



MECHATRONIC TEHNOLOGY IN THE AREA OF PNEUMATICS – PNEUTRONICS

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Abstract

This paper presents pneumatic driving systems when obtaining a good positioning precision represents an important and necessary objective. After presenting the way in which mechatronic technology contributes to accomplish this objective, the effects of physical parameters for the working environment/air are analysed, which negatively influence the positioning precision. Considering some new development directions for pneumatics, the requirements and possibilities are identified for proportional pneumatic servo distributors, essential pneutronic equipments for increasing the operation precision.

1. Mechatronics – support for developing precise driving

Mechatronic technology represents at this point the most advanced support for research and manufacturing of mechanical systems and products of medium and high complexity.

The research including: investigation of a constructional-functional idea, design, development, modeling, simulation, and optimization is computer aided, also the final stages: manufacturing, model testing, prototype testing are computer aided; this represents the most efficient approach for technical and scientific development – **computer aided engineering (CAE)**.

Mechatronics has established itself in all industrially developed countries and has significant applications in all other countries, this is proven by significant economic growth in engineering areas of over (20...50) %.

Although engineering is based on the principle “solve simply and rigorously” many technical products have been or recently became medium or high complexity and so usage by non-specialists has proved to be extremely difficult. This lead to the requirement of manufacturing “**friendly**” products, which meant taking that dedicated informatics systems took over in ensuring correct functioning, so creating a new quality for the products: **intelligence**.

Another requirement, which has a higher level of technical difficulty, is **precise driving** systems. Regardless of the driving system - conventional: mechanic, electric, hydraulic or pneumatic or non conventional: piezoelectric, magnet-stacks or memory shape materials, the precision function is defined by:

- **Control and adjustment** in a wide range for **forces and driving moments** to give the necessary response for motion and stationary stages;
- Command and control for translation and rotation components: space/displacements/stroke, speeds and accelerations that are dimensioned, which recently became **the most important factor of quality-positioning precision/stopping**. Precision driving systems have always been a target for science; their evolution has been strongly influenced by the developments in robot



precision. Contemporary robots ensure micron precision and researches head towards higher precision with nanometer as a target;

- Meeting command and control conditions for **real** time functioning – concept that will revolutionize the development of automated systems, also requires information processing - command decision –command effect/execution cycle must have a maximum value of 20 milliseconds. If informatics meets this demand, then in the area of actual execution of movements high values for velocity will be required which will jeopardize high precision positioning.

With all these aspects in mind it can be said that integrating mechanics-electronics and informatics never signified and will never signify a simple implementation of specific components for these areas. In each of these areas mechatronic technology requires new developments, usage conditions and special technical and functional characteristics. It would be wrong to state that either one of these areas has reached its maximum technical performance threshold. **Mechatronics stimulates the development of new components**, of existing components with improved characteristics through knowledge, innovation and/or inventing.

The mechatronics concept was established in a stage in which components of each area naturally reached a certain level of development. Of the many examples that can be given, a significant one is electronics. Before micro electronics, the presence of electronic components (diode, triode, transistor, etc functions solved by integrated circuits) in robots, automobiles, photo and video, could not be conceived. Although micro electronics had a serious boom in a relatively short amount of time, mechatronics found a breach in the area of power electronics. It was a challenge set for electronics by mechatronics. There are significant accomplishments at this stage, but the problem for this area still remains in the attention of electronic engineers.

It is significant to point out the influence that micro electronics had in the consolidation of mechatronics. With such a rapid evolution, microelectronics has revolutionized the technical world and promoting the concept of informatised society as a contribution of this. With respects to mechatronics the benefits for such a rapid development which lead to large scale manufacturing of components, ensured implementation in an area with the largest coverage: mechanics. It could be said that micro electronics has unlimited applications, clearly spreading further than the known sub areas of computers, radio and television.

Technical informatics has not been left without its challenges – especially sensors and transducers, also mechanics that must ensure evaluations of requirements with respect to the present offer of particular technical specifications for micro electronic and informatics components that can be operated at a certain stage. Most problems are found in the area of driving systems. In the area of hydraulic driving systems – that have the highest potential for high precision driving systems, followed by electric and pneumatic systems for developing basic equipments – servo hydraulics, where electro technical component are required – proportional electro magnets, electric micro motors, torque motors, with forces and torques that are smaller – or very close to the limit – with respect to what is required. Those that would meet such requirements don't have acceptable weights and are basically not usable. The mechanic engineers must provide innovative solutions to ensure decrease necessary force and torque elements to compatible values.

Several examples and comments can be presented, but the space for this paper does not allow it, however it is essential to point out a generalized technical responsibility, **solving such problems is directed to mechatronics that must follow its aim of "total integration of mechanics, (micro) electronics and informatics"**.



2. Present stage of development for pneumatic driving systems

As it has been stated above with respect to precise positioning systems, pneumatics has the lowest performances at this stage; at the opposite pole we find hydraulics, although both have the same type of working environment – fluid: oil in hydraulics and air in pneumatics. The differences are caused by two physical values **viscosity** and **compressibility** (both dependant on pressure and temperature) that point out clear advantages and disadvantages:

- a. with respect to dynamic viscosity** for the two fluid environments (oil and air), in normal pressure and temperature conditions: $\mu_u = 180 * 10^{-3} \text{ Ns/m}^2$ and $\mu_a = 18,09 * 10^{-6} \text{ Ns/m}^2$, with a ratio of $r_\mu \cong 10^4$, the main **advantage** of air over oil is that the friction forces are found in the same ratio (static-gas bearings have much higher friction forces than hydro-static ones); a main **disadvantage** is that small gaps, specific to relative sealing, have extremely high values for air flow losses;
- b. with respect to compressibility**, the phenomena can be related to the densities of the two work environments or with their elasticity modules, both depend on pressure or temperature as viscosity does. Using elasticity modules in normal pressure and temperature conditions: $E_u = 1,6 * 10^9 \text{ N/m}^2$ and $E_a \cong P_a$ (absolute pressure), for a relative pressure $p = 8 \text{ bar}$, we have $E_a = 9,013/1,013 = 8,89 * 10^5 \text{ N/m}^2$, obtaining a ratio: $r_E = 1,78 * 10^3$. We can conclude air is **more efficient** when absorbing energy as a damper or storing energy as an accumulator, the main **disadvantage** are large volume variations when an exterior force causes an increase in pressure on the inside (force at a pneumatic piston's rod that presses down a given volume on the piston surface and its stopping position), which leads to positioning errors, which are already a main problem in pneumatic driving systems, as it has been shown.

Regarded as fluid environments we can still mention:

- signals, air can flow through pneumatic circuits reaching the speed of sound (343,8 m/s at a temperature of 20°C) and in order to not record high pressure losses, in hydraulics speeds are limited to 10...12 m/s. Considering signal speed, the air has an advantage, but at the same time speeds determine a rapid evolution of thermodynamic processes, as the pistons move very fast in the pneumatic cylinders (positive) and positioning precision is very difficult to obtain (negative);
- air, by its nature is best suited to the concept of "**durable development**", because it is unlimited as a resource and **it does not cause pollution**.
- last but not less important, air cost is zero.

Considering all these elements and the stage of development for pneumatic driving systems it can be stated that:

- pneumatic driving systems are widely spread in equipment automation, machining and basically in all systems used in industrial areas, explosive environments, radiation areas or in areas with strict conditions for shocks and vibrations, so they are not replaceable. Although work sequences require simple automated driving systems, but the work strokes/displacement are type "all or nothing", given by the stroke limit of pistons in pneumatic cylinders;
- displacement control for the piston in the work stroke, meaning linear positioning, is determined by a quality indicator – **positioning precision**, and is still very hard to accomplish. Basically, so far, pneumatic systems are not associated with precision, a technical aspect that needs to be overcome – priority for researchers in this area.

3. Directions of development for pneumatics



Similar to all types of driving systems – hydraulic, electric or purely mechanic, **mechatronic technology must provide for precision pneumatic driving systems** in order to obtain:

- forces and driving torques with respect to an electric command unit (voltage, power) – pneumatic servo equipments that adjust pressure – $p(U_c, I_c)$, either pressure servo valves or servo regulators;
- positioning precisions with values totally dependant on the displacement velocity regimes required – fast in general and slow in the vicinity of the stopping points, controlled and ensured by the flow adjustment $Q(U_c, I_c)$ – servo equipments type servo valves or proportional valves .

Similar to precise positioning hydraulic systems, that up until the development of equipments in the area of servo hydraulics, couldn't support precision performances, pneumatic driving systems still await the development of **servo pneumatic equipments with reasonable technical and functional characteristics**. Both types of driving systems, with respect to the adjustable elements, cannot support other structures than **automated adjustment**; pneumatic systems, considering the work environment, need to have a **much smaller response time**.

Although servo hydraulic equipments operate at very high pressures 160...320 bar, they have acceptable solutions in the area of mechanics/hydraulics where pressure adjustment is ensured by the adjustment of the flow sections by precise positioning of mobile elements – plungers and small displacement valves 1,5...4 mm, and also in the electric area where components with **electro-mechanical converters** role – proportional electromagnet, micro motors or torque motors (in servo valves), ensure the necessary positioning.

In pneumatics the corresponding equipments to servo hydraulic elements are not yet developed. The essential difference is in the relative seals (clearances between seat and valve plunger; the flow losses are small).

Pneumatics, due to the very small values of viscosity for air, requires perfect sealing. This involves either canceling clearances for sealing elements (O rings, seals) that isolate reduced pressure circuits 6...10 bar but introduces friction forces that for existing electro-mechanical converters (including servo hydraulics) are not yet developed; or perfect sealing systems type "metal on metal" that by their geometry fulfill this condition: conic, cylindrical or spherical valves as mobile elements on cylindrical or spherical seats. These situations create two technical problems: placing sealing elements on the mobile element as due to their own elastic deformations do not allow for the adjustment of the flow section; controlling the position for the plunger type mobile elements -guiding elements and also placing the transducers proves to be more difficult than on the valve body.

Research with promising results has been conducted for perfect seals plunger-seat powered by electromagnets with modulated impulses (PWM) in the band/filling factor, frequency or amplitude, that cause an "all or nothing" opening of the valves that controls flows with respect to time ensuring adjustability. The work frequency for electro magnets is still below necessary, the huge number of switching in order to complete a driving/positioning sequence which increase wear and not last the noise level will be significant. These problems could be partially solved using **piezoelectric actuators** which are appropriated with regards to frequency and driving forces, but completely unacceptable as valve displacement: below 20...50 μm .

Other constructive and functional solutions for continuous/proportional flow adjustment are being researched.



It can be concluded that mechatronics in pneumatics, which has assumed the term of **pneutronics** will ensure quality in precision for this type of driving systems.

Recent published paper [1], edited in 2001 in Germany, translated and edited in 2003 in France has the suggestive title of **"The fascinating universe of pneumatics"**. 15 known specialists express and support their views on the perspectives of development for pneumatics. It can be noted that the present paper is in full agreement with these views. Here are some of the opinions presented:

- **Prof. W.Backe, R.W.T.H. Aachen:** the principles for evolved systems in automated adjustment provide numerous applications for electro-pneumatic systems in the area of positioning and adjustment; servo valves and proportional valves need to be developed first;
- **Prof. R.Schraft, I.P.A. Stuttgart:** pneumatics is an important advantage for us in automation technology; with a budget of over 25 million EURO we have the foundation to ensure consistent;
- **Prof. Von Brussel, Univ.of Louvain:** Progress in adjustment systems and informatics create conditions for development in pneumatic technology, which can lead to complex solutions an high precision;
- **Prof. P.Melcher, T.U.Dresden:** electro-pneumatic command and adjustment systems are gaining ground and offer a great perspective for pneumatics through mechatronics and automation technology;
- **Dr. K.Stall, Festo:** pneumatics is developing much faster as a concurrent engineering – integrating several areas;
- **Prof. G.Nicolic, Univ.of Zagreb:** pneumatics will keep on evolving; integration of microprocessors and sensor multiplication will turn it into a growing intelligent technology.

4. Proportional servo valves - essential equipments in pneutronics

For an efficient presentation of the results for designing and manufacturing proportional pneumatic servo valves and also considering all the views presented above, a proportional pneumatic servo valve is used – figure 1.a. The equipment is large used in hydraulic driving systems and ensures a satisfying level of positioning precision, other constructive and functional elements with respect to a pneumatic system are found in the next cases:

- uses three connection types between the circuit nozzles: P – pressure, A and B – consumers and T – tank, that is: P→A and B→T, P→B and A→T and P, A, B, T – closed, connection necessary to ensure that the hydraulic motor stop at the required position. The pneumatic systems need similar connections;
- it has relative "metal on metal" seals and so the clearances $j < 1...5\mu\text{m}$ produce internal losses, and so $1\mu\text{m}$ - technologically impossible, or sealing elements that due to the high friction forces require high driving forces F_a which the proportional electromagnet cannot provide;

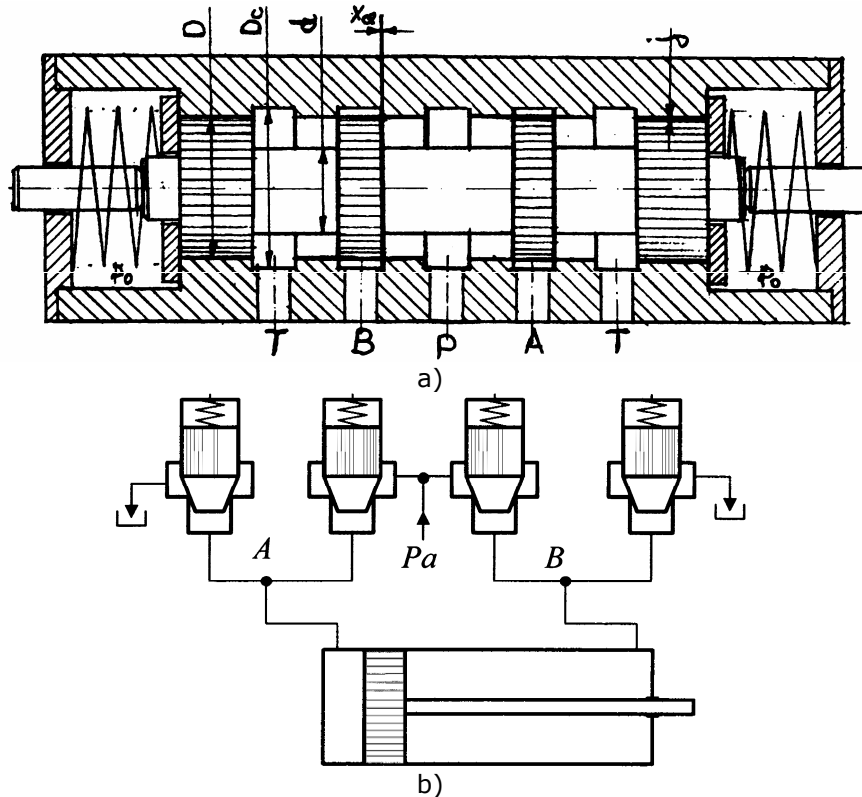


Fig.1

- the internal flow sections, that adjust the flow, are dimensioned by x openings, are theoretically zero when the coverage $x_a \leq 2\mu\text{m}$, is done precisely and symmetrical, which means that **the balance of driving forces F_a and the resultant on the extension valve F_s** , are given by continuously variable forces on " x ", such as, flow viscous friction, suction, weight and last but not least elastic forces in the springs, that ensure backwards motion for the extension valve and for the centre position (all nozzles closed). In order to obtain small velocities, from the vicinity of positioning points required at the piston's rod, the flows need to be small, and so micrometric " x " openings for the pneumatic servo valves; obtaining these based on the force balance is impossible. The only other alternative is to accomplish the opening and closing " x " using **follow driving systems, similar to the following of the cam by the tappet.**

All these negative aspects are found in hydraulic servo valves and using different structures to obtain the same functions is a known research aspect figure-1.b, through a perfectly sealed 4 valves block. Control and automatic opening for these valves should be accomplished with a higher precision, moving and stopping the piston in a hydraulic or pneumatic cylinder. In hydraulics due to the higher working pressures, at this time there are no electro-mechanical converters to overcome the forces developed by the valves.

In pneumatics the pressures are much smaller, and the extended valve solution in impossible to approach this solution proved to be feasible.

An analysis for all the approaches to develop pneumatic proportional servo distributors, with internal flow sections with conic valve opening - cylindrical ladder (optimal technological solutions) leads to the following requirements:



1. obtaining a perfect seal for all 4 internal flow sections type valve – chair with elastic deformations in the contact area (in the order of micrometers), which translates to high precision manufacturing and high density materials;
2. obtaining maximum values (equivalent to nominal diameters) for the internal flow sections with openings/displacements for the valves in the area of 0.8...1.2 mm and a driving force up to 40...50 N compatible to the values attainable from the electro mechanical converters (existing or improved) type: piezoelectric actuator, proportional electromagnet, electric micro motor with conversion mechanism for the cam-rod structure movement; mechanically in order to minimize the driving force solutions need to be researched and developed in order to balance the forces developed by the compressed air pressure;
3. continuous adjustability or incremental for the flow section through precise positioning of the valves on the entire area of the opening stroke with frequencies that need to be around 50 Hz, which implies the ability of the electro mechanical converters to meet such requirements, obtaining the positioning based on a "counting" driving system, adjusted and proportional with an electrical command tension or power;
4. ensuring synchronization for valves 2 and 4 (considered from left to right in figure 1b) for establishing simultaneous circuits $P_a - A$ and $B - T$ (T representing the atmosphere) and for valves 1 and 3 for establishing simultaneous circuits $P - B$ and $A - T$, in order to avoid oscillating displacements (due to air compressibility) of the pneumatic cylinder piston when starting and finishing the movement, which can eliminate precision when the displacements for the piston are small and causes over adjustment for amplitude and time that are not acceptable when displacements for the pistons are high.

It can be noted that considering the challenges for mechatronic technology to develop high performance proportional pneumatic servo distributors all the main areas need to be integrated: mechanics, electrics and informatics.

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