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SUBSTANTIATION OF CONTROLLED VARIABLES FOR ENERGY MANAGEMENT SYSTEM OF PISTON COMPRESSOR UNITS

Анотація. *В роботі визначені вимоги і перелік контрольованих параметрів системи двопозиційного управління з детермінованим верхнім рівнем тиску повітряних поршневих компресорних установок. Ці параметри визначені з урахуванням необхідності визначення втрат енергії в елементах електромеханічної системи "електрична мережа - привід - компресор - пневмомережа". Також вказані і описані заходи попереднє проведення яких необхідно для визначення втрат енергії в пневматичних мережах як на ділянці підвищення тиску, так і на ділянці його зниження. З викладеного матеріалу можливо зробити висновок про те, що втрати енергії у всіх елементах електромеханічної системи можливо визначити знаючи один параметр тиск в пневмосистемі і відстежуючи швидкість його зміни.*

Ключові слова: *електропривод, регулювання, компресор, електромеханічна система.*

Аннотация. *В работе определены требования и перечень контролируемых параметров системы двухпозиционного управления с детерминированным верхним уровнем давления воздушных поршневых компрессорных установок. Эти параметры определены с учетом необходимости определения потерь энергии в элементах электромеханической системы "электрическая сеть – привод – компрессор – пневмосеть". Также указаны и описаны мероприятия предварительное проведение которых необходимо для определения потерь энергии в пневматических сетях как на участке повышения давления, так и на участке его снижения. Из изложенного материала возможно сделать вывод о том, что потери энергии во всех элементах электромеханической системы возможно определить зная один параметр давление в пневмосистеме и отслеживая скорость его изменения.*

Ключевые слова: *электропривод, регулирование, компрессор, электромеханическая система.*

Abstract. *The paper defines the requirements and the list of controlled variables of the on-off control system with the deterministic upper level of pressure of air piston compressor units. These parameters are determined taking into account the need to determine the energy losses in the elements of the electromechanical system "electric grid - drive - compressor - pneumatic system". Also, the measures are determined and described, the preliminary carrying out of which is necessary to determine the energy losses in pneumatic networks both at the pressure increase section and at the site of its reduction. From the above material, it can be concluded that the loss of energy in all elements of the electromechanical system can be determined by knowing one parameter the pressure in the pneumatic system and monitoring the rate of its change.*

Keywords: *electric drive, control, compressor, electromechanical system.*

Introduction. Nowadays on-off control system is common for piston compressors delivery. The control system is applied in case there is no technological need in maintaining the stable pressure level in pneumatic system and there are no dramatic changes of compressed air consumption. Its advantages are described in terms of simplicity of implementation and reliability. The principle of on-off control system operation is based on setting of predetermined pressure limits. Reaching the upper level of pressure the compressor is switched off and it is switched in reaching the lower level.

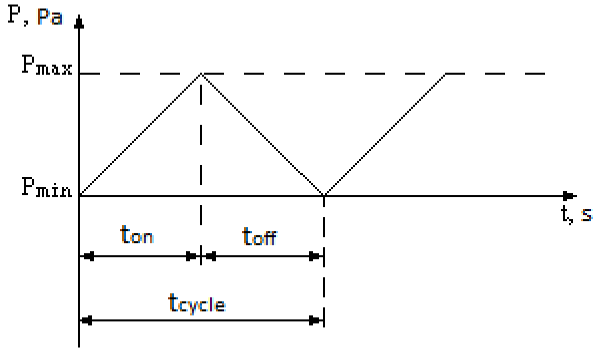

Fig.1. Principle of on-off control system operation.

This occurs under the condition of single variable change control (intake pressure) in the system (fig.1.) by means of sensor, which is installed. The regular operation of compressed air consumers is provided by means of pneumatic system pressure maintaining in the predetermined range.

Purpose statement. The main disadvantage of the system is its negligibility as for the factors influencing the general energy efficiency of «grid – compressor – pneumatic circuit» complex. It does not consider such substantial parameters as losses in power for grid, compressor, and pneumatic circuit. Hence, there is a need in describing the parameters to be changed by control system for losses determining and thus working in the proper regime of their minimizing for maintaining the regular operation of compressed air consumers.

Problem solution. To answer the question it is required that we consider the losses in power for various components of the system.

The active power losses in electric grid:

$$\Delta N_1 = 3 \cdot I^2 \cdot r_0 \cdot l = 3 \cdot r_0 \cdot l \cdot \left(\frac{N}{\sqrt{3} \cdot U \cdot \cos \varphi} \right)^2, \tag{1}$$

where *I* stands for line phase current, A; r_o stands for active electrical resistivity in the line, Ohm per km; *l* stands for line length, km; *N* stands for active power consumed by asynchronous compressor drive form the grid, kW; *U* stands for supply line voltage, kV.

The losses in asynchronous drive and compressor unit may be shown as follows:

$$\Delta N_2 = N - P_2 \cdot Q_{komp}, \tag{2}$$

where *N* stands for active power consumed by asynchronous motor, kW; P_2 stands for pressure of compressed air in the receiver, Pa; Q_{komp} stands for compressed air flow at the receiver output, m^3/sec.

The losses in the compressed air pipelines:

$$\Delta N_3 = P_2 \cdot \frac{\left(V_{res} + V_{pipes}\right)}{RT} \cdot \frac{1}{\rho} \cdot \frac{dp}{dt}, \tag{3}$$

where $\frac{dp}{dt}$ is the speed of pressure change in the pneumatic circuit, Pa/sec, is determined using regression equations [5, 6]; *T* is gas temperature, K; R = 287 J/(kg·K) is gas constant for air; ρ = 1,29 kg/m^3 is standard air density; *t* is time, sec; V_{res} is receiver volume, m^3; V_{pipes} is pneumatic circuit volume, m^3.

Considering the abovementioned issues, to enable the control system being sensitive to losses in all units of «grid – compressor – pneumatic circuit» system it is need to install:

- ammeter, A
- flow rate meter for compressed air, m^3/sec
- pressure sensor in the receiver.

If compared to on-off control system, the two devices, ammeter and flow rate meter for compressed air, are added. Thus, the cost of a control system and its assembly complexity increase, its reliability decreases. Let us consider the possibility of quantity reduction for indicators of controlled variables with maintaining the control system ability to monitor the losses in different units and thus to work in energy efficient modes.

The losses in electric grid may be linked to the active power consumption for asynchronous drive of air piston compressor unit considering its dependence on pressure rate in the pneumatic circuit and some allowances:

- power supply voltage of asynchronous motor does not depend on consumed power U = const;
- efficiency coefficient of asynchronous motor is independent from load ηmot = const;
- the influence of temperature of intake air on consumed power is neglected. The calculations should be carried out for T_1 = 20 ºC parameters, as the intake air temperature decrease for stable pressure reduces the quantity of moisture vapour resulting in its performance improvement [2].

Then we obtain the following expression for air piston compressor unit with two compression stages:

$$N = 2\frac{n}{n-1} P_1 Q_{komp} \frac{\left(\varepsilon^{\frac{n-1}{2n}} - 1\right)}{\eta_{mex}\eta_{pol}}, \tag{4}$$

where P_1 stands for atmospheric pressure, Pa; Q_{komp} stands for volumetric capacity for indraft conditions m^3/sec; *n* stands for polytropic index for air piston compressor units, n = 1,2…1,35; η_{pol} stands for compression efficiency related to compression polytropic process, equals to 0,8…0,9; η_{mex} stands for mechanical efficiency considering friction losses of crank mechanism and compressor piston, 0,85…0,95 ; $\varepsilon = \frac{P_2}{P_1}$, P_2 stands for pressure in the pneumatic circuit, Pa.

Then current consumed by electric drive from the grid is

$$I = \frac{N}{\sqrt{3} \cdot U_H \cdot \cos\phi} \tag{5}$$

The value of ΔN_1 may be calculated as based on the value of current.

The losses in compressor are calculated from formula (2) as the difference between the consumed power and product of pressure by its efficiency.

To determine the real performance of compressors and pneumatic circuit the trial run is needed. The trial run is carried out at off hours and for compressed air consumers switched off. For determining of dependence between compressor delivery and pressure the following operation procedure is needed:

- gate valves after the receivers are closed;
- one compressor is started, once it starts working in the standard operating mode the gate valve of the pump is opened, stop clock is started;
- the pressure change in the receiver is recorded for the stated pitch with stop clock up to maximum pressure.

To measure pneumatic circuit leakage:

- compressed air is pumped into the pneumatic circuit up to the maximum value (if needed, several compressors are on);
- the compressing units are turned off with simultaneous starting of stop clock, then the rate of pressure decline in the receiver is determined.

Let us show the calculations of volume flow m^3/min for normal conditions as the following expression:

$$V_{ras} = \frac{(Q_{res} + Q_{pipes})}{R \cdot T} \cdot \frac{1}{\rho} \cdot \frac{dP}{d\tau} \tag{6}$$

where *P*, *Q*, *T* stand for pressure, Pa, volume m^3, temperature, K of the gas respectively; R=287 J/9kg K) stands for air gas constant; ρ=1,29 kg/m^3 is air density for normal conditions; Q_{res} and Q_{pipes} stand for receiver volumes and feed pipelines of circuit.

Conclusions. As based on the empirical data from the expression (6) we can obtain the dependences of compressors delivery, m^3/min from pressure, Pa, and air leaks, m^3/min from pneumatic circuit pressure, Pa [4, 6]. Knowing the volume of pressure for every timepoint the volume compressor delivery may be determined, and, thus, having calculated the power consumed by asynchronous drive we may obtain power losses for compressor.

The power losses in the pneumatic circuit may be determined by controlling only a single variable – pressure, and knowing the dependence of air leakages from pressure in pneumatic circuit (3).

From the mentioned above it is clear that monitoring of a single variable, pressure, is needed, as we may calculate power losses for all elements of the electric grid – compressor – pneumatic circuit system as based on it. This means that it is possible to develop on-off control system for air piston compressor units with asynchronous drive by means of using the only one pressure controller in the air collector. And this enables modernization of existing systems being under exploitation by means of substitution of compressor controllers with programmed logic sensor with energy efficient control algorithm.

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К РАСЧЕТУ ЭНЕРГЕТИЧЕСКИХ ПОКАЗАТЕЛЕЙ ЧАСТОТНО-РЕГУЛИРУЕМОГО АСИНХРОННОГО ЭЛЕКТРОПРИВОДА В УСТАНОВИВШЕМСЯ РЕЖИМЕ

Анотація. *Електромеханічні процеси замкнутого асинхронного електроприводу, які характеризують його енергетичні показники в сталому режимі, можуть бути досліджені без урахування модуляційних пульсацій струму статора. Виконано розрахунок параметрів асинхронного електроприводу для найбільш поширеного закону управління з постійним потокозчеплення ротора в обертової системі координат, орієнтованої по потокозчепленню ротора. Отримані вирази для розрахунку енергетичних показників частотно-регульованого асинхронного електроприводу в сталому режимі.*
Ключові слова: *енергозбереження, асинхронний електропривод, закон управління.*

Аннотация. *Электромеханические процессы замкнутого асинхронного электропривода, которые характеризуют его энергетические показатели в установившемся режиме, могут быть исследованы без учета модуляционных пульсаций тока статора. Выполнен расчет параметров асинхронного электропривода для наиболее распространенного закона управления с постоянным потокосцеплением ротора во вращающейся системе координат, ориентированной по потокосцеплению ротора. Получены выражения для расчета энергетических показателей частотно-регулируемого асинхронного электропривода в установившемся режиме.*
Ключевые слова: *энергосбережение, асинхронный электропривод, закон управления.*

Abstract. *Electromechanical processes of a closed asynchronous electric drive, which characterize its energy parameters in the steady state, can be investigated without taking into account the modulation pulsations of the stator current. The calculation of the parameters of an asynchronous electric drive for the most common control law with constant rotor flux coupling is performed in a rotating coordinate system oriented along the rotor's flux linkage. Expressions were obtained for calculating the energy parameters of a frequency-controlled asynchronous electric drive in the steady state.*
Keywords: *energy saving, asynchronous electric drive, control law.*

Актуальность работы. В настоящее время асинхронный двигатель является наиболее распространенными и составляют около 90% от всего парка машин и приблизительно 55% от установленной мощности [1]. Это объясняется рядом существенных преимуществ асинхронных двигателей в сравнении с двигателями постоянного тока.

Появление надежных экономических преобразователей частоты с ШИМ, открывает широкие возможности для замены регулируемого электропривода постоянного тока частотно-регулируемым асинхронным.

Целью работы является исследование характера изменения электромагнитных параметров асинхронного электропривода в зависимости от закона управления.