Course 5: Mechatronics - Foundations and Applications

Electromagnetic actuators

Victor Konev

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Abstract

In this report the most common electromagnetic drives are described. All modern electro-magnetic drive can be broken into three basic types: group, single, multiimpellent. The direct current and the alternative current engines are view. Direct current engines can be broken down into the following groups: engines with independent excitation and engines with consecutive excitation. And alternative current engines consist of asynchronous and synchronous actuators. Also in this report you can find operation principles, mechanical characteristics, singularity of start-up and other. For synchronous engines special executions are examined.

All the materials have taken from course lection "Theory of electromagnetic actuators" by Andruschuk V.V.

SPbSPU, FTC, SAC, 2004

Contents

1   Introduction

Good afternoon, colleagues. Let me present to you a little introduction for my report. Electromagnetic drives its name of my specialization. And when I collected all materials I was scared. So many interesting thing I have. And time for report too short. That's why I decided to show you only iceberg top of theory of electromagnetic drives. And so, I start.

Today I would like to tell you about a very important thing for everyday life - it is an electromagnetic drive. We meet them everywhere but very often we don't notice them. Lifts, fans, escalators in the underground, video cameras, quartz watches and many other things contain this unit.

2   Fundamental of theory electromagnetic actuators

In the report I would like to describe the most common electromagnetic drives. And for the beginning let's see, what the electromagnetic drive is.

2.1   Basic notions

Electromechanical device intended for electrification and automation of working processes and consisting of converters, electromagnetic engines, transfer and operating devices is called an electromagnetic drive.

All modern electromagnetic drive can be broken into three basic types:

- group;
- single;
- multiimpellent.

A drive, where motion of working machines is carried out from one engine, is called a group electromagnetic drive. Transfer of movement occurs due to transmission. The structure chart is presented in figure 1.
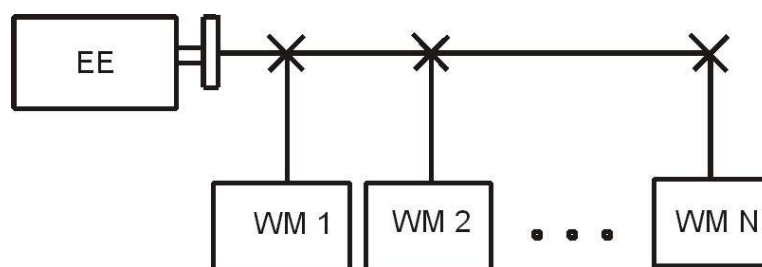

Figure 1: Structure chart of group electromagnetic actuator.

This type of electromagnetic drive was characteristic for the initial stage of industrial revolution.

Disadvantages of this type:

- low EFFICIENCY;
- irrational use of premises;
- high traumatism.

A drive when each moving machines is set in motion from the separate electromagnetic engines is called a single electromagnetic drive. The structure chart is presented in figure 2.
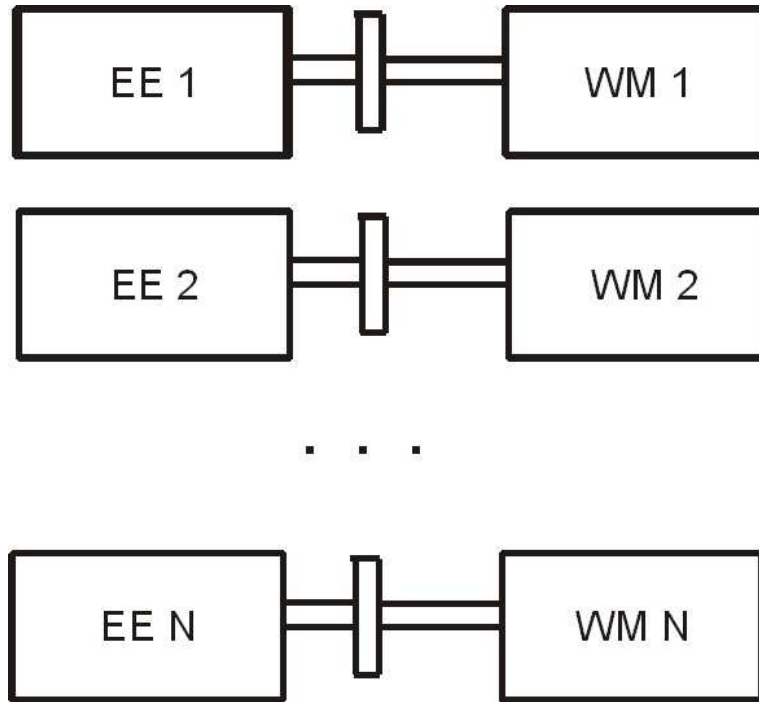
Figure 2: Structure chart of single electromagnetic actuator.

This type even now is applied in the elementary mechanisms.
Disadvantages:

- too high capacity of the engine was set because this engine puts into motion all parts of the mechanism. But the engine works with underloading. That's it has low EFFICIENCY;

- complex kinematics of the machine tool;

- installation of connecting couplings is required.

A drive in which each part of the moving machine is set in motion from the separate electromagnetic engines is called a multiimpellent electromagnetic drive. The structure chart is presented in figure 3.
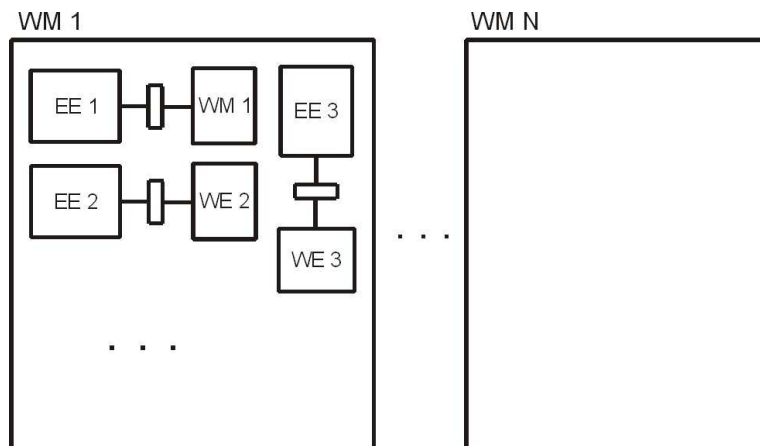

Figure 3: Structure chart of multiimpellent electromagnetic actuator.

The given type of drive is widespread in modern industry.
Advantages:

- has elementary kinematic circuits;

- the engine is built in directly into the working body;

- the maximal EFFICIENCY;

- has conditions for independent optimum control of the working body.

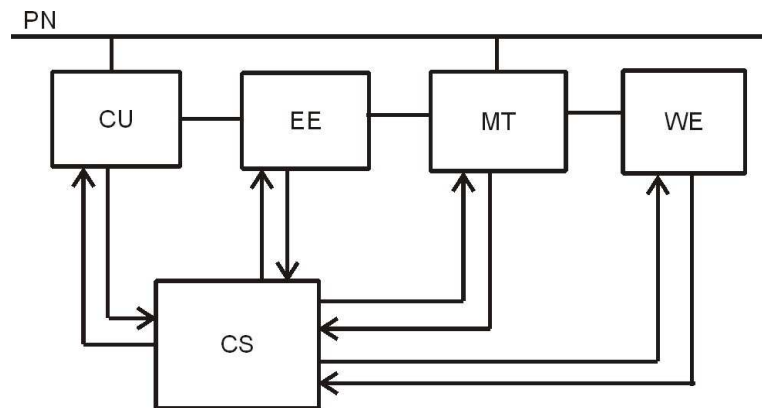In figure 4 the function chart of an electromagnetic drive is presented:

Figure 4: Function chart of electromagnetic actuator.

CU - converter unit (It's used to convert the alternative feed voltage to direct voltage or to alternative voltage another frequency)

EE - electromagnetic direct or alternative current engine

MT - mechanical transmission (Transmissions, reductions and other mechanical devices)

WE - working element (It implements technological procedure)

CS - control system (It checks all elements of electromagnetic drive and forms control signal)

PN - power network

2.2   Mechanical characteristics.

We dependence which shows the speed change under influence of the external moment of the engine is called mechanical characteristic.

$$\omega = f(M) \quad or \quad n = f(M)$$

ω - angular speed
n - frequency of rotation
M - the moment
Sometimes the following modification of mechanical characteristic is used:

$$\omega = f(I) \quad or \quad n = f(I)$$

I - current
This characteristic is called electromechanical.

Mechanical characteristics are a base for a choice of the executive mechanism engine.Distinguish natural and artificial mechanical characteristics.

The dependence $\omega = f(M)$ obtained at a nominal feeding voltage is called natural mechanical characteristic, at the nominal scheme of inclusion, at absence of additional resistance in circuits of the engine.

Dependence Dependence $\omega = f(M)$ obtained at the voltage of feed, which is different from the face value, is called artificial mechanical characteristic, at use of additional resistance in circuits of the engine and at inclusion of the engine under special schemes. obtained at the voltage of feed, which is different from the face value, is called artificial mechanical characteristic, at use of additional resistance in circuits of the engine and at inclusion of the engine under special schemes.

Mechanical characteristics are distinguished on a speed change degree from the moment: (β - slope, criterion of rigidity; $\beta = \frac{\Delta n\%}{\Delta M\%}100\%$)
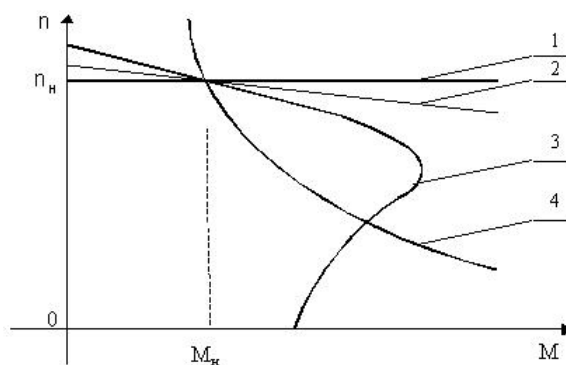

Figure 5: Examples of mechanical characteristic.

- absolutely rigid characteristics, β is equal to 0, line number 1 (synchronous engine);

- rigid characteristics, $\beta < 10$ %, lines number 2 (DC engines with independent excitation) and 3 (asynchronous engine)

- soft characteristics, $\beta > 10$ %, line number 4 (DC engines with consecutive excitation)

The type of engine characteristics will define application of this machine in industrial production: Rigid or absolutely rigid - in rolling mills Soft - in hoisting-and-transport machines

3 Direct current engines

Now I would like to bring engines of electromagnetic drives, which at present are widely used, to your attention.

I would like to start with the direct current engines. They possess some important properties as very soft mechanical characteristics and simplicity in management. Direct current engines can be broken down into the following groups: engines with independent excitation and engines with consecutive excitation.

But at present this kind of electromagnetic engines is becoming out-of-date. Their design feature is a collector. At the use of direct current engines it is necessary to have in mind, that the collector requires quite frequent service due to sparking on its "brushes". Besides it is necessary to note, that collector is a complex operation, and it raises price of direct current engines in comparison with other electric drives.
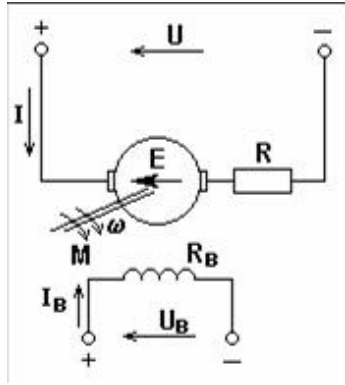
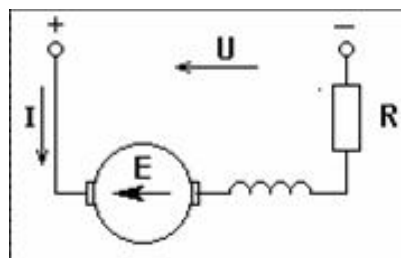Figure 6: Chart of engine with independent excitation.

Figure 7: Chart of engine with consecutive excitation.

4 Asynchronous engine

4.1 Basic notions

Symbols:
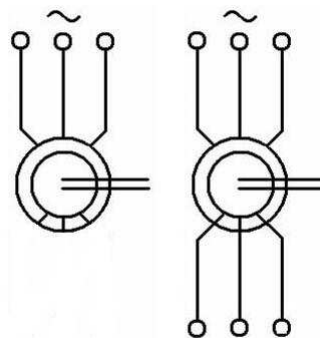
Figure 8: Asynchronous engines with short-circuit winding and with phase-wound rotor.

Stator of the asynchronous electric motor can have two connections star or triangle. A rotor usually have star connection.

ω_0 - rotation speed of the magnetic field vector (synchronous speed)

ω - rotation speed of the rotor

When rotor is moveless electromotive force will be produced in its windings and the rotor current will take place due to rotor electromotive force. As a result of interaction between

Figure 9: Operation principle of the asynchronous engine.

stator stream and rotor current the electromagnetic moment is produced, that will lead to rotor rotation with the speed $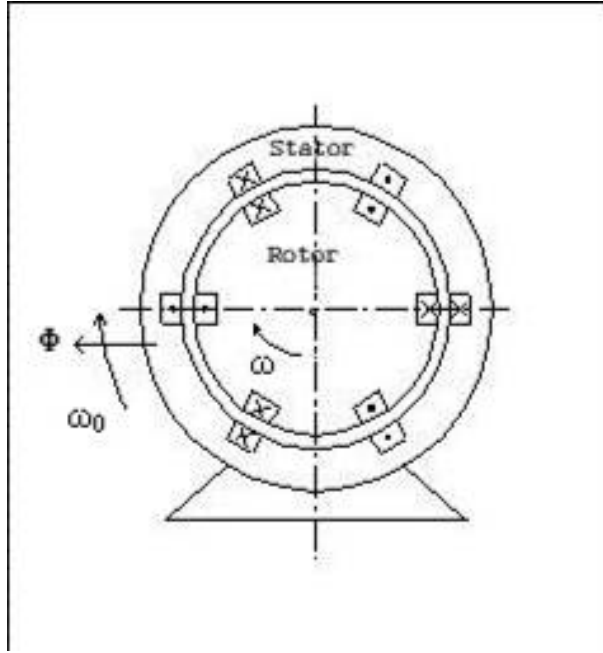\omega$. It is obvious, that if it's desirable to keep magnetic stream crossing with rotor windings, the necessary condition is as follows: $\omega_0 > \omega$

If ω_0 will be equal , then the stream does not cross the rotor winding, hence, the electromotive force of the rotor aspires to zero, the rotor current aspires to zero and the moment aspires to zero. This fact can explain the name of the engine.

To estimate a degree of rotor speed deviation from the synchronous one we introduce the notion of "sliding":

$$s = \frac{\omega_0 - \omega}{\omega_0}$$
$$If\ \omega_0 = \omega,\ then\ s = 0\ and\ M = 0$$

For synchronous speed definition:

$$\omega_0 = \frac{2\pi f}{p} \quad or \quad n_0 = \frac{60f}{p}$$

p - number of pairs of poles
f - feeding voltage frequency
If we know the value of sliding, it is possible to calculate $\omega = \omega_0(1 - s)$
At the start-up moment: $\omega = 0 \Rightarrow s = 1$

$$\left. \begin{array}{l} if\ \omega > \omega_0,\ then\ s < 0 \\ if\ \omega < \omega_0,\ then\ s > 0 \end{array} \right\} \Rightarrow -\infty < s < +\infty$$

4.2 The equation of the asynchronous engine mechanical characteristic

To finish the equation of the asynchronous engine mechanical characteristic we shall start with the Γ-shaped equivalent circuit, constructed for one phase.

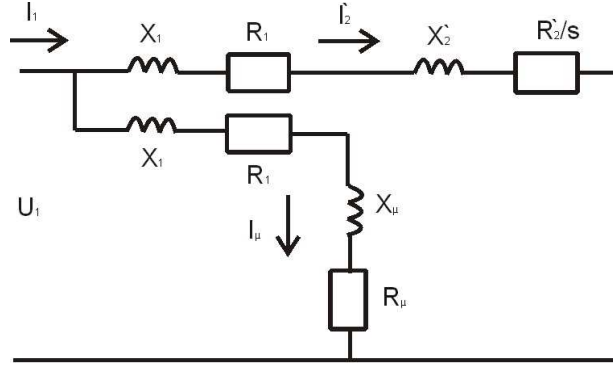We consider, that the rotor and the stator has star connections.

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Figure 10: Γ-shaped equivalent circuit, constructed for one phase.

U_1 - phase voltage stator windings

X_1 - inductive resistance of the stator windings from dispersing streams

R_1 - active resistance of the stator windings

X_2' - inductive resistance of the rotor windings from dispersing streams, estimated for the stator winding

R_2' - active resistance of the rotor windings, estimated for the stator winding

X_μ - inductive resistance from the basic magnetizing stream

R_μ - active resistance defining losses in the stator from the magnetizing current

I_μ - stator magnetizing current

I_2' - rotor current, estimated for the stator winding

$$I_1 = \sqrt{I_\mu^2 + I_2'^2}$$

$$\left.\begin{array}{l} R_2' = K_e^2 R_2 \\ X_2' = K_e^2 X_2 \\ K_e = \frac{U_1}{E_2} \\ I_2' = \frac{I_2}{K_e} \end{array}\right\} \Rightarrow I_2' = \frac{U_1}{\sqrt{(R_1 + \frac{R_2'}{s})^2 + (X_1 + X_2')^2}} \quad (1)$$

$X_1 + X_2' = X_k$ - inductive resistance of the short circuit.

The electromagnetic capacity developed in the air backlash

$P_E = M\omega_0$

Electromagnetic capacity is a capacity, generated in the air backlash at interaction of the current proceeding through the winding, with a stream which is passing through the anchor. The electromagnetic moment - the moment developed by the engine in the air backlash.

Electromagnetic power is spent for mechanical work and on losses in the rotor circuit

$\left.\begin{array}{l} P_E = P_M + \Delta P_2 \\ P_M = M\omega \end{array}\right\} \Rightarrow \Delta P_2 = M(\omega_0 - \omega)$

$M = \frac{\Delta P_2}{(\omega_0 - \omega)} \Leftrightarrow M = \frac{\Delta P_2}{\omega_0 s}$

$\Delta P_2 = mI_2'^2 R_2'$

$M = \frac{mI_2'^2 R_2'}{\omega_0 s} \quad (2)$

$(2) \quad \rightarrow \quad (1):$

$M = \frac{mR_2' U_1^2}{\omega_0 s[(R_1 + \frac{R_2'}{s})^2 + X_k^2]} \quad (3)$

From (3) it is clear, that dependence of the electromagnetic moment on sliding represents a complex function. For definition of an extremum we shall take derivative of expression (3) and we shall equate it to zero.

$$s_{kp} = \pm \frac{R_2'}{\sqrt{R_1^2 + X_k^2}}$$

$$M_{kp} = \frac{mU_1^2}{2\omega_0(\sqrt{R_1^2 + X_k^2} \pm R_1)}$$

ε - relative sliding $\varepsilon = \frac{R_1}{\sqrt{R_1^2 + X_k^2}}$

Having substituted in (3) the value of the critical moment is:

$$M = \frac{2M_{kp}(1+\varepsilon)}{\frac{s}{s_{kp}} + \frac{s_{kp}}{s} + 2\varepsilon} \qquad \leftarrow \; Kloss\ formula \; (4)$$

In big capacity engines the resistance is not sufficient, hence, the relative sliding aspires to zero, so:

$$M = \frac{2M_{kp}(1+\varepsilon)}{\frac{s}{s_{kp}} + \frac{s_{kp}}{s}} \qquad (5)$$

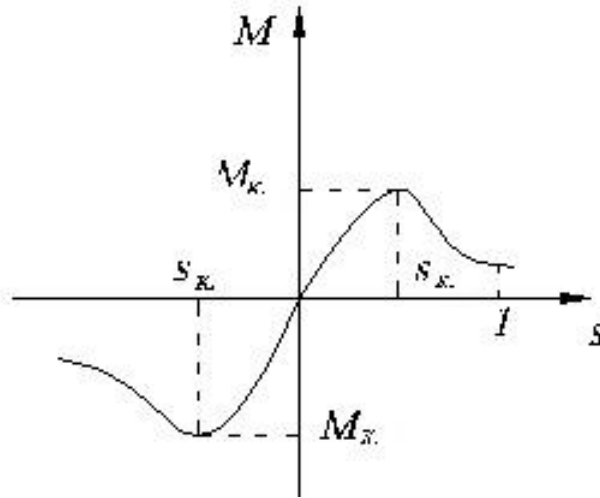Using formulas (4) and (5), we draw up mechanical characteristics

Figure 11: Asynchronous engine mechanical characteristic

The concept maximal moment frequency rate is inserted.

$\lambda_M = \frac{M_{kp}}{M_H}$

It shows possible reloading ability of the asynchronous engine.

In the asynchronous engine of common industrial application $\lambda_M = 1{,}8$ - $2{,}2$;

in special (a crane-metallurgical series) $\lambda_M = 2{,}3$ - $2{,}8$.

4.3 Voltage fluctuation influence in asynchronous engine mechanical characteristics in the power line.

Earlier it has been established, that the critical moment

$$M_{kp} = \frac{mU_1^2}{2\omega_0(\sqrt{R_1^2 + X_k^2} + R_1)} \qquad \sim \; U_1^2 \quad (6)$$

$$s_{kp} = \frac{R_2'}{\sqrt{R_1^2 + X_k^2}} = const \quad (7)$$

The asynchronous engine (especially with a short-circuited rotor) is very sensitive to voltage fluctuation of the feed and when one chooses an asynchronous engine it is necessary to make necessarily check at the lowered voltage of the feed.
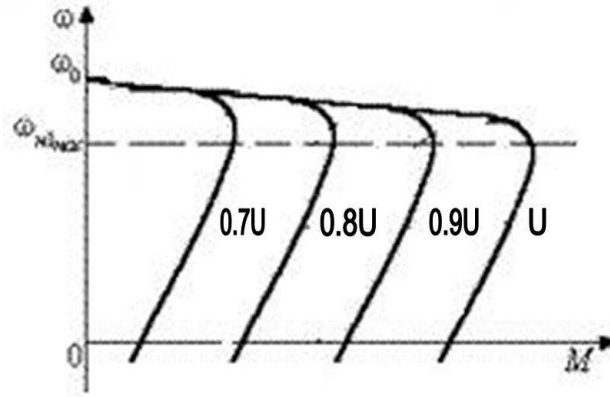
Figure 12: Voltage fluctuation influence on asynchronous engine.

4.4 Inclusion of the active resistance in the stator circuit asynchronous engine

It is done with the purpose of voltage reduction and, hence, the starting current of the asynchronous engine also reduce. In some cases it is necessary for starting moment reduction to lower shock loadings and to provide smooth start-up.

It is reasonable especially for short-circuited rotor asynchronous engine since it is impossible to influence on the rotor. Sometimes throttle is included.

5 Synchronous engine.

5.1 Basic notions

The synchronous engine stator is similar to the asynchronous engine stator and has three-phase winding, forming a rotating magnetic field. On the rotor constant magnets are located. The rotor can have salient-pole and implicit-pole execution.
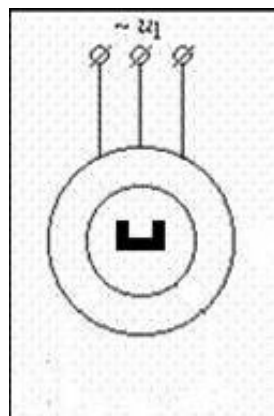

Figure 13: Symbol of synchronous engine with constant magnet.

Synchronous engines of the big capacity have electromagnetic excitation, and the rotor is conducted through rings and brushes.
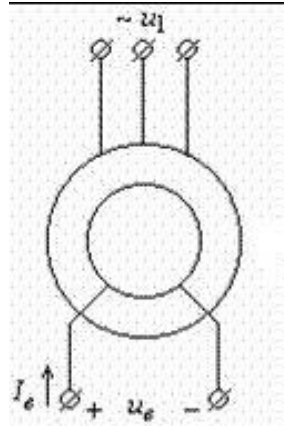
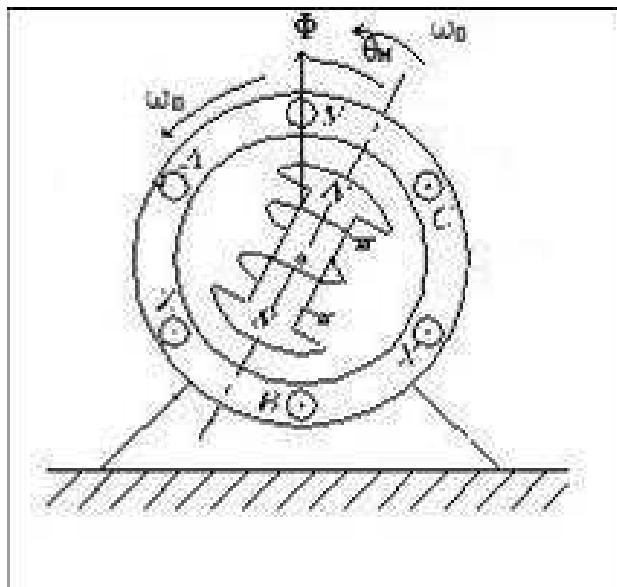Figure 14: Symbol of synchronous engine with electromagnetic excitation.

Figure 15: Operation principle of the synchronous engine.

The electromagnetic moment results from interaction of the stator magnetic fields and the rotor. The stator field carries away the attraction of the rotor pole, and the rotor will rotate with synchronous speed.

$\omega_0 = \frac{2\pi f}{p}$ or $n_0 = \frac{60f}{p}$

p - number of pairs of poles.

θ_M - angle between the stator stream vector and the rotor.

Thus, the speed of rotation of the rotor is equal to ω_0. At fluctuations of the loading the angle between the stream vectors also changes.

$$M \uparrow \rightarrow \theta_M \uparrow$$

At the analysis of the processes in the synchronous engine the electric angel θ is used (between voltage and electromotive force vectors).

$\theta_M = \frac{\theta}{p}$

$if\ p = 1,\ then\ \theta_M = \theta$

The mechanical characteristic of the synchronous engine in this case will be presented by a line which is passing through ω_0. It also will be absolutely rigid.
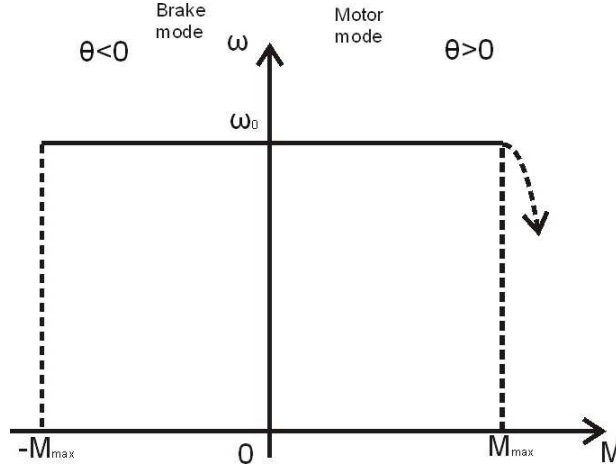
Figure 16: Mechanical characteristic of the synchronous engine.

The shown characteristic corresponds to the synchronous operating mode, when ω *is equal to* ω_0 At loadings more than $M_{\max}$ the rotor leaves the synchronous mode, and ω_0 will be greater than ω. We have asynchronism. In this link start-up of the synchronous engine is significant. At switch of the stator windings into the network a rotating magnetic field is instantly formed, and the rotor remains motionless (the synchronous mode is absent). There is a necessity to accelerate the rotor till the speed is close to the synchronous one. To start-up the engine a special short-circuit (starting) winding is placed.

At the moment of start-up only the starting winding works.

5.2 Features of the synchronous engine start-up.

At start-up of the synchronous engine M_a (active component of synchronous moment) does not develop (it is equal to zero), hence, it is necessary to use auxiliary means. The rotor is accelerated by means of driving engine, or starting winding.

And the period of start-up significant starting currents develop in the stator.

$I_\Pi = (5 \div 7)I_H$

For restriction I_Π it is necessary to include stator on the lowered voltage (to switching from the star connection to the triangle connection) or to include additional starting rheostats into the rotor circuit. With voltage reduction on the stator $I \sim U$ and $M \sim U^2$.

During start-up in the rotor winding the electromotive force which can reach great values (dangerous for the rotor) is induced. Therefore, for restriction of the current in the rotor circuit from the directed electromotive force it is necessary to switch the rotor excitation winding on additional resistance.

$R_{ad} \approx 10R_2$

The rotor winding is not supposed to be disconnected from the power supply. Due to significant electromotive force it is possible to punch isolation of the winding.

5.3 Synchronous engines of special execution.

5.3.1 Synchronous engines with constant magnets.

Synchronous engines with electromagnetic excitation have the following advantages:

- high EFFICIENCY;
- high $\cos\varphi$ (it is possible to change the character of any jet current);

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- the big starting moment;

- high reloading ability.

Occasionally such synchronous engines surpass asynchronous engines. Therefore synchronous engines with electromagnetic excitation are widely used in drives of the average and big capacity. However, in automatic systems low powers and micromachines are basically used thereof, synchronous engines with electromagnetic excitation are not applied in automatic systems because of:

- Presence of two power supplies (direct and alternating current);

- Presence of rings and brushes on the rotor (complication of design and reduction of reliability);

- " Complexity of the start-up (presence of a starting winding and necessity to switch the excitation winding on the power supply after acceleration).

With development of new magnetic materials synchronous engines with constant magnets have been designed. In this case the synchronous engine comes nearer to the asynchronous engine with short-circuited rotor (there are no power supply, brushes, simple start-up, keeping of EFFICIENCY and $\cos\varphi$).

Structurally synchronous engines with constant magnets do not differ from asynchronous engines. Stator is analogous (a three-phase winding).
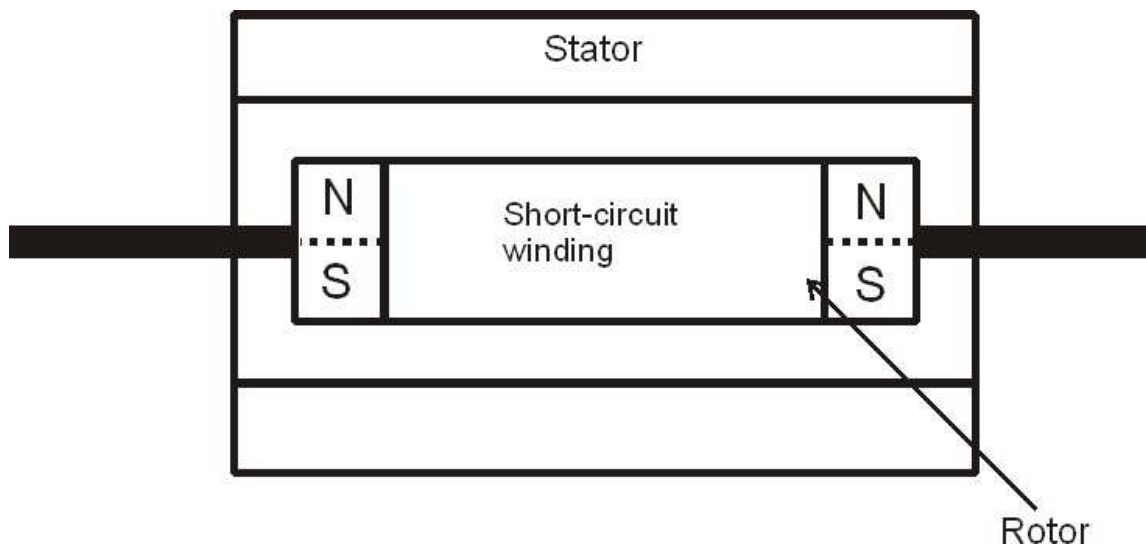

Figure 17: Structure of synchronous engines stator and rotor.

Start-up of the synchronous engine occurs due to the short-circuited winding, as at the asynchronous engine. When the rotor achieves the synchronous speed its poles will slowly pass the stator stream vector, and the rotor will be instantly put into the synchronous mode. Synchronous engines with constant magnets are used in installations where high accuracy of speed and rigidity of characteristics are required.

5.3.2 Synchronous jet engines.

The most widespread synchronous engine of low power. It is used where it is necessary to receive a constant speed, low material inputs and simplicity of management. Synchronous jet engines of the average and greater capacity are not issued because of their:

- High weight and dimensional parameters;

- Low EFFICIENCY;

- Low cos
  $varphi$.

Structurally synchronous jet engine does not differ from the asynchronous engine.

Stator and rotor are made of electrotechnical steel. On stator there is a three-phase winding (probably single-phase execution). The rotor should have salient-pole. It's easier to get a rotor of the synchronous jet engine from a short-circuited rotor of the asynchronous engine.
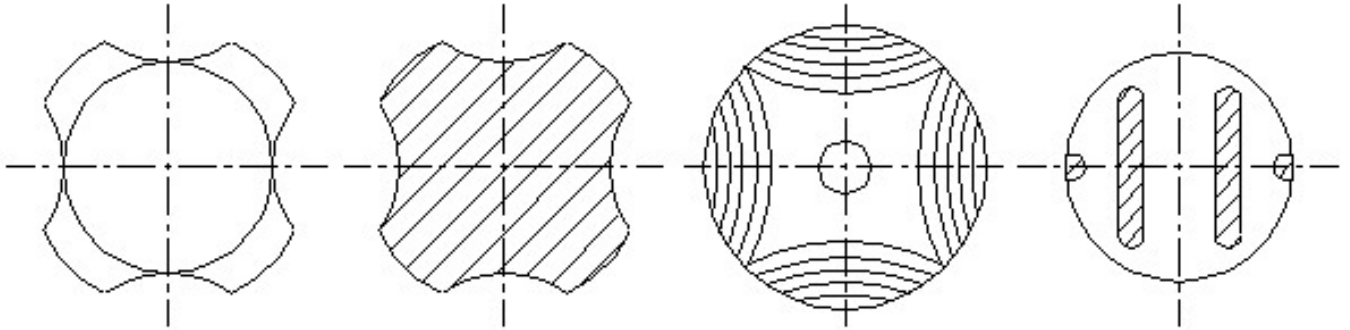
Figure 18: Synchronous jet engines rotors.

At such design the start-up of the synchronous jet engine occurs due to the short-circuited winding. In this case the jet moment will be the most important thing.

$M_p = \frac{mU_1^2 \sin 2\theta}{2\omega_0}(\frac{1}{X_q} - \frac{1}{X_d})$ $(*)$

Value of M_p is essentially less than M_a, hence, specific parameters of the synchronous jet engine will be essentially low then parameters of the asynchronous engine, so the dimension is approximately twice as much as at the asynchronous engine.

Reloading ability is within the limits of $\lambda_M =$1,5 (it is not enough!).

The synchronous jet engine is inclined to self-oscillations, which arise at reception and dump of loadings. The synchronous jet engine is less steady, than the synchronous engine with constant magnets. From the expression $(*)$ it is clear, that $M_{max} \sim U_1^2$, i.e. strongly depends on the power line. Also its clear, that for increase of M_{max} it is necessary to aspire to increase $(\frac{1}{X_q} - \frac{1}{X_d})$. However, such decision leads to the negative consequences. The increase in depth of phase will lead to the growth of an equivalent air backlash between the stator and the rotor, as well as the magnetizing current and losses in the stator windings. Hence, all these leads to EFFICIENCY and $\cos\varphi$ reduction.
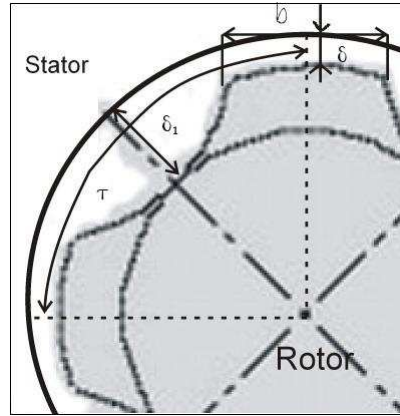
Practice has shown:

Figure 19: Rotor of synchronous jet engine.

Optimum:

$$\frac{b}{\tau} = 0.5 \div 0.6$$
$$\tau = \frac{\pi D}{2p}$$
$$\frac{\delta}{\delta_1} = \frac{1}{10}$$

Only in this case:
$\cos \varphi \approx 0.4 \div 0.5$ and EFFICIENCY at a level of 50

5.3.3 Slow-moving (geared) synchronous jet engine.

At frequency of the power line it allows to reach an ultra-low frequency of the rotor rotation without a reducer. Structurally the stator and the rotor have a gear structure. There more teeth on the rotor then on the stator on even number.
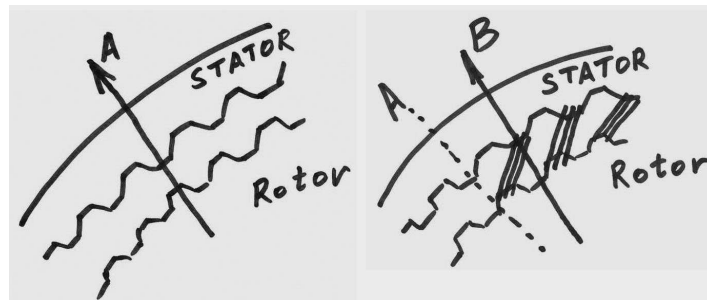

Figure 20: Operation of slow-moving synchronous jet engine.

$$Z_p > Z_{cm}$$
$$Let's\ Z_p = 18\ and\ Z_{cm} = 16,$$
$$then\ \omega = \omega_0 \frac{Z_p - Z_{cm}}{Z_p} = \frac{2\pi f_0}{p} * \frac{Z_p - Z_{cm}}{Z_p}$$

In the starting position the rotor settles down so that the pole of the rotor is situated opposite to the stator pole, providing the minimal magnetic resistance (position A). On the stator the three-phase winding settles down and produces a rotating field. During the following moment of time the stator stream vector will take position B. And owing to different polar division of the stator and the rotor, the pole of the rotor will be displaced relatively to a stator

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tooth. Magnetic power lines pulling is formed and the rotor will turn on a difference of the polar divisions.

$$\left.\begin{array}{l} \frac{360°}{Z_{cm}} = \alpha_{cm} = 22.5° \\ \frac{360°}{Z_p} = \alpha_p = 20° \end{array}\right\} \Rightarrow rotor \text{ displacementis} 2.5°$$

Generally:

$$\omega = \omega_0 \frac{Z_p - Z_{cm}}{Z_p} \Rightarrow \omega = \frac{1}{9}\omega_0$$

If to take $Z_p = 400 \; and \; Z_{cm} = 398$ then the factor of a reduction will be equally 200.

Thus, it is possible to reach a low synchronous speed that can be used in the slow-moving mechanisms without mechanical reduction.

Power parameters are the lowest.

5.3.4   Synchronous hysteresis engine.

Low power parameters of the synchronous jet engine have led to creation of the synchronous hysteresis engine. Structurally it differs slightly from the synchronous jet engine: the stator has a three-phase winding (single-phase execution probably) which forms a rotating magnetic field. The rotor is made from magnetic hard material.
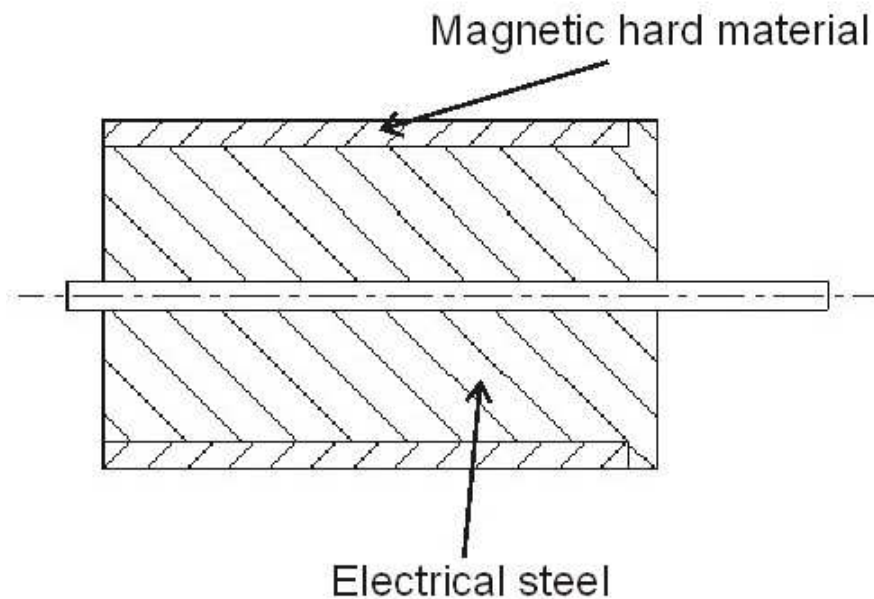

Figure 21: Rotor of synchronous hysteresis engine.

At excitation of the rotor domains of magnetic hard material settle down along the power lines of the magnetic stream.

At stator windings stream moving domains are kept in the former position due to the internal molecular friction. It will lead to tension of magnetic power lines. The magnetic moment caused by the phenomenon of hysteresis is created. Besides, due to vortex streams in the core the electromagnetic moment of asynchronous type that provides the start-up of the engine is created.

Let's define the compound moments of the synchronous hysteresis engine.

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Losses in the rotor of the machine are proportional to the current frequency induced in it.

$P_\Sigma = P_\Gamma + P_B$

P_Γ - losses on hysteresis;

P_B - losses on vortex currents.

Losses in the rotor of the machine are proportional to the current frequency induced in it.

$f_2 = f_1 s$

f_1 - frequency of the power line.

$P_\Gamma = P_{\Gamma 0} s$

$P_{\Gamma 0}$ - losses on hysteresis at frequency f_1.

$P_B = P_{B0} s^2$

P_{B0} - losses on vortical currents at f_1.

$P_\Sigma = P_{\Gamma 0} s + P_{B0} s^2$

$M_\Sigma = \dfrac{P_\Sigma}{\omega_0 s} = \dfrac{P_{\Gamma 0} s}{\omega_0 s} + \dfrac{P_{B0} s^2}{\omega_0 s} = M_\Gamma + M_B$
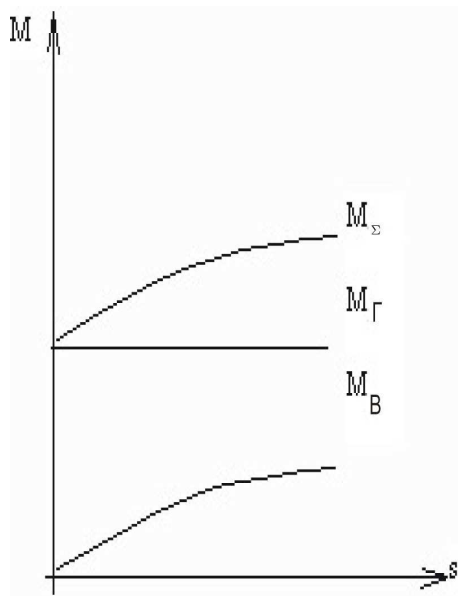

Figure 22: Dependence M=f(s).

The obtained dependence shows, that the synchronous hysteresis engine provides a steady start-up of the rotor due to the asynchronous moment and an input in synchronism due to the hysteresis moment. Losses on vortex currents will be significant, however, they are short-term. At transition into the synchronous mode losses on vortex currents are excluded. Synchronous hysteresis engines have EFFICIENCY equal to $0.4 \div 0.5$ and $\cos\varphi$ equal to $0.3 \div 0.4$.

6 Step-by-step engines.

The step-by-step engine represents a version of the synchronous jet engine. Difference is the rotor of the step-by-step engine moves discretely on each impulse acting in stator winding, thus transformation of an electric impulse to an impulse of movement takes place. It is applied in automatic mechanisms, machine tools with CNC (computer numerical control), computers, military technics and others. It is notable for simplicity and reliability.

The setting generator forms the sequence of impulses, which acts in the device forming impulses with the necessary duration and steepness of the front. Further the switchboard transforms the sequence of impulses into a multichannel signal, then, after passing the amplifier of capacity this signal influences on the step-by-step engine.
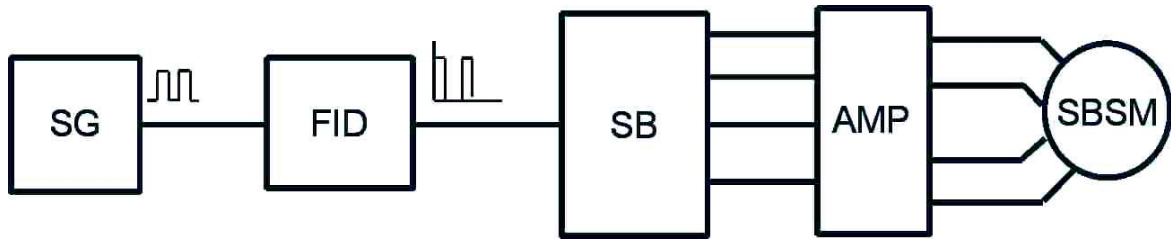
Figure 23: Control system of step-by-step motor.

We have got a simple control system without feedback, providing moving of the rotor on to the set angle, which is defined by the number of input impulses on the step-by-step engine.

The missing of the impulses is inadmissible!

The rotor can have salient-pole design and it can be classified as an active rotor or jet (passive) one. At presence of the constant magnets on the rotor (stator) fixing of the rotor in an initial status takes place. The direction of the rotor movement is defined by the sequence of stator windings inclusion. If impulses are missed accumulation all mistakes can not be corrected because of feedback absence.

The principle of step-by-step engine operation is similar to the synchronous jet engine. We shall consider the work done by the step-by-step engine with the jet rotor, which has 4 poles on stator and 2 - on a rotor.
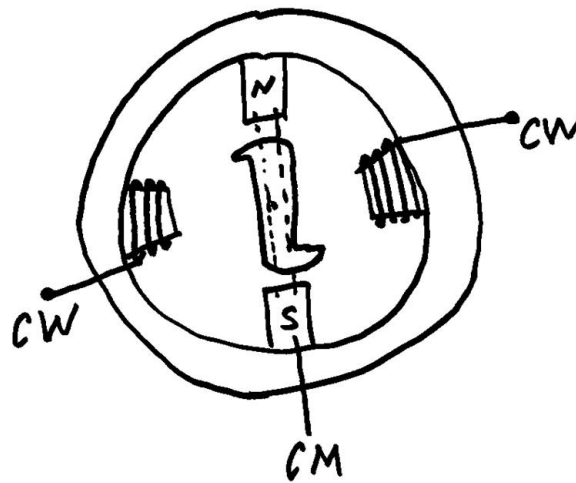

Figure 24: Operation of step-by-step motor.

On the rotor poles beak-shaped tips are located. These tips define a direction of the machine movement (only towards the beak). In the poles, on which the winding of management is located, the stream that is approximately twice as much as on the constant magnets is formed. At inclusion of the winding of management with a drive of the first impulse, the rotor turns counter-clockwise and takes horizontal position. With the arrival of the following impulse the winding of management is disconnected, and the rotor is drawn to the constant magnets and takes vertical position, etc.

$$\Delta\alpha = \frac{360°}{2p_{cm}} = \frac{360°}{4} = 90°$$

If impulses of management act continuously with frequency f, the rotor will rotate with $\omega = \frac{2\pi f}{2p_{cm}}$

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To change a direction it is necessary to change the tips.

The given engine has a big step. For its reduction it is necessary to increase the number of the stator poles. It is necessary to remember, that the increase in the number of poles and transition to the gear execution leads to the electromagnetic moment reduction, therefore there should be a reasonable limit. For the step engine reduction at rather small number of poles, 3 stator the step-by-step engine is used, thus 3 stators are placed in one case, these stators are shifted on some angle. In the process of machine operation the combination of stator pole switching and a certain sequence of the stators switching is provided. Besides, the step can be reduced by a combination of several stator inclusions.

7 AC converter-fed engines

Ac converter-fed engines got wide application last decade. They are used where the wide range of regulation, high accuracy, extremely high dynamics, reliability, high accuracy of regulation of the moment are required. Initially at the solution of the problem the direct current engine was used. But now we know all disadvantages of the direct current engines.

Principle of operation the ac converter-fed engine coincides with the direct current engine. And constructively the ac converter-fed engine coincides with the synchronous engine. And the rotor position gouge, which definitely switches the phase (section) of the anchor winding should carry out the function of collector, so that the resulting vector of the anchor winding current or of the anchor winding stream reaction vector would be orthogonal to the excitation stream vector.

In view of the stated function, the chart of the ac converter-fed engine has the following appearance:
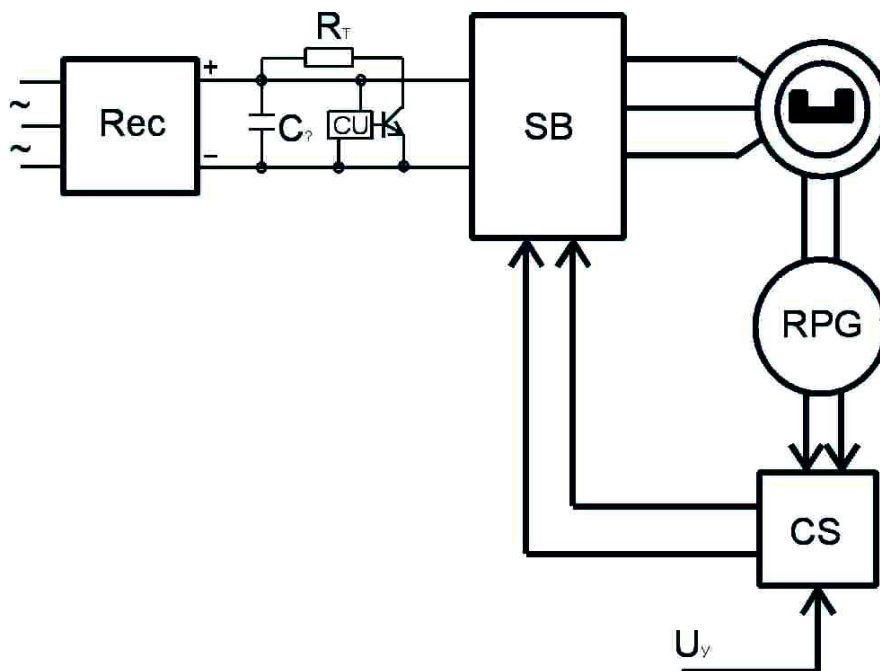

Figure 25: Function chart of the AC converter-fed engine.

A feed of the ac converter-fed engine is carried out from the source of the direct voltage formed by the rectifier and the filter (C_Φ). Further this voltage moves onto the switchboard of the anchor windings section (phases). The synchronous engine is connected with output SB with constant magnets on the rotor is connected with output SB. The rotor position gouge

supervises position of the rotor stream relatively to the anchor (stator) windings. In the view of signal of management and signals of the gauge of rotor position in the control system the impulses providing switching of phases in the stator to winding are formed.

Condition of optimum ac converter-fed engine work will be orthogonal Φ_0 and Φ_a.

This condition is carried out by the certain arrangement of the rotor position gouge on the axis of the synchronous engine rotor. The value of synchronous engine moment is defined by the amplitude of the signal of management, as in the direct current engine.

There are two basic ways of switching the stator windings:

- discrete;

- continuous (sinus).

At discrete switching impulses of management are formed through discrete angles of rotor turns. Light-photo diodes, gauges of the Hall photon-coupled pairs and others are used as the rotor position gauges.

At continuous management information micromachines are used:

- selsyns;

- sine-cosine rotary transformers.

8   Conclusions

Time of my lection goes to the end. But there are a lot of information for you. May be next time I'll tell you about engines modes, influence of an engine parameters on its characteristics, special schemes of the engine inclusion. But now I'll stop.

Thank you for your attention!