Software and hardware complex for research and management of the separation process

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Abstract. The article is devoted to the development of a program for studying the operation of an asynchronous electric drive using vector-algorithmic switching of windings, as well as the development of a hardware-software complex for controlling parameters and controlling the speed of rotation of an asynchronous electric drive for investigating the operation of a cyclone. To study the operation of an asynchronous electric drive, a method was used in which the average value of flux linkage is found and a method for vector-algorithmic calculation of the power and electromagnetic moment of an asynchronous electric drive feeding from a single-phase network is developed, with vector-algorithmic commutation, and software for calculating parameters. The software part of the complex allows to regulate the speed of rotation of the motor by vector-algorithmic switching of transistors or, using pulse-width modulation (PWM), set any engine speed. Also sensors are connected to the hardware-software complex at the inlet and outlet of the cyclone. The developed cyclone with an inserted complex allows to receive high efficiency of product separation at various entrance speeds. At an inlet air speed of 18 m/s, the cyclone's maximum efficiency is achieved. For this, it is necessary to provide the rotational speed of an asynchronous electric drive with a frequency of 45 Hz.

1. Introduction

The ambient air surrounding the person is continuously exposed to contamination. The air of industrial premises is polluted by the emissions of process equipment or during technological processes without the localization of waste materials.

Air purification is one of the most important tasks at all plants where powdered raw materials are received, stored and transported by air. Therefore, the purification and separation of air mixtures is one of the most important and widespread processes. Currently, there are three ways to clean the process air: gravity cleaning, inertial and filtration [1].

The quality of air purification in dust collectors depends not only on such parameters as the flow velocity, the size of the particles being separated, but also on the ratio of the geometrical dimensions of the dust collector. The advantage of cyclones is the simplicity of the configuration. Also, the cyclones provide a degree of purification of up to 90% and are characterized by a low degree of trapping of particles of a size of 20 μm or less. One of the main parameters of cyclones is the input speed.

Frequency converters are used in electric drives to regulate the speed of the electric drive. The use of a regulated electric drive makes it possible to exclude the mechanical component of complex mechanisms and simplify the kinematics of machines, and the development of technological processes and the application of automated and software control systems require maintaining high accuracy and speed of the working mechanisms of the mechanisms.
Frequency converters are used to accurately regulate the speed of the drive and at the same time provide protection such as inrush current and power consumption of the device. With their help, it is possible to carry out remote monitoring and control of an asynchronous electric drive.

2. Relevance
The efficiency of the existing cyclones is 80-90%, with a potential of 99%. Cleaning can also take place through filter cloths that need to be changed during operation, as well as cyclones that are unable to capture dust with a small particle size and have little durability (especially when cleaning gases from dust with high abrasive properties). The main parameters that characterize the operation of the cyclone are hydraulic resistance and cleaning efficiency, which depend on the design features of the apparatus and the speed of the dust-gas flow. The technical requirements for the cyclone, as well as for any dust collector, consist in the greatest possible degree of purification at the lowest energy costs.

Therefore, the regulation of the speed of the electric motor in cyclone systems is actual.

3. Principle of operation
The functional diagram of the cyclone is shown in Figure 1 [2].

![Figure 1. Functional diagram of the cyclone.](image)

The air mixture on the material conduit enters the inlet snail 4 of the cyclone. The input snail serves to communicate the rotational axisymmetric motion to the product and thereby create conditions for the separation of the product from the stream. Exiting the swirler, the flow enters the conical part of the cyclone and acquires additional rotational screw motion due to the screw insert 5.

Large particles of the product rush to the walls of the cyclone due to the effect of the centrifugal force arising in the rotating flow, as a result of which their main mass enters the slit to catch large dust and precipitates in boxes located at different heights. The rest of the dust, along with the air, moves axially to the lower part of the cyclone, where, under the action of inertia, the dust enters the cone-cone 3 for additional cleaning of the air, and the purified air leaves the exhaust pipe at the lowest resistance.
Changing the gap between the cochlea to which the screw insert is fixed and the resistance of the cyclone changes with the outer cone. Within the permissible limits, raising the cochlea does not significantly change the efficiency of the cyclone.

To study the efficiency of the cyclone, it is necessary to use a frequency converter to regulate the speed of the air flow. A single-phase - three-phase frequency converter in a single-phase network can be used as a frequency converter. When this frequency converter is used, a certain sequence of transistors connected in accordance with the scheme [3] commences in both positive and negative half-periods of the supply voltage to create a magnetic field of the stator of the asynchronous electric drive in order to provide fixed magnetic flux positions. This method makes it possible to obtain the necessary current direction in the stator windings, thereby creating a rotating magnetic field, which provides vector-algorithmic switching of the windings of the asynchronous electric drive.

Control transistors are included in three zero-phase single-phase counter-parallel rectification circuits designed to enable the direction of rotation of the magnetic flux vector of the stator field to change. The corresponding middle point of the rectification circuit is connected to the input of the stator windings. The windings of the asynchronous electric drive are connected to a star. Control transistors need to be selected based on currents and voltages passing through the motor.

For the study of the modes of operation of the engine using vector-algorithmic commutation, current sensors (Figure 2a) and voltage are used (Figure 2b).

![Figure 2. Current and voltage sensors used to study the characteristics of an asynchronous motor.](image)

The current sensor is implemented on the ACS712 module on the Hall effect. The current sensor can measure current up to 30A and is connected to the ADC of the controlling microcontroller. The voltage sensor is implemented on the standard module "voltage sensor for Arduino".

### 4. Software and hardware

To study the operation of an asynchronous electric drive using vector-algorithmic switching, software was developed that receives data from current and voltage sensors. The use of methods for determining the electromagnetic moment and the power of an asynchronous three-phase electric drive fed from a single-phase alternating current network is impossible with vector-algorithmic commutation, since using vector-algorithmic commutation there is no continuous sinusoidal voltage, since the control transistors in a certain sequence apply voltage to two or three windings of an asynchronous three-phase electric drive and, accordingly, a simultaneous inequality of these voltages in each moment of time on different windings of the electric drive. Therefore, a method was used in which the average value of flux linkage is found and a method for vector-algorithmic calculation of the power and electromagnetic moment of an asynchronous electric drive fed from a single-phase network is developed for vector-algorithmic commutation. Depending on the type of connection of the windings of the asynchronous three-phase electric drive, the calculation procedure will differ because in view of the different voltage applied to the windings of the electric drive, there will be a different way of adding these vectors. Then the calculation method will be the same and consists in relation to the power on the motor shaft when powered from a single-phase circuit and a three-phase circuit, respectively.

The oscillogram of the stator windings is shown in Figure 3.
Figure 3. The window for outputting the oscillograms of the stator windings.

The software-hardware complex consists of several functional blocks connected to the microcontroller, presented in Figure 4.

![Block diagram of the control system.](image)

The software part of the software-hardware complex [4] allows to regulate the speed of rotation of the motor by vector-algorithmic switching of transistors or, using pulse-width modulation (PWM), set any engine speed. Connected sensors of current and voltage allow in real time to receive data from the engine and, based on the mechanical characteristics of an asynchronous motor, to calculate the speed of rotation of the motor shaft, and also to study the operation modes of an asynchronous electric drive in vector-algorithmic commutation and fix emergency regimes. When using a cyclone battery, the developed software-hardware complex allows to record the increase or decrease of the load on the cyclones and, accordingly, to correct the engine speed. Also sensors complex at the inlet and outlet of the cyclone are connected to the software-hardware.

After the development and testing of the control system, experimental studies were carried out [5].

At the first stage of experimental research, the dependence of the air velocity on the radius of the cone was revealed (Figure 5).
Figure 5. The graph of the dependence of the air velocity on the radius of the conical part of the cyclone.

As can be seen from Figure 5, with an increase in the radius of the cone, the airflow velocity decreases, which leads to a decrease in the efficiency of the cyclone operation.

The next part of the experimental studies consisted in determining the air velocity at the inlet to the cyclone, at which the maximum separation efficiency was achieved.

Experimental studies (Figures 6, 7) were carried out using a single-phase three-phase frequency converter to obtain different air velocities. The experiments were carried out on a conventional cyclone and a cyclone with a screw insert.

Figure 6. Characteristics of a cyclone without an insert depending on the speed of the engine.
Figure 7. Characteristics of a cyclone with an insert depending on the speed of the engine.

For the experiment, weighed samples of the product weighing 100 gr. and poured into the receiving cyclone hopper.

It can be seen from Figures 6 and 7 that a cyclone with an insert develops a high input speed, which allows increasing the cleaning efficiency of a cyclone separator.

The results of the experiment carried out for the flour fed to the air flow are shown in the graph shown in Figure 8.

Figure 8. The plot of the efficiency of the separation of the product from the input air velocity.

It can be seen from Figure 8 that the developed cyclone allows obtaining high efficiency of product separation (more than 99%) at different input speeds. At an inlet air speed of 18 m / s, the cyclone's maximum efficiency is achieved. For this, it is necessary to provide the rotational speed of an asynchronous electric drive with a frequency of 45 Hz.
The most effective separation of the solid fraction of the flour from the aerodisperse flow is observed at the plant at an input speed of 18.2 m/s and a concentration of 43.2 g/m³ (99.7%). At a speed less than or higher than this value, a reduction in separation efficiency was observed.

5. Conclusion
The developed system allows to explore an asynchronous motor when it is connected to a single-phase alternating current network, and also to simulate the processes occurring in it. The developed software-hardware complex allows to regulate the speed of rotation of an induction motor connected to a single-phase alternating current network, which affects the efficiency of cyclone purification. The carried out experiment showed that the highest degree of purification is achieved at a frequency of rotation of the electric drive of 45 Hz.

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