Выводы

Как видно из полученных результатов, применение индивидуального привода с асинхронными двигателями позволяет значительно сократить энергопотребление при одном цикле запуска (за один цикл перемещения сляба), что в свою очередь способствует повышению показателей энергоэффективности предприятия в целом и , как следствие, снижению себестоимости выпускаемой продукции.

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OPTIMUM POWER PARAMETERS OF OPERATION OF ELECTROMECHANICAL SYSTEMS WITH A RECIPROCATING COMPRESSOR

Анотація. *В роботі визначені вимоги при формуванні математичної моделі, що дозволяє визначати оптимальний режим роботи системи виробництва і розподілу стислого повітря, що складається з наступних елементів "електрична мережа - привид - компресор - пневмомережа". Розглянуто питання про обмеження кількості пусків, яке вводиться для створення режиму роботи приводу згідно його паспортним даним і умова щодо забезпечення пневмоприймачів стислим повітрям. У моделі використовуються такі припущення: напруга живлення асинхронного двигуна незмінна, значення ККД при коефіцієнті завантаження більшому 0,3 - 0,4 залишається практично незмінним, вплив температур всмоктування повітря на споживану потужність покладається несуттєвим.*

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

Аннотация. *В работе определены требования при формировании математической модели, позволяющей определять оптимальный режим работы системы производства и распределения сжатого воздуха, состоящей из следующих элементов "электрическая сеть – привод – компрессор – пневмосеть". Рассмотрен вопрос об ограничении количества пусков, которое вводится для создания режима работы привода согласно его паспортным данным и условие по обеспечению пневмоприемников сжатым воздухом. В модели используются следующие допущения: напряжения питания асинхронного двигателя неизменно, значение КПД при коэффициенте загрузки большем 0,3 – 0,4 остается практически неизменным, влияние температур всасывания воздуха на потребляемую мощность полагается несущественным.*

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

Abstract. *The requirements for the formation of a mathematical model allowing to determine the optimum operating mode of the compressed air production and distribution system consisting of the following elements "electric network - drive - compressor - pneumatic network" are defined in the work. The issue of limitation of the number of starts is considered, which is introduced to create the operating mode of the drive in accordance* *with its passport data and the condition for providing pneumatic receivers with compressed air. In the model, the following assumptions are used: the supply voltage of the induction motor is invariable, the efficiency value for the load factor greater than 0.3 to 0.4 remains practically unchanged, the influence of air intake temperatures on the power consumption is assumed to be unimportant.*

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

The system of on-off pressure control is widely used in reciprocating compressor systems. The normal operation of compressed air consumers is provided by means of pressure maintaining in the system in the fixed interval ($P_{min} \div P_{max}$).

The general increase of energy efficiency level for the system «power grid – drive – compressor – pneumatic circuit» may be attained by «floating» of upper level of pressure. The paper [1] introduces coefficient of efficiency as the efficiency criterion for a control system and determination of upper pressure level within a single pumping-discharge cycle of pressure. The substantiation of the power index is based on the determination of the interdependences of different indicators for the components of the whole system, the distinguishing of the major components from the point of view of energy losses, components of electromechanical system and their interdependences.

In [2] the interdependences between the measured parameters and capacity loss for different components of the unit were determined with respect to the existing links between them, which enables study of the actual state of losses change for different operation modes of manufacturing equipment. It was suggested that the losses for different components of power complex to be compared as energy losses, which is the most correct from the point of view of power. The energy consumed by a compressor drive may be described as:

$$Э = \sum_{i=1..T} N_i \cdot t_i , \qquad (1)$$

where N_i is power consumed by compressor drive, kilowatt; t_i is sampling interval, h.

The correct choose of the interval is of a great importance here. This simplifies the calculations of energy losses for the components of power complex, as the calculations in the form of power losses are less resource-intensive from the point of view of computational capability of control system.

The next step consisted in the development of mathematical model, which enabled determination of optimum operation mode for the system equipment. As the components of electromechanical system are significantly different, e.g.: electrical and pneumatic circuits, and so are their parameters, the single approach to the analysis of their power parameters was worked out. This enabled unification of parameters of operation modes of electromechanical system and accurate and correct determination of control criteria.

Thus, the conditions were provided for the problem definition of conditional parametric optimization with one optimizing parameter $P_{мах}$ determining maximum coefficient of efficiency level of electromechanical system per cycle for different consumed volumes of pressed air by pneumatic receptors.

As we deal with optimization problem solution, the model includes optimally criterion being described by means of analytic (objective) function.

$$F_{opt}(X) = \eta(P_{махopt}) \rightarrow мах . \qquad (2)$$

The determination of dependence bounding the levels of pressed air consumption and coefficient of efficiency indicator of a system in general is the main purpose (aim) of the developed mathematical model. This enabled tracking of mode interdependence of components of the complex and obtaining the results in analytical and graphic forms. The analysis of the dependence was carried out from the point of view of determining of time point of control influence on asynchronous drive of reciprocating compressor unit. As the mathematical model is focused on operation control and controlled parameters are minimized, the dependence is determined between the parameters under control and coefficient of efficiency indicator. The specifics of such a dependence determination is that the visibility of data providing is needed to determine the optimum parameters of operation mode of electromechanical system. The parameters provide the maximum coefficient of efficiency. The control influences are produced in the time moment corresponding to optimum parameters of operation mode of electromechanical system. This enabled obtaining of maximum value of coefficient of efficiency indicator and, thus, determination of optimum parameters of operation mode of electromechanical system in definite time interval.

The developed mathematical model enables determination of the moment of creation of control influence on asynchronous drive of reciprocating compressor unit. To provide adequacy of the developed model it is needed to recognize and substantiate the assumptions and limitations.

The mathematical model considers the operation modes of all segments of electromechanical complex to determine its power index (coefficient of efficiency) and defines the optimum value of upper limit for pressure level P_{opt} per pumping-discharge cycle under the conditions of coefficient of efficiency maximum for electromechanical complex – minimum energy losses for its segments.

In such a case the following limitations for the mathematical model are considered:

- the condition of providing of pneumatic receptors with pressed air;
- the limitation of number of starts of drive asynchronous motor per hour (protection of asynchronous drive from overheat).

The model is developed with respect to the following assumptions:

- supply voltage is constant *U* = const;
- as based on the analysis of running characteristic $\eta = f(\frac{N}{N_{nom}})$ of asynchronous drives of compressors working into load, the coefficient of efficiency value is almost unchanged and equals to η_{nom} for demand factor exceeding 0,3 – 0,4 [3], as the demand factor of asynchronous drives of reciprocating compressor units changes from 0,6 to 0,9 in case of their operation beyond the pressure from $P_{\min}$ to $P_{\max}$ of the on-off system;
- influence of air intake temperature on the consumed power is considered as insignificant and may not be taken into account;
- the calculations should be made for the parameters with T_1 = 20 °C, as the decrease of air intake temperature for stable pressure decreases the content of evaporated water, which leads to performance improvement [4].

The limitations $W_i(\overrightarrow{X})$ are for domain of existence for the parameter being optimized [5, 6]. The optimization problem solution should be found for the pressure of pneumatic circuit $P_{\min} \le P_2 \le P_{\max}$. As it was mentioned above, the mathematical model should consider the condition of providing of pneumatic receptors with pressed air and limitation of number of starts of drive asynchronous motor per hour (protection of asynchronous drive from overheat), so the problem of parametric optimization should also consider the limitations as follows:

$$P_{\min} < P_{\max opt} \le P_{\max} \tag{3}$$

The optimum (maximum) upper level of pressure in pneumatic circuit P_{opt} should be within the pressures interval from $P_{\min}$ to $P_{\max}$. The number of starts determines the minimum cycle duration.

$$M \le M_{pasp}; T_{c.\min} = \frac{60}{M} \tag{4}$$

Thus, the problem of conditional parametric optimization with one optimizing parameter ($P_{мах}$) determining optimum (maximum) coefficient of efficiency level of electromechanical system per cycle was formulated with respect to its specific parameters, operation modes, limitations and assumptions.

Later the analysis of search methods for determining of optimum point within the specified interval was carried out. The analysis has shown that the scan technique is the most preferable one with respect to the peculiarities of the optimization problem. This is due to the fact that the P_2 parameter change is of variable step type.

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