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METHOD OF SOFTWARE CONTROL OF MOTION PARAMETERS OF THE OUTPUT ELEMENT OF THE PNEUMATIC UNIT BY CHANGING THE EFFECTIVE AREAS OF CONTROL LINES

Control of position pneumatic units includes tasks of precise positioning, speed and acceleration control, as well as ensuring reliability and safety of operation. Existing control methods can range from simple mechanical solutions to complex programmable systems using modern automation technologies and intelligent algorithms. In the context of dynamically changing production requirements and the need to improve the accuracy of operations, the development and implementation of new control methods become particularly relevant. This requires a deep understanding of both physical principles of pneumatic units operation and modern approaches to automation and control of technological processes. Two available methods of program control of pneumatic unit output motion parameters exist. The first method consists of changing the effective areas of control lines, and the second – is changing the value of braking force developed by the external braking device. The first method is suggested for the open loop program-time control, as the second method will cause energy losses due to the need to work to overcome the friction force developed by the braking device. A control algorithm for a position pneumatic unit is proposed, which is a set of consecutive values of the control signal. These values are not connected with each other by analytical dependence, so the simplest way of their assignment is tabular. It is assumed that the entire set of control signal values is simply entered into the controller's memory, and at set intervals the control signal is changed according to the table. The described control algorithm is quite simple to implement. It is possible to use two methods of regulation at open-loop program-time control, depending on the type of applied distribution equipment – analog and discrete-analog. The analog method allows the setting influence to be worked out more accurately but requires more expensive hardware costs; the discrete-analog method is less accurate, easier to implement, and more reliable. The essence of the discrete-analog method of regulation consists in replacement of exact analog values of effective areas by approximate ones, which are chosen as the nearest from a limited range of values provided by discrete distribution equipment.

Keywords: position pneumatic unit, control algorithm, distribution equipment, effective area, controller, control signal.

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МЕТОД ПРОГРАМНОГО РЕГУЛЮВАННЯ ПАРАМЕТРІВ РУХУ ВИХІДНОЇ ЛАНКИ ПНЕВМОАГРЕГАТУ ЗА ДОПОМОГОЮ ЗМІНИ ЕФЕКТИВНИХ ПЛОЩ ЛІНІЙ УПРАВЛІННЯ

Управління позиційними пневмоагрегатами включає в себе задачі точного позиціювання, контролю швидкості та прискорення, а також забезпечення надійності та безпеки роботи. Існуючі методи управління можуть варіюватися від простих механічних рішень до складних програмованих систем, що використовують сучасні технології автоматизації та інтелектуальні алгоритми. В умовах динамічно мінливих виробничих вимог і необхідності підвищення точності операцій, розробка і впровадження нових методів управління стають особливо актуальними. Це вимагає глибокого розуміння як фізичних принципів роботи пневмоагрегатів, так і сучасних підходів до автоматизації та контролю технологічних процесів. Існує два доступних способи програмного регулювання параметрів руху вихідної ланки пневмоагрегата. Перший полягає у зміні ефективних площ ліній управління, а другий – у зміні величини сили гальмування, що створюється зовнішнім гальмівним пристроєм. Для розімкнутого програмно-часового управління пропонується використання першого способу, оскільки під час використання другого з'являються енергетичні втрати, зумовлені необхідністю здійснення роботи з подолання сили тертя, що створюється гальмівним пристроєм. Запропоновано алгоритм управління позиційним пневмоагрегатом, який являє собою сукупність послідовних значень сигналу управління. Ці значення не пов'язані між собою аналітичною залежністю, тому найпростішим способом їхніх завдань є табличний. Передбачається, що вся сукупність значень сигналу управління просто вводиться в пам'ять контролера, і через задані проміжки часу відбувається зміна сигналу управління відповідно до таблиці. Описаний алгоритм управління досить простий у реалізації. Можливе використання двох способів регулювання під час розімкнутого програмно-часового управління, що залежать від типу застосованої розподільчої апаратури, – аналоговий і дискретно-аналоговий. Аналоговий спосіб дає змогу точніше відпрацювати вплив, що задає, але потребує дорожчих апаратурних витрат, дискретно-аналоговий – менш точний, простіший у реалізації та має вищу надійність. Суть дискретно-аналогового способу регулювання полягає в заміні точних аналогових значень ефективних площ наближеними, які обирають найближчими з обмеженої низки значень, що забезпечуються дискретною розподільною апаратурою.

Ключові слова: позиційний пневмоагрегат, алгоритм управління, розподільча апаратура, ефективна площа, контролер, сигнал управління.

Introduction. Pneumatic units that use compressed air as a working medium play an essential role in the automation of production processes and the mechanization of various operations [1; 2]. They are widely used in areas such as assembly, packaging, material handling, and many others. The efficiency of pneumatic units largely depends on the methods used to control their positioning systems [3]. Control of position pneumatic units includes tasks of precise positioning, speed and acceleration control, as well as ensuring reliability and safety of operation [4; 5].

Existing control methods can range from simple mechanical solutions to complex programmable systems using modern automation technologies and intelligent algorithms [6; 7]. In the context of dynamically changing production requirements and the need to improve the accuracy of operations, the development and implementation of new control methods have become particularly relevant [8; 9]. This requires a deep understanding of both physical principles of pneumatic units operation and modern approaches to automation and control of technological processes.

The study of control methods for position pneumatic units is relevant due to several key factors. Firstly, with the increasing competition in the market, companies are looking to improve the productivity and efficiency of their processes. With their high responsiveness and ease of use, pneumatic units are becoming the preferred choice for many applications. However, to maximize efficiency, modern control methods must be applied to ensure accurate and reliable operation [10; 11].

Secondly, with the increasing complexity of production processes, there is a need for more flexible and adaptive control systems. Modern technologies, such as artificial intelligence and machine learning, open up new opportunities for optimizing the operation of pneumatic units [12; 13]. Research and implementation of such methods allow not only to improve product quality but also to reduce the time required to perform operations [14].

Moreover, the safety and reliability issues of pneumatic unit operations are becoming more and more relevant in light of increasing requirements for labor safety and accident risk reduction. Effective control methods can minimize the probability of errors and ensure safe working conditions.

Thus, the study of control methods of position pneumatic units is an important task that contributes to the development of automation technologies, increasing the competitiveness of enterprises and ensuring safe working conditions.

Analysis of the state of the issue. One of the advantages of open-loop control is the simplicity of design and circuit solution, which consists of the absence of the need to use feedback sensors, as well as sensor communication devices with the model of the control system. This leads to a significant reduction in the cost of the pneumatic unit design; however, the lack of feedback on position increases the error of working out the set point effect [15].

The considered approach to constructing the control system will be expedient in those cases when high requirements for the accuracy of the pneumatic unit are not imposed.

As discussed in the papers [16; 17], two available methods of program control of pneumatic unit output motion parameters exist.

The first method consists of changing the effective areas of control lines, and the second – is changing the value of braking force developed by the external braking device. Obviously, for the open-loop program-time control, the first method will be the most rational, because when using the second method, there will be energy losses due to the need to perform work to overcome the friction force developed by the braking device [9].

Main part. Let's consider the algorithm of pneumatic unit control based on program-time change of values of effective areas of its control lines. The simplified structural scheme of the unit with such a control algorithm (see Fig. 1) includes pneumatic engine 1 with inertial load 2, pneumatic engine control lines with effective areas f_1^e and f_2^e, distribution equipment 3, and controller 4.

The process of program-time control can be represented as follows: according to the program entered into the controller memory, the control signal $U(t)$ values are determined, depending on time and the computational algorithm embedded in the program. Further, from the controller output, the control signal is fed to the electromagnets of the distribution devices, which transform the control signal into values of the effective areas of the control lines, which are also functions of time $f_1^e(t)$ and $f_2^e(t)$.

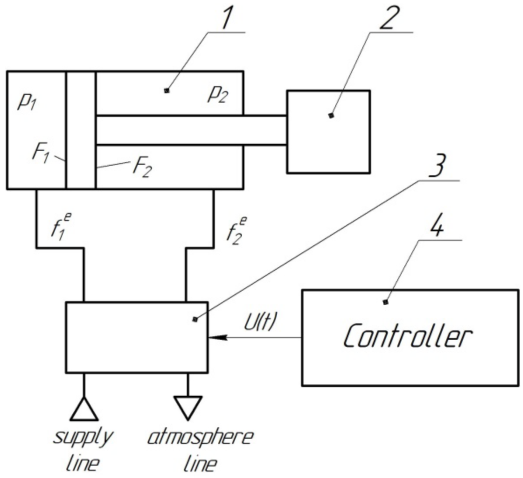

Fig 1. Structural scheme of the pneumatic unit

The input for the control system is information about the movement parameters of the actuator, and the output is a control signal.

In a control system based on a controller, the control signal is changed discretely at specified time intervals Δt_y according to some algorithm set by the designer. The following number of main factors determines the choice of Δt_y value:

- the speed of the control system model (CSM), the higher the speed of the electronic units, the smaller Δt_y can be;

- the number of operations that the controller must perform to work out a given algorithm. The simpler the algorithm, the fewer operations, and therefore the smaller the value of Δt_y can be;

- the speed of the object communication devices (OCD), the higher the speed of the OCD, the smaller the value of Δt_y can be.

To properly model an accurate scale program-controlled pneumatic unit system, it is very important to consider the distributing devices' response time or electro-pneumatic converters' response time.

Let the response time of the electropneumatic converter be equal to t_e (if there are several electropneumatic converters in the pneumatic unit system, it is necessary to take the response time of the slowest of them as t_e), and the time of performing operations of the CSM – t_m; the speed of the interface, or OCD – t_u. Then the following relations can be used to choose Δt_y:

$$\Delta t_y = t_e \text{ when } t_m + t_u < t_e; \ \Delta t_y = t_m + t_u \text{ when } t_m + t_u > t_e. \quad (1)$$

By choosing Δt_y according to (1), we consider the actual capabilities of the CSM and the actuator.

Thus, changes in the values of effective areas $f_1^e(t)$ and $f_2^e(t)$ occur discretely at time intervals Δt_y. To the above, the process of determining the control algorithm can be divided into several stages:

1. determination of the value Δt_y from conditions (1);
2. determination of the law of motion of the output link, providing the specified technical characteristics;
3. determination of the law of change of effective area corresponding to the chosen law of motion and program controllability criteria;

4. determination of the law of change of the control signal;

5. determination of the control algorithm, or program algorithm for the controller, providing the obtained law of change of the control signal.

The second step may not be necessary if the unit performs a contour control task and the motion law has already been set according to the process requirements.

In the third stage, to determine the time law of effective area change, it is necessary to use the dependencies given in paper [18], obtained for solving the inverse problem of pneumatic unit dynamics. However, since the effective area will change discretely and the time interval remains constant, it is necessary to average the obtained values of $f_1^e(t)$ and $f_2^e(t)$ when solving the inverse problem. In this case, finding the time law of change of $f_1^e(t)$ and $f_2^e(t)$ is somewhat more complicated and will consist of a sequential solution of the direct and inverse problem [19]. In this case, the direct problem is solved with averaged values over the interval Δt_y, and its solution is necessary for obtaining initial data for solving the inverse problem. After finding the law of effective area change, the law of control signal change, providing the given law of effective area change, can be found using the switchgear model [20].

Results of the analysis. In accordance with the above, a simplified flowchart of the process of determining the control algorithm can be presented (Fig. 2).

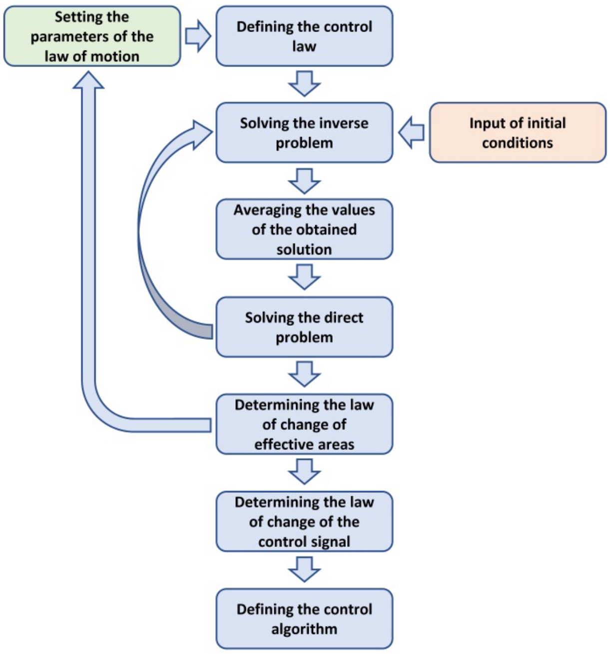

Fig 2. Flowchart for determining the control algorithm of a positional pneumatic unit

The resulting control algorithm will be a set of successive control signal values. As a rule, these values are not connected with each other by analytical dependence. Therefore, the simplest way of setting them is the tabular method. In this case, the entire set of control signal values is simply entered into the controller memory, and at specified time intervals Δt_y the control signal is changed in accordance with the table.

Conclusions. The described control algorithm is quite simple to implement. At the same time, it should be noted that there are two possible ways of regulation at open loop program-time control, depending on the type of applied distribution equipment – analog and discrete-analog.

The analog method allows the setting influence to be worked out more accurately but requires more expensive hardware costs; the discrete-analog method is less accurate, easier to implement, and more reliable. The essence of the discrete-analog method of regulation consists in the replacement of exact analog values of effective areas $f_1^e(t)$ and $f_2^e(t)$ by approximate ones, which are chosen as the closest from a limited range of values provided by discrete distribution equipment.

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