STUDY OF THE ANGLE OF DEPHASING BETWEEN THE VECTORS OF ROTOR AND STATOR MAGNETIC FLOW IN A SYSTEM OF CONTROL THROUGH ORIENTATION OF A MAGNETIC FIELD

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This article presents results received from the study of a system of control of three-phase asynchronous motor through an orientation of a magnetic field. The controller does stabilization of the vector of rotor magnetic flow. The purpose of this study is to find how the angle of dephasing between the vectors of magnetic flows in the rotor and stator changes. This is necessary in order to choose the method of control for the relevant induction machine. The studies are done with the software MATLAB with parameters of real three-phase asynchronous squirrel cage induction motors. The results are shown in table and graphic mode.

Keywords: induction motor, rotor flux, stator flux, revolutions, torque

1. INTRODUCTION

It is known that up to now the newest and, at the same time, the best methods of control of tree-phase asynchronous squirrel cage induction motors are the methods for vector control and control through an orientation of the magnetic field. They facilitate the control of electromechanical converters of this type considerably since one separated control of a magnetic flow and a torque is achieved like in the direct current machines. On the other hand, the use of these types of control results in saving of great quantity of electric energy. This is achieved by the fact that the asynchronous motor is always supplied with such a small amount of electric energy (with a certain amplitude and frequency), that the conditions of retaining of a motive torque speed of the rotor etc. to be met.

This article aims at presenting elaboration of a system for control through an orientation of the magnetic field of three-phase asynchronous motors. The second aim is to study how the angle of dephasing between the vectors of the stator and rotor magnetic flow changes, since its change results in changing the motive torque.

2. Statement.

All modern systems for vector control or through an orientation of the magnetic field are built up by DSP processor or another type of controller. Their work is based on a software apparatus built in them in advance. The software is formed from mathematical models of the whole system of control. Figure 1 presents a system of control of three-phase asynchronous motors through an orientation of the magnetic field. It is designed in such a way that if signals from two censors measuring the tension in two of the phases supply are passed into them, the system will be able to determine speed, torque, magnetic flows in the rotor and stator without the use of censors for these quantities. On the other hand, it does stabilization of the vector of the rotor magnetic flow.

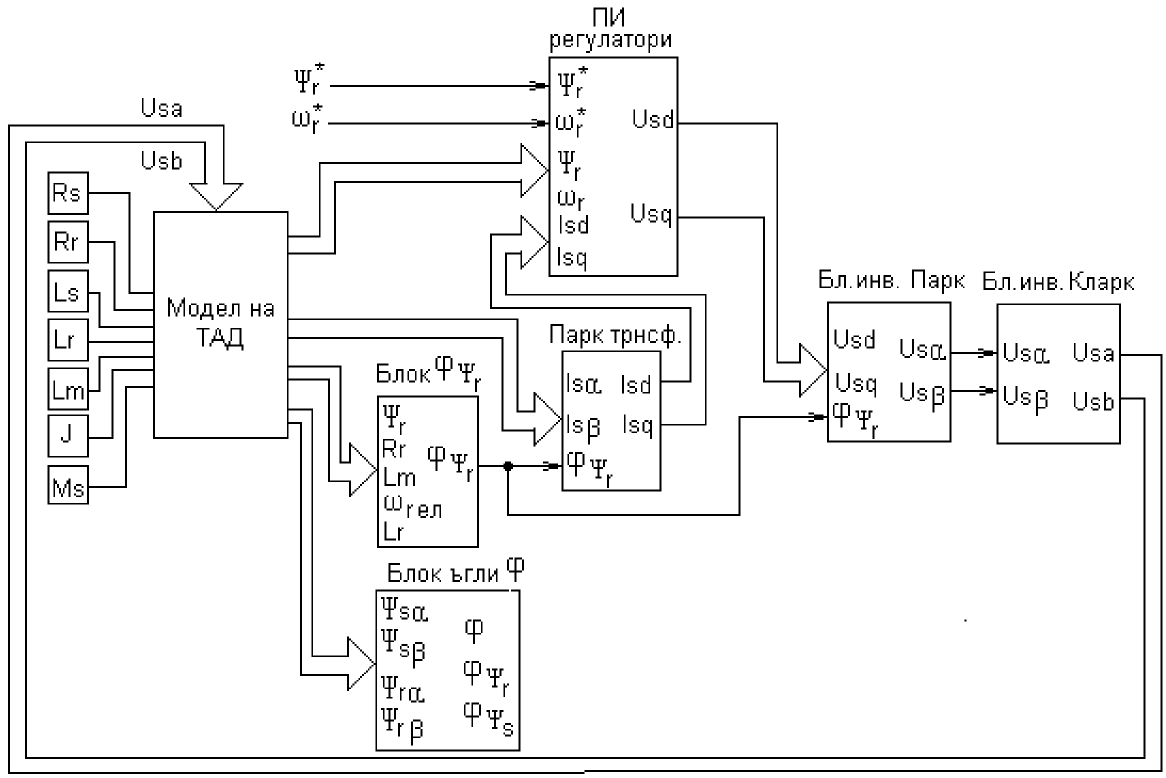

Fig.1 System for control of three-phase asynchronous motor through an orientation of magnetic field

Since the system for control is designed for a particular type of motor, the parameters for the particular motor to be examined are entered in the system's left part. These are active resistances in rotor R_r and stator R_s, inductiveness in the stator L_s, rotor L_r and in the air gap L_m, number of pairs of poles Z_p, as well as a cumulative torque of inertia J. These quantities are entered in a model of a three-phase asynchronous motor. It is built on the basis of some principal equations from the theory of the electromechanical transformation [1,2,4,5], more important of which are shown below:

(1) $$\frac{d\Psi_{s\alpha}}{dt} = U_{s\alpha} - \frac{R_s.L_r}{L_s.L_r - L_m^2}.\Psi_{s\alpha} + \frac{R_s.L_m}{L_s.L_r - L_m^2}.\Psi_{r\alpha}$$

(2) $$\frac{d\Psi_{s\beta}}{dt} = U_{s\beta} - \frac{R_s.L_r}{L_s.L_r - L_m^2}.\Psi_{s\beta} + \frac{R_s.L_m}{L_s.L_r - L_m^2}.\Psi_{r\beta}$$

$$(3)\quad \frac{d\Psi_{r\alpha}}{dt} = -\frac{R_r.L_s}{L_s.L_r - L_m^2}.\Psi_{r\alpha} + \frac{R_r.L_m}{L_s.L_r - L_m^2}.\Psi_{s\alpha} - \omega_{ел}.\Psi_{r\beta}$$

$$(4)\quad \frac{d\Psi_{r\alpha}}{dt} = -\frac{R_r.L_s}{L_s.L_r - L_m^2}.\Psi_{r\beta} + \frac{R_r.L_m}{L_s.L_r - L_m^2}.\Psi_{s\beta} + \omega_{ел}.\Psi_{r\alpha}$$

where:

$\Psi_{s\alpha}$ and $\Psi_{s\beta}$ – are longitudinal and transverse component of the stator flow

$\Psi_{r\alpha}$ and $\Psi_{r\beta}$ – are longitudinal and transverse component of the rotor flow

$\omega_{ел}$ – electrical speed of the rotor

The model gives the data for magnetic flows in the rotor Ψ_r and the stator Ψ_s the motive torque M, mechanical and electrical speed of the rotor, and the stator current I_s as well. In fact, this is one of the advantages of the system – it is not necessary to install additional censors for determining of these quantities because they are obtained in a mathematical way. This will result in a considerable reduction in the price of the elaboration if it is realized in reality.

The received components of the stator current $I_{s\alpha}$ and $I_{s\beta}$ are passed into a block for transformation of Park, where with the help of the momentary angle of turning the vector of the full rotor flow $\varphi_{\Psi r}$ they are transformed into direct-current signals. The received in this way currents I_{sd} and I_{sq} do not depend on the frequency of the power line. Further, these two parameters together with the mechanical speed φ_r and magnetic flow Ψ_r obtained from the model of the motor are passed to a block of PI-controllers. It compares the set speed and flow with the real ones, where the differences is compensated by two separated PI- controllers. Two tensions, which are direct-current quantities, are received at the output of this block. They are transformed into sinusoidal ones in the block for inverse transformation of Park. The received in this way tensions $U_{s\alpha}$ and $U_{s\beta}$ enter into a block of inverse Klark where they are transformed from two-phase system into a three-phase one. These two signals are passed into the model of the rotor in the form of a feedback. In the real systems of control through an orientation of the field, the received tensions α-β are passed into a block of space-vector modulation. Signals controlling the power devices of three-phase inverter that supplies the motor are received from its output.

The studies are done with three types of three-phase asynchronous motors where the results are shown in a table and graphic mode. The purpose of this study is to find out how the angle of dephasing "φ" between the vectors of the stator and rotor full flow changes when the motor is loaded (see fig.2).

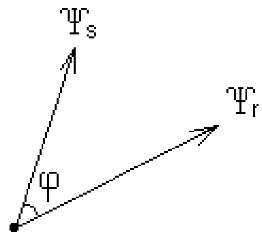

Fig.2 Diagram of the angle of dephasing between Ψ_s and Ψ_r

In the systems for vector control an orientation of the field, this parameter has an effect on the moment of the motor in a way shown by the equations 5 and 6[1,2,3]:

$$(5)\quad M = \frac{m.Z_p}{2}.\frac{k_r}{L_s^{'}.k_s}.tg\varphi.\Psi_r^2$$

$$(6)\quad M = k_{м}\frac{tg\varphi}{1+tg^2\varphi}.\Psi_s^2$$

where:

m is the number of the supplying phases;

Z_p – number of pairs of poles;

k_r – coefficient that is determined by the correlation L_m/L_r;

k_s – coefficient that is determined by the correlation L_m/L_s;

k_m – coefficient of proportionality;

L_s – set inductiveness in the stator;

It is necessary to take into consideration that the equation 5 refers to a system that does stabilization of the rotor full flow. Such is the system shown in fig.1. The equation 6 refers case the stabilization is done for the stator magnetic flow.

The results received from these studies will be base ones when comparing similar ones, done with a system for control in relation to the vector of the stator full flow.

Study of ASM-1

ω_r set = 147,7 rad $^{-1}$, Ψ_r set=1,073, Wb **Table-1**

M,Nm	1	2	3	4	5	6	7	8	9
Ψ_r, Wb	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073
Ψ_s, Wb	1.121	1.121	1,122	1,122	1,123	1,124	1,125	1,126	1,128
ω_r, rad^1	147,7	147,7	147,7	147,7	147,7	147,7	147,7	147,7	147,7
φ °	0.6978	1.395	2,093	2,789	3,485	4,179	4,873	5,565	6,255

Table-1 extension

M,N.m	10	11	12	13	14	15	16	17	18
Ψ_r, Wb	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073
Ψ_s, Wb	1,129	1,131	1,133	1,135	1,137	1,139	1,142	1,145	1,148
ω_r, rad^{-1}	147,7	147,7	147,7	147,7	147,7	147,7	147,7	147,7	147,7
φ°	6,944	7,631	8,315	8,997	9,676	10,35	11,03	11,7	12,37

If you pay attention on the results from table 1, you will ascertain that with increasing of the loading of the motor, the rotor flow Ψ_r as well as the speed ω_r retain their values and they remain equal to set ones. This shows that the system designed in this way works adequately and correctly. On the other hand, it was ascertained that the angle of dephasing φ between the vectors Ψ_s and Ψ_r increases with the increasing of the loading. The same applies to the stator full flow too. The graphic dependence of the ratio φ=(M) for ASM-1 is shown in a fig.3

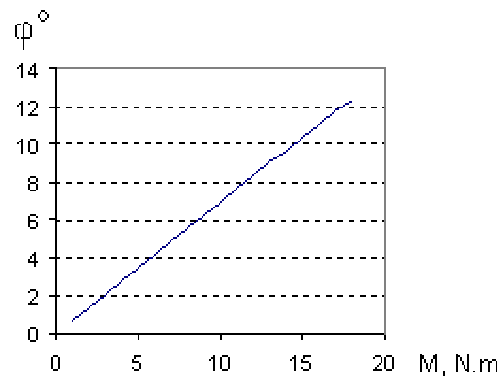

Fig.3 Graphic dependence of the ration φ=(M) for ASM-1

Similar are results from the study of ASM-2 and ASM-3. They given in the tables 2 and 3.

Study of ASM-2

ω_r set = 143,7 rad $^{-1}$, Ψ_r set=1,073 Wb **Table-2**

M,N.m	0.5	1	1.5	2	2.5	3	4	5	6
Ψ_r, Wb	0.5927	0.5927	0.5927	0.5927	0.5927	0.5927	0.5927	0.5927	0.5927
Ψ_s, Wb	06565	0.6568	0.6575	0.6583	0.6595	0.6608	0.6643	0.6688	0.6742
ω_r, rad^{-1}	143.7	143.7	143.7	143.7	143.7	143.7	143.7	143.7	143.7
φ °	1.119	2.237	3.354	4.468	5.578	6.685	8.882	11.05	13.19

Study of ASM-3

ω_r set = 143,7 rad $^{-1}$, Ψ_r set=0,5927 Wb **Table -3**

M,N.m	2	4	6	8	10	12	14	16	18
Ψ_r, Wb	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073
Ψ_s, Wb	1,123	1,124	1,125	1,126	1,128	1,131	1,133	1,136	1,140
ω_r, rad^{-1}	147,7	147,7	147,7	147,7	147,7	147,7	147,7	147,7	147,7
φ °	1,100	2,200	3,298	4,394	5,486	6,574	7,657	8,736	9,808

Table -3 extension

M,N.m	20	22	23	24	25	26	27	28	29
Ψ_r, Wb	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073
Ψ_s, Wb	1,144	1,148	1,150	1,153	1,155	1,158	1,160	1,163	1,166
ω_r, rad^{-1}	147,7	147,7	147,7	147,7	147,7	147,7	147,7	147,7	147,7
φ °	10,87	11,93	12,46	12,98	13,50	14,02	14,54	15,05	15,56

The graphic representations of the function φ=(M) for ASM-2 and ASM-3 are shown in fig.4. Like one in fig.3, here the graphics also show the linear nature of this dependence. They show well how with the increasing of the loading, the angle between the two vector increases too. Increasing of this parameter has an effect on the torque produced by the motor in a way shown by the equation 5. It obvious that a maximum torque will be received at φ=45° since tg φ=1.

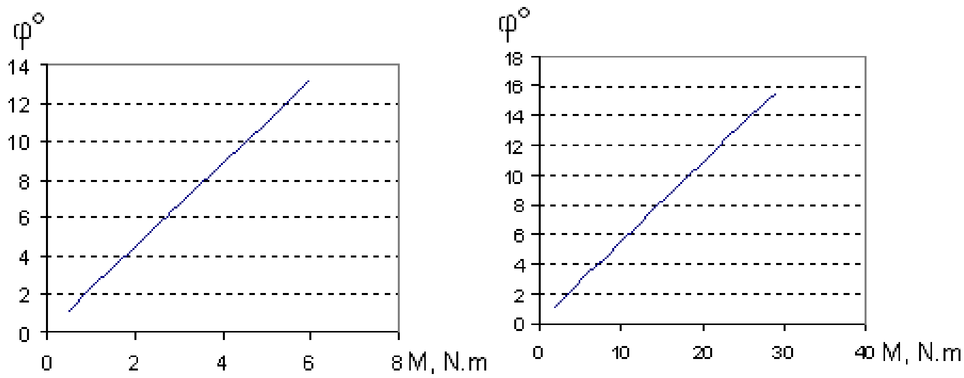

Fig.4 Graphic dependence of ratio φ=(M) for ASM-2 and ASM-3

3. Conclusion

In conclusion it can be said that the results received in this way give response to the simply theoretical question how the angle of dephasing between the vectors of the stator and rotor magnetic flow in a system for control through an orientation of the magnetic field changes. This is essential question for the theory of the electric drive since the choice of the system for control of three-phase asynchronous motors depends on this parameter. The results will be used further as a base comparison when studying the system for orientation of the magnetic field in relation the vector of stator full flow.

4. References

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