International Journal on
"Technical and Physical Problems of Engineering"
(IJTPE)
Published by International Organization of IOTPE

ISSN 2077-3528
IJTPE Journal
www.iotpe.com
ijtpe@iotpe.com

June 2020 Issue 43 Volume 12 Number 2 Pages 35-39

ASYNCHRONOUS MOTOR CONTROL OF SHIP ANCHOR-MOORING GEAR IN STATIC MODE WITH FREQUENCY CHANGE

E.A. Hasanov

Azerbaijan State Marine Academy, Baku, Azerbaijan, hasanov.079@mail.ru

Abstract- Asynchronous motor control of ship anchor-mooring gear in static mode with the change of rotation frequency is considered in the paper. Having performed calculations for various frequency values in the Simulink section of Matlab program according to the conditions of static moment and power constancy, mechanical and electromechanical characteristics of main working winding of the asynchronous motor were constructed. It was established that the control of electric drive of the anchor-mooring gear by means of frequency converters has a number of technical and economic advantages.

Keywords: Ship, Anchor-Mooring, Asynchronous Motor, Rotation Frequency, Frequency Control, Power, Static Moment.

1. INTRODUCTION

Ship anchor-mooring gears ensure that the ship is moored to the bridge, is anchored within the port and is safely anchored on the bridge, as well as near other ship during loading and unloading operations [1].

The degree of automation of anchor-mooring gears used on transport ships engaged in the transport of freight, in comparison with other ships is at more limited level. In this type drives mainly local manual and remote control methods are used. But at the same time, recently also devices that automatically regulate the tensile force of mooring ropes and remotely control the anchor lowering into the water are found on ships.

According to the requirements of the International Maritime Organization, anchor-mooring gears must be reliable, easily controlled, speed must be regulated within a wide range, the volume and weight must be small, and the electric drive must provide a 30-minute continuous operation. In addition, the electric motor must withstand the energized riding mode in the anchor mechanism for 30 seconds and in the mooring mechanisms for 15 seconds [1].

2. DATA AND METHODS

The anchor-mooring gears are considered the most important facilities of ship. However, the electric drives of asynchronous motors of anchor-mooring gears installed on ships do not meet modern requirements for the engine design and control principle.

It should be noted that the volume and mass of these motors (MAP 622-4/8/16) compared to conventional asynchronous motors with a single-winding squirrel-cage rotor are large and they do not perform the required speed control in anchor- mooring gears [2].

Almost 90% of the work on the anchor chain folding and anchor lifting is performed by the working winding ($2P=8$) and in this case the motor load changes on a large scale. It stays even under load for a short period (in short-circuit mode). While the motor is under load, the current it takes from the network increases by 4-6 times compared to the nominal value, and this mode is considered very heavy and destructive for the motor.

The main reason for the appear of short-circuit mode in electric motor of anchor gear is that when the anchor is torn off from the seabed, as a result of its claws catching on the seabed, the resistance moment formed on the motor shaft increases several times. In this case, the value of the resistance moment formed on the motor shaft is greater than the maximum (critical) moment created by the motor, and the motor stays under load.

If the anchor uses frequency converters with longitudinal momentum modulation for the control of electric drives, then it is possible to prevent the motor from being under load [6]. Of course, it is impossible to reduce the resistance moment formed as a result of the anchor claws catching on the seabed, but at that it is possible to increase the maximum moment created by the motor by changing the frequency converter control law [4]. Therefore, special motors are manufactured for anchor gears that can withstand their operating mode. Lets' consider the parameters of one of these motors (MAP 622-4/8/16) used on ships in Azerbaijan.

Here ($2P=16$) is a low speed winding, and after pulling the anchor out of the water, it starts and passes the anchor into hawse at low speed. A high speed winding ($2P=4$) is used to reduce the looseness of the mooring rope during mooring. From the above it becomes obvious that the high speed ($2P=4$) and low speed ($2P=16$) windings are auxiliary windings and they operate for a short period of time. Therefore, when controlling the motor of the anchor-mooring gear by means of frequency converter, only the average speed winding ($2P=8$) is used and its required operating modes will be checked.

It is known that there are 2 types of control methods by means of frequency [3]:

1. The stator frequency and voltage are used as a control action.
2. The stator frequency and current are used as a control action. This method is called a frequency-current control method.

During the control of both methods the formation of mechanical characteristics should solve two problems:

1. Obtaining the required loading capacity over the entire speed control range;
2. Creating the required strictness in the mechanical characteristic over the entire speed control range.

The strictness of the mechanical characteristic can be implemented by speed feedback. The required load capacity is determined by performing a certain "voltage – frequency" ratio. When we say load capacity, we mean the constant "critical moment - static moment" ratio in any mechanical characteristic during speed control.

$$\lambda = \frac{M_k}{M_s} = \text{const}$$

If stator winding is not taken into account

$$M_{kn} = \frac{3U_{1nk}^2}{2\omega_0 X_k} M_{kn}$$

Taking into account that

$$\omega_0 = 2\pi f_{1n}$$

$$X_k \equiv f_{1n}$$

$$M_{kn} = A\frac{U_{1n}^2}{f_{1n}^2}$$

where, A is constant quantity depending on motor parameters.

For any static moment, in order to obtain the constant load capacity of the motor, we find the necessary condition from the following expression:

$$\frac{M_k}{M_s} = \frac{M_{kn}}{M_{sn}} \text{ or}$$

$$\frac{M_k}{M_s} = \frac{M_{kn}}{M_{sn}} = \frac{U_1^2}{f_1^2} \div \frac{U_{1n}^2}{f_{1n}^2} = \left(\frac{U_1}{U_{1n}}\right)^2 \div \left(\frac{f_{1n}^2}{f_1}\right)^2 \tag{1}$$

where,

$$\frac{U_1}{U_{1n}} = \frac{f_1}{f_{1n}}\sqrt{\frac{M_s}{M_{sn}}} \tag{2}$$

where, U_{1n}, M_{sn}, f_{1n} are motor's rated voltage, rated moment and rated frequency respectively; U_1, M_s, f_1 are motor's voltage, moment and frequency corresponding to control process.

As can be seen from the obtained expression, when the speed is controlled by the frequency, the voltage change law depends on both the frequency value and the static moment change law. Let's consider the following special cases:

1. Static moment M_s remains constant regardless of speed, i.e. according to $M_s=M_{sn}$ (2)

$$\frac{U_1}{U_{1n}} = \frac{f_1}{f_{1n}} \text{ or } \gamma = f^* \tag{3}$$

Therefore, under conditions of constant static moment, during speed control, the voltage applied to the stator must change in proportion to the frequency.

2. During speed control, the power on the motor shaft remains constant: $P_s=P_{sn}$=const.

Moment of motor shaft

$$M_s = \frac{P_{sn}}{\omega} = \frac{M_{sn}\omega_n}{\omega} = \frac{M_{sn} f_{1n}}{f_1}$$

According to expression (2)

$$\frac{U_1}{U_{1n}} = \frac{f_1}{f_{1n}}\sqrt{\frac{M_s}{M_{sn}}} = \frac{f_1}{f_{1n}}\sqrt{\frac{M_s f_{1n}}{f_1 M_{sn}}} = \sqrt{\frac{f_1}{f_{1n}}} \tag{4}$$

or $\gamma = \sqrt{f^*}$

Therefore, under conditions of constant static moment, during speed control, the voltage applied to the stator must change in proportion to the square root of the frequency value.

Let's perform the calculation according to below parameters of average speed winding ($2P$=8) of MAP 622-4/8/16 type asynchronous motor:

P_n=30 kVt; n_n=750 rev/min; U_{1n}=220 V; η=90.5%; cosφ=0.81; X_m=9 ohm; r_1=0.177 ohm; x_1=0.47 ohm; r'_2=0.087 ohm; x'_2=0.67 ohm.

Let's perform the calculation by means of Matlab/Simulink program [5]. At first, we calculate the below auxiliary parameters:

$$\omega_{1n} = \frac{\pi . n_{0n}}{30} = \frac{3.14 \times 750}{30} = 78.5 \text{ rad/sec}$$

$$\tau_1 = \frac{X_1}{X_m} = \frac{0.47}{9} = 0.052$$

$$\tau_2 = \frac{X_2'}{X_m} = \frac{0.67}{9} = 0.074$$

$$\tau = \tau_1 + \tau_2 + \tau_1\tau_2 = 0.052 + 0.074 + 0.052 \cdot 0.074 = 0.13$$

$$b = \tau_1(1+\tau_2) = 0.177(1+0.074) = 0.13$$

$$c = X_m\tau = 9 \times 0.13 = 1.17$$

$$e = 1 + \tau_1 = 1 + 0.052 = 1.052$$

Let's calculate values of the motor and auxiliary parameters:

$$I_1 = U_{1n}\gamma\sqrt{\frac{\left(r_2^{'}/X_m\right)+(1+\tau_2)S_m^2}{\left(b^2+c^2 f^{*2}\right)S_m^2 + 2r_1 r_2^{'} f^{*2} S_m + (d^2+e^2 f^{*2}) r_2^{'2}}} = \\ = 220\gamma\sqrt{\frac{0.000093+1.15S_m^2}{\left(0.036+1.37 f^{*2}\right)S_m^2 + 0.0308 f^{*2} S_m^2 + \left(0.00039+1.107 f^{*2}\right)0.0076}} \tag{5}$$

$$M = \frac{3U_{1n}^2}{\omega_{1n}}\gamma^2 \frac{\left(r_2^{'}/X_m\right)^2 S_m}{\left(b^2+c^2 f^{*2}\right)S_m^2 + 2\cdot r_1 r_2^{'} f^{*2} S_m + \left(d^2+e^2 f^{*2}\right) r_2^{'2}} = \\ = 1849.7\gamma^2 \frac{0.087 S_m}{\left(0.036+1.37 f^{*2}\right)S_m^2 + 0.0308 f^{*2} S_m^2 + \left(0.00039+1.107 f^{*2}\right)0.0076} \tag{6}$$

$$\omega = 78.5\left(f^* - S_m\right) \tag{7}$$

1) Let's perform the calculation according to M_s=const condition. According to this condition, the $\gamma=f^*$ expression should be used. We construct the mechanical characteristics of asynchronous motor for $\gamma=f^*$=1; 0.8; 0.5; 0.3; 0.1 values using Table 1 , as well as expressions (6) and (7).

Table 1. Given values for the construction of mechanical characteristics of asynchronous motor according to M_s=const condition

f^*	1.0	0.8	0.5	0.3	0.1	Note
γ	1.0	0.8	0.5	0.3	0.1	M_s=const
f (Hs)	50	40	25	15	5	
U, (V)	220	176	110	66	22	

Calculation of mechanical characteristic of average speed winding (2P=8) of asynchronous motor for values γ=f*=1;0 performed in Matlab/Simulink program is shown on Figure 1 [5].

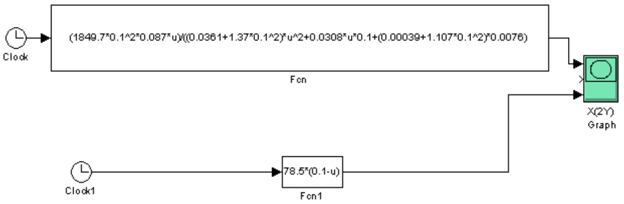

Figure 1. Calculation program for mechanical characteristic of asynchronous motor

Mechanical characteristics of average speed winding (2P=8) of asynchronous motor for different frequency values (f=50; 40; 25; 15 and 5 Hz), calculated by means of this program and according to the M_s=const condition are shown in Figure 2.

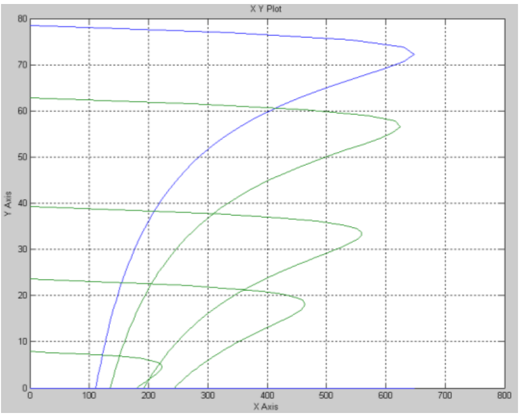

Figure 2. Mechanical characteristics of average speed winding (2P=8) of asynchronous motor for different frequency values according to M_s=const condition

We construct the electromechanical characteristics of average speed winding (2P=8) of asynchronous motor for γ=f^*=1; 0.8; 0.5; 0.3; 0.1 values using Table 1, as well as expressions (5) and (7**)**.

Calculation of electromechanical characteristic of asynchronous motor for values γ=f^*=0;1 performed in Matlab/Simulink program is shown on Figure 3 [5].

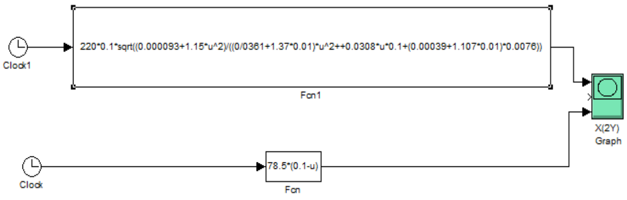

Figure 3. Calculation program for electromechanical characteristic of asynchronous motor

Electromechanical characteristics of average speed winding (2P=8) of asynchronous motor for different frequency values (f=50; 40; 25; 15 and 5 Hz), calculated by means of this program and according to the M_s=const condition are shown in Figure 4.

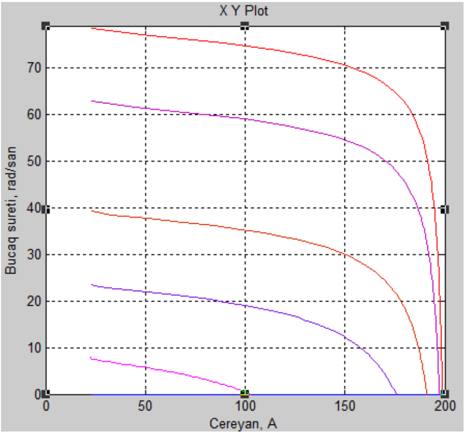

Figure 4. Electromechanical characteristics of average speed winding (2P=8) of asynchronous motor for different frequency values according to M_s=const condition

The stator current curves for asynchronous motor for different frequency values (f=50; 40; 25; 15 and 5 Hz) according to the condition M_s=const are presented in Figure 4. As is obvious from these curves, with the frequency reduction the stator actuation current values decrease very slightly at frequency values close to the nominal value. And at small frequency values this decrease is even more noticeable.

The reason for this is the high value of the inductive resistance relative to active resistance at high frequency values and the voltage change proportional to the frequency. The voltage change proportional to frequency causes the voltage change proportional to inductive resistance, and this ensures the constantly of current. Some reduction of current occurs due to active resistance. Since at low frequencies the active resistance value is within the range comparable to that of inductive resistance, then the current value is determined by the voltage varying by frequency in proportional law, as well as the values of active and inductive resistances.

Therefore, at small frequency values, the current value decreases even more.

2) Let's perform the calculation according to P_s=P_{sn}=const condition. According to this condition, the $\gamma=\sqrt{f^*}$ expression should be used. We construct the mechanical characteristics of asynchronous motor for γ=f*=1; 0.8; 0.5; 0.3; 0.1 values using Table 2, as well as expressions (6) and (7).

Table 2. Given values for construction of mechanical characteristics of asynchronous motor according to P_s=P_{sn}=const condition

f^*	1.0	0.8	0.5	0.3	0.1	Note
$\gamma=\sqrt{f^*}$	1.0	0.894	0.707	0.548	0.316	P_s=P_{sn} =const
f (Hz)	50	40	25	15	5	
U (V)	220	196.7	155.5	120.6	69.5	

Mechanical characteristics of asynchronous motor for different frequency values (f=50; 40; 25; 15 and 5 Hz), calculated according to the P_s=P_{sn}=const condition are presented in Figure 5.

The analysis of mechanical characteristics shows that with the frequency decrease, as the synchronous speed of the motor decreases, according to the condition P_s=P_{sn}=const, the critical moment of the motor must increase (Figure 5).

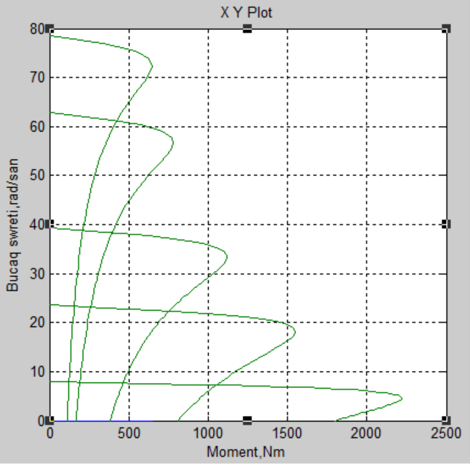

Figure 5. Mechanical characteristics of average speed winding (2P=8) of asynchronous motor for different frequency values according to P_s=P_{sn}=const condition

We construct the electromechanical characteristics of average speed winding (2P=8) of asynchronous motor for γ=f^*=1; 0.8; 0.5; 0.3; 0.1 values using Table 2, as well as expressions (5) and (7**)**.
Electromechanical characteristics of asynchronous motor for different frequency values (f=50; 40; 25; 15 and 5 Hz), calculated according to the P_s=P_{sn}=const condition are presented in Figure 6.

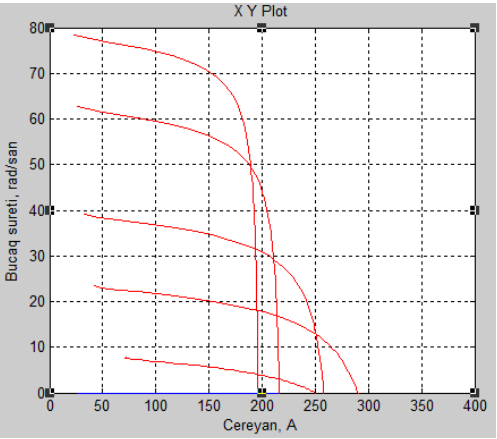

Figure 6. Electromechanical characteristics of average speed winding (2P=8) of asynchronous motor for different frequency values according to P_s=P_{sn}=const condition

The analysis of electromechanical characteristics shows that with the frequency reduction, when the synchronous motor speed decreases, the motor actuation current increases to a certain frequency value. The reason is the inductive resistance change proportional to the frequency, and the voltage change according to the law $\sqrt{f^*}$. That is, with the frequency rise, the decrease of inductive resistance due to voltage increases. At even lower frequency values, when the active resistance can be compared with the inductive resistance, the certain decrease of current takes place.

3. CONCLUSIONS

During the speed control of electric motor of anchor-mooring gear by means of a frequency converter, the speed control limits are wide, the operation of drive is simplified and reliability, being considered very important for ship conditions, is increased. At the same time, it provides the gear with a very necessary feature of fast operation to prevent accidents during mooring operations (the ship struck against a bridge, the mooring rope got tangled the screw, etc.)

In addition to these advantages, it is possible to eliminate the motor staying under load (short-circuit mode) at increase of maximum moment formed by the motor by means of frequency converter to pull the anchor from the seabed.

The conclusion we reach is that at constant static moment during speed control, the change of voltage applied to the stator should change in proportion to the frequency, and at constant power on the motor shaft during speed control, the change of voltage applied to the stator should change proportionally to the square root of frequency.

The investigations carried out and performance characteristics of mooring mechanisms show that there is a number of technical and economic advantages of the control of electric drive of anchor-mooring gear by means of frequency converters, and they meet the requirements of the International Maritime Organization.

REFERENCES

[1] G.A. Mehtiyev, Z.A. Hasanov, T.G. Shabanov, "Ship Automated Electric Drives", Ed. Nurlan, p. 358, Baku, Azerbaijan, 2005.
[2] G.A. Mehtiyev, E.A. Hasanov, "Investigation of Operating Modes of a Frequency-Controlled Electric Drive of a Ship's Anchor Gear", Bulletin of Odessa National Maritime University, Ukraine, No. 3, Vol. 52, pp. 142-153, 2017.
[3] G.G. Sokolovsky, "AC Electric Drives with Frequency Regulation: Textbook for Universities", Publishing Center Academy, p. 277, Moscow, Russia, 2007.
[4] E.F. Sultanov, E.A. Hasanov, "The Main Advantages of the Electric Drive Control of Anchor Gear Using Frequency Converters", Scientific Works of the Azerbaijan State Maritime Academy, No. 2, pp. 201-208, Baku, Azerbaijan, 2015.
[5] I.V. Chernykh, "Modeling of Electrical Devices in Matlab SimPowerSystems and Simulink", p. 288, Saint-Petersburg: Piter, Russia, 2008.
[6] D.G. Holmes, "Pulse Width Modulation for Power Converters: Principles and Practice", Wiley-IEEE Press, p. 734, New York, 2003.

BIOGRAPHY

Elsevar Akif Hasanov was born in Lachin, Azerbaijan ion March 24, 1979. He graduated from Azerbaijan State Marine Academy, Baku, Azerbaijan on the specialty of Electrical Engineering and Automatics of Ships, and was given Bachelor degree in 2000 and Master degree in 2004. At the present time, he is a doctorate student of Department of Marine Electrical Automation of Azerbaijan State Marine Academy. He is senior lecturer in the same department and co-author of 18 papers and publications.