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Trends in pneumatics – digitalization

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Abstract The paper presents an overview of the latest technology trends in pneumatic automatization at Festo, focusing on digitalization from a component to a system level. The Festo Motion Terminal (VTEM) is valve terminal, designed for digitalization. Unique valve unit design allows valve functions to be defined by a software and to be changed in a running system very quickly, even on the fly. Model based applications on a valve controller offer many advanced functionalities such as: pneumatic servo positioning, force and torque control of pneumatic drives and pressure or flow regulation in pneumatic systems. VTEM native connectivity with higher order controllers adds a possibility to seamlessly integrate it on all levels, from the field to the cloud. User control logic and/or AI algorithms in a combination with digitalized pneumatics allows new services, such as: auto-commissioning, predictive maintenance, increased energy efficiency, automatic leakage detection within pneumatic systems and many others.

Keywords: • digitalization • festo motion terminal • mechatronic • pneumatics • Industry 4.0 •

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1 Introduction

Digitalization is changing the world; it is penetrating into all aspects of our lives and data is its propellant. Industry has a great potential to benefit from digitalization with clear goals such as: seamless connectivity, increased modularity, higher machine output and productivity, predicting incidents before they happen, predicting and optimizing quality of the produced products, predicting, and minimizing energy losses, preventing machine downtimes due to wear of components.

Modern mechatronic solutions for Industry 4.0 consume raw sensor data and turn it into valuable information. This process is utilized by physical models, AI or combination of both. Transition from a product to a solution requires much more than just analyses of the raw data acquired form the sensors. Data must be interpreted within all possible aspects, that might have an influence on a process. Interconnectivity, interoperability and flexibility of devices and services on a whole scale is a key factor to success.

State-of-the-art hardware for industrial applications should be designed according to the statements listed above.

2 Digitalized pneumatic valves

Introducing piezo technology in pneumatic valves has opened new potentials in design and control, where traditionally solenoid valves were dominant. With clear advantages over the existing technology, such as small footprint, low energy consumption, high switching speed, proportional behaviour, long service life and low cost makes piezo valves ideal for integration as an active drive component in pneumatic valves and valve terminals.

2.1 Piezo element as a bender actuator

Piezoelectricity is a physical phenomenon where materials such as certain crystals, ceramics, polymers, and some biological structures generate measurable electricity when exposed to mechanical strain. The process is reversable, which means that piezoelectric structures deform, when a voltage is applied. This principle is known as inverse piezoelectric effect and is a general principle of any piezo electromechanical transducer. Piezo transducers that generate mechanical motion or oscillations under applied voltage are also known as piezo elements (Figure 1).

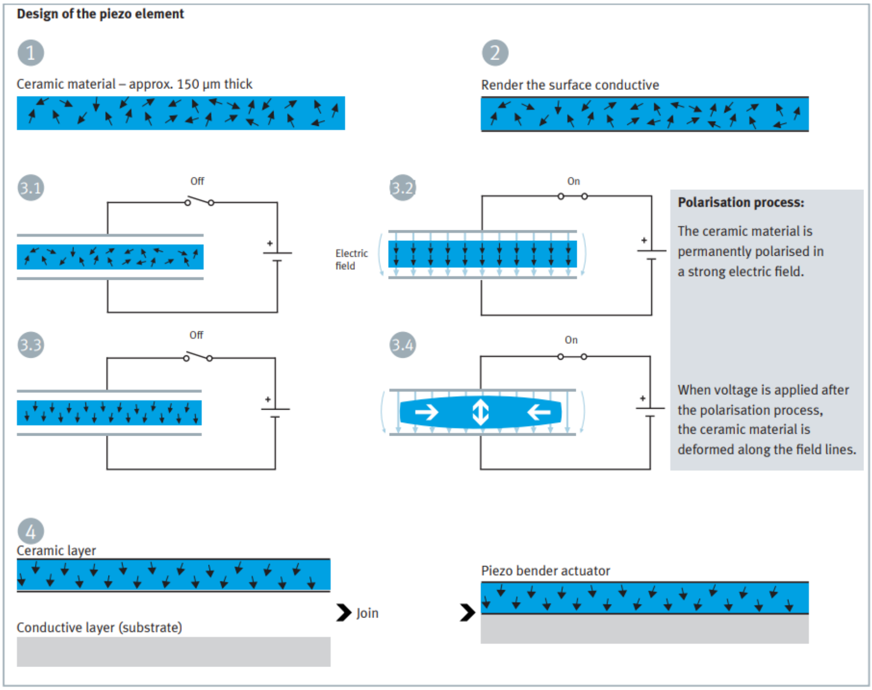

Figure 1: Design of the piezo element [1].

Piezo bender actuator is the fundamental component of a 2/2 piezo valve (Figure 2). When a voltage is applied, the piezo element bends due to a reduction in longitudinal direction, consequently opening a channel for gas medium to flow from inlet towards outlet pneumatic port.

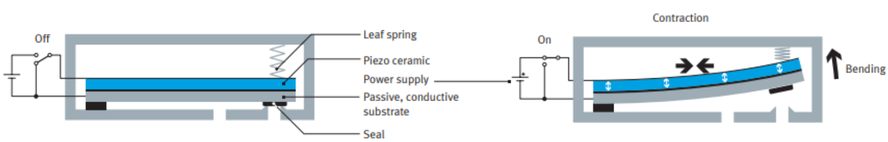

Figure 2: Function of the bender actuator in the piezo valve [1].

Piezo valves are proportional by its design. The more voltage is applied to the bender actuator the wider gap is established between both ports and the bigger medium throughput is established. Compared to solenoid valves, piezo valves need no holding current to maintain a switching state. The higher supply voltage required by piezo valves in comparison with solenoid valves is of significance only during the switch-on phase. Even then, the switch-on energy consumed is well below the actuation power levels normal in pneumatics.

Piezo transducers are like capacitors from an electrical point of view, energy is needed only in charging phase. Thanks to their capacitive principle, piezo valves require virtually no energy to maintain an active state.

Since ultimately all pneumatic processes in an application are analogue, this is an unbeaTable advantage: there is no need for pulse width modulation and the associated noise problems as a means of trying to achieve a certain proportionality when switching solenoid valves. This means that piezo valves are very resistant to wear and need only minimal energy input. Combined with their short response times, the proportionality of piezo valves makes them ideal actuators for all higher-level control systems [1].

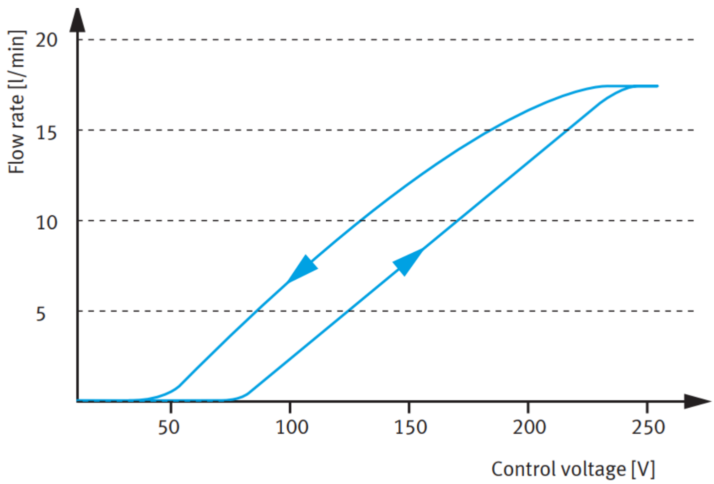

Figure 3: Flow rate as a function of applied voltage in piezo valves – proportional characteristic with hysteresis [1].

2.2 VTEM Motion Terminal – hardware overview

In 2019 company Festo SE & Co. KG introduced VTEM - the pneumatic cyber-physical automation platform (Figure 6). VTEM is a valve terminal with configurable proportional valves, integrated sensors, bus connection and a controller with software-based pneumatic functions [2], [3]. A single unit could cover functionality of more than 50 different individual pneumatic components including more complex modules such as: flow control valves, directional control valves, proportional regulators.

Pneumatics, sensors, electronics, and software are all integrated on a single piece of hardware, which enables development of advanced applications and services like pneumatic motion, preventive maintenance using condition monitoring, energy efficiency with leakage detection and many others [4].

Every valve unit on Motion Terminal consists of four 2/2-way diaphragm poppet valves, connected in series to form a full bridge. Each of 2/2-way diaphragm poppet valves is position driven by two 2/2-way piezo pilot valves integrated into single cartridge.

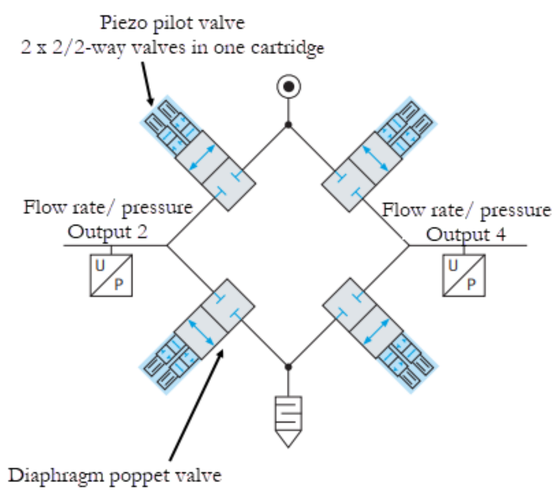

Figure 4: Pneumatic bridge principle [1].

Valve controller is constantly monitoring process parameters such as: 2/2-way diaphragm poppet valves analogue position, analogue pressure at ports 2 and 4 and temperature of the air. Self-learning functions constantly compare the setpoint and actual data and immediately corrects the driven parameters in case of any deviations.

Hardware design (Figure 5) makes VTEM an extremely versatile and flexible pneumatic component which is currently unique on the market. With different control algorithms and software-based models literally any known pneumatic valve function could be implemented on a single valve unit.

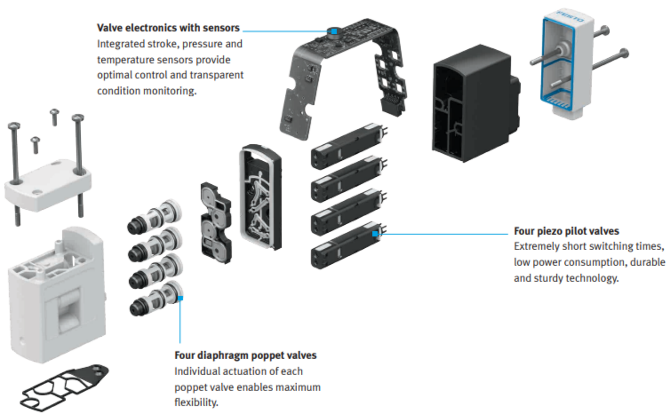

Figure 5: Hardware architecture of VTEM valve unit [1]**.**

With this valve structure, many basic pneumatic functions can be realized without additional mechanical components. The proportional control behaviour allows the mapping of specific sizes or flow rates as well as supply or exhaust air throttles for cylinder drives.

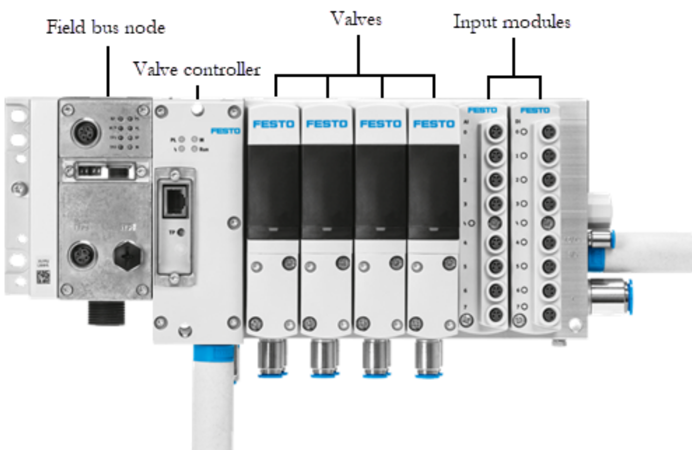

Figure 6: Festo Motion Terminal – layout [1]**.**

2.3 Motion Apps - digitally selecTable valve functions and applications driven by software

Hardware architecture of VTEM allows valve functions to be selected and determined by software. Master system, usually a programmable logic controller (PLC), is communicating with Motion Terminal over integrated fieldbus or Industrial Ethernet node. Communication consists of telegrams, containing information of selected valve function, its dedicated parameters and sensor data [5].

There are several standard valve functions available on VTEM which could be activated via licensees accessible from cloud.

2.3.1 Directional control valve functions

Standard directional control valve functions: 2x2/2 with ports normally closed; 2x3/2 with ports normally closed; 2x3/2 with ports normally opened; 3/2 with ports normally opened + 3/2 with ports normally closed; 4/2 bisTable or monosTable, 4/3 with ports normally closed; 4/3 with ports pressurized; 4/3 with ports exhausted.

Any of these functions could be assigned as often as necessary for example from 4/2-way to 4/3-way or 3/2-way, even during continuous operation.

2.3.2 Proportional directional control valve

Two proportional flow control functions have been integrated in one valve and on one platform. This function enables to use selecTable degree of valve opening between 0 and 100 % on each or both working ports (4/3 or 2 x 3/3). Possible use in industry would be a smooth start-up of a pneumatic drive or a painting application.

2.3.3 Supply and exhaust air flow control

The supply and exhaust air flow control function allows tamperproof software speed adjustment of a pneumatic drive connected to a valve unit. This function eliminates the need for separate flow control valves on the actuator and reduces risk of unauthorized manipulation. It also introduces new motion sequences, such as dynamic flow control adjustments.

2.3.4 Leakage diagnostics

With Leakage diagnostics function system learns characteristics of the process in predetermined diagnostic cycles and allows to set user defined threshold values. Leaks could be individually detected and pinpointed to a specific actuator. It reduces system downtime with preventive maintenance and faster fault detection.

2.3.5 ECO drive

The actuator is operated with the minimum pressure necessary based on the Load and shuts of air supply as soon as the cylinder reached the end position. This eliminates the rise in pressure in the drive chamber at the end of the movement. Energy savings can easily reach values above 70 %. Cylinder limit switches are necessary for the operation.

2.3.6 SelecTable pressure level

Enables the pressure for selected movements to be reset to a reduced level also within a stroke movement. Energy efficient complex movements, such as: quick start-up, smooth travel into the end position, powerful press-fitting and return stroke with reduced pressure are possible. Also enables the speed to be controlled by adjusting the flow control valve setting.

2.3.7 Pre-setting of travel time

The exhaust air flow control function adapts itself to the travel time for retracting and advancing and then maintains it. By continuously comparing the setpoint and actual default values the system automatically adjusts the values in the case of influences such as increased friction due to wear. Cylinder limit switches are necessary for the operation.

2.3.8 Proportional pressure regulation

Pressure and vacuum can be controlled digitally – simultaneously and individually. Each valve unit allows proportional pressure regulation on both working ports independently.

2.3.9 Model-based proportional pressure regulation

By storing fewer boundary parameters for the system, such as tube length, tube diameter and cylinder size, the anticipatory control system ensures maximum accuracy, as the app can compensate for a drop in pressure and volume using the mathematical models in software. No external sensors are needed for that function.

2.3.10 Soft Stop

Highly dynamic, but smooth end-to-end positioning. With analog position transmitters installed only at each end of the pneumatic actuator, drive position is monitored at the end of each stroke. Parameters of a valve unit are adjusted in software control loop to meet the specified setpoint values for a consistent travel time. Active breaking principle is being used to gently stop the drive without any mechanic shock absorbers installed. Eliminating impact shocks at the end of the stroke has a significant impact on increased life span of the pneumatic drive.

2.3.11 Positioning

The pneumatic actuator can be positioned freely along the entire working distance. Positioning task on a pneumatic drive is carried out in a closed loop, so an analogue position transmitter is needed along full stroke. The cylinder movement can be controlled by specifying limits for the parameter of position, speed, acceleration, and jerk. By specifying limit values, the pneumatic drive can travel smoothly to the work area.

2.3.12 Flow control

Flow rate of compressed air and gases up to 600 l/min is digitally regulated for several independent channels at the same time. In general, integrated sensors are sufficient for basic applications. In applications where very precise metering is needed it is possible to add external analogue flow sensors and use their signals as a feedback in the control loop.

Beside all standard applications, that were already mentioned, it is also possible to develop tailored valve functions based on a mathematical or statistical model of a process.

3 Use case from the industry

3.1 Flexible gripping

Robots can perform a wide range of tasks by simply changing the end-of-arm tooling (EOAT), which is equipped with various components. The Motion Terminal offers flexibility during operation: no matter how many different EOATs are used on a robot, they could be controlled centrally from the same hardware. Design and commissioning become much easier while all the changes can be made within software.

3.2 Possible future advanced use of Digitalized pneumatics

3.2.1 Automated Commissioning Process (published by W. Gauchel and W. Wiegand) [6]

Commissioning of pneumatic drives is in theory a very simple process. Connect a defined cylinder chamber to a defined port of the valve terminal with a tube of an adequate length. In reality, this is a complex and difficult process, lots of tubes possibly not marked all look the same. Sometimes the tubes are very long, tubes are channelled e. g. in energy chains, tubes are bundled together, or they run all cross the machine. Thus, the commissioning of pneumatic drives is a time-consuming process which causes substantial costs.

Basic idea: Automated Commissioning Process, connect the end-position switches (or other sensors) electrically to the valve terminal, plug the tubes to any random port of the valve terminal, start a self-identification process: Which tube belongs to which cylinder chamber? Sequential venting of all valve ports, interpreting the signals of the end-position switches (and other sensors). Aim: Faster and error free, thus cost-effective commissioning of pneumatic systems.

Why is the Festo Motion Terminal helpful for automated commissioning?

- It has uniform hardware, only one type of valve slice, it is not necessary to select in advance a defined valve type to control a specific cylinder.
- Proportional valve functionality.
- Different cylinder sizes can easily be controlled by one valve size (only one tube diameter necessary).
- Pressure signal can be used for identification.
- Independent control edges in every valve slice.
- The pneumatic full bridge can be divided into two independent half bridges.

- The two chambers of a double acting cylinder can be connected to half bridges of different valve slices.
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3.3 Integration of digitalized pneumatics into a higher level systems

Combining digitally driven pneumatic and electric components with AI driven algorithms utilises new concepts in industry. Industrial solutions are now ready to be designed in a way to continuously improve overall equipment effectiveness. Process data from digital components is fed to a system which could detect anomalies based on a model powered by computer learning algorithms (Figure 7).

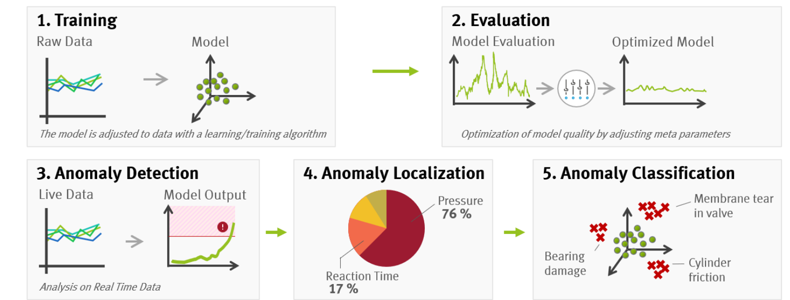

Figure 7: Anomaly detection and classification, Source: Festo SE & Co. KG.

3.4 Segments in industry, where digitalized pneumatics combined with AI could significantly contribute in OEE rise

3.4.1 Predictive quality

Improves overall production quality by continuously monitoring and analysing production data and detecting quality issues. To ensure the quality of the products is consistent throughout the entire production, it is necessary to permanently monitor and analyse all the relevant parameters and data (via algorithms based on artificial intelligence and machine learning) – technology independent, from component level up to complete machines and production lines. Business Case: Increase yield by reducing number of rejected parts.

3.4.2 Predictive energy

Optimises energy usage by continuously monitoring and analysing energy consumption as well as detecting anomalies.

In order to ensure the lowest possible energy consumption on the shop floor as well as the entire factory, it is necessary to permanently monitor and analyse all of the relevant parameters and data (via algorithms based on artificial intelligence and machine learning) – technology independent, from component level up to complete machines and production lines [8]. Business Case: Cut costs by reducing energy consumption.

3.4.3 Predictive maintenance

Predicts failures and reduces unplanned downtime by continuously monitoring and analysing asset data To ensure the constant performance of components during production, it is necessary to permanently monitor and analyse all of the relevant parameters and data (via algorithms based on artificial intelligence and machine learning) – technology independent, from component level up to complete machines and production lines [9] Business Case: Increase machine uptime by reducing unplanned downtime.

4 Conclusion

Fundamentally different engineering design of a valve terminal has brought an option to define valve functions inside Festo Motion Terminal solely within a software. New generation of pneumatic valves have become flexible cyberphysical systems which are operated digitally by a dedicated integrated controller. Application process data from valve controller and data from integrated sensors are available to higher order control systems through various industrial communication standards. Finally, it is possible to claim that pneumatic components are also ready for Industry 4.0.

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