ORIGINAL PAPER

ELECTRICAL PLATFORM FOR DRIVE OF AC ASYNCHRONOUS MOTORS AND SERVOMOTORS USING FREQUENCY CONVERTERS

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Abstract. *The development of industrial automation has implicitly led to the improvement of electric drive systems, especially since such installations are the most common form of conversion of electricity into mechanical energy. The electric drive can be defined and studied only if we consider the whole assembly of which it is part, such as the automation of a technological production process. This paper describes the design and practical implementation of a laboratory stand with a teaching feature. The designed stand is a study support for various applications used in the industrial area, offering the possibility of experimentation on programming and parameterization of frequency converters in the laboratory of "Electrical machines and drives" of the Faculty of Electrical Engineering, Electronics and Information Technology at the University of Valahia from Targoviste.*
Keywords: *modern electric drive systems; torque and engine speed control; mechanical characteristics of electric drive machines; electric drive stand for asynchronous motors.*

1. GENERAL INFORMATION ON CURRENT ELECTRICAL DRIVE SYSTEMS USED IN MODERN PRODUCTION SYSTEMS

Development of industrial automation has implicitly led to the improvement of electric drive systems, especially since such installations are the most common form of conversion of electricity into mechanical energy.

Electric drive can be defined and studied only if we consider the whole assembly of which it is part, such as the automation of a technological production process. The production process for which the electric drive is performed has in its structure the following main component elements: the electrical motor; motion transmission elements; working machine.

The technological manufacturing process is performed by the working machine, which is driven by the electrical motor through the transmission elements. Often, in modernized production systems, multiple electrical motors are used, each driving the working machine through a transmission system [1-2].

One of the most important applications in the industry is fault detection. Failure to detect faults can cause drastic damage to some companies, and if not detected and remedied in time, a fault can lead to prolonged shutdown of production lines. This is especially important for automatic and autonomous production, where there is minimal or no staff. This is because, in the case of electrical motors, some of them can produce noise, excessive heat, abnormal vibration or even smoke as warning signs of a possible failure [3].

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Losses on smaller motors also have a relatively lower value, but the motors are still subject to thermal problems. Therefore, special attention should be paid to the thermal analysis of engine performance, which can lead to significant improvements in engine performance [4].

Real-time response systems are used with confidence by electric drive developers to test their control systems and converters. Such systems are called Hardware-in-the-Loop (HiL) and Power Hardware-in-the-Loop (PHiL) systems [5].

The use of electrical motors allowed the transition to individual drive, in which each working machine has its own drive motor, obtaining the advantage of disposing machines in technological flow and replacing old drive methods using transmissions through bulky belts, compact transmissions with individual gears. The requirements for obtaining superior performance on working machines, given the increase in production capacity, have led to the improvement of electric drive systems [6].

The electric drive system for speed and torque control consists of the following elements: power electronics, electric motor, control system and drive mechanism. The drive mechanism will be used to transmit the mechanical forces and torques required to perform a number of desired functions [7].

In the category of electric motors considered are included today not only the classic electric motors, such as direct current, asynchronous and synchronous, but also new architectures of them. That led to the development of power electronics, but also to the existence of new materials, such as for example with permanent magnets. Today, as a result of industrial progress, energy consumption is optimized. Electric motors are the most common electricity consuming assets in the industry, with about 66% of the electricity consumed. As a result, adapting more efficient motors is one of the most important issues in the industry today. The comparison of different types of motors according to the degree of efficiency was described by the authors of References [8-11].

2. MECHANICAL CHARACTERISTICS AND WORKING MACHINE REGIMES

The behavior of an electric drive system depends on the mechanical characteristics of the electric drive machines and the working mechanisms.

For the design and operation from a technical-economic point of view of an electric drive system, the characteristics of the working machines must be identified, which conditions the functional interdependence between the electric driving machine and the working mechanism of the technological process.

Therefore, these mechanical characteristics clearly express the dependence between the torque produced according to different parameters that characterize the operation of the machine according to the developed torque.

The total torque M_R has two components: M_{Rf} - the component due to friction and M_{Ru} - the component due to the working mechanism.

$$M_R = M_{Rf} + M_{Ru} \tag{1}$$

A more common case is the working mechanisms on which the developed M_R couple depends on speed, so that the general experience of this dependence will be as follows:

$$M_R = M_{R0} + (M_{RN} - M_{R0}) \left(\frac{\Omega}{\Omega_N}\right)^a \tag{2}$$

where, M_{R0} - the torque determined by friction; M_{RN} - nominal torque, developed at nominal speed, Ω_N; a - coefficient included in the value range (-1 ÷ 2). When a = -1 the previous relation becomes:

$$M_R = M_{R0} + (M_{RN} - M_{R0})\frac{\Omega_N}{\Omega} \tag{3}$$

For paper or sheet metal wrapping mechanisms, the technological process imposes a wrapping speed (v) and a stretching force F_{Ru}. As a result, the diameter D of the paper or sheet cylinder increases during wrapping, and the angular velocity decreases and the useful torque increases:

$$\Omega = \frac{2v}{\Omega}; \quad M_{Ru} = \frac{1}{2}\,DF_{Ru} \tag{4}$$

Another group is the machines and working mechanisms that produce resistant M_R torque, depending on the rotation angle of the crankshaft. This includes the connecting rod-crank mechanisms, found in pumps, piston compressors, sheet metal shears, mechanical presses, and the torque equation is given by the relation:

$$M_R = \frac{F\cdot r}{i\cdot\eta}\frac{\sin(\alpha+\beta)}{\cos\beta} = \frac{F\cdot r}{i\cdot\eta}\left[\sin\alpha + \frac{r}{2l}\cdot\frac{\sin 2\alpha}{\sqrt{1-\left(\frac{r}{l}\right)^2\sin^2\alpha}}\right] \tag{5}$$

The mass in alternating motion determines a pulsating component of the torque, the expression of which is expressed by the second term in the equation of motion in a final form:

$$M - M_R = J\frac{d\Omega}{dt} + \Omega^2\frac{dJ}{dt} \tag{6}$$

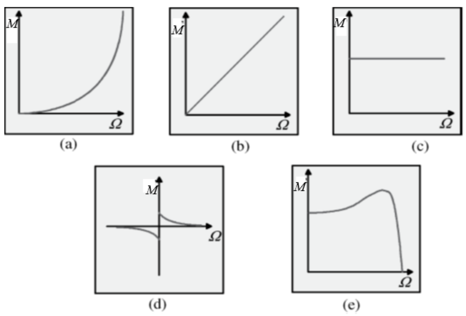

Figure 1. (a) blower ~Ω2, (b) piston pump ~Ω1, (c) lifting ~Ω0, (d) the influence of static friction ~Ω1, (e) load for an asynchronous motor connected directly to the mains

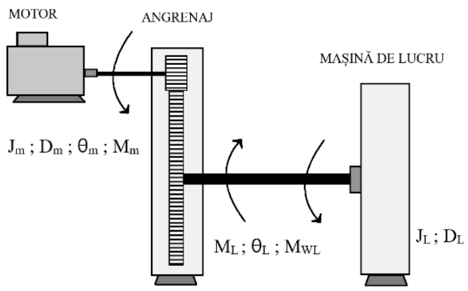

Figure 2. The rotational movement of the motor shaft transmitted to the work machine by mechanical gearing

3. DESIGN AND CONSTRUCTION OF THE ELECTRIC DRIVE STAND

The didactic stand aims to highlight two possibilities of electric drive of alternating current electrical motors. It is composed of up-to-date electrical equipment, with the help of which the speed and torque of the asynchronous electric motor can be controlled. It can also be considered that the set is part of the energy efficiency methods in the electric drive of the three-phase asynchronous motor with short-circuit rotor, found mainly in most drives of industrial technological processes.

As it is known from the specialized literature, by changing the speed of a hydraulic pump, its adjustment curve changes. This represents an adjustment variant encountered when operating some work devices of the production line for the preparation and inspection of the rolls of electrotechnical sheet that we will deal with in the work.

In the process of long-term operation of variable frequency electric drive pumps, the parameters of pumping equipment and pipelines change significantly [13].

The hydraulic system simulated by the stand made, practically consists of a group of two hydraulic pumps and one for oil filtration. The hydraulic pumps are, as previously specified, axial piston pumps, which achieve the output flow due to the alternating axial movement of a number of pistons. The pistons are placed inside on the disc inclined with the angle α thus forming the pump rotor [14].

The explained location mode gives the pump a small size but also a balance of the moving elements.

3.1. COMMANDER SK - FREQUENCY CONVERTER

The Commander SK frequency converter, produced by Control Techniques, is an electronic device for speed and torque control, with high energy potential (through the increased efficiency of the machine / processes) therefore reducing the consumption of raw materials and losses of them throughout their life [15].

In common applications, these positive effects on the environment far outweigh the negative impact of product manufacturing and longevity [16].

Commander SK is a variable speed converter that performs open loop vector control. It is used to control the speed of an AC asynchronous motor / servomotor.

Open loop vector control is used to maintain almost constant flow in the motor by dynamically adjusting the motor voltage according to the motor load.

The output AC voltage control consists of a change in the input AC voltage through a rectifier bridge and then smoothed through the high voltage capacitors to produce a DC voltage bus (DC - BUS).

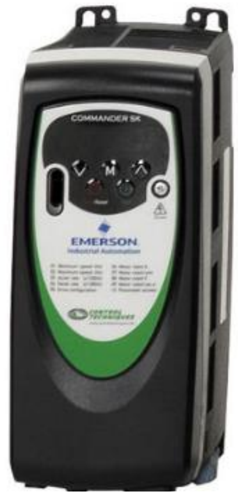

Figure 3. Commander SK frequency converter used for the realization of the experimental stand

3.2. SOFTWARE CTSOFT - WORKING ENVIRONMENT (PUTTING INTO OPERATION), THE ONE THAT GIVES THE OPPORTUNITY TO CONTROL AND FULLY DISPLAY ALL THE PARAMETERS CORRESPONDING TO THE DIFFERENT TYPES OF CONVERTERS

CTSoft is a commissioning program that can run with the Windows operating system, with which we can fully control and display all parameters corresponding to the types of converters, Unidrive Classic, Unidrive SP, Unidrive ES, Unidrive PV, Commander GP20, Commander SK, Digitax ST Base, Digitax ST Indexer, Digitax ST Plus and MentorMP drive ranges [17].

For most of these units, CTSoft also offers quick guided configuration tools, and for the Digitax ST Indexer and Plus variants, the easy-to-use tool for parameterizing how the electric motor works.

CTSoft provides the user with a graphical interface logically divided into a series of dialog boxes, which provide quick and easy viewing and, where appropriate, the ability to edit parameter values. Detailed parameter information can be displayed at any time, showing the parameter function, type and range of allowed values.

The parameter set of the frequency converter consists of a series of related groups or menus. Many of these menus have an associated graphical chart that can be displayed and used interactively in CTSoft.

The user has the possibility to adapt the parameters to suit the desired application. The backup file of this modified parameter set can be created to be downloaded to the converter's memory when the user completes the parameterization or programming in CTSoft online. This parameter file has the fixed name UserDataAutoBackup; it can be found in the Parameter Files menu in the application interface. The user can then reload this file as a parameter set for download to the converter's memory. Reloading is done automatically.

3.3. MOT.3 TYPE FLANGED ASYNCHRONOUS MOTOR UNDER CONSTRUCTION, OFFERED BY TECHNO VOLT SRL

The stand also contains an asynchronous AC motor from Lucas Nuelle, imported and sold by Techno Volt SRL, type VDE 0530, according to the IEC34 - 5 standard [18], insulation class IP20 with the functional characteristics inscribed on its own plate.

The asynchronous machine is an alternating current machine for which the ratio between the frequency of the current exchanged with the grid at the terminals and the rotor speed is not constant, but varies when the machine load and the operating mode vary.

Usually, in the asynchronous machine, the stator and rotor windings are not electrically connected, but only inductively, for this reason the asynchronous machine is also called induction machine. Mainly, asynchronous machines are built either as single-phase machines or as three-phase machines. Asynchronous short-circuit rotor motors are the most manufactured and are widespread in all industrial sectors. This is due to the advantages that these engines have compared to other types of engines: simple construction, low manufacturing price, high reliability, superior efficiency, simple maintenance and repair, etc. [19].

Figure 4. Three-phase asynchronous motor with short-circuited rotor used to design and build the experimental stand

4. DESIGN AND CONSTRUCTION OF THE ELECTRIC DRIVE STAND

The optimal variants that the stand highlights, represent in particular the regulation or the control of the flow of some pumps with pistons, composing the hydraulic system of some lines of technological processes. The hydraulic system, composed of two hydraulic pumps, drives the working devices of the production line. The speed adjustment of the piston pumps is done using power electronics equipment, so that the piston pumps will have new properties:

- Large pump speed and flow adjustment range;
- Speed change in a continuous way and without pressure shocks;
- The pump does not need fittings for pressure or flow regulation;
- When reducing the flow, the speed of the hydraulic pump with pistons is also reduced;
- The operation of the pump can follow an imposed load curve;
- The advantage of adjusting the piston pump is the possibility to control the speed over a long range with the help of the frequency converter, according to the sizes of the hydraulic installation and of course those of the production process. The pressure transducer permanently indicates the actual value of the pressure in the hydraulic system generating a signal in the form of current or voltage. The modification of the loads implicitly leads to the appearance of a pressure difference, a resultant aspect of the self-correction for the nominal value of the pressure. The working devices of the roller preparation line being hydraulically actuated, of course it also has a hydraulic station composed of three asynchronous motors with short-circuited rotor, respectively a filter pump necessary for the return of the oil to the tank.

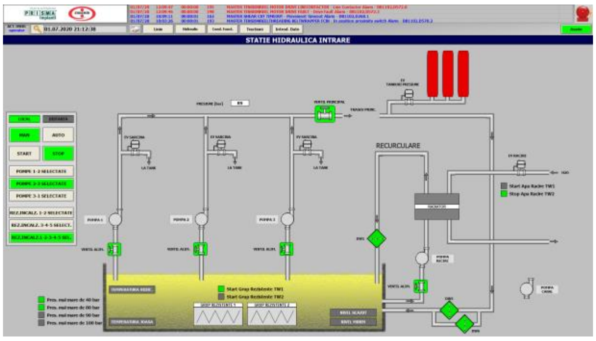

Figura 5. Hydraulic station.

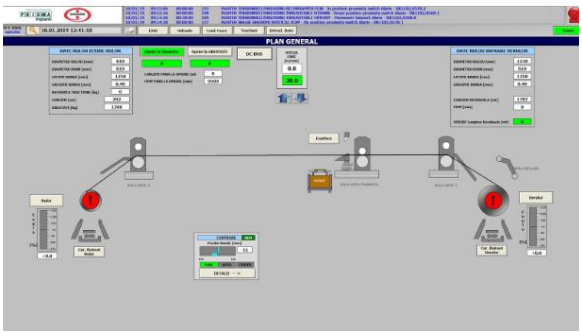

Figura 6. Roll preparation line.

The problem described above can be designed with the CTSoft work environment with the specification that the parameterization was performed in Offline communication mode, as shown in the following images.

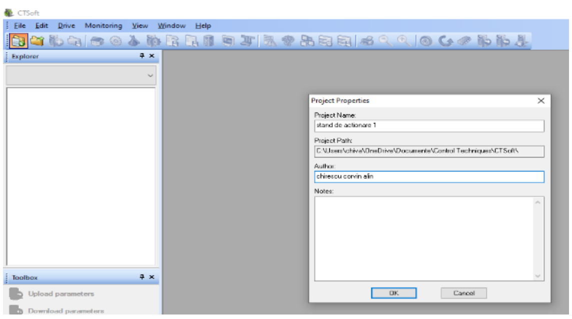

Figure 7. Opening a project file.

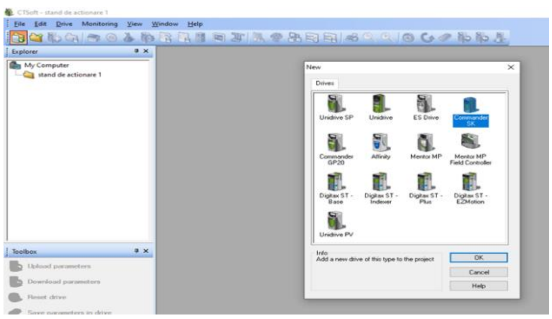

Figure 8. Choosing Commander SK.

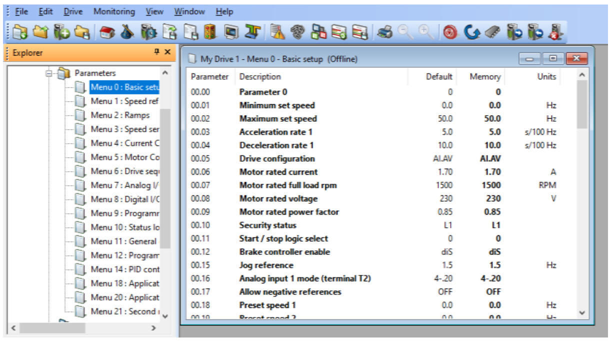

Figure 9. Opening the list of parameters

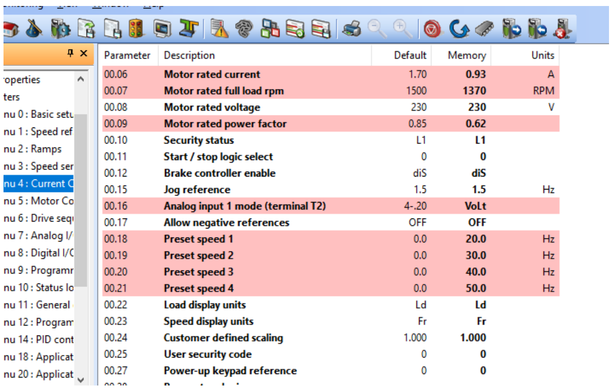

Figure 10. Selecting parameters from menu 0

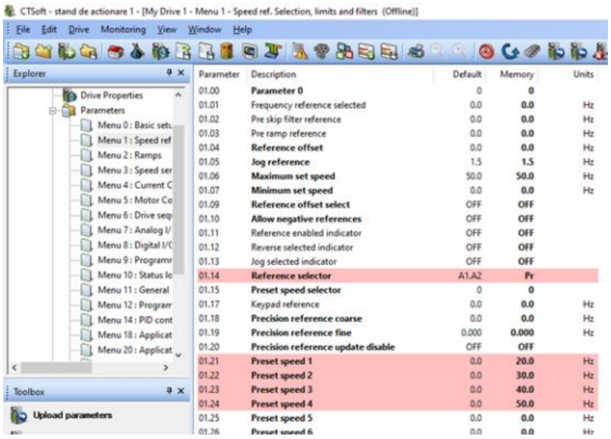

Figure 11. Selection of working speeds

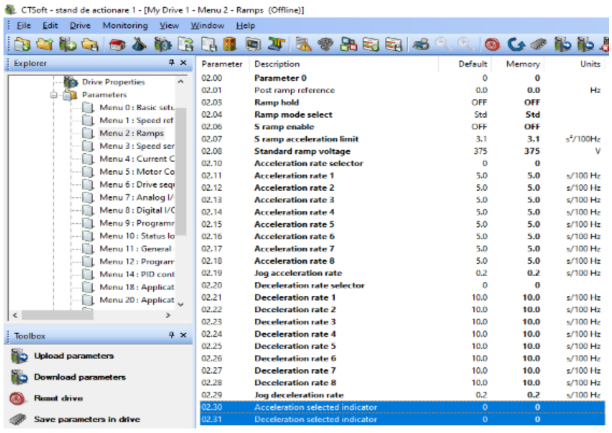

Figure 12. Selection of acceleration and deceleration

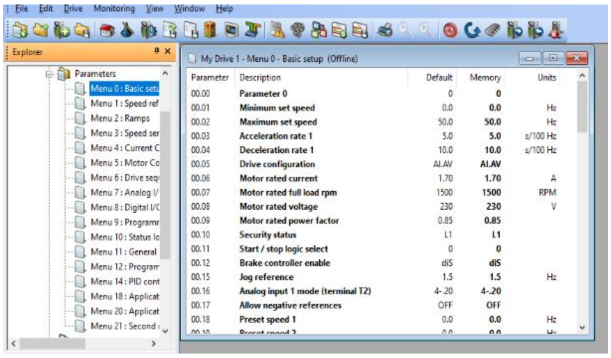

Figure 13. Torque selection

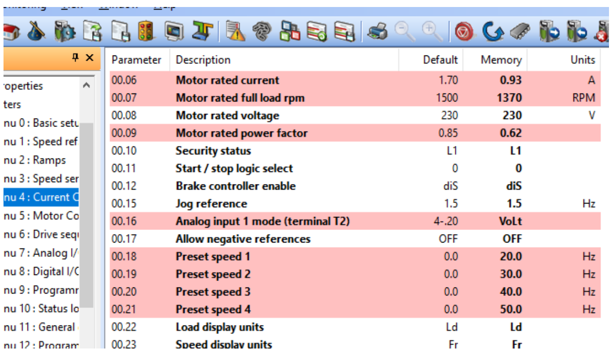

Figure 14. Selection of control parameters

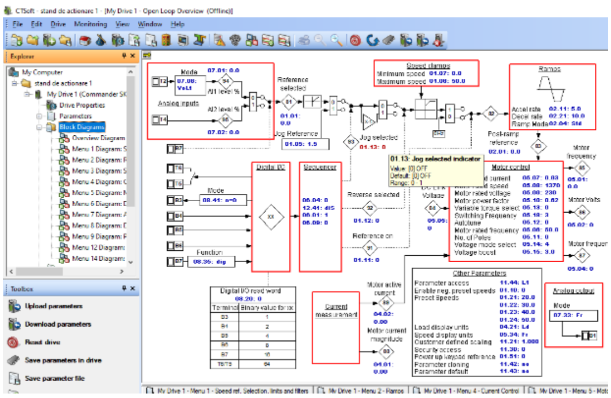

Figure 15. Overview blocks diagrams

Figure 16. The final shape of the experimental stand

Figure 17. Electrical control and signaling components

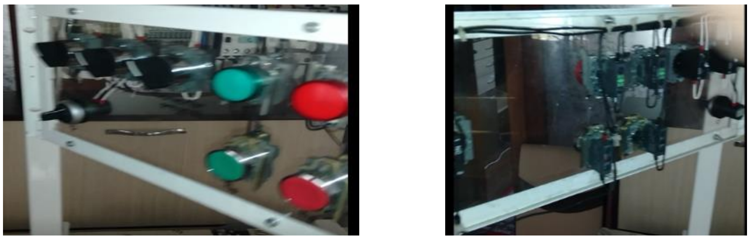

Figure 18. The front panel of the drive stand contains the electrical control and signaling components and is mobile

Figure 19. Internal components of the drive stand

Inside the drive stand of the asynchronous motors and actuators we find several components: a contactor that has the role of power-up the frequency converter, the protection elements F1 and F2 for the power circuit and, respectively, for the control circuit , the frequency converter and various assembly elements that interconnect all elements, including the asynchronous motor. Power-up is as follows:

The fuse F1 is activated and on the front panel we will have the signal No control voltage because the fuse F2 is switched off.

The fuse F2, corresponding to the control circuit, is activated and the signaling lamp is switched off, which indicates that there is a control voltage at this time.

Power up the frequency converter from the ***Bp*** button.

A signal light comes on to confirm that we have powered the frequency converter (Converter on). This can also be seen on the converter display, but in this state it cannot be ordered. It is in the ***Ih*** state, *Inhibited,* ie the converter is said to be "***inhibited***" because there is no activation command.

Figure 20. Light signaling: ”No control voltage”

Figure 21. Light signaling: ”Coupled converter”

In order to be able to operate the motor, we must operate the ready-made converter key. The converter displays ***rd*** on the display, ie it shows that it is ready to send voltage to the asynchronous motor in a constant value U / f ratio. With the forward key we will start the engine.

Figure 22. Actuator key ready and rd status display (READY)

Figure 23. The forward key by which the start is made

The engine will rotate at a certain speed. In the real case, the speed change will be based on the data collected by a pressure transducer. In the experimental stand, we simulated this pressure transducer by means of a potentiometer marked with ***P***.

Figure 24. Starting the asynchronous motor in a certain direction, with a certain speed and the P potentiometer that simulates the pressure transducer

We can consider that for a low engine speed, the hydraulic system will no longer be used. By rotating the potentiometer P we will increase the motor speed. After accelerating the motor rotor, we reduce the speed to zero and switch via the reverse key. In this way, we make a change in the direction of rotation of the motor. On the converter display we will notice that the minus sign in front of the operating frequency values shows that the direction of rotation has changed.

5. LOAD OPERATION OF THE ASYNCHRONOUS MOTOR WITH THE HELP OF THE EXPERIMENTAL STAND

Load operation can be studied through the characteristics of the asynchronous machine. These represent dependencies between the following parameters: rotor speed n; useful mechanical torque developed M2; slipping s; yield η; cos power factor; the absorbed current I1; absorbed power P1 and mechanical power P2.

The efficiency characteristic $\eta = f\,(P2)$ represents the variation of the efficiency with the useful mechanical power at the shaft. This highlights the efficiency of the machine's operation at various tasks. The maximum efficiency of the asynchronous motor is obtained at a load of 0.6 ÷ 0.8 from the rated power P2.

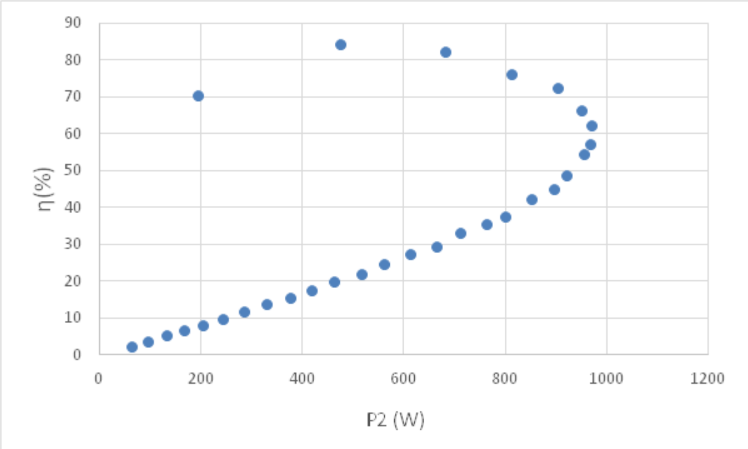

Figure 25. Yield characteristic

The characteristic of the power factor cosϕ = f (P2) represents the variation of the power factor imposed on the supply network with the useful mechanical power. This feature indicates the extent to which the asynchronous motor operates at a certain load to charge the reactive power supply. This feature is particularly important in achieving energy balances.

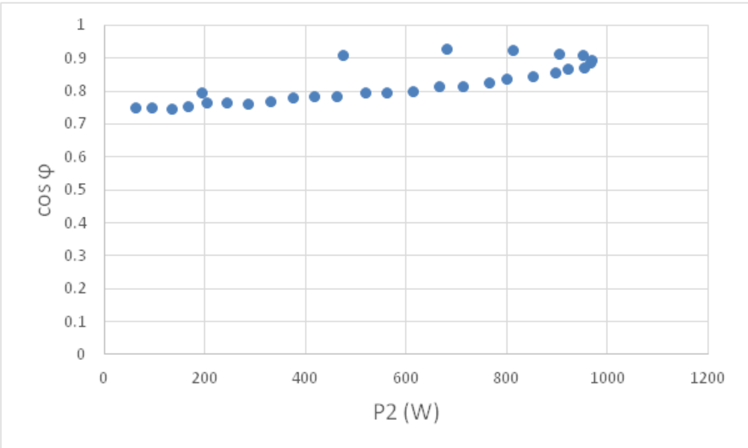

Figure 26. Power factor characteristic

The slip characteristic s = f (P2) represents the variation of the slip with the payload at the shaft. The higher the slip, so the lower the rotor speed, the higher the Joule losses in the rotor winding.

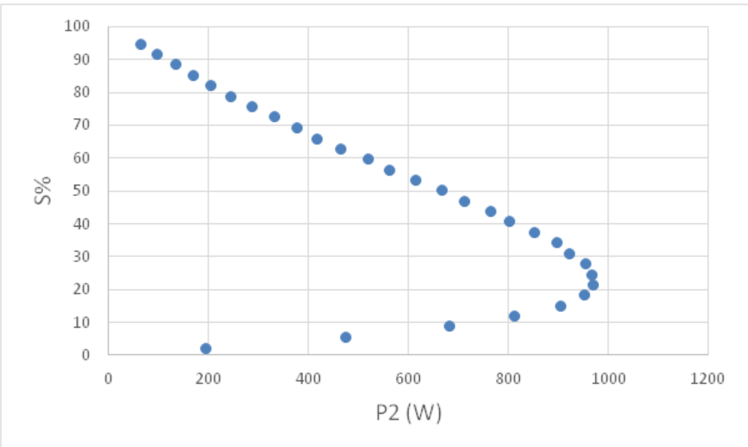

Figure 27. Slip characteristic

The characteristics I1 = f (P2), P1 = f (P1) highlight the variation of the electric quantities current and power absorbed by the motor with the variation of the useful mechanical power at the shaft.

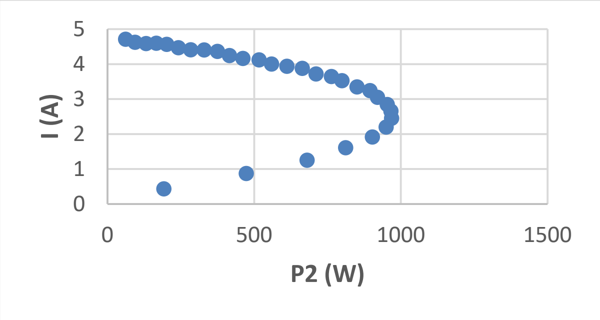

Figure 28. Characteristic of the absorbed current

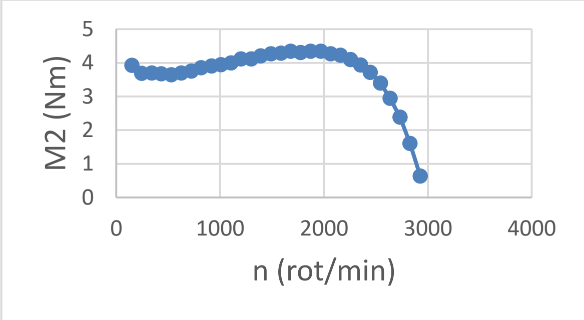

Figure 29. Mechanical characteristic

The mechanical characteristic n = f (M2) represents the dependence between the rotational speed n of the rotor and the useful torque M2 on the shaft. This feature highlights how the rotor speed changes as the load on the shaft changes. The mechanical characteristic of the three-phase asynchronous motor is a rigid characteristic. The rotor speed decreases slightly as the shaft-resistant torque increases.

6. CONCLUSIONS

The technological process presented during the research is used for a continuous adjustment of the speed of a.c. motors and servomotors. It has the advantage of continuously adjusting the flow for a large range of values, without predetermined steps, which leads to substantially improved efficiencies in the field of actuated loads. The amortization of the investment by adjusting the speed using frequency converters is achieved through electricity savings due to operating characteristics with the most convenient shapes. The use of modern technology is suitable for more complex but functionally efficient situations. Due to the current use of electric machines and associated energy flows, it has been possible to introduce more efficient electric drives with significant benefits even for the environment, and electrical specialists have managed to introduce modern, efficient electric drive equipment in a multitude of industrial processes.

This paper describes the design and practical implementation of a laboratory stand. The designed stand is a study support for various applications used in the industrial area, offering the possibility of experimentation on programming and parameterization of frequency converters in the laboratory of "Electrical machines and drives" of the Faculty of Electrical Engineering, Electronics and Information Technology at the University of Wallachia in Târgoviște [21]. The stand designed and made practically contains modern electrical equipment commonly encountered in the automation of industrial processes.

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