\overset{*}{I}$ -its conjugate.

Applying 1-6 and 8, we can write the formulae of EMSh torque as :

$$M_{1,2}=\frac{U_f^2 mp}{2\omega_0}\left\{\frac{\left(r_1+r_{d1}+\frac{r_2}{s}+\frac{r_{d2}}{s}+\frac{r_0}{s}\right)(1-\cos\alpha)}{\left(r_1+r_{d1}+\frac{r_2}{s}+\frac{r_{d2}}{s}+\frac{r_0}{s}\right)^2+\left(x_k+x_0\right)^2}+\right.$$

$$\frac{\left(r_1+r_{d1}+\frac{r_2}{s}+\frac{r_{d2}}{s}+\frac{r_0}{s}+\frac{2r_m}{\sqrt{s}}\right)(1+\cos\alpha)}{\left(r_1+r_{d1}+\frac{r_2}{s}+\frac{r_{d2}}{s}+\frac{r_0}{s}+\frac{2r_m}{\sqrt{s}}\right)^2+\left(x_k+x_0+\frac{2x_m}{\sqrt{s}}\right)^2}\pm$$

$$I\sin\alpha\left[\frac{x_k+x_0}{\left(r_1+r_{d1}+\frac{r_2}{s}+\frac{r_{d2}}{s}+\frac{r_0}{s}\right)^2+\left(x_k+x_0\right)^2}-\right.$$

$$\left.\left.\frac{\left(x_k+x_0+\frac{2x_m}{\sqrt{s}}\right)}{\left(r_1+r_{d1}+\frac{r_2}{s}+\frac{r_{d2}}{s}+\frac{r_0}{s}+\frac{2r_m}{\sqrt{s}}\right)^2+\left(x_k+x_0+\frac{2x_m}{\sqrt{s}}\right)^2}\right]\right\}$$

Here: (+)-Represent torque of 1st motor; (-)-the second ; Representing all parameters through xk torque finaly will have the following form:

To compare the behavior of EMSh system with each way, we have first drawn mechanical characteristics -in case when motors carry the same load (α=0)-figures 2, 3,and 4- for the first, second, and third ways consequently. Characteristics show that all these approaches can provide a fair working characteristics for system in symmetric load regime.

Fig.2 reflect the characteristics of stator rheostat regulating .

$$M_{\bullet 1,2}=\frac{M_{1,2}}{M_m}=\left\{\begin{array}{l}\dfrac{\left(k_{S1}+k_{d1}+\frac{k_{r2}}{s}+\frac{k_{d2}}{s}+\frac{k_1}{s}\right)(1-\cos\alpha)}{\left(k_{S1}+k_{d1}+\frac{k_{r2}}{s}+\frac{k_{d2}}{s}+\frac{k_1}{s}\right)^2+(1+q_1)^2}+\dfrac{\left(k_{S1}+k_{d1}+\frac{k_{r2}}{s}+\frac{k_{d2}}{s}+\frac{k_1}{s}+\frac{2k_2}{\sqrt{s}}\right)(1+\cos\alpha)}{\left(k_{S1}+k_{d1}+\frac{k_{r2}}{s}+\frac{k_{d2}}{s}+\frac{k_1}{s}+\frac{2k_2}{\sqrt{s}}\right)^2+\left(1+q_1+\frac{2q_2}{\sqrt{s}}\right)^2}\pm\\ \sin\alpha\left[\dfrac{1+q_1}{\left(k_{S1}+k_{d1}+\frac{k_{r2}}{s}+\frac{k_{d2}}{s}+\frac{k_1}{s}\right)^2+(1+q_1)^2}-\dfrac{1+q_1+\frac{2q_2}{\sqrt{s}}}{\left(k_{S1}+k_{d1}+\frac{k_{r2}}{s}+\frac{k_{d2}}{s}+\frac{k_1}{s}+\frac{2k_2}{\sqrt{s}}\right)^2+\left(1+q_1+\frac{2q_2}{\sqrt{s}}\right)^2}\right]\end{array}\right\}$$

$M_m = U_f^2 mp/2\omega_0 x_k$ -critic torque of shorted rotor induction machine $Kr_2 = r_2/x_k$;*Kd1=rd1/x*$_k$; *Kd2=rd2/x*$_k$ $k_1 = r_0/x_k$;q1= x_0/x_k ; $k_2 = r_m/x_k$;q2= x_m/x_k .

For calculation deferent IR parameters can obtained from the practical notion, that IR power factor is about .7-.8 and the parameters of IR windings(*xo,ro*) are very low before r_m: (0.1 - 0.2) r_m. Taking that in account all IR parameters will be expressed in function of k2 :
q2=tgφ.K2; k1≈q1=(.1-.2) [1].

To draw graphs for simplicity was chosen two identical motors with the same parameters.

The calculation were performed with parameters of motors type AK/51/4 with Pn=2.8kw and n_0= 1500min-1.

III. Graphs' Analisis and Commentary :

Fig.2 shows angular characteristics drawn with deferent slip values . As it is seen with slip increasing the synchronizing capacity of system will increase.

The slip increasing in EMSh is possible by several ways. In our paper we will investigate three of them: 1) by regulating additional rheostat from stator circuits;2)by regulating additional rheostat from rotor circuits ;3) by changing IR parameters.

Let's to declare at first that the 1st and the 2sd ways can have a forward–easy access to their regulation .The third is not.

As it is seen these characteristics is similar to those of individual induction machine having a constant resistance in rotor circuit and regulating resistance from stator circuit.

The fig3 and fig4 characteristics are similar to those of individual induction machine when regulating rheostat from rotor circuits.

Characteristics of fig.4 are obtained changing all IR parameters in function of its active resistance .

All these characteristics may meet the needs of load with ,for example, constant character . All these ways have one in common : the slip increasing as their parameters increase.

The behaviour of each way in case of asymmetric load carrying (α =90) can be shown plotting synchronizing ST torques in function of slip. The ST in EMSh (the part of torque with sin(α))as its predecessors , can be given as[1,2,3]:

$$M_S=\left(\frac{1+q_1}{\left(k_{S1}+k_{d1}+\frac{k_{r2}}{s}+\frac{k_{d2}}{s}+\frac{k_1}{s}\right)^2+(1+q_1)^2}-\frac{1+q_1+\frac{2q_2}{\sqrt{s}}}{\left(k_{S1}+k_{d1}+\frac{k_{r2}}{s}+\frac{k_{d2}}{s}+\frac{k_1}{s}+\frac{2k_2}{\sqrt{s}}\right)^2+\left(1+q_1+\frac{2q_2}{\sqrt{s}}\right)^2}\right)\sin\alpha \quad ...(11)$$

the graphs ,for each way consequently, are presented in fig.5,6 and 7. As it shows characteristics : only IR parameters changing can improve the ST torques.

As we drew the characteristics the losses in stator circuits has been ignored . This would not influence the 2nd and 3rd ways in case of medium-high power machines . For the 1st approach this can not be said . This why the characteristics of 1st way are only qualitative and are enough to evaluate

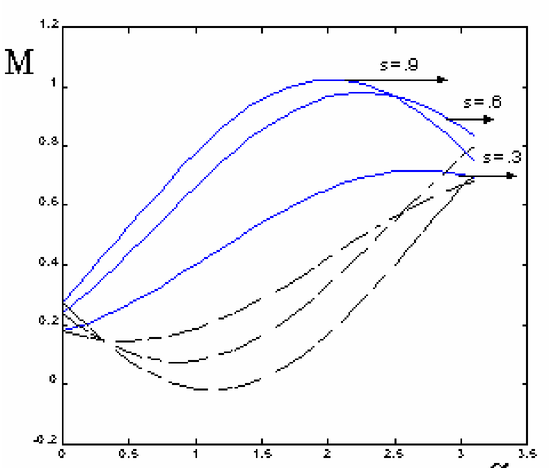

Fig.2

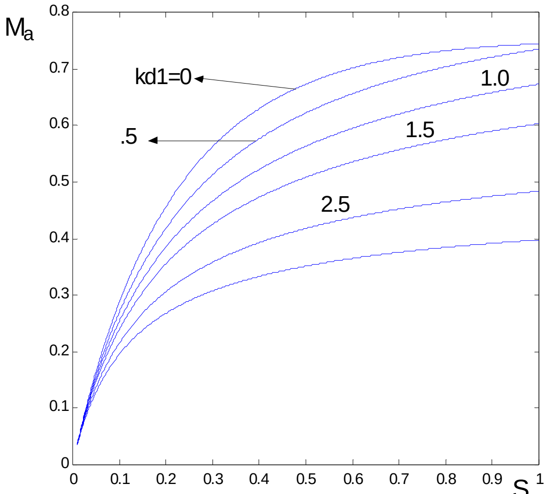

fig.3

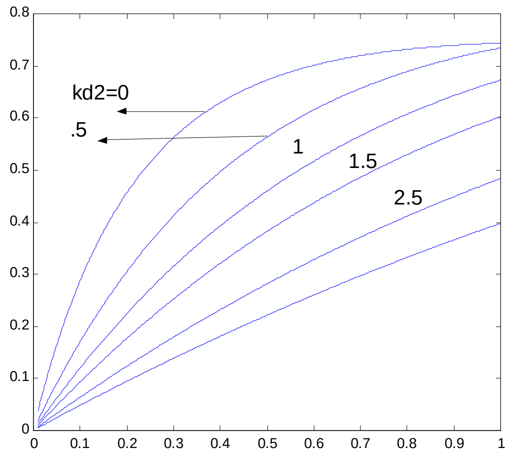

fig.4

this approach . The real characteristics of this way ,as it is easy to judge viewing (7) , will be more curvy and the ST torque yet by far worse . The real stator parameters considering may be in accommodate manner got, as in induction machines , using diagram circle method. Both the circle diagram and the analytical developing of (7) did not stand as aim in this paper .

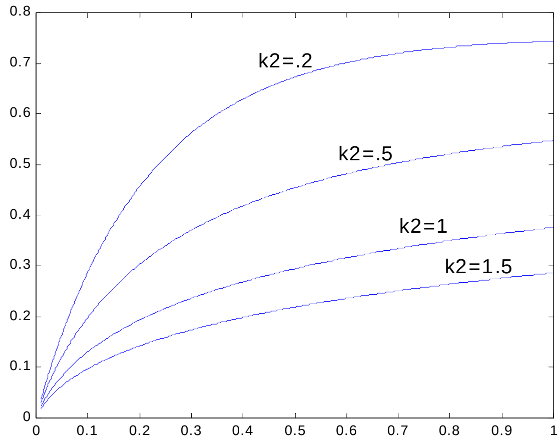

fig.5

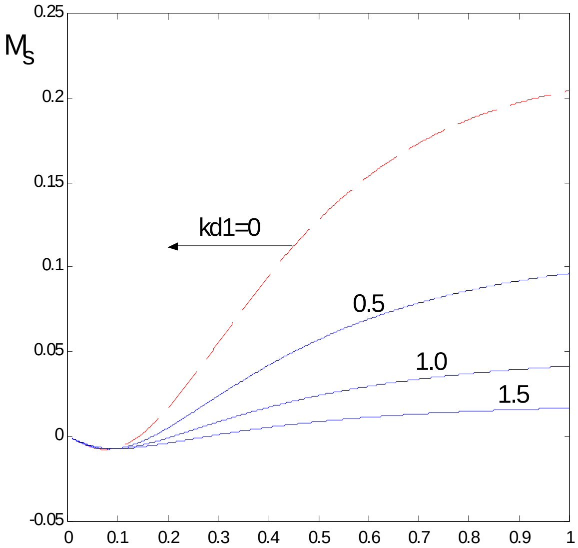

fig.6

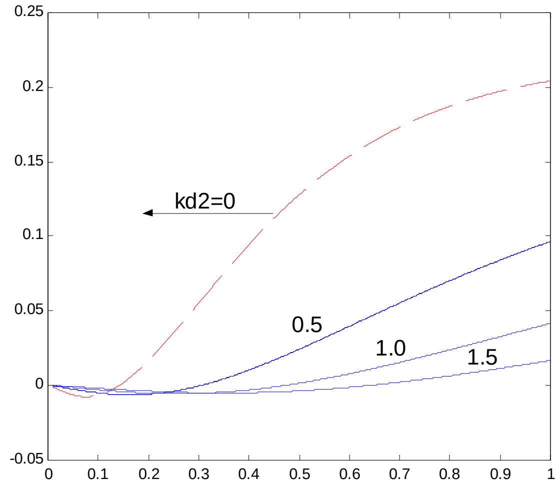

fig.7

In the end it is to mention that the influence of slip in Esh (electrical shaft) has been reported in many earlier works. Sometimes had been used the rotation of ESh anti-field to increase slip and therefore the ST torques .Had been used ,either , its increasing by regulating the common resistance [3,4]. The works in case of additional rheostat in rotor and

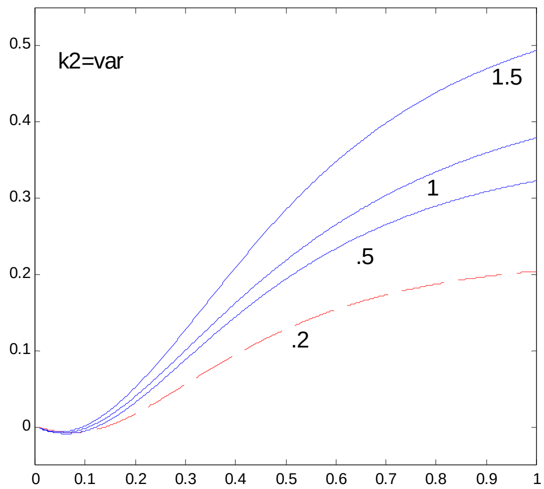

fig.8

stator circuits for EMSh system (and also it would be said for ESh), and also their presentation as ways for slip changing is for the first time.

IV. CONCLUSION

The study have shown that the slip increasing though do not affect EMSh system in symmetric load carrying by the several presented ways the ST torques can only be improved acting on induction rheostat parameters. Regardless that because of the forward–easy regulation access, the remain ways can be recommended for EMSh speed regulation in symmetric regimes.

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