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Study of Master Controller Structure for Multiple Air Compressor System

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Abstract

Compressed air is an important medium for energy transfer in industrial processes. It drives various actuators, which create a large force for significant movements and a high operation speed. Thereat, these mechanisms are quite small, and the design is simple and reliable. They are applicable in food and pharmaceutical technologies. Compressed air systems belong to the largest energy consumers at such enterprises. They consist of several compressors, and the drive of one of them is powered by a frequency converter in order to save electrical energy. This is called a multiple air compressor system, and its operation is controlled by a separate controller – master controller. The paper discusses the results of developing the master controller design and its operation algorithm. As an additional informative signal in the developed design of the master controller, air flow rate measurements are used; additionally, the speed of the air flow rate variation is analysed.

Keywords: multiple air compressor system; compressor; compressed air; programmable logic controller; variable-frequency drive.

1. Introduction

Compressed air is an important medium for energy transfer in such industrial processes as cutting out and moulding of items out of sheet polymer and metal materials, in various food technologies for isolation valves and robotic production lines, in pharmaceutical processes. It is used in oxidation, cooling, filtering, blowing, drying, and aeration. These processes consume compressed air in large volumes, and it is generated by powerful compressor systems [1].

Compressed air generation is very energy-consuming. At European and Australian enterprises, air compressor systems consume about 10% of the enterprises' total electricity consumption, while in the US this index reaches as high as 30% [2].

A combined system of several compressors with different capacities is called a multiple air compressor system [2], [3]. A control system of the multiple air compressor system generating compressed air under the pressure of 6-8 bar powers the processing and control equipment of the above-mentioned industrial processes.

2. General description of a multiple air compressor system with a fixed rotation speed of compressor drives

The typical multiple air compressor system comprises 3-4 separate compressors with a common air receiver. They are controlled by local controllers, which implement a cascade control system [4]. The air pressure is set at a level that is higher than the consumer needs to reduce the number of starts and shut-offs of the compressors, switch-overs of the compressors from the unload mode into the load mode and vice versa and to ensure the permissible output pressure drop of the multiple air compressor system for cases of abrupt increase in the air consumption. The choice of the set point of the output air pressure of the multiple air compressor system depends on the volume of the receiver or a bank of receivers, but the receiver volume also has its optimal limits [5]. Besides, the diameter of the

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pipes along which the compressed air is transported to specific processing units or lines should also be selected to minimize friction and avoid additional pressure losses. A positive effect can also be obtained from the restriction or stabilization of the air flow rate in such periodic processes as aeration, blowing, etc.

The above-listed reasons for raising the air pressure set point above the value sufficient for powering the processing equipment are direct energy losses at the operation of the multiple air compressor system [2], in which the drives of all the compressors run at a constant rotation speed. The major reason is the first one, i.e. a higher output pressure of the multiple air compressor system is selected in order to avoid abrupt pressure drops in transient processes; this phenomenon is called the loss of control of the multiple air compressor system [3].

3. Building a control system for the multiple air compressor system using a frequency converter for powering the drive of one of the compressors

In order to increase the energy efficiency of multiple air compressor systems and ensure flexibility of control of such a system, the drive of one of the compressors is equipped with a frequency converter, while the control systems of the other units stay unchanged [6]. This engineering solution makes it possible to reduce the output pressure of the system and make it approach the value sufficient for powering the processing equipment. Control of such a multiple air compressor system is to be implemented by a separate master controller with preserved local control systems of the individual compressors, whose drives operate in a steady-state mode with a constant supply voltage frequency. In case of this solution, the energy efficiency of the system will be defined by the design and parameters of this controller, and both the design and the parameters can change during the operation.

The master controller performs the following functions:

1. Generating a set point for the frequency converter of the variable-frequency drive of the compressor.

2. Generating control signals for starts and shut-offs in the unload mode of the compressors operating under a constant load.

3. Sending control signals for switching over the running compressors from the unload mode into the load one and vice versa.

4. Correcting the set point for the frequency converter of the variable- frequency drive of the compressor at loads/unloads of the other compressors.

It is advisable to choose the design of the main controller and select the values of its parameters and time intervals for implementing the control signals, and parameters of the circuits correcting set points for the frequency converter after experimental studies, recording and analysis of the trends of variation of the output pressure and air flow rate of the operating multiple air compressor system. In the multiple air compressor system being studied, the frequency converter is installed on the compressor with the output in the nominal mode of 1100 m^3/h reduced to standard conditions and demand of 110 kW. The variation range for the supply voltage frequency after the frequency converter is selected within 25-50 Hz; thereat, the upper frequency value can be extended to 60 Hz, if there is a need to offset the outputs of the other compressors during the switch-overs.

The study established that to generate control signals, in addition to the pressure value at the output of the common receiver of the multiple air compressor system, it is advisable to use the signal of the air flow rate. In the control system of the multiple air compressor system being studied, a differential pressure flow meter was used, which ensured the desired operation speed. To minimize losses, the flow restrictor (the diaphragm) was designed for the pressure differential of 6.3 kPa for the maximum output of the multiple air compressor system, and to extend the measurement range, a differential manometer with the permissible value of the main reduced error of 0.1% was used. The flow rate measurements in this case are purely technological; they are used only for generating an additional informative signal and for relative estimation of the energy efficiency. Therefore, the flow restrictor can be designed even for a smaller pressure differential, departing from the requirements of the documents regulating restrictors' design.

4. Development of the flow diagram of the master controller of the multiple air compressor system

To develop the flow diagram of the master controller of the multiple air compressor system, a number of experimental studies were conducted [7], during which different approaches and flow diagrams for the control of this system were tested. There were analysed the trends in the variation of the output pressure of the system and in the air flow rate variation. These studies were carried out on the system that was providing compressed air for the operating industrial process [8]. This imposed certain restrictions on the experiments, especially when testing the modes that were close to the critical ones. Therefore, a priori viable solutions and flow diagrams of the master controller were tested, and this same approach was used for selecting and changing the parameters of the controller parts.

Based on these experimental studies, we proposed the final flow diagram of the master controller of the multiple air compressor system, which is shown in Fig. 1.

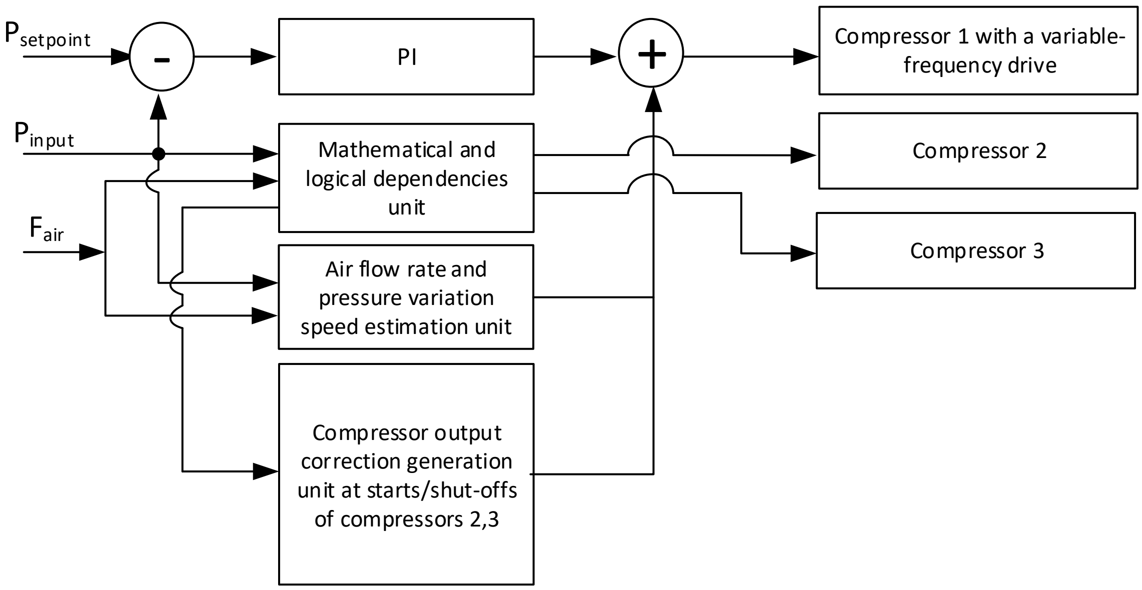

Fig.1. Flow diagram of the master controller of the multiple air compressor system

The main control circuit in this diagram is the pressure control circuit with a PI controller that generates a set point for the frequency converter of the compressor 1 depending on the set point pressure and output air pressure of the multiple air compressor system. To implement control of the compressors 2 and 3, a mathematical and logical dependencies unit was incorporated into the structure of the master controller, which, based on the signals of pressure and air flow rate variation, generates start/shut-off commands for the compressors 2 and 3 and commands for their switching into load/unload modes. It is obvious that at switching over to the load/unload modes, the PI controller will not manage to control the multiple air compressor system. This is why the design of the master controller is supplemented with two additional units: a unit of analysis of the air flow rate and pressure variation and a unit generating the compressor 1 output correction at starts/shut-offs of the compressors 2 and 3. In other words, in the proposed design of the master controller of the multiple air compressor system, the signal after the PI controller is corrected, which is the set point for the frequency controller of the compressor 1. The value of the correction, made by the unit analysing the air flow rate and pressure variation, is calculated based on the signal of the output pressure of the system and air flow rate. The correction made by the unit generating the output change at starts/shut-offs of the compressors 2 and 3 has fixed, experimentally selected values, for which the time intervals for the start and end of the correction were also selected.

5. Study of transients for a variable rate of air flow from the multiple air compressor system

The developed design and algorithm of the operation of the master controller of the multiple air compressor system were implemented on a separate programmable logic controller S7-1200. Its functions are limited to the implementation of the master controller of the system and control of the frequency converter of the variable-frequency drive and local systems of two constant speed compressors via the Profinet network.

Fig. 2 shows the transient of the output pressure control of the multiple air compressor system at the Carlsberg Ukraine PJSC, Lviv.

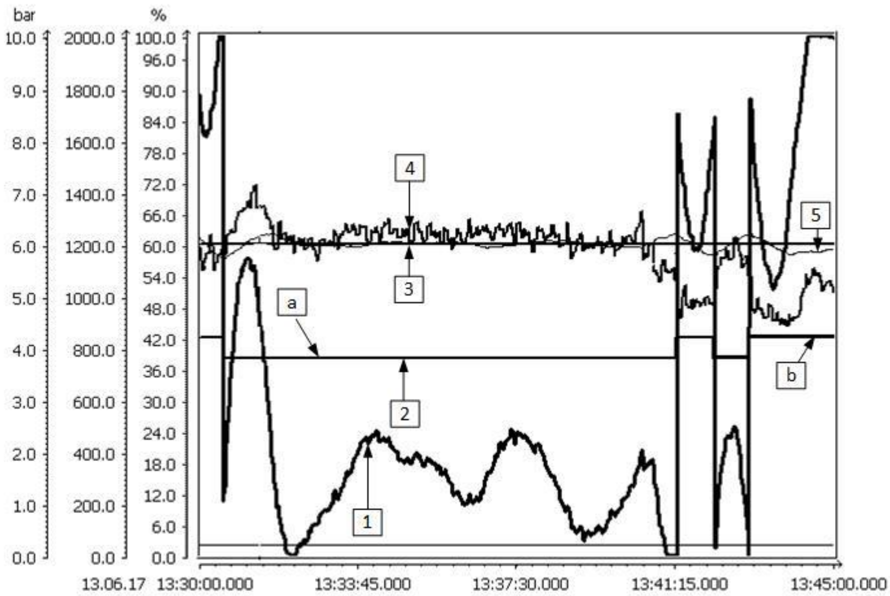

Fig. 2. Transient of compressed air output pressure variation of the multiple air compressor system vs air flow rate: 1 – set point for the frequency converter; 2 – load curve of the constant speed compressor (a – load, b – unload); 3 – pressure set point; 4 – air flow rate; 5– output pressure of the multiple air compressor system.

The transient curves show that for the variable compressed air flow rate in the industrial process, there is no loss of control of the multiple air compressor system, and the compressed air output pressure falls within the permissible variation range. It is seen that the output pressure of the multiple air compressor system is maintained at the level of the minimum permissible value for the processing equipment operation, i.e. 6 bar. This is the major factor of reducing the electricity consumption. Besides, the developed control algorithm decreases the number of short-time starts of the compressors operating with a constant output, and this raises their life and promotes energy saving. This accuracy is maintained in the load change range between 600 m^3/h and 1700 m^3/h reduced to standard conditions. When the compressed air flow rate is less than 600 m^3/h, the compressor with variable frequency drive switches to the loads/unloads mode. This is the minimum possible flow rate that this compressor can provide.

The proposed design and algorithm of operation of the master controller of the multiple air compressor system were implemented at the Carlsberg Ukraine PJSC, Lviv and have proved their efficiency for the last two years of operation.

6. Conclusion

Based on the experimental data, the structure of the master controller of the multiple air compressor system was proposed. It consists of three compressors, and the frequency converter powers the drive of one of them. The algorithm of operation of the master controller is implemented on a separate programmable logic controller, which involves an additional informative signal of the air flow rate. The operation trends of the control system of the multiple air compressor system in the real industrial process implemented according to the proposed design and algorithm of operation of the master controller were studied. Transfers factors for the correction circuits of the controller, parameters of the unit estimating the speed of pressure and air flow rate variation and time intervals for the algorithm of starting and switching over the constant speed compressors into the load/unload modes were experimentally selected.

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Дослідження структури головного регулятора мультикомпресорної установки для одержання стисненого повітря

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Анотація

Стиснене повітря є важливим енергоносієм для ряду виробництв. Вони приводять в рух різноманітні виконавчі механізми, які розвивають великі зусилля при значних переміщеннях і високій швидкодії. При цьому розміри цих механізмів відносно невеликі, конструкція проста і надійна, і вони можуть бути виконані для застосування в харчових і фармацевтичних технологіях. Системи для одержання стисненого повітря є одним з найбільших споживачів електричної енергії на таких підприємствах. Вони складаються з декількох компресорних агрегатів і привід одного з них для економії електроенергії живиться від частотного перетворювача. Така система називається мультикомпресорною установкою і її роботою керує окремий головний регулятор – мастер. Результати розробки структури головного регулятора та алгоритму його роботи розглядаються в цій статті. Як додатковий інформативний сигнал в розробленій структурі головного регулятора застосовується вимірювання витрати споживаного повітря, при цьому додатково аналізується швидкість зміни цієї витрати.

Ключові слова: мультикомпресорна установка; компресорний агрегат; стиснене повітря; вільнопрограмований логічний контролер; частотно-керований привід.