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CURRENT TRENDS IN ACTUATORS FOR INDUSTRIAL ROBOTS

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Abstract: *Nowadays the industrial robots are mostly driven by conventional actuators: electric, pneumatic and hydraulic motors. These conventional actuators can provide for required position accuracy, dynamics and reliability of robot's operation. However in consequence of their high mass these machineries may be energy intensive, their construction is often rigid. These factors can complicate sharing of working place of technologic machinery. The aim is to use in the industrial robots design the actuators which power to weight ratio would be comparable with human muscle. There are in the paper compared characteristics of the conventional and nonconventional actuators and advantages and disadvantages of their using for actuation of industrial robots.*

Key words: *actuator, industrial robot, mechatronics, artificial muscle.*

1. INTRODUCTION

Static and dynamic characteristics of the industrial robots are considerable dependent on their driving mechanism. That is why there are demands for industrial robots actuators [12, 13]:

- maximal movement speed and excellent dynamics on the grounds of minimal secondary handling times,
- shock-less starting and braking on the grounds of object carriage safety and oscillation exclusion in the end position,
- high position accuracy,
- good position stiffness,
- minimal weight and dimensions,
- and other standard requirements for equipments in manufacturing process (reliability, high efficiency, low noise etc.).

Fulfillment of these demands requires applying in the new design of industrial robots novelties from the area of conventional actuators but noncoventional actuators too, which power to weight ratio would be comparable with human muscle.

2. CONVENTIONAL ACTUATORS

Three main types of actuation have been the core of motion and force power for all present robotic systems. They are pneumatic, hydraulic, and electric motors. These three come from two main types of power conversion. The first two are considered fluid machines in that they use fluid to create mechanical motion whereas the electric motor converts electrical energy into mechanical energy [10].

Each of these actuators has advantages and disadvantages for using in robot's driving mechanism. Some of their advantages and disadvantages are briefly described in Table 1.

Table 1

A brief comparison of the conventional actuators

Actuator	Advantages	Disadvantages
Pneumatic	**quick response**, simple control, inexpensive	**compressibility,** problematic position control, high noise
Hydraulic	**big forces**, high power to weight ratio, practically zero compressibility	**leakages - frequent service** lower reliability, combustible fluids, temperature dependence
Electric	**possibility of the precise position and speed control**, silent running, relatively inexpensive	**low power and moment to weight ratio**, limited using in explosive medium

Pneumatic actuators are used for actuation of robots with lower carrying capacity. Current trends in pneumatic actuators:

- Rate of flow increase and valve miniaturization – that allows use lower diameter piping for decrease of investment costs.
- Improvement of position accuracy by magnetic sensors in pneumatic cylinder.
- Decentralized solutions on the base of small operation units combined by pneumatic and electronic components and communication with superior system.

Hydraulic actuators are used for actuation of robots with higher carrying capacity. Further trends:

- For basic control of movement aren't used valves yet, but flow is controlled directly by change of rotation speed of the hydrogenerator.
- Integration of the electronic modules into valves enables to process information about position and pressure directly in valve and in this way the feedback control can be realized directly in valve too.

Electric actuators are nowadays the most widely used actuators for new industrial robots. Current trends in electric actuators [11]:

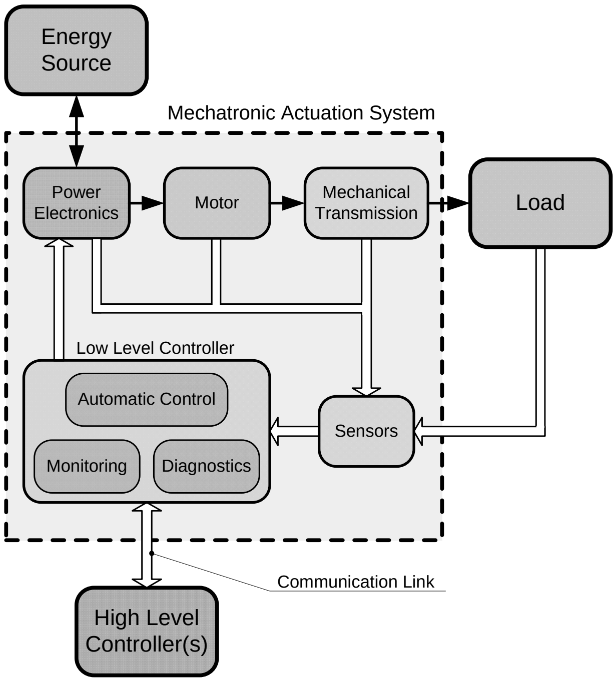

Fig. 1. Mechatronic actuation system.

- DC electric drives are gradually replaced by AC electric drives which are controlled by modern control methods as Pseudo and Vector Control, Direct Torque Control (DTC) and Direct Torque and Flux Control (DTFC).
- Linear motors based on AC motors with permanent magnets enable to simplifying of robot's kinematic structure, they reach high values of acceleration and accuracy and they have minimal wear.
- Megatorque motors for direct drives without gearbox (DDR – Direct – drive rotary) on the base of AC motors with permanent excitation – their advantage is practically no backlash in mechanism, minimal maintenance, higher efficiency, high dynamics and accuracy, smaller dimensions and lower noise.

The mechatronic actuation system originates by integration of the all functional parts of the actuator into compact module (Fig. 1).

Mechatronic actuation system can by defined as integration of mechanical parts, electronic parts (microelectronics, power electronics, sensors system) and information technology (theory of systems, automatic control, artificial intelligence, software engineering) into one system [15].

3. NONCONVENTIONAL ACTUATORS

An attempt to replace heavy electric motors and hydraulic actuators with actuators which power to weight ratio would be comparable with human muscle leads to use noncoventional actuators too for actuation of industrial robots. Recently the research works in field of nonconventional actuators have been focused on:

- shape memory alloys (SMA) actuators,
- piezoelectric and electrostrictive/magnetostrictive actuators,
- electro-rheological and magneto-rheological actuators,
- actuators based on electroactive polymers,
- pneumatic artificial muscles (PAMs) based actuators.

Shape memory alloys actuators exploit of shape memory effect (SME) of the SMA materials as for example Nitinol (Nickel-Titanium alloy). The basis for the shape memory effect is the phase transformation that the crystal structure of the alloy exhibits when its temperature goes above or below its transformation temperature. Below the transformation temperature alloys are in soft martensite phase and can by deformed up to approximately 8 - 10 percent. Above the transformation temperature martensite phase is transformed into a stronger austenite phase in which the material recovers the undeformed shape. This change of shape can by used for linear movement (during recovery SMA is able to exert a high force). The shape transformation of SMA when heated shows similarities to the contraction of biological muscles when activated by neural stimulation. The big advantage of the SMA actuators is high power to weight ratio, constant force in whole range of displacement and silent operation. The SMA has limited cycling-life time and its performance can be effected by too extensive strain-activation in its history. Another drawback of SMA is its slow frequency response, which is limited to about 1 Hz [4].

Piezoelectric and electrostrictive actuators based on electroactive materials (for example Lead Zirconate Titanate – PZT, Lead Magnesium Niobate – PMN) exploit a dimension change of the some ceramic materials when electric voltage is applied (piezoelectric or electrostrictive effect). These actuators have some very good characteristics as for example excellent position accuracy and dynamics, high force to dimension ratio and high stiffness. However typical values for maximum strains achieved along the direction of applied field are around 0.1 % and therefore their primary application is focused on micromanipulation. Another disadvantage of piezoelectric actuators is that they need high-voltage actuation. One common way to reduce the applied voltage to more practical levels is to use multilayer ceramics.

Actuators based on change of a fluid viscosity exploit properties of the electrorheological fluids (ERF) or magnetorheological fluids (MRF). Rheological fluids are made from suspensions of an insulating fluid base and extremely fine particles (0.1 – 100 μm). Upon application of an electric (for ERF) or magnetic (for MRF) field the fluid changes consistency from liquid to gel. Response time is on the order of milliseconds. Rheological fluids offer the following advantages: quick response, relatively large forces transmissions, small size and light weights. The main drawback of actuators based on rheological fluids is high voltages required to produce the output forces. Their application in robotics is limited by now [8].

Electroactive polymers (EAPs) are polymers which respond to electric stimulation with a substantial shape and size change and large actuation strains. Based on their activation mechanism they can be grouped in two categories – dielectric and ionic EAPs [14].

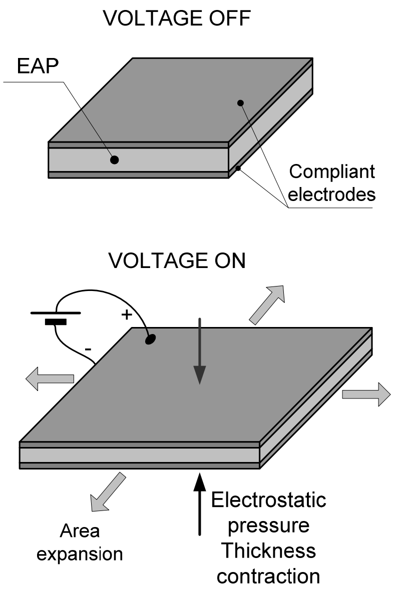

Fig. 2. Basics of EAPs technology.

Dielectric EAPs are basically made up of a film of an elastic dielectric material that is coated on both sides with another expandable film of a conducting electrode. When voltage is applied to the two electrodes a Maxwell pressure is created upon the dielectric layer (Fig. 2). The elastic dielectric polymer acts as an incompressible fluid (as the electrode pressure causes the dielectric film to become thinner, it expands in the planar direction) [3]. Electrical force is converted to mechanical actuation and motion. Response rate of the dielectric EAPs is fast and their force output is high. They require almost no current to hold a position. However the applied electric field with relatively high voltage rates can cause uncomfortable electric shocks.

Ionic EAPs work on the basis of electro-chemistry (mobility or diffusion of charged ions). They include ionic polymer gels, conductive polymers, carbon nanotubes and ionomeric polymer-metal composites. A low voltage applied electric field causes a movement of ions and material deformation. The advantage of ionic EAPs is high enlargement under low voltage. Their main disadvantages are relatively low actuation force and a slow response speed. The other is that they generally need to be wet and so must be sealed within flexible coatings [1, 14].

Electroactive polymers are an emerging actuation technology that offers the potential to displace many traditional actuation technologies. Some polymer actuators are called "artificial muscles" because they can duplicate the behavior of natural muscles. SRI International (SRI) developed a technology based on a particularly promising class of electroactive polymers, dielectric elastomers, that can be used as actuator components in a wide variety of applications. This technology has been named electroactive polymer artificial muscle (EPAM™) by SRI and AMI (Artificial Muscle, Incorporated – company based by SRI, now an independent company with the investment of venture capital funds) [2]. On the base of EPAM™ technology AMI developed the Universal Muscle Actuator (UMA™) which is the basic building block for AMI's initial , back-to-back and joined at their centres

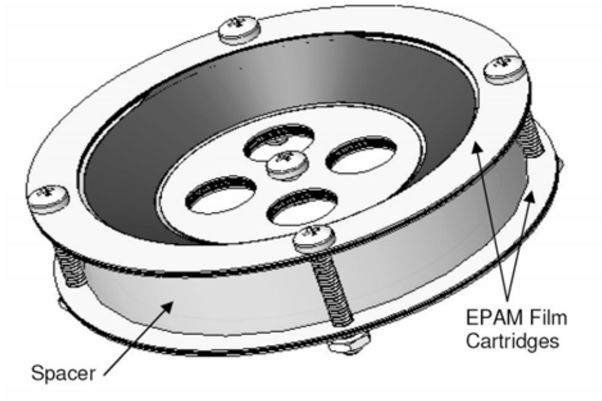

Fig. 3. Universal muscle actuator (UMA™) [7].

(Fig. 3). When the voltage is applied to one of the films, film expands, pre-strain is relaxed and movement occurs.

Pneumatic Artificial Muscles (PAMs) are contractile and linear motion engines operated by gas pressure. Their core element is a flexible reinforced closed membrane attached at both ends to fittings along which mechanical power is transferred to a load. When the membrane is inflated it bulges outward. When the gas is sucked of membrane it is squeezed. Together with this radial expansion or contraction, the membrane contracts axially and thereby exerts a pulling force on its load. The force and motion thus generated by this type of actuator are linear and unidirectional [5].

Displacement (contraction) of PAMs depends on their construction but is typically 30-35 % of the dilated length, which is comparable with natural muscle. The PAMs are highly flexible, soft in contact and have excellent safety potential. This gives a soft actuator option, which is again comparable with natural muscle. The contractile force for a given cross-sectional area of an actuator can be over 300 N/cm^2 for the PAM compared to 20-40 N/cm^2 for natural muscle. An interesting feature possessed by PAMs is their ability to operate in an antagonistic mode (like natural muscles); this introduces the inherent ability to modulate stiffness/compliance. This is a feature not generally found in conventional actuators but it is an ability that has a number of benefits in particular applications [6].

The major problem of using of the PAMs actuators in robotics is that the control of these actuators is much more complicated than the control of electrical motors especially due to strongly non-linear properties of the muscles.

4. CONCLUSIONS

Although electric drives through the development of electronics has found enormous applications in all motion operations the conventional hydraulic and pneumatic drives are used and probably will be used in future as actuators for industrial robots in applications with specific requirements (for example hydraulic drives for high power and force-to-weight outputs actuators, pneumatic drives for low-cost, low-precision actuators). But era of dominance of DC drives has came to an end, trend is in AC drives (rotary and linear too) consigned as compact mechatronic modules.

a

b

Fig. 4. Deflated (a) and inflated (b) PAM [9].

In field of nonconventional actuators for industrial robots are mainly perspective pneumatic artificial muscles due to improvement of their characteristics in commercial production. A big effort is now devoted to improvement of modelling of PAMs and development of new control algorithms of PAM based actuators for achievement of better position accuracy.

EAP based actuators are very perspective too, because they can be smaller, lighter, cheaper, and quieter than conventional electromagnetic actuators as well as competing new actuation technologies. EAP actuators can be utilized for a broad range of applications. An intensive research and development works of their application possibilities can be supposed in near future.

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