Designing of a technological line in the context of controlling with the use of integration of the virtual controller with the mechatronics concept designer module of the PLM Siemens NX software

K Herbuś¹ and P Ociepka²
¹,²The Silesian University of Technology, The Faculty of Mechanical Engineering, The Institute of Engineering Processes Automation and Integrated Manufacturing Systems, Konarskiego 18A, 44-100 Gliwice, Poland

E-mail: krzysztof.herbus@polsl.pl

Abstract. In the work is examined the sequential control system of a technological line in the form of the final part of a system of an internal transport. The process of designing this technological line using the computer-aided approach ran concurrently in two different program environments. In the Mechatronics Concept Designer module of the PLM Siemens NX software was developed the 3D model of the technological line prepared for verification the logic interrelations implemented in the control system. For this purpose, from the whole system of the technological line, it was distinguished the sub-system of actuators and sensors, because their correct operation determines the correct operation of the whole system. Whereas in the application of the virtual controller have been implemented the algorithms of work of the planned line. Then both program environments have been integrated using the OPC server, which enables the exchange of data between the considered systems. The data on the state of the object and the data defining the way and sequence of operation of the technological line are exchanged between the virtual controller and the 3D model of the technological line in real time.

1. Introduction
The dynamic development of systems of the CAD/CAE class allows performing numerical simulations depending upon the area of the analyzed problem. The field of researches could be related with, inter alia: simulation of a movement of a technical system (kinematic analysis and dynamic one) [1-8], simulation of operation of a technical system in the context of its controlling (verification of logic interrelations implemented in the control system) [9-16], strength analysis [17-19], or analysis of vibrations occurring in the analyzed system [20].

Designing is the first stage of the design-construction-manufacturing process, which results in the form of the conception of a technical means. At this stage, with regard to the design of technological lines, the main focus is on verifying the operating of the system of the concept being developed. The operation of the system is dependent on the accepted logic of its operation. In the case of pneumotronic logic controllers, their logic is stored in the control program in the PLC controller. Therefore, to validate the operation of this class of systems is reasonable to use the mechatronic designing methodology. In this case, the process of the system designing proceeds in the context of its controlling and consists in verifying its mechatronic function. The basic elements determining the correct operation of sequential
control systems of technological lines are the drives. The choice of actuators and the clock cycle in which they operate, within the control system, depends on the description of the expected operation of the system. The expected operation of sequential systems may be presented in the form of a verbal description, symbolic one or functional block diagram. The first step of verifying the concept of the sequential control system is related with verifying the sequence of the motions performed by the drives in the context of the control process. To ensure this, one must integrate the virtual model of the control system with the real PLC controller or a virtual one. From the point of view of the virtual model of the system, it does not matter whether the control signals come from the real or virtual controller. At this stage, the geometric form of elements associated with the drive system of the designed technical system is not taken into account.

2. 3D model of a robotized technological line

In the paper is considered the sequential control system of a technological line in the form of the final part of a works transport system (figure 1). This system allows packaging and transporting the produced item to one of the two stands. In the first stand, the worker performs a manual process of picking up and storing the produced items (stand5). However on the second stand, this task is performed by an industrial robot (stand6). The storage process, using this system, is preceded by:

- the packaging process of the manufactured item in the package, which takes place at stand1,
- the process of closing and gluing the package that takes place at the stand2,
- the process of transporting the package together with the item, which is performed at the stand3 (buffer),
- the process of separating the transported component that takes place at stand4.

In this work one focused on the sequential system realizing the packaging process of produced items at the stand1. The considered stand consists of three actuators in the form of two-way pneumatic cylinders. The actuator A and the actuator C are equipped with two sensors that read the starting position and the end one of the actuator’s pistons. Actuator B is equipped with three sensors that read the starting position, the middle one and the end one of the piston of this actuator. The 3D model of the packaging stand is shown in fig. 2. The works related with elaborating the 3D model of the sequential packaging
system for verification of its mechatronic function was performed using the Mechatronics Concept Designer module of the PLM Siemens NX system.

In the module were defined the following types of objects:

- **“Basic physics”** – these components include 3D models of components with respect to which the physical properties are assigned (e.g.: piston and piston-rod of the actuators). Whereas one element may consist of any number of components that do not change their position relative to each other during movement;
- **“Joints and constraints”** – these objects determine the allowed path and range of moves for object of the “basic physics” type;
- **“Sensors and actuators”** – objects of the “sensors” type record the position of moving objects of the “basic physics” type, while objects of the “actuators” type determine the motion parameters (speed, displacement) of the objects of the “basic physics” type according to the relationships defined in the objects of the “joints and constraints” type;
- **“Signals”** – these objects are the source of information about the state of the system derived from the objects of the “sensors” type and determines the operation of the system;
- **“Operation”** – these objects initialize the movement of the objects of the “basic physics” type according to the relationships defined in the objects of the “joints and constraints” type with assumed parameters of the objects of the “actuators” type.

3. Determining the clock cycle of work of the sequence control system using the algorithmic method

The algorithmic method supports the process of designing the pneumatic and electropneumatic sequential control systems. This method can also be adapted for the design of electropneumatic systems with PLC controllers (pneumotronics). It was assumed that the analyzed subsystem carrying out the packaging process operates according to the following symbolic description:

\[ S\pm, A+, A-, C+, B+, C-, B-, C-, B+, C- \]  

where:  
\( S\pm \) - press the start button,  
\( A+, B+, C+ \) - start of the actuatorA, actuatorB, actuatorC,  
\( A-, B-, C- \) - return of the actuatorA, actuatorB, actuatorC.
According to previous assumptions in the virtual driver environment (FluidSIM) was created the virtual model of the designed control system (figure 3a). This model includes three actuators in the form of double acting cylinders, three adjusting elements: 4/2-way solenoid impulse valves and 4/3-way solenoid impulse valves, six control elements in the form of one-way flow control valves and a source of compressed air. At this stage of the design, the developed model is used to verify the logic of operation. Therefore all actuators have the same features and parameters (stroke – 100 mm, diameter of piston – 25 mm, diameter of piston-rod – 10 mm). The value of the working pressure of the control system was established on 0.6 MPa, and the air flow intensity is equal to 50 l/min.

Basing on the symbolic description of the expected operation of the system, a signal flow graph was created (figure 3c). Basing on the signals flow graph was developed the operation logic of the sequential control system (Fig. 3d). The sequence of operation of the control system, basing on the developed logic

**Figure 3.** Description of the action logic of the sequential control system.
of operation, has been verified on the basis of the obtained cyclogram of work (figure 3b). The obtained cyclogram reflects the symbolic description of the expected operation of the analyzed control system.

4. Integration of the virtual controller with the Mechatronics Concept Designer module of the PLM Siemens NX software

The OPC server was used to integrate the elements of the virtual 3D model of the packaging subsystem with the virtual controller. The OPC server allows exchanging information between the Mechatronics Concept Designer module of the PLM Siemens NX software and the FluidSIM software. It was distinguished two types of data: data on the state of the object from the sensors located in the 3D model of the technological line, which are transmitted to the virtual controller (PLM Siemens NX → virtual controller) and data defining the way and sequence of action of the technological line, which is transmitted from the virtual controller to the 3D model of the technological line (virtual controller → PLM Siemens NX).

![Diagram](image)

**Figure 4.** Integration of the 3D virtual model with the virtual controller with use the OPC server.
In figure 4 is shown the diagram of the relationship between the integrated programs. Forwarding information about the state of the control system (positions of actuators) to the OPC server is done by the components of the “signal” type named: “start_position” of the A, B, C actuator, “middle position” of the B actuator, “end_position” of the A, B, C actuator and “presence_of_object” (the components of the virtual 3D model). Then this information is passed to the virtual controller via the component “FluidSIM Input Port” to the components A0, A1, B0, B1, B2, C0, C1, A00 (the components of the virtual controller). The data defining the method and the sequence of operation of the sequential control system are transferred from the virtual controller to the OPC server using the component “FluidSIM Output Port” by the components A+, A-, B+, B-, C+, C- (the components of the virtual controller). Then data is transferred to the virtual 3D model using the components of the “signal” type named A_Plus, A_Minus, B_Plus, B_Minus, C_Plus, C_Minus (the components of the virtual 3D model). All components of the “signal” type were defined as variables of the “bool” type.

Table 1. Basic parameters of work of the control system.

| Parameter                                | Value     |
|------------------------------------------|-----------|
| Diameter of piston of A, B, C actuators  | 50 mm     |
| Diameter of piston rod of A, B, C actuators | 20 mm   |
| Stroke of A actuator                     | 800 mm    |
| Stroke of B actuator                     | 900 mm    |
| Stroke of C actuator                     | 400 mm    |
| Mass of the shifted element              | 0.5 kg    |
| Working pressure                         | 0.6 MPa   |
| Air flow intensity                       | 50 l/min  |

Basing on the developed method of integration, a series of numerical analyzes were carried out related with the verification of the performance of the packaging subsystem in the control of its controlling. The simulations allowed selecting the basic parameters for the actuators of the proposed system, which are presented in table 1. The value of parameters also depends on the geometrical form of the technological line subsystems with which the proposed system interacts.

5. Conclusion
The elaborated method of integration of the virtual model of the technological line, which is prepared in the PLM Siemens NX system, with the virtual controller, allows verifying the mechatronic function of the system.

The algorithmic method of designing the sequential control systems allows determining the logic of pneumatic, electropneumatic and pneumatomic control systems. The utilization of this method allows studying the operation of the 3D model of the control system without the need for using control and setting elements, as the operation of the setting elements is stored within the control program structure while the operation of the control elements is stored within the logic components of the 3D model.

The Mechatronics Concept Designer module of the PLM Siemens NX software enables the preparation of a 3D model of the control system to simulate its operation both in the context of the part assembly and control.

The method, proposed in the work, of integrating a virtual controller with a virtual 3D model of the designed technological line enables to conduct the process of concurrent designing of technical systems taking into account their control procedures.
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