Automated Commissioning of Pneumatic Systems

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A significant part of the costs of a pneumatic motion in a machine is caused by commissioning. Today every cylinder chamber needs to be connected by tube to the exactly right port of the valve terminal. In this paper a new concept for commissioning pneumatic systems is presented, where the tubes can be plugged in any arbitrary port of the valve terminal. So the commissioning can be fastened – and money can be saved. The concept bases on the Festo Motion Terminal, a new valve terminal whose valve slices can exercise different valve functions. The functionality change is made only by software. This versatility can be used for the automated commissioning.

Keywords: Commissioning, Digitalisation, Business Model
Target audience: Pneumatics, Special machinery

1 Motivation

The commissioning of pneumatic drives as part of a machine or plant is in general a very simple process. The technician needs to connect a defined cylinder chamber to a defined port of the valve terminal with a tube of an adequate length. Nevertheless in reality this is a complex and difficult process. There can be lots of tubes, they are often not marked and all look the same. Sometimes the tubes are very long, they are channelled e.g. in energy chains, they are bundled together or they run all cross the machine. In such cases it is very difficult to answer the question: Which tube belongs to which port (compare *Figure 1*)*?* Thus the commissioning of pneumatic drives is a time consuming process which causes substantial costs.

The idea behind this paper is to simplify and shorten the commissioning process. Our goal is: Each tube coming from the cylinders can be connected to any arbitrary port of the valve terminal. After that the valve terminal will start an identification process, which valve port is connected to which cylinder chamber. So we are allowing a "chaotic" hardware installation of the tubes and clear it up later by software.

Figure 1: Which tube belongs to which port? [Source Dürr]

Basis of this new, patented /1/ commissioning technology is the Festo Motion Terminal VTEM, which is described in chapter 2. In chapter 3 the basic concept of the automated commissioning process is presented. The total process from planning to operation of the pneumatic system is described in the following chapter 4. The verification of the developed automated commissioning process is shown by a dynamic demonstrator (chapter 5). The paper ends with a summary and a conclusion in chapter 6.

2 Festo Motion Terminal and its suitability for automated commissioning

The principle of the new commissioning technology bases on the functionality of the Festo Motion Terminal (*Figure 2)* - a new valve terminal with the maximum of eight valve slices with two working ports each. The control edges on the valve slices are not coupled, this means every valve slice comprises two 2/2- ventilation valves and two 2/2- exhaust valves which are arranged to a pneumatic full bridge (*Figure 3)*. Each 2/2-valve has two Piezo-proportional valves as pilot-stage. In combination with an integrated pressure sensor the pressure on each working port can be controlled in closed loop. The proportional functionality is helpful for the automated commissioning because different cylinder sizes can easily be controlled by one valve size and the pressure signal can be used for the identification of the tubes.

Basic idea of the Festo Motion Terminal is to realize different valve functions with the same valve slice. On conventional valve terminals, there are used different valve slices (e.g. 4/2-valves, 5/3-valves, …) which are selected for a specific task. This hardware complexity is reduced by the Festo Motion Terminal. There is only one type of valve slice – which can realize all the different functionalities only by software changes. This basic idea is also very helpful for automated commissioning, because it is not necessary to select a defined valve type to control a specific cylinder in advance.

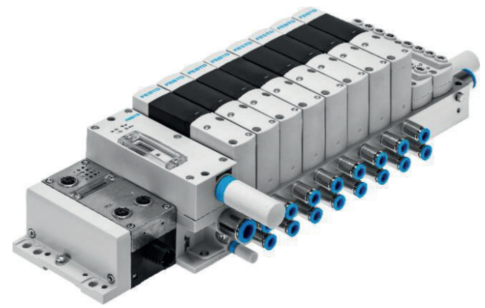


Figure 2: Festo Motion Terminal VTEM

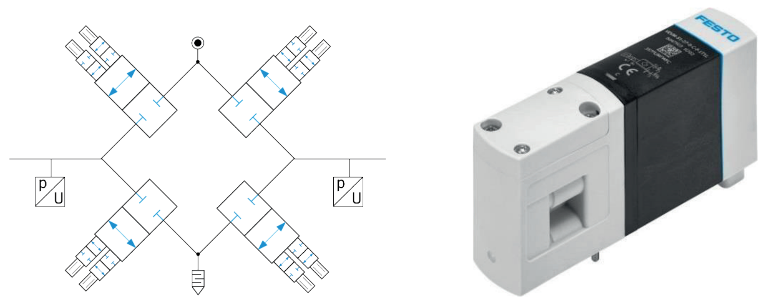


Figure 3: Circuit diagram of a valve slice of the Festo Motion Terminal

Aiming to connect each tube to any arbitrary port of the valve terminal another benefit of the circuit configuration of the Festo Motion Terminal needs to be used. The pneumatic full bridge can be divided into two independent half bridges. For the movement of the pneumatic cylinder it is not necessary that his ports are connected to the two half bridges of the same valve slice. The cylinder can be connected to the two half bridges of different valve slices – as long as this information is considered in the control strategy. It is basic principle of the Festo Motion Terminal that every half bridge on every valve slice is identical – so there is a free choice where to connect the different cylinder chambers (compare *Figure 4)*.

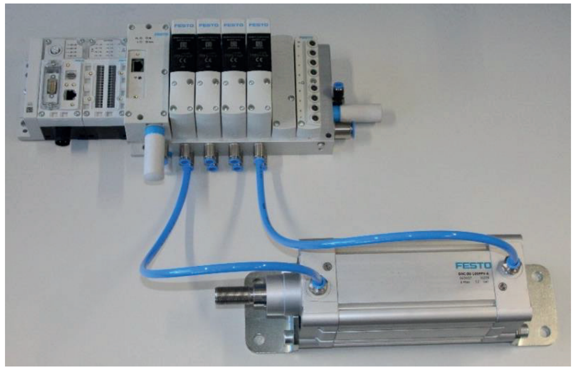


Figure 4: Pneumatic double acting cylinder connected to halve bridges of different valve slices

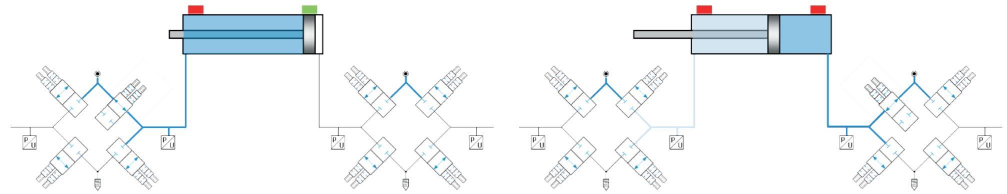
3 Basic concept of the automated commissioning process

For comprehensibility reasons in this chapter the basic concept of the automated commissioning process is described by the example of a double acting cylinder. But certainly, the process also works with single acting cylinders, vacuum generators, rotary indexing tables, … The only requirement is, that the ventilation of a valve port results in a reaction of an actuator, thus a measurable signal change of a connected sensor is generated (e.g. end-position switch, position sensor or vacuum switch).

In the starting situation, the pneumatic system is in a defined state. At both end positions of every cylinder there is an end-position switch mounted which is ready for operation. Every cylinder is placed in one of his end positions, thus the corresponding end-position switch is activated. All cylinder chambers are exhausted and all four 2/2-way-valve of every valve slice are closed.

Then the first ventilation valve is activated, thus a rise of pressure in one cylinder chamber occurs. Then there are two possibilities.

- The pressure pushes the piston further into the end position (case A in *Figure 5*). After a while the total system pressure is reached in the cylinder chamber. In this case the cylinder chamber cannot be identified during this step, because there is no change in state of an end-position switch. Thus the valve port is exhausted again and the process goes on with the next valve port.
- The cylinder starts to move (case B in *Figure 5*). When the cylinder has left the end position, the corresponding end-position switch will change his state from activated to deactivated. This means: The connection between cylinder chamber and valve port is identified. During the further cylinder movement there will be a rise of pressure in the second cylinder chamber. Depending on cylinder size and tube length and diameter this rise of pressure will be smaller or larger. When it is large enough, that it can be measured by the pressure sensor of the second connected half bridge, the cylinder is completely identified. When it is too small, the second end position will be reached. Thus the second end-position switch is activated and the cylinder is in a defined state again. After that the valve port is exhausted and the process goes on with the next valve port.



case A: no cylinder movement   case B: cylinder moves

Figure 5: Identification of cylinder chamber connections by ventilating valve ports sequentially

When every half bridge was pressurized once, every cylinder has been moved. Then some (or all) cylinders are fully identified and some (or all) cylinders are in the second end position. When all not identified valve ports are again ventilated sequentially according to the described process, after a second round all cylinders are fully identified.

In reality the process can´t be as simple as described with the basic concept. In the following sub-chapters the three main challenges of identification the connection between cylinder chamber and valve port and how to solve them are described. These are possible collisions between cylinders or components mounted to them (chapter 3.1) gravity and/or process forces pushing back the cylinder (chapter 3.2) and delayed movements e.g. generated by friction or adhesive effects (chapter 3.3).

3.1 Challenge collisions

An essential requirement for an automated commissioning process is, that the machine and it´s components is not damaged during the commissioning process. So it must be ensured, that the cylinders cause no collision when they randomly move out. Thus the commissioning engineer needs to guarantee, e.g. by fixing add-on parts later or not mounting the cylinder in his final position, that every cylinder is able to fulfil at least a partial stroke without causing a collision. In *Figure 5* an example is given. When cylinder A is in the extracted position, cylinder B is not allowed to make a full stroke, this would cause a collision. The commissioning system can stop the movement of cylinder B by exhausting the cylinder chamber immediately, when the corresponding end-switch is deactivated. Then the cylinder movement will stop after a while (partial stroke). To avoid collision every cylinder must be able to make such a small, partial stroke.

To stop the cylinder movement in a middle position is not possible in in every case. It depends on the respective application, if a partial stroke is possible. For cylinders which long strokes it is easier, also a small death volume (short and small tubes) compared to the cylinder volume is helpful.

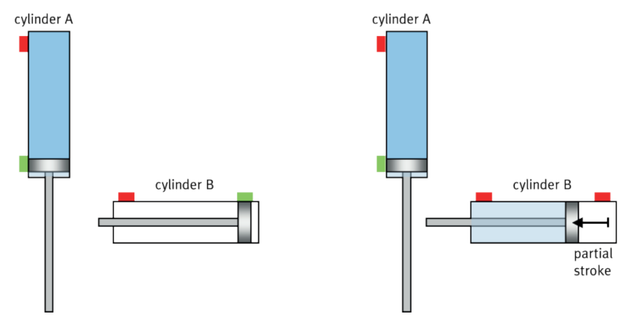


Figure 6: Avoiding a possible collision by using a partial stroke

For an efficient commissioning process the usage of the partial stroke should be reduced to cylinders, where it is really necessary. Thus it is helpful to know, under which conditions (positions of the other cylinders) a collision may occur or vice-versa a full stroke is allowed. These information must be extracted from planning data, thus the Festo Motion Terminal needs access to a defined description of possible collisions.

3.2 Challenge gravity and/or process forces

In the description of the basic concept, the double acting cylinder is mounted in horizontal position and no other forces are acting on him. Thus the cylinder will be stable when he reaches the second end position or stops for a partial stroke (compare chapter 3.1) and the cylinder chamber is exhausted. These conditions are certainly not always given in reality. When the cylinder is in a vertical position, a mass is mounted or process forces are acting on the cylinder, a stable position is not guaranteed any more.

The first step to handle this challenge is to detect it. This can be done by using waiting times. When a cylinder has reached the second end position and the cylinder chamber is exhausted it is helpful to wait a few seconds, if the end position is left again. Also when a partial stroke was executed a small waiting time is needed to look, if the cylinder is pushed back to the end position.

When such a push back caused by gravity and/or process forces is detected, the second step is to compensate it. To hold the cylinder in the second end position the pressure control of the Festo Motion Terminal can be used. The pressure in cylinder chamber can be controlled in closed loop to compensate the gravity and/or process forces. Because the cylinder should move when his second chamber is vented during the commissioning process it is advisable to have a low pressure in the first chamber. So a stepwise approach is recommended: Set a defined pressure, detect if the cylinder is still pushed back and if necessary enlarge the set pressure.

When a push back in a partial stroke situation should be compensated it is better to enclose an amount of air in the pressure chamber and not to use the pressure control in closed loop. Because a small movement of the piston results in pressure changes, which are directly compensated by the pressure control. Thus a continuous movement of the cylinder may happen. When the cylinder chamber is enclosed, small vibrations in the cylinder position will not lead to a continuous motion.

3.3 Challenge delayed movements

Due to friction and/or adhesive effects, the reaction of the cylinders to pressure changes can be delayed. An illustrative example is a vertically mounted cylinder which is loaded with a small mass. The lower position in the first end position is stable. After the movement into the second end position and the exhaust of the cylinder chamber the piston may stick on the end cap of the cylinder. This effect could be a combination of sealing friction on the one hand and adhesive forces between piston and end cap on the other hand. After an unpredictable while this cylinder may start to move, e.g. caused by vibrations resulting from the movement of another cylinder. This can lead to an incorrect assignment because the inflating of the second cylinders triggers two signal edges.

Another example for delayed movements is a cylinder which fulfilled a partial stroke. Then the piston is somewhere in between the end positions and the gravity forces, friction forces and pressure forces from the enclosed amount of air are balancing each other. Due to leakage the pressure in the enclosed cylinder may drop, thus the force balance is disturbed and the cylinder starts to move – at an unpredictable time. This can lead to an incorrect assignment as well.

To solve the challenge of delayed movements there are two steps advised. The first step is to monitor, if two or more edge signals from end-position switches or other sensors occur after venting a cylinder chamber. This should be taken into account in the commissioning strategy.

The second step is to implement control loops. When a cylinder is fully identified, it can easily be tested if the two chambers are really belonging to the same cylinder. Especially when different time intervals are used a reliable verification of a correct assignment can be ensured.

4 Automated commissioning process

In chapter 3 the basic concept of the automated commissioning process as well as challenges during identification were described. In this chapter the perspective should be widened. This is necessary because the total automated commission process needs to comprise more than the identification. The total process can be divided in 4 steps, which are described below.

1. Preparation
2. Identification
3. Verification
4. Reconfiguration

During the **preparation process**, there are several tasks to be fulfilled by the commissioning engineer.

As a matter of course it needs to be guaranteed, that nobody will be harmed or endangered during the commissioning. Because the cylinders move randomly a special attention needs to be given to safety aspects.

To avoid collisions and mechanical damages to cylinders, add-on parts or other components (compare chapter 3.1) the system needs to be prepared. Therefore the mechanical engineer needs to ensure, that every cylinder can make at least a partial stroke without causing a collision. This can be done e.g. by fixing add-on parts after the identification process or even mount the cylinders later. It also can be an option, to limit the cylinder stroke mechanically, so that not a full stroke but a predefined partial stroke to a temporary end-position is done.

As described in chapter 3, before the identification process starts, the system must be in a defined position. This means, the commission engineer has to mount the end-position switches mechanically and electrically and put them into operation. Further one every cylinders must be moved in an end position. This means, the corresponding end-position switch is activated.

Finally the Festo Motion Terminal needs access to the planning data. Which type of cylinders (single acting, double acting) are in the system? Which sensor (end-switch) signal belongs to which cylinder chamber? Which cylinders are allowed to make a full stroke or might cause a collision?

And certainly the commissioning engineers needs to connect the pneumatic tube to the valve terminal. Therefore – and this is the main idea – it is not necessary to choose a predefined valve port. The tubes can be plugged in any port of the Festo Motion Terminal. Unused ports needs to be locked.

Before the **identification process** starts, the commissioning engineer needs to confirm, that he has finished the preparation process successfully. In detail he needs to confirm the following three questions:

- Are all unused ports closed?
- Are all cylinders allowed to do a partial stroke?
- Are all cylinders in an end position?

Then the sequential ventilating of the ports of the Festo Motion Terminal as described in chapter 3 can be started. At the end there is an internal list stored in the Motion Terminal, which valve port is connected to which cylinder chamber.

As explained in chapter 3.3 it is helpful to verify the identification results in a **verification process**. Before the total system is finished and the preconditions like ‘every cylinder can make at least a partial stroke without causing a collision’ are not fulfilled anymore it should be checked that no wrong mapping has happened. This could for example be done by actuating all cylinders one after another.

The last step is the **reconfiguration process**. The user don´t want to deal with the identified connections between half-bridges and cylinder chambers. His PLC-programming must be limited to “extract cylinder A” and “retract cylinder C”. During the preparation there is a chaos in tubing allowed. The firmware on the Festo Motion Terminal untangles this chaos. Only this reconfiguration generates an added value to the customer.

A further subtasks of the reconfiguration is to save the results of the identification process stable and long lasting, both for the standard pneumatic movement as well as for the Motion apps of the Festo Motion Terminal /2, 3/. After a restart, after a power failure or after whatever it needs to be guaranteed, that the system can start immediately. In every case it must be prevented, that the automated commissioning process must be repeated, because the preparation process is very complicated when the system was finished once.

Last but not least the firmware needs to be prepared for system changes in the future. It is necessary, that the maintenance staff has access to the results of the identification process, can make changes and use it for documentation purposes.

5 Dynamic demonstrator automated commissioning

To prove the functionality of the described automated commissioning process a demonstrator was build up which is shown in *Figure 7*. On the left side of the display a Festo Motion Terminal with eight valve slices is fixed – thus 16 half-bridges can be used. The pneumatic system is placed on the right side of the display. It consists of different single and double acting cylinders in vertical and horizontal mounting position. To show, that the concept is not limited to cylinders, furthermore a rotary indexing table, a pneumatic gripper and a vacuum cup with vacuum generator is integrated. All these components build a dummy process that transport a plastic workpiece from a start position to an end position.

Figure 7: Dynamic demonstrator automated commissioning

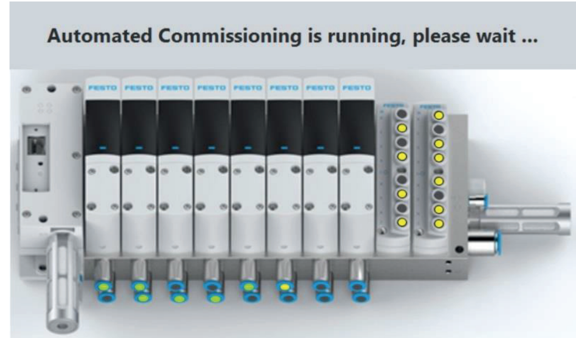


Figure 8: Visualising the identification progress

The conditions for the dynamic demonstrator are a little bit different to a real production process. To demonstrate the automated commissioning the tubes needs to be reordered very often. The tubes, as well as the fittings were not constructed for frequent connecting and disconnecting. That´s why in the demonstrator all tubes are bundled together and are connected to an array of safety couplings. The array is placed in the lower left part of the display behind a safety door. So the user of the dynamic demonstrator can change the connection between valve ports and actuators as desired.

A screen is used to inform about the identification process. On the first slide the user gets about the three questions presented, which describe the preparation process (compare chapter 4). By pressing a button the automated commissioning is started, the progress is shown by green and yellow points on a picture of the Motion Terminal (compare *Figure 8*). When the identification process is finished the dummy process can be started by pressing a button. A successful run of the dummy process, thus if the workpiece can be transported to the target position, verifies a successful identification.

6 Summary and Conclusion

In this paper an idea to automate the commissioning process of pneumatic systems is presented. It bases on the functionality of the Festo Motion Terminal and allows to plug each tube coming from cylinders and other pneumatic actuators to any arbitrary port of the valve terminal. Then an automatic identification process is started, who identifies the chosen connection. The presented process will probably not work for every pneumatic system or machine. But in many cases it opens a chance to reduce the costs of commissioning. It is easier, when tubes are shorter and cylinders have a longer stroke. Also a system with less possible collision is simpler to handle.

The functionality of the automated commissioning process was proven by a dynamic demonstrator. Thus the basic principle is working. But to solve real application there are still some open questions. For example, how to deal with documentation requirements? Or how to transfer the connection flexibility to a circuit diagram. Beneath this more administrative points there are also more technical issues open. For instance, how to deal with many pneumatics tubes? If two or more Festo Motion Terminals are needed: How can the identification process as well as the operation be realized then?

References

/1/ Gauchel, W., *Pneumatisches System und Verfahren zur Inbetriebnahme eines pneumatischen Systems*, patent specification, DE 10 2015 219 164, 2015.

/2/ N.N., *Digital simplicity: Festo Motion Terminal VTEM*, Product Brochure Festo AG & Co. KG, 2017.

/3/ N, N., *Festo Motion Terminal*, http://www.festo.com/motion-terminal, visited on July 28, 2017.