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The pneumatic and electropneumatic systems in the context of 4th industrial revolution

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Abstract. Pneumatic systems belong to the group of the oldest drives and control systems used in industry. The pneumatic drives are primarily characterized by the simplicity of construction and the good performance-to-mass ratio. Despite the fact that the generation and preparation of the compressed air is a quite energy-consuming and expensive process, the use of pneumatic systems is profitable due to the durability, the simplicity of construction and – as a result – the simplicity of servicing. The machines that are made entirely on the basis of pneumatic systems still constitute a significant percentage of all machines used in the modern industry and still perfectly fulfil their role. Their replacement is always associated with the significant costs. Taking into consideration the context of the "Industry 4.0" and the cyber-physical systems, there is the wide range of problems to discuss, concerning especially the border between the old and the new control technology. This paper addresses the problem of adapting the old pneumatic and electropneumatic control systems to the modern requirements. The basis for these considerations is the existence of some common features in the methods of describing the pneumatic or electropneumatic systems operation and in the methods of programming of the PLC-based systems.

1. Introduction

The pneumatic systems are one of the most commonly used methods of driving industrial machines. It should be mentioned that the working medium in the form of compressed air has many advantages, like for example:

- unlimited resources – the air is taken directly from the environment,
- compressed air is not contaminated when used in drives and control systems, so it can be returned directly to the environment,
- compressed air retains its properties in a wide range of temperatures, it is resistant to chemicals, radiation, magnetic and electrical fields,
- compressed air does not cause explosion hazard, it can be used in hazardous environments,
- thanks to the compressibility, compressed air can be easily stored in tanks, and the drives powered by it can be overloaded until they stop completely,
- compressed air can be used as a medium that transfers energy, as an information carrier and also as a base medium in the transport of liquids or loose solids.

The pneumatic drive has also plenty of advantages, like for example:

- good mass to efficiency ratio,
- simple construction,
- the simplicity of realizing the linear and rotational motion,
- very simple control principles,
- the possibility of achieving high speeds and torque/force.

As it was mentioned, the compressed air could be also the carrier of information, what is used in fully pneumatic-based control system. The other possibility is to use electric energy in the control system and the compressed air in actuators/motors. Such mixed approach is used in electropneumatic systems. The use of electric components opens the way for applying the programmable logic controller (PLC) that allows implementing more advanced control strategies. The block diagrams of pneumatic and electropneumatic system structures are shown in figure 1.

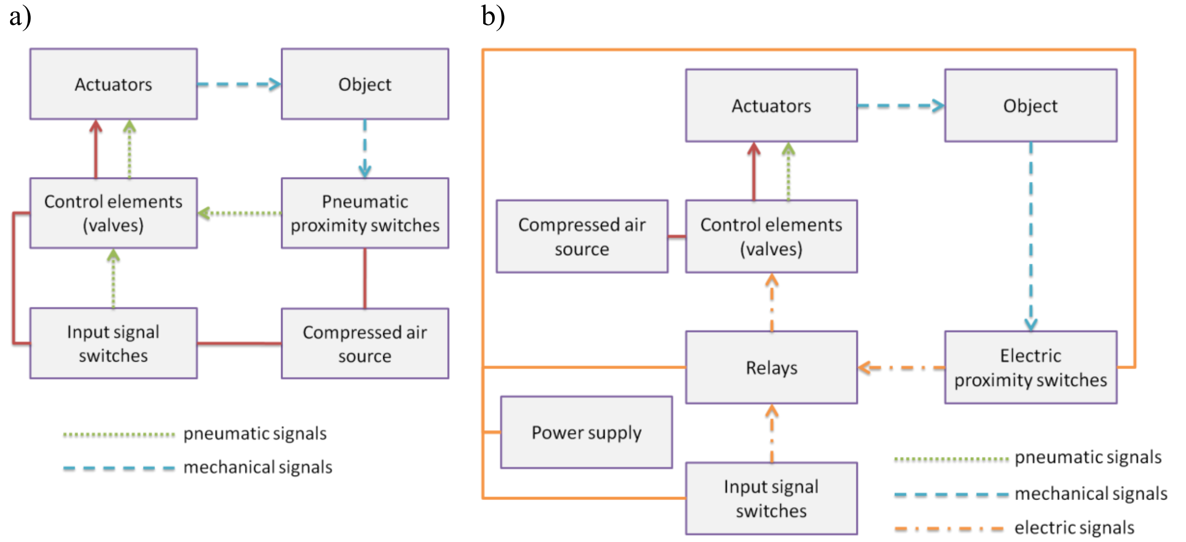

Figure 1. The structure of pneumatic system (a) and electropneumatic system (b).

The “Industry 4.0” philosophy is built on the base of cyber-physical systems (CPS). In very simple words, the CPS is a network-oriented device, equipped with actuators and sensors. Cyber-physical systems combine two layers: the physical hardware layer and the logical data layer. The data layer is associated with the virtual model of the system, so each CPS has its virtual counterpart. The term "cyber" refers to the close relationship between the physical part of the device and the computing resources. Cyber-physical systems are the base for evolution of intelligent and self-adaptive machines [1,2]. In this context, referring to older pneumatic or electropneumatic systems, it is difficult to say that they offer any computing power, even in comparison with the weakest and smallest computers. Modern electric drives often replace pneumatic elements, because of easy application and the use of the common medium for power supply and data transmission. On the other hand, there are still areas where the use of pneumatic drives is not only convenient, but sometimes also necessary. The replacement of a pneumatic system by the electric one is also expensive operation – even more expensive, when there is necessity to operate them in e.g. explosive environment.

This paper will address the problem of adapting older pneumatic or electropneumatic systems, based on a sequential control, to the requirements of a modern enterprise that implements the "Industry 4.0" philosophy. In the further part of the paper, the relationship between the description of classic, pneumatic-based or relay-based control systems and PLC-based control systems will be indicated.

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2. Cyber-physical systems

Cyber-physical systems are the core component of the "Industry 4.0" compliant manufacturing. According to Lee [3], the cyber-physical system is "*a complex engineering system that integrates physical, computation and networking, and communication processes*". The author further states that the cyber-physical system can be presented as a physical device that has its virtual counterpart in cyberspace. Using the network functions, the virtual part of the CPS can monitor and control the physical part, while the physical part provides the data necessary to update the state of the virtual model.

In order to better understand the idea of CPS, Drath and Horch [4] presented three hypotheses regarding the relationship between CPS and the Industry 4.0 philosophy. The first hypothesis concerns the availability of communication infrastructure in industrial applications. The authors predict that it will be widely implemented and will become an integral part of industrial systems. The researchers are also convinced that the development of industrial networks is proceeding naturally, without any pressure. The second hypothesis relates to the growing number of devices equipped with the possibility of network communication. As a result the information generated by them will be accessible from anywhere in the world. The last hypothesis is related to the second one, because it concerns the possibility of saving information in the "cloud". Data sent by devices to the network resources reflect the actual state of the physical object and contain knowledge about it. In this way it is possible to form the virtual identity of the particular device. In conclusion, the authors state that CPS requires the existence of three levels: physical devices, data models of the physical objects in the cloud infrastructure and services that base on the data.

2.1. The 5C architecture of cyber-physical systems

The 5C architecture of cyber-physical systems is shown in figure 2. The name "5C" refers to the five levels of the pyramid that contain the letter "C" in their names. These are respectively: Smart Connection, Data-to-information Conversion, Cyber, Cognition and Configuration levels [1,3,5-6].

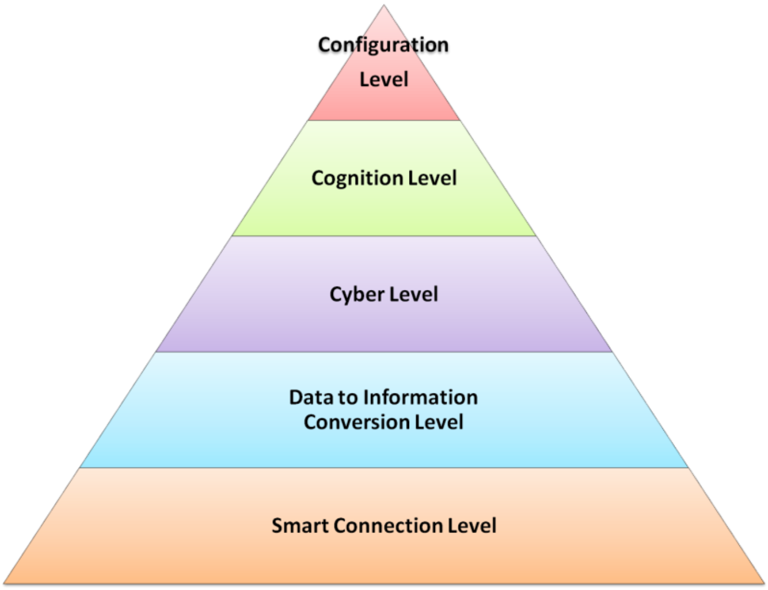

Figure 2. The 5C architecture of the cyber-physical systems [1,3,5-6].

In order, the short characteristics of the individual levels will be presented [1,3,5]:

- *Smart Connection Level* – this level is responsible for data acquisition from machine controllers, sensors, etc.; the data are sent through the network to the servers,

- *Data to Information Conversion Level* – on this level the data are analyzed and transformed into valuable information (e.g. tool degradation level, machine health, performance prediction); data mining and intelligent analysis algorithms are used,
- *Cyber Level* – here exists the virtual model of a system; the model is frequently updated on the basis of valuable information,
- *Cognition Level* – on this level the knowledge about the monitored system is gathered and presented in details; the knowledge can be used as a support for expert users during the decision-making process,
- *Configuration Level* – provides the feedback from virtual space to physical space; this feedback can be provided either by a human or a control system as a result of decision-making process, where the decisions may have corrective or preventive character.

Referring to the arrangement of individual layers of 5C architecture, some similarities to a typical system with a feedback loop can be noted. This is obviously a big simplification, due to the amount of information processed by the cyber physical system and the related computing power demand. On this basis it can be concluded that cyber-physical systems are not something fundamentally new, but they constitute an advanced development of existing technology.

3. Pneumatic and electropneumatic control systems

Pneumatic control systems usually perform simple sequences based on a cascade or chain connection of control valves and units performing the logic functions. In this manner, basic control systems are created, such as triggers, counters and shift registers. Currently, native pneumatic control has been consequently replaced by electropneumatic control systems that primarily ensure miniaturization and the possibility of using integrated circuits, what results in the possibility of building complex control systems.

3.1. Selected methods of description of pneumatic and electropneumatic systems operation

From the point of view of the use of pneumatic and electropneumatic systems to control and drive industrial machines, the most important aspect is the description of the principles of operation of a given system. Nowadays the most frequently used methods of description are:

- schematic diagrams,
- description in the symbolic form,
- the GRAFCET flow diagram representation,
- representation in the form of a graph.

In order to illustrate the selected principles of pneumatic and electropneumatic systems description, consider the arrangement shown in figure 3. The package is transported on the conveyor and then is placed on the platform. After placing the package on the platform, the actuator A moves the platform up. Next, the actuator B pushes the package to the second conveyor. Then the actuator A moves the platform down and actuator B retracts the piston rod. This sequence could be written in symbolic form as:

A+, B+, A-, B-

The actuators are equipped with the pneumatic proximity switches, respectively marked as *a0*, *a1*, *b0*, *b1*. The GRAFCET flow diagram is shown in figure 4a. Taking into account that the system can be controlled electropneumatically, figure 4b shows the corresponding schematic diagram of the electrical part of the control system.

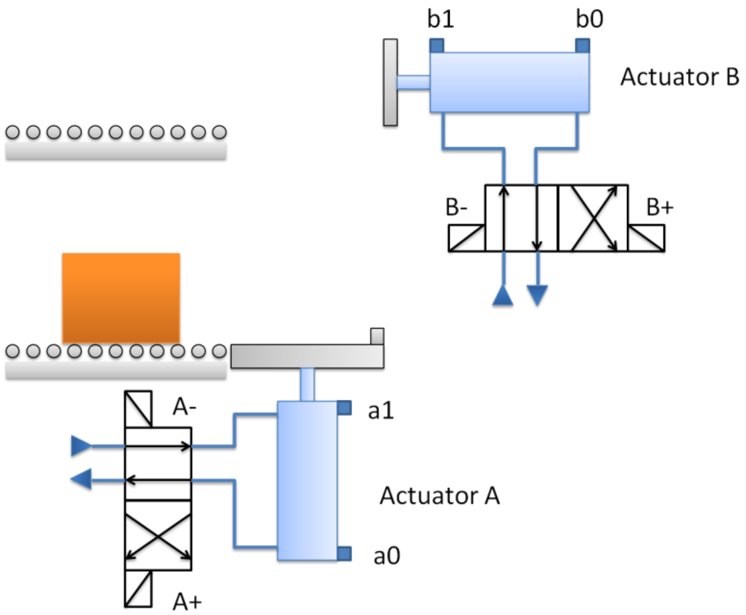

Figure 3. The analyzed system.

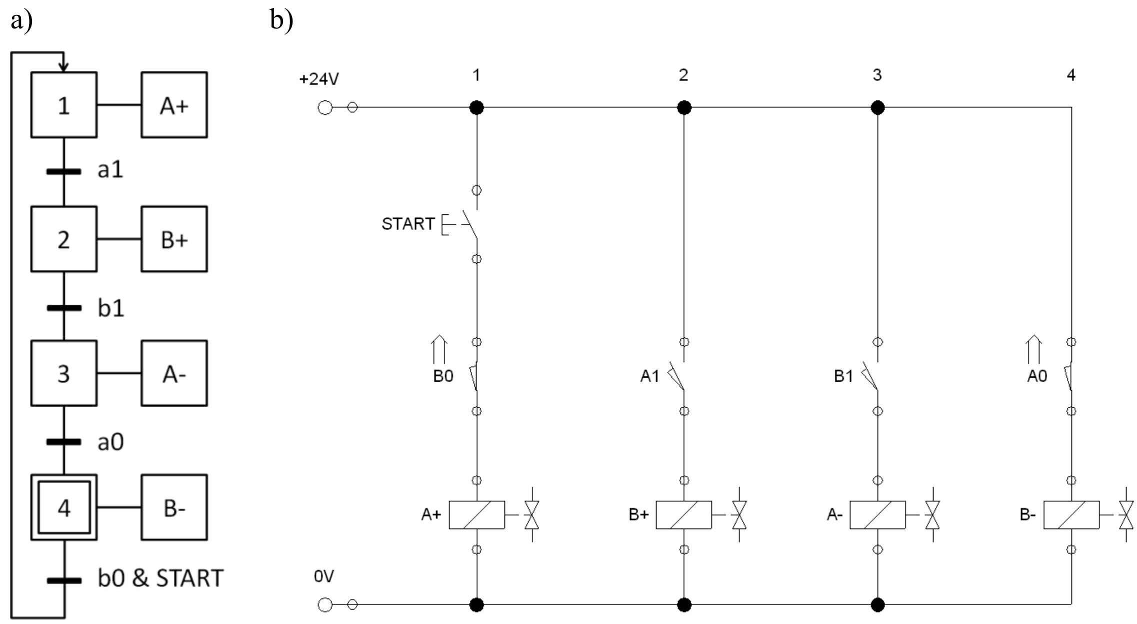

Figure 4. The GRAFCET flow diagram (a) and electropneumatic control circuit (b) of the system shown in figure 3.

3.2. The connections between GRAFCET flow diagram, schematic diagrams of the electropneumatic system and the PLC programming

Considering the presented example and the representation of its operation principle in the form of GRAFCET flow diagram and the electric schematic diagram, some similarities to the PLC programming languages could be noted.

The IEC 61131-3 standard defines the SFC (Sequential Function Chart) language as the one of the PLC programming standards. In practice, this language has the same graphical form as GRAFCET

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flow diagram. Thus, it is possible to seamlessly convert the sequence of actions realized by the pneumatic or electropneumatic system into a program for the PLC.

A similar observation can be made in context of the graphical representation of the electrical part of the electropneumatic circuit. Referring to the another PLC programming language, called Ladder Diagram, which is also defined in IEC 61131-3 standard, it must be said that it uses the same methodology for program representation as the schematic diagram of electrical part of electropneumatic control system. This is due to the fact that LD was created with the intention of easily transferring the principle of operation of relay systems to the PLC platform.

As it can be seen transferring the operating principle of a pneumatic or electropneumatic system to a PLC controller is not a problem, but it should be kept in mind that in the case of pneumatic systems, it will also be necessary to replace the sensors.

4. Conclusions

The popularity of pneumatic drives in industry still remains high. New implementations already have modern control systems that are operating on the basis of PLC and there are also components that are compliant with the "Industry 4.0" guidelines. The research are also carried out on precise pneumatic drives with high positioning accuracy [7-9] – these drives are used i.a. in pneumatic manipulators [10].

Many factories still use machines with pneumatic or relay control systems. They are fully functional, but the used control method does not allow them to operate in the "Industry 4.0" environment. The cost of replacing the entire machine is very high, but often it is possible to replace only the control system, what could significantly reduce the price. In this paper, it was pointed out that the transfer of operating principles of a given machine to the new control system based on a PLC, does not require to start writing the software from scratch, but this process could be simplified, taking into account the assumptions of IEC 61131-3 standard. For obvious reasons, the cooperation of engineers and programmers is required, but in many cases the modernization of the control system can be carried out with a lower cost than the purchase of a new machine.

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