Pneumatics- Future through mechatronic Integration and Efficiency

Frank Schnur

Norgren GmbH, Stuttgarter Strasse 120, D- 70736 Fellbach
frank.schnur@norgren.de

Dr. Maik Fiedler

Norgren GmbH, Stuttgarter Strasse 120, D- 70736 Fellbach
maik.fiedler@norgren.de

Abstract

This paper shows a survey of market requirements, research and development activities of pneumatic components and systems, independently from suppliers.

The market stream, driven by legal and society requirements for saving resources, moves to overall energetic consideration of fluidic and electric drives or handling systems.

Besides savings in electric power supplies of components as well as savings of compressed air by lowering the pressure level, reduction of compressed air leakages, recuperation of exhaust air and compression losses, this paper summarises the benefits of higher integration designs by minimising the amount of parts, size, weight, and costs.

Densification of functionalities in subsystems allows online condition monitoring and remote control.

Using well improved software tools for system calculations, pneumatic drives and components can be used with tremendous saving potential of compressed air. Over engineered layouts will be replaced by miniaturisation and design according to required function. Miniaturisation, light weight design and smart combination of modern production technologies enable further reduction of moving masses and electric power supply e.g. of industrial robots.

A rich variety of benefits and improved functionality will justify the future of pneumatics.

KEYWORDS: pneumatic future, integration, MID, energy saving, efficiency, mechatronics, intelligent pneumatic systems

1. Introduction

For several decades, pneumatic motion drives provided a high value in the mechanical and plant engineering. The reasons for this are their high flexibility, their low costs of acquirement and maintenance, their robustness, the integrated overload protection and in particular the high power density. For the realization of industrial handling tasks mainly pneumatic motion drives are used (**figure 1**).

Required compressed air is produced by a compressor and distributed to the application via a permanent pressure net. The supplies are going through the components (filters, regulators, tubing, fittings, valves, actuators and exhaust mufflers) of the pneumatic system, using the air as a pressure transfer medium.

Figure 1: example of conventional pneumatics with field bus connection (source: Norgren)

In addition to their restricted application area (process between front and end position) one characteristic trait of such solutions is certainly, that they often are over engineered in dimensions or the operating pressure. On one hand, since many years route causes of this are none available software tools for calculations and specialists in the field of pneumatics and on the other hand in missing industrial necessity of application based and energy saving solutions.

The enhancement of simple pneumatic drives with sensor system (position, pressure, flow, temperature), matching electronic and software, increases the industrial application area of pneumatic motion drives. New functionalities like e.g. the setting up of various inclined positions are convertible. Furthermore, motivated by rising costs of raw material and energy as well as human caused climatic changes, the development and the application of energy and resource saving products are getting into the focus of users and producers of pneumatic components and systems. In this relation, pneumatic motion drives must compete to alternative technologies more and more.

Apart from achievable pulling loads and speed of movements, smooth operation and high repeatability are important evaluation criteria.

In this interplay the article aims on describing and showing the currently existing possibilities of pneumatic motion, how it can assert itself versus the background of increased efficiency requirements.

2. The way to integrated, intelligent solutions

Since about two decades, the integration of various valve functions is realised with base plates or modular valve islands (**figure 2**). These valve island systems, besides their logical and clear structured setup, show benefits in centralised, easy accessible installation and provide high maintenance comfort.

Figure 2: base plate valve systems and valve islands (source: Norgren)

Pressure supply is mostly provided via pneumatic circuits (main ring line) on a constant pressure level, typically with p = 3…6 bar. Different pressure levels can be realised by additional intermediate plates. Today, electrical power supply and communication is realised by field bus technology, which allows remote control and condition monitoring from a centralised control room or cabinet. Trying to avoid additional power supply units, components are required which offer low operating power (e.g. solenoid valves, sensors). Using those, the plant engineer is able to stay with the maximum power supply of the field bus system. For proper operation, the design engineer also needs to watch the warming of solenoids, mounted very narrow side by side, leading to increased coil resistance, decreasing electromagnetic force and subsequently to reduced security in operation. Centralised location of valve technology within the machine or plant requires long lengths of tubing for pressurisation and exhaust to the actuator devices such as cylinders and rotational drives.

Besides reduced dynamic response in motion, this leads to increasing compression losses and hence into opposition to energy efficient solutions for pneumatic actuator solutions.

To counteract a centralised valve technology, highly integrated designs were developed (**figure 3**). These actuators (cylinders, rotational drives and lift armatures) show integrated valve technology, sensors and open or closed loop electronic controls. Thus, requirements for high speed response times and reduction of compression losses are obtained. In addition, the effort for cabling, the number of single components, costs and potential sources of defects are minimised. Space requirements of modular solutions shown in **figure 3** are more or less equivalent to standard pneumatic cylinders.

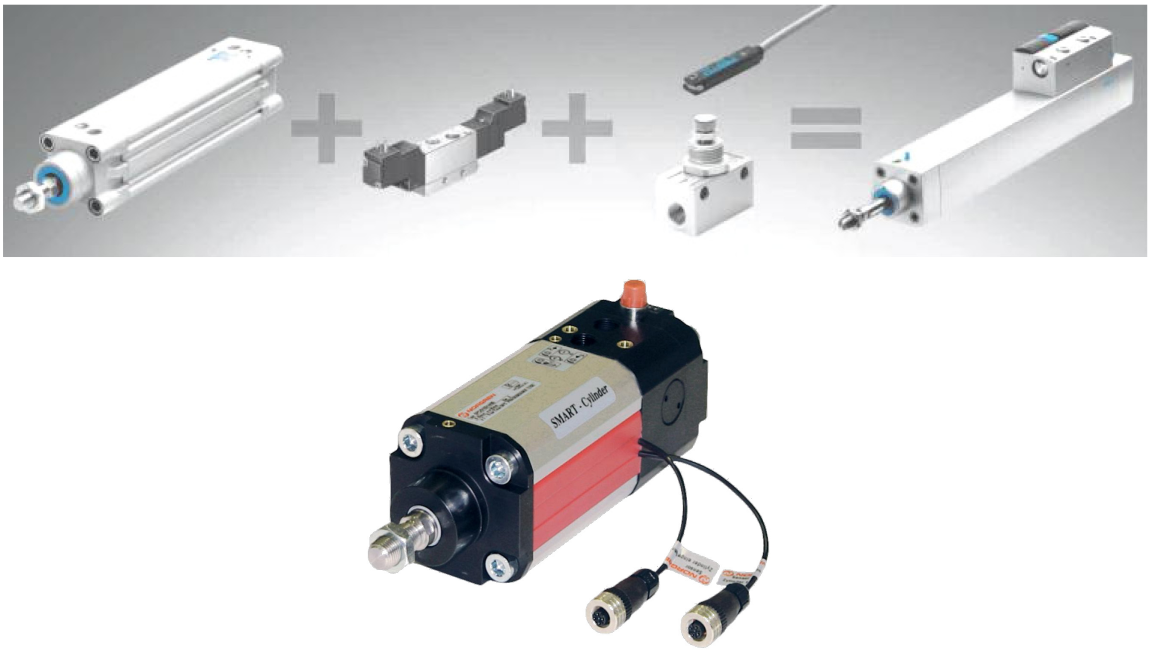

Figure 3: pneumatic actuators with integrated valves and sensors (sources: Festo /1/, Norgren)

Comparable attempts can be identified in proportional technology. Here, for position or/and pressure control, proportional control valves or on/off valves are used in highly integrated pneumatic motion drives (**figure 4 and figure 5**).

Implementing modern, adaptive and/or self adjusting control algorithms, these systems are, depending on the set point, now in the position to work as subsystems (e.g. „positioning“ or „ move into final position without vibrations”). In consequence, they can be integrated directly into the machine’s conceptional design.

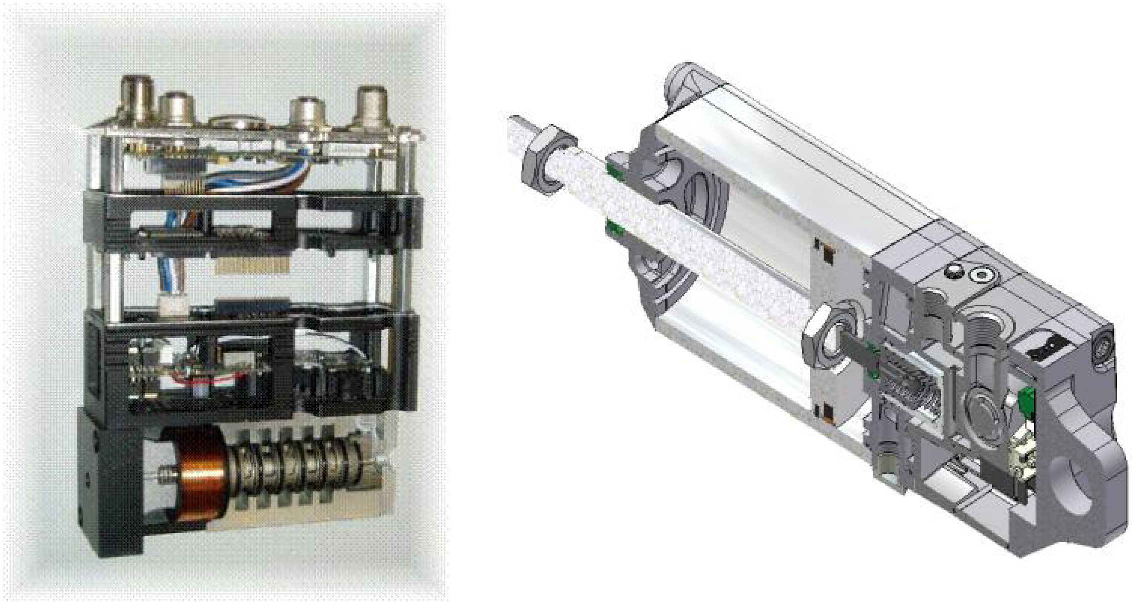

Figure 4: proportional valve with integrated sensors and electronics as well as pneumatic actuator integrating valves, pressure and position sensors and control electronics (source: Norgren)

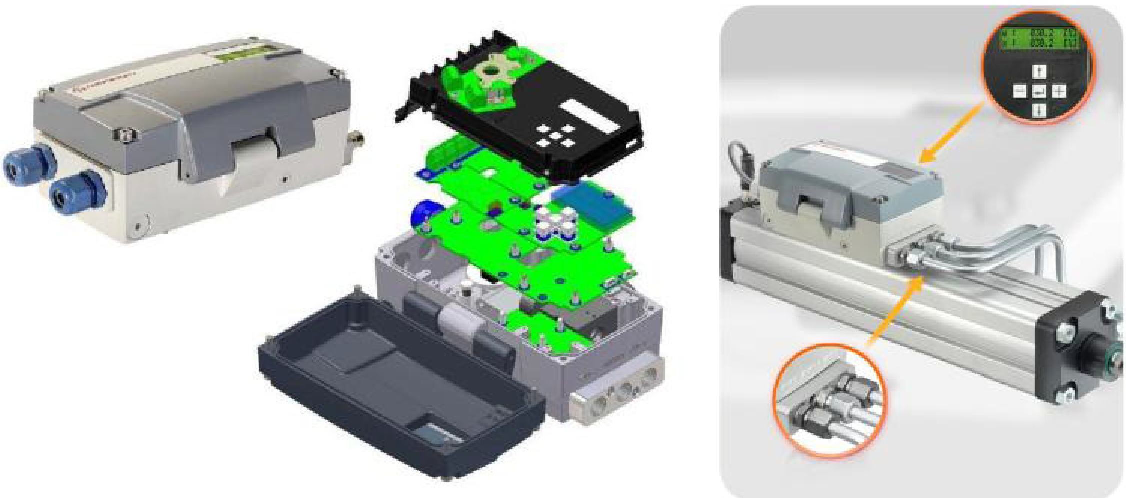

Figure 5: highly integrated positioner for rotational drives or cylinders (source: Norgren)

Above described pneumatic motion drives can be remote controller by a main computer, but in general they are not able to communicate system information in reverse direction (remote diagnostics). To monitor and interpret the status and to define adequate action, these systems require implementing a condition monitoring system. E.g. air consumption, pressure level, flow rates or humidity can be checked /2/. The pneumatic system needs to be equipped additionally with sensors and evaluation electronics, which monitors cyclic signals and interprets analytically or by comparison to a quantification sheet, shown as an example in **figure 6** .

As soon as the monitored force of the cylinder deviates from the set curve, a validation is done, if this deviation is in the field of acceptable or none acceptable ranges and corrective actions are started.

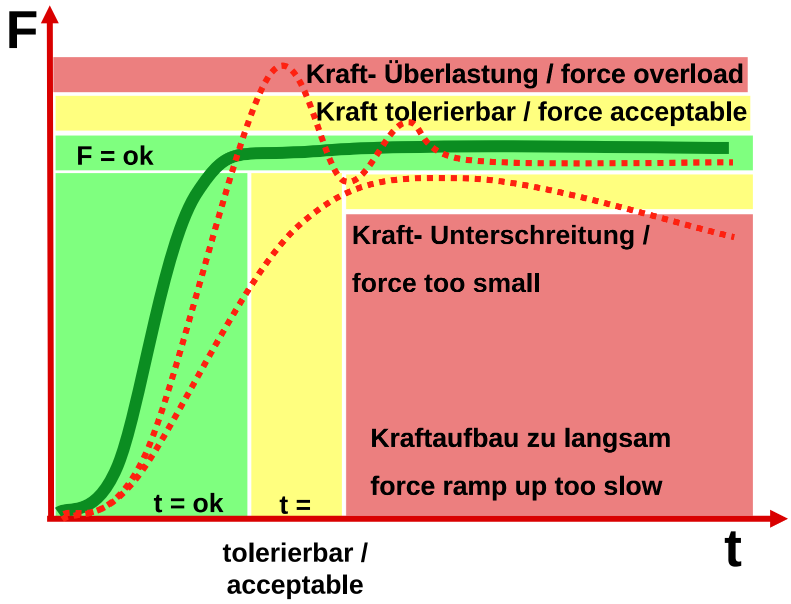

Figure 6: validation chart for force control in servo pneumatic spot welding guns (source: Norgren)

Described developments of mechatronic devices into the direction of so called „Smart Systems“ offer a further step of evolution towards intelligent machines with decentralised intelligence, **figure 7**.

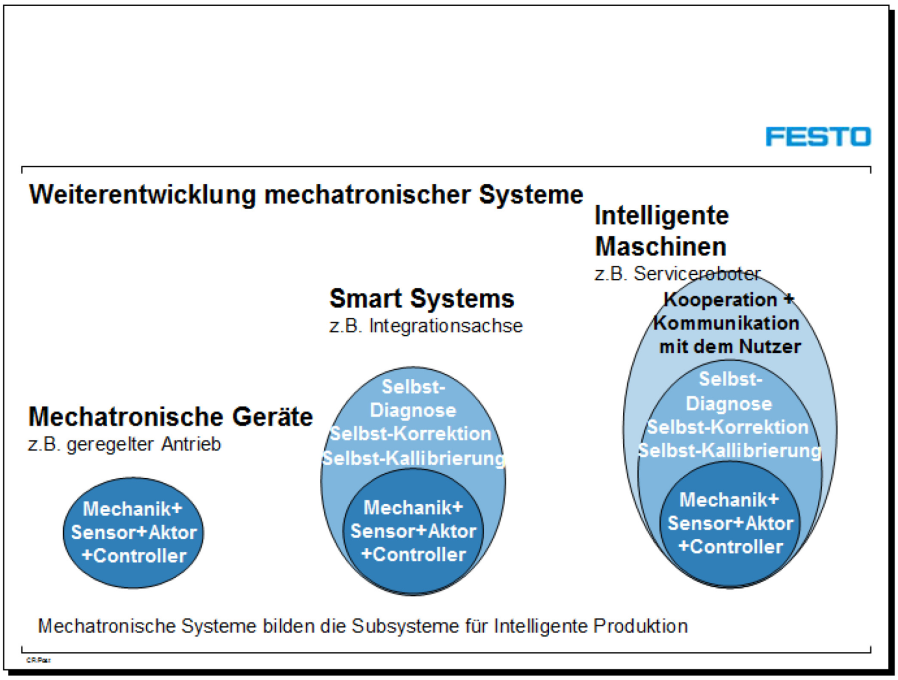

Figure 7: evolution of mechatronic devices towards intelligent machines (Source: Festo /3/)

They enable fully autonomous behaviour, but require an intuitive use of human-machine-interface (e.g. for service robots). Further, they should improve the operational safety (e.g. limitations of speed or force) and provide a self adjusting or adaptive behaviour, depending on varying modes of operation or environmental conditions. In general the question occurs, if solely pneumatic motion drives should be used, due to the wish for low life cycle costs, which leads to energy efficient solutions. /4/.

There is a fair possibility that hybrid combinations of pneumatic and electric actuators will exist, because there is an increasing number of variants of both technologies to provide forces up to 10000 N. The saving potential of smart arrangement of diversified technologies can be unlocked especially in very complex industrial automation. For suppliers and users there is a strong need for objective and application based comparison of most efficient and cost effective motion drives /5, 6/.

Consequently, not only the application's spotlighted requirements such as acquisition costs, weight, stroke or dynamics should be taken into account, but also life cycle criteria, additional cooling, environmental conditions or response times with their related costs.

3. Reduction of energy and use of efficient pneumatic solutions

In the field of automation, pneumatic drives are well accepted and preferred for handling operations, because they offer benefits in functionality, robustness and purchasing costs in comparison to electric drives. Today, well designed systems do not show external leakage, but anyway, there are huge losses due pressure and compression losses within the components. They reduce the degree of efficiency and increase the costs of operation. To ensure competitiveness of pneumatic motion solutions and to take the aspects of environmental protection into account, their efficiency has to be improved. First of all due to the fact, that there is still a big reservoir for energy saving /7, 8/. Alongside the reduction of external leakages, following chances have to be discussed:

- Realisation of alternative modes of operation
- Use of resolved (single acting) control edges
- Use of appropriate pressure levels and tubing length
- Choice of appropriate size of actuator or
- die implementation of power reducing devices (electronics)

Also, new developments such as compact unit X-Block® for providing pneumatic actuators according to the requested force (**figure 8**) or decentralised generation directly at the actuator show a good step towards energy efficient solutions.

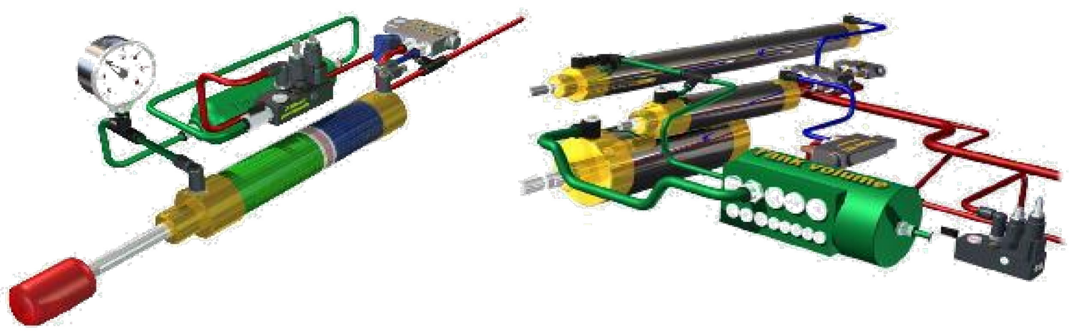

Figure 8: use of closed loop controls for energy saving (source: X - design AB /9/)

3.1. Concepts for improved use of energy and recuperation

The fluid technology companies and institutes, organised in VDMA, did allocate these challenges (**figure 9**) and initiated, besides others, the following fields of research:

- A supply tailored to suit the intended use of actuators
- Methods and tools for overall balancing and evaluation of energy efficiency
- Costs of generating compressed air: reduction of efforts to generate pressure
- System approach for energy efficiency of machines and facilities

Figure 9: future potential, current situation of fluid power industry 2011 (source: VDMA Forschungsfond Fluidtechnik /10/)

3.2. Efficiency improvements by reduction of moved masses, light weight construction, miniaturisation and combination of production processes

3.2.1. Reduction of masses

With bespoke requirements for speed and resulting reduction of cycling times in production, size and weight of components are more and more within focus.

Using industrial robots in areas like automotive production, food and beverage industry, wood processing etc., the reduction of masses for the mounted and moved pneumatic systems offers selection of smaller size robots. Thus, initially costs for capital expenditure are dropped dramatically. Secondly, required power supplies for motors decrease by handling smaller masses and the work can be fulfilled in a much more energy efficient way.

Target of many users is to drop the pressure supply within the ring line to as lower level.

Operating pneumatic systems with smaller actuators and appropriate pressure levels, smaller compressor units, tubing sizes and length, vessels etc can be chosen /11/. Aside to the result of minimised effort for generating pressure, also the costs for acquisition and maintenance for the infrastructure of the arrangement drop.

Through minimised use of energy calculated for the life time of the production equipment, the ecological balance of a machine, measured in emissions of CO_2, NO_x, etc., is getting much more environmental friendly. The reduction of emissions today is one of the headlines of many companies /12/, measured, monitored continuously and controlled.

3.2.2. Lightweight design by use of alternative materials

Accompanied by minimisation of sizes, alternative materials, e.g. for pneumatic actuators, replace aluminium and aluminium pressure die cast by using alternative materials to save weight (and costs).

Below there is described, which benefits appear, when the cylinder tube is developed and produced from high performance polymers e.g. such as Lauramid® /13/. In addition to reduction of masses, these cylinders can be designed more compact and offer still similar forces like actuators build from metal material. The barrel of the actuator is taking only minor parts of the stability of the actuator structure.

Although providing low weight, attributes like stiffness of the structure, long life time and reliability must be guaranteed also in rough environmental conditions.

Positive experiences were monitored in food production and spot welding in automotive plants.

According to a manufacturer, pneumatic actuators in bespoke polymer design can achieve a reduction of masses by up to 60% and allow, depending on design, very high forces.

Another advantage is simple integration of volumes, measuring points or sensors directly into the barrel.

3.2.3. Miniature Design

If, during the design process of a machine, considering to locate valves decentralised, means directly at the actuator, a dramatic reduction of tubing and reduction of losses by restrictions, leakage, heat transfer losses and exhaust volumes can be achieved.

As a consequence, the request increases for valves with smaller outer shape and orifice.

Nowadays, lots of miniature- and microvalves can be purchased or produced on the pneumatic market (**figure 10**). They can be flange mounted to or directly integrated as a cartridge into the actuator.

Figure 10: Selection of common miniature valves from various manufacturers. (sources: Asco /14/, FAS, Nass /15/, Norgren, Staiger, /16/)

Besides to common use of solenoid coils, already elements like control electronics, Led’s or power reduction devices can be realised.

These valves offer a wonderful possibility to integrate them directly to electronic circuit boards, avoiding extensive and expensive plugs and wiring. Furthermore, some manufacturers offer „Airbords“. The PCB is CNC- machined and by lamination of the Layers, pneumatic „tubing“ are already part of the PCB. (**figure 11**). Avoiding tubes and fittings reduces again sizes and weight.

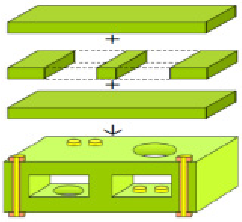

Figure 11: schematics of an „Airbords“ (source: Andus Electronic, 2010, /17/)

Other developments show use of piezo actors, electrostatic actors /18/ and thermal response actors in microvalves alternatively to common coils.

3.2.4. Increasing density of mechatronic integration by combining modern production technologies.

Coming from classical designs, first improvements in integration can be reached by consequent use of polymer injection moulded parts. The design engineer is offered complicated shapes, but also requires experience for implementing electronic boards.

Space and costs for mounting, plugs and sensors have to be considered.

During a variety of research programs and cooperations, different production processes were combined in design and production approach to make a big step towards miniaturisation with parallel improved functionality.

Now, polymer parts with their intended use to build the mechanical structure e.g. for valve housings, cylinder lids or sensor housings, can also host directly printed circuit board tracks or electronic components /19/

With the process of MID (moulded interconnected devices) complicated multifunctional 3D- packages can be realised. Specifically modified polymers transform by embossment or by laser direct structuring (LDS) already into a PCB and make internal plugs obsolete. The final part builds not only mechanical shape and structure but also partially wiring tracks, housing and fixation of electronic parts (**figure 13**) and sensors.

Taking a fitting for example (**figure 12**) it is shown, how this technology provides higher grade of electronic density by processing the signals directly at the measuring point.

Figure 12: fitting with integrated MID structure & pressure sensor (source: Festo /20/)

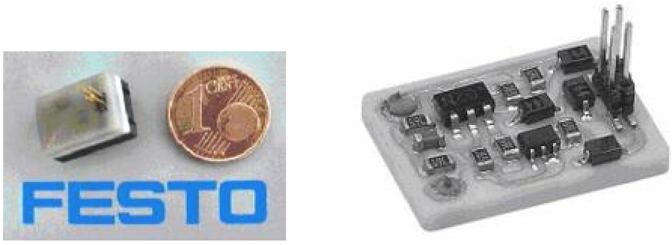

Figure 13: Micro- Piezo- Valve (source: Festo, IMSIP /19/)

3.2.5. Total mechatronic approach to design pneumatic systems

Automisation technology requires pneumatic multiple axis systems. Variations of mounting pneumatic actuators result in reactions for the complete system and it's pattern of movement.

Research programs and prototypes such as the Bionic Handling Assistant /21 & 22/ demonstrate a mechatronic system (**figure 14**), using consequently the interaction of lightweight design, integrated actuators, sensors, new generic production methods like laser sintering of flexible polymers and the ability of adaption of appropriate mechanical layout. The result offers a tremendous ability in movement and adaption.

Figure 14: Bionic Handling Assistant Robotino® (source: Festo /22/)

3.3. Modern system calculations with the assistance of simulation methods

Today's possibilities in simulation allow calculations of dynamic behaviour of pneumatic systems and decrease the amount of development times and costs.

Current approaches in research try to improve these tools furthermore:

- Improved model setup in pneumatics
- Modelling friction forces on sealing contacts in pneumatics

4. Summary

Pneumatic motion drives highlight their benefits like flexibility, low acquisition costs, simple installation, etc.

Increasing requirements by law and society for saving resources and protecting the environment also question pneumatic systems critically, which have to compete with other technologies.

Asides systematic comparisons between electric and pneumatic motion systems, some pneumatic manufacturers offer new, integrated solutions to serve these requirements with reduced air consumption and also offer calculation tools to assist with pneumatic design for systems (**figure 15**).

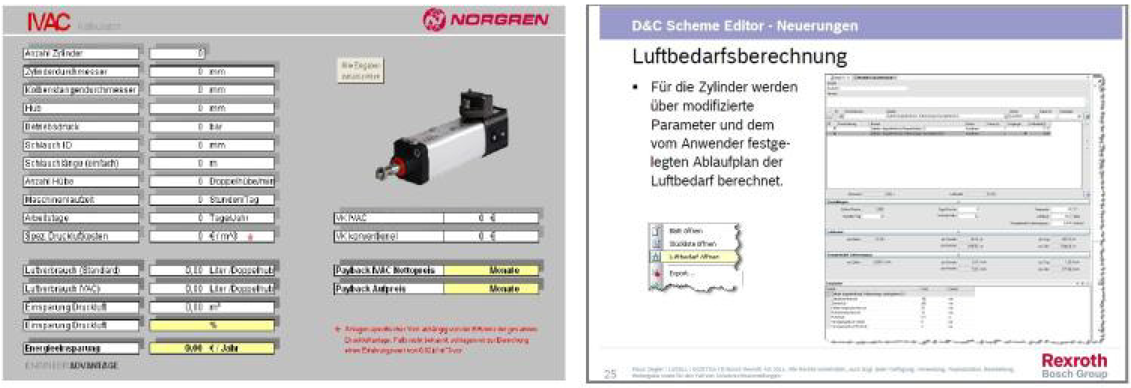

Figure 15: Tools to calculate air consumption (source: Norgren, Bosch Rexroth /23/)

Many above described research projects show us the way, how the pneumatics industry can consequently design their products and achieve savings in space, size, weight, material and resulting energy consumption of compressed air to create a competitive future.

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