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The Hermetic Synchronous Engines for Pumping the Aggressive Liquids

The paper covers brief information about asynchronous and synchronous engines used for driving centrifugal pumps. It is argued the fact that asynchronous engines do not, actually, satisfy the requirements for hermetic engines designed for pumping radioactive and chemical liquids, because they possess low technical and economic indexes. Modification of rotor construction of these engines gives the possibility to increase these indexes. The shortcut rotor was replaced with a ferromagnetic rotor in hermetic asynchronous engine serially produced and permanent magnets had been inserted into its body. Different synchronous engine constructions with permanent magnets had been analyzed and developed, which operating characteristics had been compared with those of the asynchronous one.

Keywords: hermetic motors, permanent magnets, protection cylinders, synchronism, magnetic field image

1. Introduction

The pumping of the liquid substances is an actual problem for national economy and in global view. Saving consumed energy for realizing this process depends on the technical and economical level of pumps used for these purposes. Particular interest in this context is hermetic pumps used for pumping liquids that are in chemically terms, radioactive and aggressive.

Modern hermetic electric pumps represent a mono block, which includes the electric motor, usually asynchronous, and the centrifugal pump. Aggressive fluid pumped serves also as cooling element for motor, penetrating its air gap. Figure 1 presents the longitudinal section of a hermetic centrifugal electric pump with the rotor and stator protected by stainless steel cylinders.

The usage of asynchronous motor as electric drive is efficient from constructive reasons. The asynchronous engine with shortcut rotor excludes the electric contact, permits to realize the protection of rotor and stator and of the respective windings from the aggressive liquid because of the protection cylinders pressed from the inner part of the stator pack and outer part of the rotor pack.

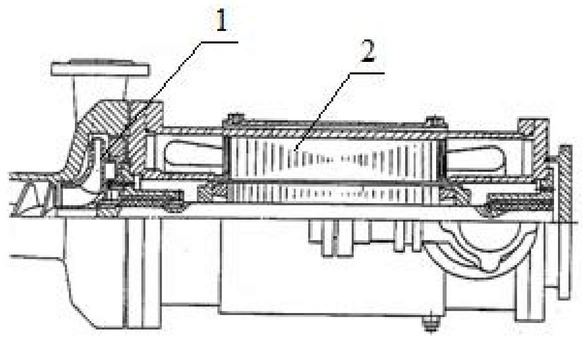


Figure 1. Mono block hermetic pump CE 100/125H
1) the pump; 2) hermetic electric motor

Besides the performances mentioned above, the asynchronous driving engine mounted inside of the mono block of the centrifugal pump has, also, same basic disadvantages as:

– losses presence inside of rotor winding;

– a reduced efficiency and power factor as a result of magnetization current increase;

– decreased angular speed of the rotor, because of increased value of sliding.

It was found [1], [2] that the replacement of shortcut rotor in hermetic asynchronous engines with a rotor with permanent magnets contributes to:

- majority of electromagnetic requests, i.e. the magnetic influence and linear current load;
- exclusion of electric losses inside of the rotor;
- increase the angular speed of the rotor;
- decrease the noise and vibration in engine, by replacing the rotor with a massive ferromagnetic rotor;
- the simplification of the production technology of massive ferromagnetic rotor;
- reducing network losses due to high power factor.

2. Start particularities of the permanent magnets motor.

Along with compelling performances indicated above, a key deficiency is the realization of synchronous motors start by connecting directly to the network. Using the start method in asynchronous by connecting to the network is more difficult as asynchronous and synchronous motors with electromagnetic excitation, because in case of starting the permanent magnet synchronous machine, the excitation flux is maximal.

The problem is further complicated when it comes to permanent magnet synchronous motors, used to drive centrifugal pumps with high speed and network voltage drops.

To ensure the startup of the permanent magnet synchronous motors developed basing on an asynchronous engine, it was necessary to modernize the rotor. Permanent magnets were installed on the asynchronous motor's rotor, the shortcut winding being used as the starting winding.

In order to achieve the synchronization process of synchronous motor [3, 4], two conditions need to be assured: provide starting torque in charge and clamp torque in synchronism. These two contradictory conditions can be achieved by changing the rotor construction. In this case there are executed and tried more constructive schemes of rotors. Is was done as follows in one of the simplest transformations of asynchronous engine into synchronous with permanent magnets: in the body of shortcut rotor there were milled two notches (for the engine with two poles) with the polar arc $\sim_{¢} \cdot^{2}$ (figure 2), in which were mounted the permanent magnets.

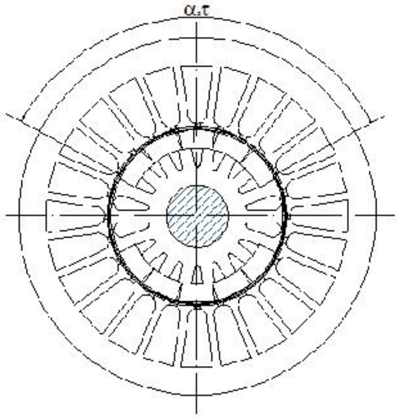


Figure 2. Cross section of the serial asynchronous motor

The achievement simplicity of this construction is obvious, but the parameters of stator and rotor winding are essentially changing, which leads to increased current density inside stator winding and worsening of the engine's start feature changed into a synchronous one.

It was further proposed more reliable construction easier to be technologically implemented [5], [6]. The rotor in this construction is made of solid ferromagnetic material, the permanent magnets being mounted in milled notches between the rotor poles.

It was found that fitting of permanent magnets in the notches has consolidated the permanent magnets with the massive rotor material (figure 3). Simultaneously, the synchronous motor starting torque has increased in asynchronous starting regime, because the teeth between the permanent magnets serve as bars of a shortcut winding of rings formed on the rotor front parts. The main drawback of this sample is the increase of dispersion flows closed by the ferromagnetic teeth between magnets.

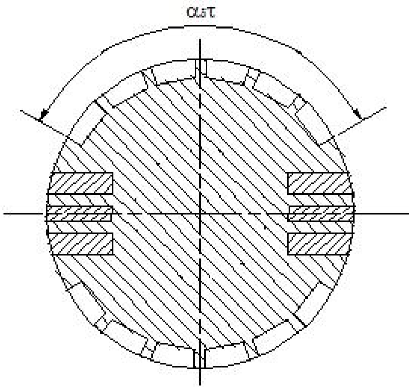


Figure 3. Cross section of the synchronous motor with stainless steel cylinders

In the third experimental sample copper bars were mounted on the massive ferromagnetic rotor inside the notches shortcut with rings on the front part of the rotor (figure 4). High bars were made to increase the starting torque. But this construction does not provide asynchronous start at voltage decrease by 10% from the nominal one, condition imposed by the beneficiary. The stainless steel cylinders had been replaced in the sample mentioned above with ferromagnetic material cylinders with the magnetic permeability value close to that of electro-technical stainless steels in order to overcome this condition. The air gap decreased by 1 mm, this increased the starting torque for the studied engine. The cylinders pressed on the stator and rotor perform the function of protecting the motor winding of synchronous engine, concomitantly providing reliable fixation of the magnets mounted inside the rotor body.

The developed construction, tested in factory laboratory, showed that asynchronous start takes place even at stator voltage reduced down to 10% of nominal voltage. Operating characteristics compared with those of the asynchronous engine are presented below, which correspond to the realized and tested samples.

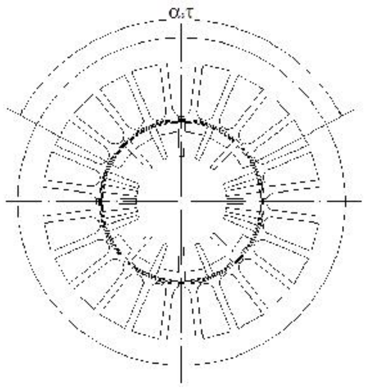


Figure 4. Cross section synchronous motor with cylinders made of ferromagnetic material

3. Magnetic field in hermetic electric motors.

Research and study of the magnetic field inside the electric machine was and is a current issue since the distribution of magnetic flux lines and the form of the magnetic induction curve in the air gap determine the quality of energy conversion in this electromechanical converter. Development of new methods for describing magnetic field using computer software gave the possibility to study deeply this phenomenon at electromagnetic energy conversion from one form to another.

The finite element method in the study of electric machines is extremely advantageous and universal in its calculation of the magnetic field view. As a result of this calculation, the magnetic field is shown in graphical and numerical form. Magnetic flow lines indicate their closing paths, the distribution of magnetic induction being determined for each sector of the magnetic circuit [7].

Based on the geometry and parameters of the stator winding of the serial asynchronous motor proposed for being transformed into a synchronous motor, it was determined its magnetic field view.

Figure 5 shows the view of the magnetic field of asynchronous motor, calculated with FEMM application for comparison. Flux axis coincides with the magnetic axis of AX phase, because in this phase the current is allowed to have maximum value.

To obtain the magnetic field view under no-load regime of the asynchronous serial motor, arbitrary values of the no-load currents are taken for those three stator phases, appropriate to the given time, the current in the rotor being neglected.

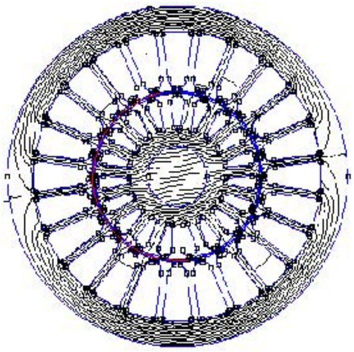


Figure 5. View of magnetic field of the asynchronous motor in no-load regime

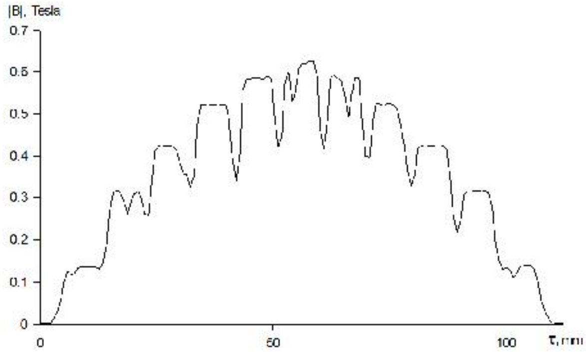


Figure 6. Variation curve of magnetic induction inside air gap of asynchronous motor in no-load regime

The variation curve of magnetic induction (figure 6) of the asynchronous motor air gap corresponds to the arc of the polar step ² in no-load regime.

The magnetic field view of synchronous motor with permanent magnets was calculated for no-load operating modes using FEMM application (figure 7). Due to the rectangular shape of polar magnets the curve of the magnetic induction in the air gap is more distorted than (figure 8) that of the asynchronous motor. This deficiency can be removed by selecting the form of the poles.

The start of synchronous motor with permanent magnets occurs if connecting the stator winding to the network [8]. The rotating magnetic field induces an electromotive force inside the start winding, under this action the rotor currents are closing.

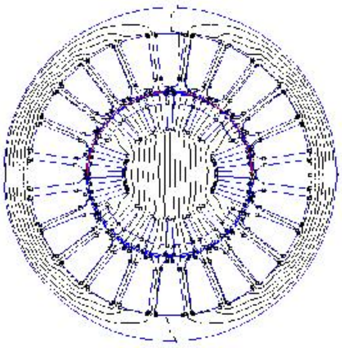


Figure 7. View of the magnetic field of synchronous motor produced by permanent magnets in no-load regime

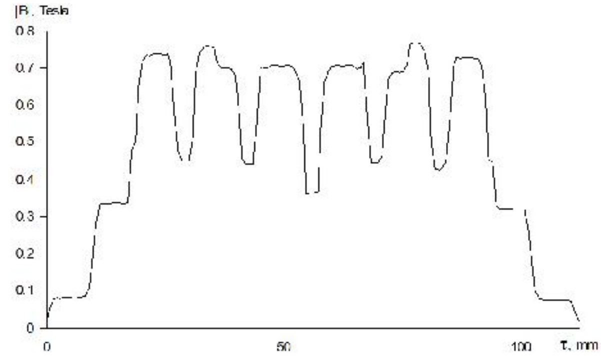


Figure 8. Variation curve of magnetic induction inside the air gap of synchronous motor

The interaction of the rotating magnetic field with the rotor currents produces the electromagnetic torque and the rotor starts. It is important to note that the magnetic field produced by permanent magnets, induces inside the rotor winding an electromotive force of variable frequency

$$e_1 = \mu \cdot \Psi_p = 2® \cdot f \cdot \Psi_p ,$$

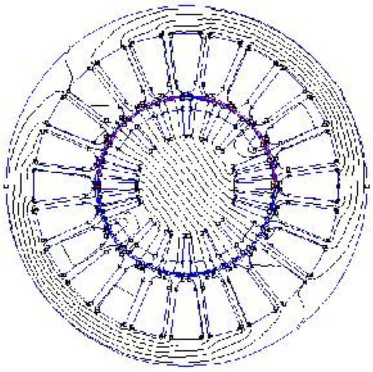
where v_p is the total flux produced by permanent magnets.

Thus, the synchronous motor, which is operating in asynchronous mode startup, is working together as a synchronous generator connected to the network, producing a variable frequency current closed inside the network. Due to this, there is a corresponding braking torque corresponding to variable frequency currents. The value of this current is large enough, because the network resistance is very small. In order to reduce the braking torque for the proposed construction, the start winding is made from high bars to increase the asynchronous starting torque.

In addition to the braking torque produced by permanent magnets of the synchronous motor under asynchronous regime, synchronous couples appear caused by stator and rotor notches. The rotor bars and permanent magnets have inclination in relation to the generator rotor cylinder for reducing the braking torques.

Figure 9 shows the view of the magnetic field corresponding to the constructive scheme of synchronous engine with permanent magnets and ferromagnetic cylinders under load regime.

Values of the magnetic induction and flux from the stator yoke are shown in figure 10.



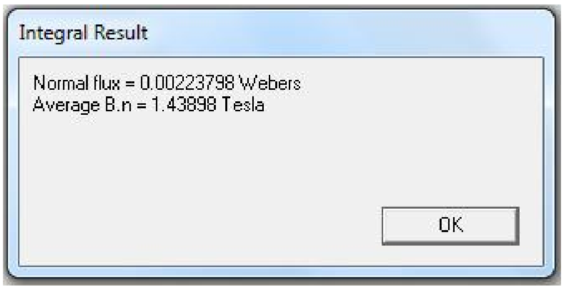
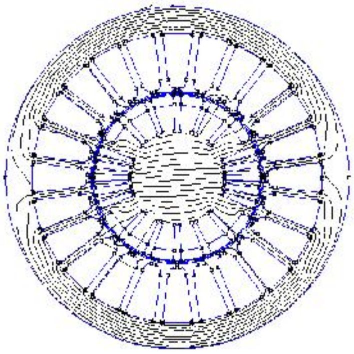


Figure 9. View of the magnetic field of synchronous motor in load regime

Figure 10. Value of magnetic induction form the yoke of synchronous motor in nominal load regime

Reaction magnetic field lines of the synchronous motor, transformed from asynchronous engine, are mainly confined by the zone corresponding to the small size of the air gap (figure 11). It is evident that the induction increases for the cylinders made of ferromagnetic material (figure 12).



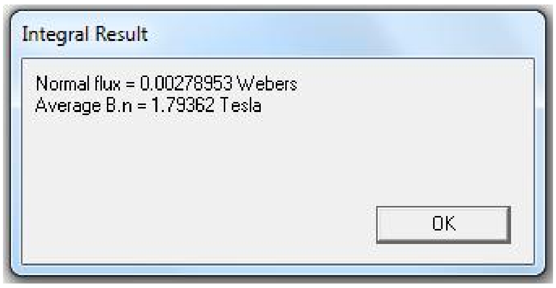


Figure 11. View of reaction magnetic field in synchronous motor with cylinders made of ferromagnetic material

Figure 12. Value of magnetic induction in the yoke of synchronous motor with ferromagnetic cylinders

4. Experimental test results.

According to theoretical research carried out using the FEMM application, experimental samples had been made at "Moldovahidromaş" plant, CTŞ branch. Samples were tested in factory conditions.

The developed samples must satisfy two basic requirements for motor’s load operation regime:

- ensure the motor’s start under asynchronous regime at the low network supply voltage, according to STAS;
- provide power factor and the efficiency higher than that for asynchronous motor in nominal operating regime.

The operating features of experimental samples of synchronous motors with permanent magnets and rotors of various constructions are presented as follows. Operating characteristics of asynchronous motor (figure 13), under which were developed experimental samples of synchronous motors with permanent magnets are presented for comparison.

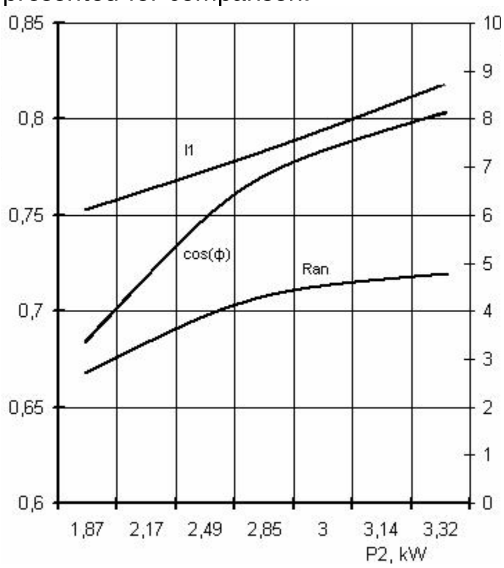


Figure 13. Operating features of synchronous motor

Figure 14. Rotor of hermetic asynchronous motor with stainless steel cylinders serially produced

Engine parameters executed in series:

A) W1 = 184; dgol = 0,95 mm;
Q = 7,5 m^3/h
H = 54,41 m
I_1 = 8,08 A
P_2 = 3009,4 W

Initially, it was developed the constructive scheme made of solid ferromagnetic material, which is shown in figure 15. The permanent magnets were installed in notches for this variant, but the shortcut start winding was fitted in rotor notches made so that the magnetic induction in the teeth area would be uniform.

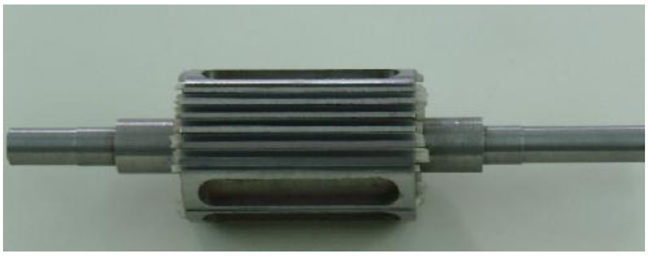


Figure 15. Rotor of synchronous motor made of ferromagnetic material

Parameters of the sample of synchronous motor:

$W1 = 184$; $dgol = 0{,}95$ mm;
$Q = 12\ m^3/h$
$H = 53{,}75$ m
$I_1 = 7{,}85$ A
$P_2 = 3460{,}5$ W

The graphics engine's operating features of synchronous motor were built basing on the performed tests results (figure 16).

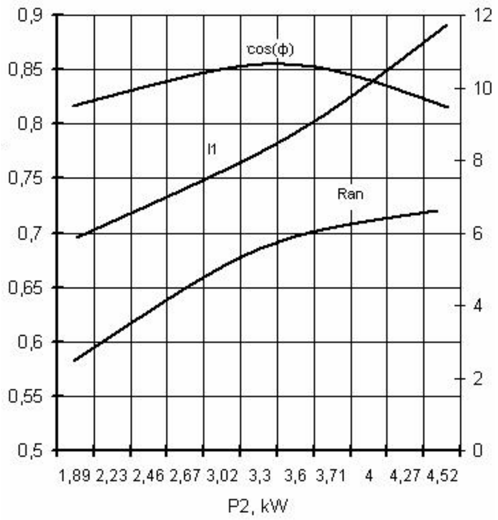


Figure 16. Operating characteristics of the synchronous motor with stainless steel cylinders

The synchronous motor power increased compared to the asynchronous motor power compared to about 15%, the power factor increased, but the motor's efficiency decreased insignificantly. The load starting is difficult for the proposed design scheme of the synchronous motor with permanent magnets.

The rotor construction presented in figure 17, with the starting winding interspersed with permanent magnets and cylinders of ferromagnetic material, solved the problem of starting the synchronous motor under load and made it possible to increase the efficiency and power factor, while being, also, increased the power to the motor shaft.

Sample's parameters of synchronous motor with ferromagnetic cylinders:

$W1 = 184$; $d_{gol} = 0{,}95$ mm;
$Q = 15\ m^3/h$
$H = 51{,}7$ m
$I_1 = 8{,}25$ A
$P_2 = 3978$ W

In this case, the motor power has increased relatively to the power of the used asynchronous motor. Operating characteristics (figure 18) show that the power factor and efficiency had increased [9].

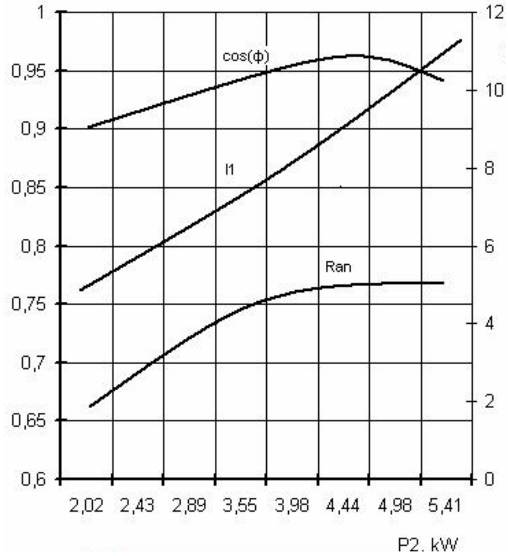


Figure 17. Constructive scheme of the synchronous motor with cylinders made of ferromagnetic material

Figure 18. Operating characteristics of the synchronous motor with ferromagnetic cylinders

Test results of industrial samples of asynchronous and synchronous motors with permanent magnets, performed basing on hermetic asynchronous motor with 3kW power are shown in table 1.

Table 1. Test results

Nr	Sample's parameters	Asynchronous motor	Synchronous motor 1	Synchronous motor 2
1	Power, kW	3	3,46	3,98
2	Efficiency	0,72	0,7	0,758
3	Power factor	0,79	0,86	0,967
4	Productivity m^3 /h	7,5	12	15
5	Hydraulic height H, m	54,41	53,75	50,67

4. Conclusion

Rotor modernization of the asynchronous motor gave the possibility to obtain a synchronous motor with high economic and technical indexes.

Study of magnetic field with the application of finite element method contributed to accurate calculations of synchronous motor with permanent magnets.

Optimum option of synchronous motor assures the start in asynchronous mode and the auto-synchronization with the network, at voltage lower by 10% than asynchronous motor.

References

[1] Ambros T., Convertizoare electrice si electromecanice speciale. Ed. Tehnica-Info, Chisinau, 2008, p.148-154.

[2] Lubin T., Mezani S., Rezzoug A., 2D-Exact Analytical Model for Surface-Mounted Permanent-Magnet Motors with Semi-Closed Slots. IEEE Transactions on Magnetics, Vol. 47, No. 2, feb. 2011.

[3] Ambros T., Burduniuc M., Iazlovetchi L., Autosincronizarea motorului sincron cu magneti permanenti. Revista U.T.M., Meridian ingineresc, – Nr.4, Chisinau, 2006.

[4] Salminen P., Pyrhonen J., Libert F., Soulard J., Torque Ripple of Permanent Magnet Machines with Concentrated Windings. ISEF 2005.

[5] Jacek F., Permanent Magnet Motor Technology, New York, Basel, 2002.

[6] Zarko D., Ban D., Lipo T., Analytical Solution for Cogging Torque in Surface-Permanent-Magnet Motors Using Conformal Maping, IEEE Transactions on Magnetics, Vol. 44, No. 1, ian. 2008.

[7] Chen J., Nayar C., Xu L., Design and Finite-Element Analysis of an Outer-Rotor Permanent-Magnet Generator for Directly Couple Wind Turbines. IEEE Transaction on Magnetics, 2000, 36(5).

[8] Ambros T., Piroi I., Iazlovetchi L., Burduniuc M., Modelling the start process of the syncronous motors hermetically closed, with permanent magnets. Buletinul Institutului din Iasi, Tomul (LII) LVI 12–14, 2006.
[9] Ambros T., Burduniuc M., Pierderile in ecranele motorului sincron ermetizat excitat de magneti permanenti. Editura AGIR, nr.4/2012, Suceava, Romania, p. 91-94.

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