

Course 5: Mechatronics - Foundations and Applications

# Hydraulic and Pneumatic Actuators and their Application Areas

Elena Ponomareva

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## **Abstract**

Modern robotic systems are difficult. drives are a mechanical part of this systems. Three types of drives are basically used now: electric, pneumatic and hydraulic. Each type has its own advantages and disadvantages.

In this paper I'm going to tell you about pneumatic and hydraulic actuators, about their advantages and disadvantages, about their types and variants of design.

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# 1 Introduction

Modern robotic systems are difficult. drives are a mechanical part of this systems. Three types of drives are basically used now: electric, pneumatic and hydraulic. Each type has its own advantages and disadvantages.

In this paper I'm going to tell you about pneumatic and hydraulic actuators, about their advantages and disadvantages, about their types and variants of design.

Functional schemes of pneumatic and hydraulic drives are similar. We'll discuss one of them.

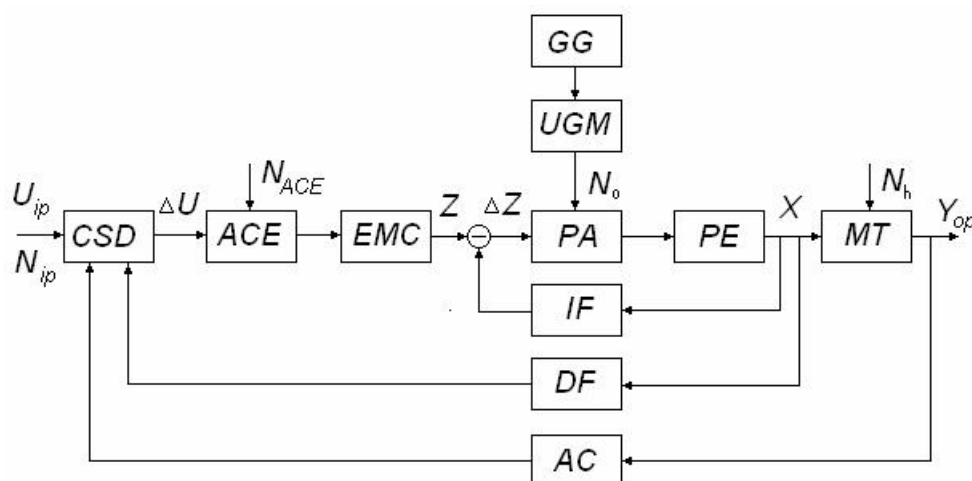


Figure 1: Automatic Pneumatic Drive

Automatic pneumatic drive, its function scheme is shown in the fig. A, generally represents a complex of devices and consists of a source of gas energy, units of gas networks and mains (UGM), pneumatic amplifiers (PA), pneumatic engines (PE), the mechanism of transfer (MT) and directors, converting and summing device (CSD), amplifiers of capacity of electric signals (ACE), electromechanical converters (EMC), devices of feedbacks (DF), adjusting circuits (AC) and internal feedbacks (IF).

All complex of these devices is intended for amplification and transformation of a low-power input signal into mechanical moving of the target shaft of the executive mechanism.

The initial drive size of a drive is electric signal  $U_{ip}$  of low power  $N_{ip}$  which is corrected and amplifies with the help of additional feed energy of the capacity amplifier in the converting and summing device (CSD). The amplified control signal moves on electromechanical converter (EMC) that accordingly moves the managing body of pneumoamplifier (PA) on the size value  $z$ . The angle of the turn of electromechanical converter's (EMC) axis in direct ratio corresponds to the size value  $z$ . Due to rigid mechanical connection of the axis of the torque motor with the axis of pneumatic amplifier (PA) jet tube of or with the motion of the choke, the valve or the rod of PA valve, control of the gas stream proceeding from a source of gas energy (GG), through UGM and PA in pneumatic engine (PE) is occurred. Proportionally to the value of the main signal  $U_{ip}$ , the gas stream  $N_0$  is moved into the engine that transforms this stream into mechanical displacement of the  $X$  enging output link. For connection of the engine with loading capacity  $N_c$  stipulates the mechanism of transfer (MT) which rigidly connects the moving of the rod of the engine with the movement of the loading  $Y_{op}$  of the working mechanism.

To increase dynamic properties and accuracy of reproduction of the input signal the automated drive has feedbacks EF and DF and adjusting circuits (AC) on speed, acceleration

and loading.

## 2 Pneumatic Actuators

Physical processes proceeding in pneumatic drives are submitted to the gas laws.

The gas laws are a set of laws that describe the relationship between thermodynamic temperature (T), pressure (P) and volume (V) of gases. Three of these laws, Boyle's law, Charles's law, and Gay-Lussac's law, may be combined to form the combined gas law

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2} \quad (1)$$

which with the addition of Avogadro's law later gave way to the ideal gas law. Other important gas laws include Dalton's law of partial pressures. The kinetic theory of gases, Graham's law of effusion and root mean square velocity explains how individual molecules act in a gas and their relation to pressure, volume, and temperature.

A gas that obeys these gas laws is known exactly as an ideal gas (or perfect gas). An ideal gas does not exist; however, some gases follow the laws more closely than the others in given standard conditions.

The most important gas law is the ideal gas law, which states that:  $PV = nRT$

Other gas laws, such as van der Waals equation, seek to correct the ideal gas laws to reflect the behaviour of actual gases. Van der Waals equation alters the ideal gas law to reflect how actual gases function using a series of calculated values called van der Waals constants.

It is also possible to apply Boltzmann's analysis to determine further information about gases. With the equation:

$$\frac{1}{2}m \langle c^2 \rangle = \frac{3}{2}kT \quad (2)$$

detailed information about the speeds of the atoms in a gas, the kinetic energy, and the temperature conditions under which it exists can be gleaned.

### 2.1 Different kinds of Pneumatic Actuators

#### 2.1.1 Classification of pneumatic actuators

A set of devices into with one or more pneumoengines, which are determined to start mechanisms or some other objects by means of pressed working gas is called pneumatic actuator, or pneumoactuator.

The devices intended for transformation of potential and kinetic energy of the stream of compressed gas in mechanical energy of the output link that can be, for example, a rod of the piston, a shaft of the turbine or the case of the jet device is called pneumatic engines of the automated actuator.

All pneumatic actuators can be subdivided into the following types:

- diaphragm pneumatic actuators;
- pneumatic power cylinders;
- gas-engine pneumatic actuators;
- turbine pneumatic actuators;
- jet-stream pneumatic actuators;
- pneumomuscles;
- combined pneumatic actuators.

The principle of transformation of potential or kinetic energy of the gas stream into mechanical energy of the engine output link of the engine provide the base for division into types.

### 2.1.2 Diaphragm pneumatic actuators

Diaphragm pneumatic actuators include membrane and syphon pneumoactuators. Potential energy of gas stream, i.e. energy of static pressure is used in diaphragm pneumatic actuators. The difference of static pressure in receivers of the actuator transforms into the effort on the output element of the drive - the rod. Pneumatic actuators can be executed both on one-sided (not reversible), and on double-sided (reversible) scheme.

The basic scheme of the membrane pneumatic actuator is shown in figure 2 A.

Work of the pneumatic actuator consists in moving of a rod under influence of the difference of pressure  $p_1 - p_2$  in cavities that is formed due to the difference of gas charges  $G_1 - G_2$ .

The syphon pneumatic engine functions by the same principle. Its scheme is shown in figure 2 B.

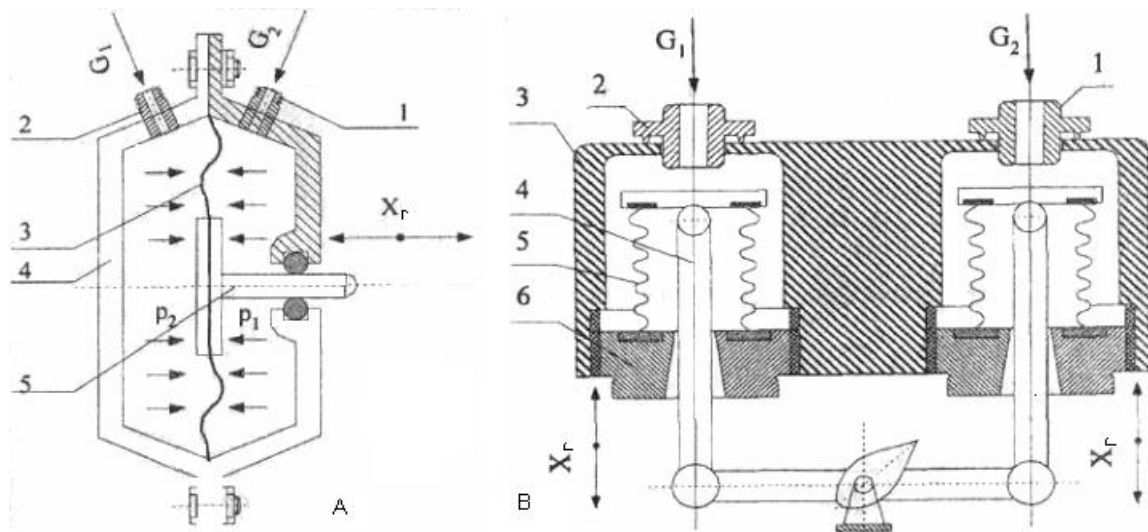


Figure 2: A - The membrane pneumatic actuator; B - The syphon pneumatic actuator.

### 2.1.3 Pneumatic power cylinders

Air, or pneumatic cylinders are devices that convert power of compressed air into mechanical energy. This mechanical energy produces linear or rotary motion. In this way, the air cylinder functions as the actuator in the pneumatic system, so it is also known as a pneumatic linear actuator.

Devices with forward linear movement are divided into single-acting and double-acting pneumocylinders, with rod and rodless. Rod pneumocylinders in turn can have a through-pass or a no-go rod. Devices with rotary (rotational) movement are divided into pneumocylinders with rotary movement of the output link and rotational pneumocylinders.

Structurally pneumatic power cylinders can be piston, membrane, syphon and hose.

The air cylinder consists of steel or stainless steel piston, piston rod, cylinder barrel and end covers.

In piston pneumatic cylinders, as well as in diaphragm, potential energy of the compressed gas is used, but presence of the piston with mobile condensation allows to reach big movements of the output link.

As compressed air moves into the cylinder, it pushes the piston along the length of the cylinder. Compressed air or the spring, located at the rod end of the cylinder, pushes the piston back.

For compression a cuff from elastic material is installed into the rod in a cover of the cylinder. The bush serving as direction for the rod, allows to increase the allowable cross-section effort of the loading on to the rod, especially for big lengths. The ring that prevents dust and firm particles hitting the cylinder is inserted into the cover, in front of the bush. Volume changing of the working cavities is into proportionally to the moving of the rod. Thus, the additional volume can be reductioned to a minimum, determined only by the volume of the pipelines.

Some form of cushioning is normally required to reduce the rate of the cylinder travel before the piston strikes the end cover. Reducing the piston velocity at the end of its travel lowers the stresses on the cylinder while reducing vibration in the structure of which it is part. Efficient cushioning is usually necessary in applications, in which precision is required. Basically, this problem can be solved in one of three ways: by means of simple impact cushioning, by pneumatic cushioning or by fitting shock absorbers.

Valves control the flow of compressed air to the cylinder.

Different types of cylinders include standard, short-run, flat, rodless, rotary cylinders.

The two basic types of standard air cylinders, based on their performance, are as follows: single acting and double acting. The single acting cylinder is able to perform an operating motion in only one direction.

Ram cylinder - a cylinder in which the movable element is the piston rod.

A double acting pneumatic cylinder — has two-directed powered motion in, with pressure on both sides.

When a cylinder is pushed out in one direction, compressed air moves it back in the opposite direction. Air lines running into both ends of the cylinder supply the compressed air. The flow of the compressed air is controlled with valves both in single- and double-acting cylinders.

Spring return cylinder - a cylinder in which a spring returns the piston assembly.

A single acting - spring return air cylinder - has air pressure on one side of the piston flange, supplying force and motion, and the spring supplying the return force after the pressure release. Single acting cylinders require approximately a half of the amount of the air used by a double acting cylinder for a single operating cycle.

Double-acting double-rod cylinder - double-acting cylinder with a piston rod extending from each end. The piston rods are connected with the same piston. Double rod cylinders provide equal force and speed in both directions.

Double acting with magnetic piston according to DIN ISO 6431/VDMA 24562 (cylinders with piston rod on both sides)



Figure 3: The ZSC series.

This series (figure 3) has been specially developed for vertical applications and has just the right contours for this position. Slim and light, but with incredibly precise movement;

an extremely flat design makes it possible to position the ball-bearing system between both pistons. This series is a concept with clear advantages. Thanks to the double-acting principle, both piston rods and the guide system work together precisely and parallel. The ball-bearing circulating guide guarantees a longer service life when operated vertically and the double pistons provide a high level of force, in spite of the flat design. This flexible and light design, as well as precise movements, make it possible to use the slide in dynamic applications. Numerous holes also provide a wide variety of mounting options and facilitate machine layout.

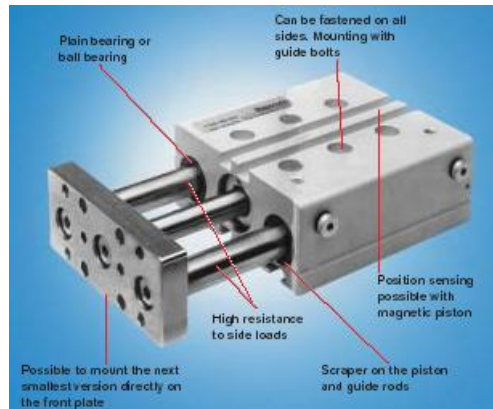


Figure 4: The GPC series.

Another series (figure 4) is ideal for all applications that demand absolute precision and side load capacity. Compared to standard cylinders, cylinders from this series offer extremely precise movement, high side load capacities, and also torsion protection. This results in fewer outer guides to design and set up machines. It optimally designed for handling technology. Thanks to a wide range of technical features, the guided precision cylinder is the perfect product for automation tasks. For example: The next smallest cylinder fits directly on the front plate of the larger cylinder. The TopLoader version even has an additional mounting surface on the top that can be used to attach extra components and objects. It runs smoothly and precisely thanks to efficient plain bearing guides or ball bushing guides, making separate guides unnecessary. Guide cylinders from this series are the top choice for the following applications:

- As a stop in a guide system
- To fasten workpieces for machine processing or spot welding
- As a support for a second axis
- To hold mechanical grippers or suction cups for handling tasks
- For pick and place systems.

The tandem-cylinder represents two cylinders of bilateral action with the general rod, incorporated in one case. By connecting 2, 3 or 4 cylinders with the same piston diameter and stroke in series, the force in the advance stroke (thrust) can be doubled, tripled or quadrupled in comparison to a single cylinder. Tandem-cylinders are applied where it is necessary to develop significant efforts at the limited cross-section sizes of the cylinder.

In the course of rodless cylinders three principles of constructive design were used: tape or rope cylinders, cylinders with condensation longitudinal of spline and cylinders with magnetic socket.

The scheme of the rodless cylinder with consolidation longitudinal spline is shown in the picture (figure 5).

The output part of the rodless pneumocylinder is the carriage to which the loading is connected. The effort from the piston is transferred to the carriage through consolidation longitudinal spline. In the cylinder, along all length of the case there is a through slit. The carriage is rigidly connected with the piston. This connection is carried out with the help of the element sliding in spline of the case pipe of the cylinder. Consolidation spline is provided with a steel tape which adjoins to the internal side of the spline. Each cavity of the cylinder is hermetically sealed with the consolidation established on the piston. Between these consolidation the tape is bent and passes under the element connecting the piston with the carriage. The second tape consolidates spline outside, that protects the cylinder from the hit of pollution from the outside.



Figure 5: The rodless cylinder with consolidation longitudinal spline.

In comparison with the usual cylinder of double-action the rodless cylinder possesses smaller length of the design. Restrictions of cross-section loading on the working body, as against the roding cylinder, are removed. The rodless cylinder can be applied at courses up to 10 m.

The tape cylinder transfers force from the piston to the carriage with the help of the tape covering it. At an output from working volume of the cylinder the tape passes through consolidation in covers of the cylinder.

The cylinder with magnetic coupling of double action consists of cylindrical case, rodless piston and mobile external carriage sliding on the external surface of the case of the cylinder, having in cross-section section the form of a circle. On the piston and on the carriage the constant magnets, cooperating with each other themselves are placed, i.e. transfer of effort for moving loading from the piston to the carriage is carried out with the help of magnetic coupling. After the air have been submitted to the cylinder, the carriage and the piston move simultaneously. The cavity of the cylinder is tight and has no mobile consolidation adjoining to the environment. It completely excludes an opportunity of outflow of air from the cylinder.

It is possible to relate pneumoengines of back and forth motion conditionally to the hose pneumocylinders (figure 6), which are used in transporting mechanisms with significant movings (up to 10 ì), but with small moved weights.

Rollers of the carriage swage the elastic hose. When the air is submitted to the end of the hose and the other end is connected with the atmosphere while the control valve takes position



A, the carriage starts to move together with the moved object due to the hose deformation caused by compressed air. Back-movement of the carriage takes place at switching the control valve in position B.

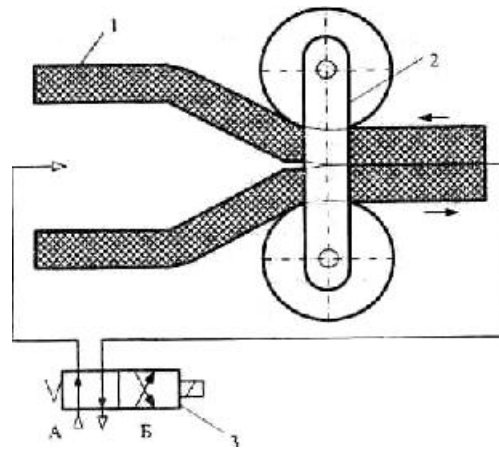


Figure 6: The hose pneumocylinder.

Rotary pneumoactuators basically are constructed on the principle of mechanical transformation of progress of the piston in rotary movement of a target link.

#### 2.1.4 Pneumomuscles

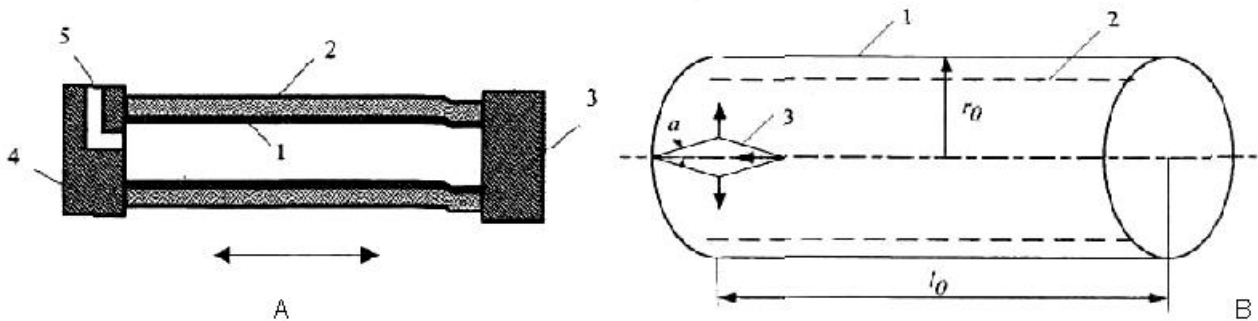


Figure 7: A - Pneumomuscle; B - Geometrical parameters of reduced pneumomuscles

Pneumomuscles are linear pneumatic drives which can reproduce the movements similar to natural muscles. In comparison with power cylinders they develop the big initial efforts to the same working diameters. We distinguish lengthen and reduced pneumomuscles. Character of movement is defined with geometry of a braid of a pneumomuscle. The scheme of a lengthen pneumomuscle is given in fig 7 A.

The internal elastic tube has the braid with three-dimensional cellular structure. Cells have the form of rhomboid. When the channel pressure moves into the feed, the tube starts to extend in its both sides, as it is shown in figure 7B, if the both covers are not fixed. If one of the covers is fixed, an output part of this drive will be the other cover. The design has no moving mechanical parts and it is reliable. The working course of the output link is up to 25 percents from the length of the pneumomuscle.

The effort developed by the drive has the maximal size at the beginning of the working course and further it practically decreases linearly. It allows to realize significant acceleration of the output link in a combination with the smooth and exact approach to the desirable final position.

Comparative characteristics of the output efforts of the power cylinder(1) and the pneumomuscle (2) for the same working diameter and feed pressure in the function of a working course are in fig. 8.

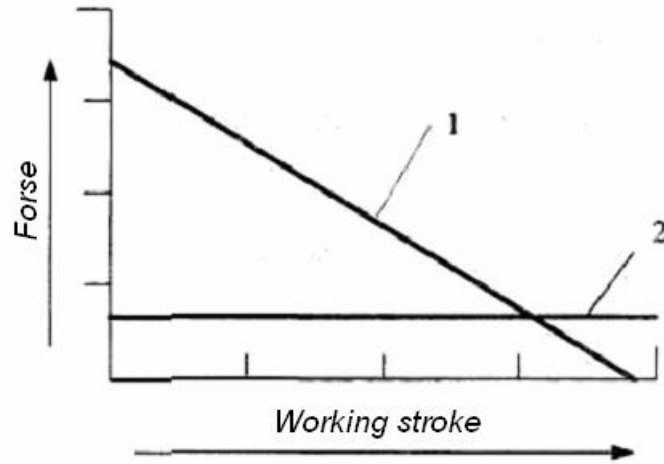


Figure 8: Comparative characteristics

Unlike lengthening pneumomuscles reduced pneumomuscles have a braid in the form of cells, which form is a grid from pantographs and transform the pressure inside the elastic tube when it reduces into length.

Due to symmetry of the braid the pneumomuscle always keeps the cylindrical form. The initial angle  $\alpha$  is defined as the angle between the longitudinal axis of the pneumomuscle and the side of the cell when the working pressure is absent. Parameters  $r_0$  and  $l_0$  are initial radius and length of a pneumomuscle.

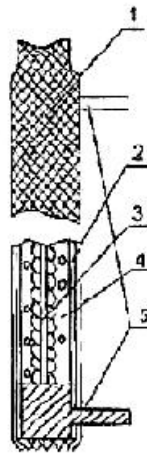


Figure 9: The artificial muscle

The variant of the pneumatic artificial muscle, in which the process of gas pressing takes

place directly in the tube as a result of heating by an electric current, is shown in fig. 9. When the electric current passes through the thermoelement 3 special filler 4 is heated up and eduse gas. As a result the pressure grows inside the tube and it blows out and reduces its length. After switching-off of the current filler cools and again absorbs the educed gas, the muscle comes back to the initial condition.

Length of the muscle is 150-300 $\mu$ m, diameter of 3-5 mm. Size of reduction - 10-15 percents. Developed effort - 1-3  $\mu$ N, at weight of a muscle - units of grammes. The main drawback of this muscle - very low speed: time of compression is more then 30 seconds, and it is 2-3 times as mush as the return relaxation. Other variant of the similar pneumatic muscle with thermal influence - filling of the tube by low-boiling liquid while the external sourse of heat influences on it.

### 2.1.5 The combined pneumatic actuators

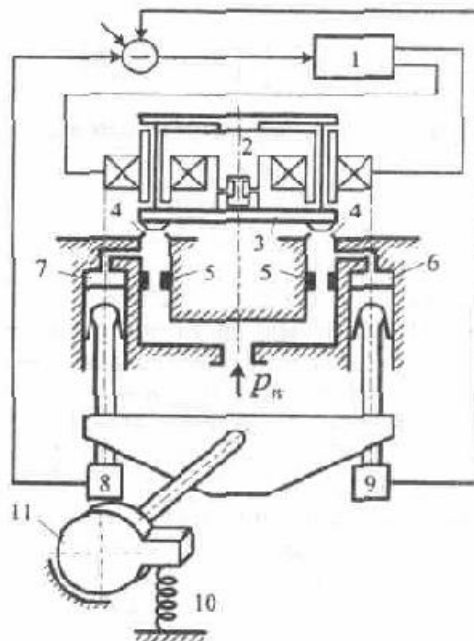


Figure 10: The electropneumatic actuator

In particular, electropneumatic actuators considered to be combined drives. In electropneumatic drives executive engines, electromechanical converters and amplifiers are applied. For example, we shall consider the circuit of an electropneumatic follower drive, in which hot gas serves as a work environment (fig. 10.).

The drive consume gas from the source of constant pressure. Basic elements of the drive are the amplifier 1 of direct current, the electromechanical converter 2 with  $\emptyset$ -shaped stator, choker 3 that is elastic fixed on stator, nozzles 4, throttles 5, executive pneumocylinders 6 and 7, sensors 8 and 9 of feedback by speed and on position of a conducted link - the shaft connected to loading. Item loading is given by a spring 10, and inertial loading - a flywheel 11. Besides it is supposed, that the loading from hydraulic friction is also created.

In the given drive, the executive engines are pneumocylinders that are connected directly to the channels of the pneumoamplifier with managing element of nozzle- choker type, therefore due to the use of energy produced by gas which is under pressure only one step of amplification is carried out.

Choker 3, controlled by the electromechanical converter, carries out regulation of gas streams through out the constant throttles 5.

### 2.1.6 Recuperation of energy in drives

Drives of the robots work basically in transitive cyclic modes dispersal - braking type. Therefore as one of the most important ways to economise on energy at them is to use the idea of energy recuperation. It is especially important for mobile robots with independent power supply. Moreover the speed of operation also raises frequently. Recuperation of energy is based on its storage during braking and feedback at the subsequent acceleration. There are two basic ways of such storage of energy: storage of mechanical energy (with the help of flywheels, springs) and electric (in accumulators, condensers, inductive coils).

A principle of mechanical energy recuperation with the help of springs has got application in Russian cyclic industrial robots. That is why they have very good power characteristics. The spring that provides cyclic movement of the manipulator in the mode of resonant not fading fluctuations with zero speed in extreme points is installed into the cyclic drive. The drive engine carries out the energy charging in the middle of the way at the maximal speed of movement, replenishing the energy loss by the drive while performing its work. Thus, in the final points of movement there is no impact on useless dispersion of the kinetic energy saved up by a drive. Thus, it is possible to reduce energy consumption by 3-4 times and the capacity of the engine can be accordingly reduced. The similar effect can be reach in drives of manipulators' claw devices.

## 2.2 Advantages and disadvantages of Pneumatic Actuators.

Advantages:

- simplicity of realization relatively to small back and forth motions;
- sophisticated transfer mechanisms are not required;
- low cost;
- high speed of moving;
- ease at reversion movements;
- tolerance to overloads, up to a full stop;
- high reliability of work;
- explosion and fire safety;
- ecological purity;
- ability to accumulation and transportation.

Disadvantages:

- compressibility of the air ;
- impossibility to receive uniform and constant speed of the working bodies movement ;
- difficulties in performance at slow speed;
- limited conditions - use of compressed air is beneficial up to the definite values of pressure;
- compressed air requires good preparation.

## 3 Hydraulic Actuators

### 3.1 The Laws The Work Of Hydraulic Actuators Is Based.

Liquid is the physical body possessing fluidity. Fluidity is understood as easy mobility of particles, i.e.(that is) ability beyond all bounds to be deformed and come in movement under action of insignificant forces.

Due to fluidity liquids practically without efforts get the form given by space, and in balanced condition do not perceive tangents strain.

Liquids show resistance to shift in direct dependence on speed of shift deformation and to compression. They don't practically resist to stretching except in cases under special conditions, for example at all-round negative pressure or at attempt to tear off the piston from liquid in the cylinder.

However liquids considered technically pure, in practical conditions contain small impurity and dissolved air, therefore they are not capable to maintain even insignificant stretching strain.

Taking into account mechanical properties we can distinguish two types of liquid: low-compressible (dropping) liquids which insignificantly change the volume when temperature and pressure change, and compressed (gaseous). The difference of mechanical properties of these two types of liquid is insignificant, if it is possible to neglect compressibility of gases namely when differences of temperatures and pressure are small, and speed of movement less than 70 km/s. In these cases the laws received for drop liquids, can be frequently fair for gases. From physics approach the difference between these kinds of liquid is significant. Drop liquids have quite certain volume and consequently fill in only that part of space which is equal to their volume. They can form a boundary free surface, and at insignificant volumes are capable to keep the drop shape.

The phenomenon arising in the moving liquid when pressure decline up to elasticity of saturated vapor and an ambient temperature is named cavitation. Cavitation is accompanied by formation of steam-to-gas bulbs that move with a stream of liquid in area with higher pressure, slam and radiate shock wave. Slamming bulbs near borders of the current can course the destruction of firm surfaces.

Cavitation can arise at low pressure in pipelines, pumps - everywhere where the stream of liquid is exposed to bends, to narrowings expansion (valves, throttles, etc.) followed by.

As a rule, cavitation is the undesirable phenomenon, and should be eliminated from hydrosystems because cavitation can course erosion of surfaces, destruction of elements of hydromachines and hydrosystems. It can increase the resistance of pipelines and sharp by reduce efficiency of hydromachines.

Boiling and cavitation breaks homogeneity of liquids and limits a scope of the laws based on homogeneous nature of the liquid medium.

Silting of narrow cracks and backlashes owing to adsorption (adjournment) of polar-acting molecules of liquid on their walls is called obliteration. The layer of liquid formed at walls gets properties of quasisolid state which viscosity differs from viscosity of liquid. As a result, the part of a boundary layer sticks to a surface of a crack. The thickness of this layer for oils is 4...5 microns, which can essentially reduce a cross-section of slot-hole channels and backlashes or even overgrow them completely.

In fluid dynamics, Bernoulli's equation describes the behavior of fluid moving along the streamline. There are typically two different formulations of the equations; one applies to incompressible flow and the other applies to compressible flow.

The original form, for incompressible flow in a uniform gravitational field (such as on Earth), is:

$$\frac{v^2}{2} + gh + \frac{p}{\rho} = const \quad (3)$$

The equation is named after Daniel Bernoulli although it was first presented in the above form by Leonhard Euler.

The second, more general form of Bernoulli's equation may be written for compressible fluids, in which case, following the streamline:

$$\frac{v^2}{2} + \varphi + \omega = const \quad (4)$$

The constant on the right hand side is often called the Bernoulli constant and denoted  $b$ . For steady inviscid adiabatic flow with no additional sources or sinks of energy,  $b$  is constant along any given streamline. More generally, when  $b$  may vary along streamlines, it still proves a useful parameter, related to the "head" of the fluid.

When there are shock waves present, in a reference frame moving with a shock, many of the parameters in the Bernoulli equation suffer abrupt changes in passing through the shock. The Bernoulli parameter itself, however, remains unaffected. An exception to this rule is radiative shocks, which violate the assumptions leading to the Bernoulli equation, namely the lack of additional sinks or sources of energy.

## 3.2 Different Kinds of Hydraulic Actuators

### 3.2.1 The Structure of Hydraulic Cylinders

Hydraulic cylinders widely apply in building, digging, hoisting-and-transport, road machines, automobiles, and also in the processing equipment - metal-cutting machine tools, forge - pressing machines.

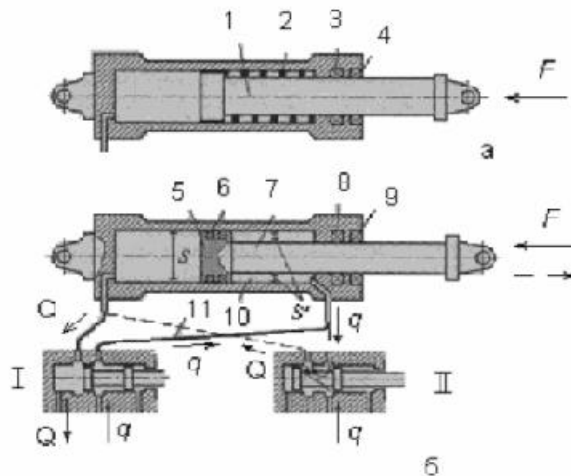


Figure 11: The hydraulic cylinder

The hydraulic cylinder of one-sided action (fig. 11, a) has a plunger 1, moved by force of pressure of liquid to one side. Reverse motion of the plunger is made under action of external force  $F$  if it operates continuously, or spring 2. The unique external condensation of the plunger consists of the basic 3 and antisplash 4 condensing elements. The hydraulic cylinder of double-sided action (fig. 11, b) has the piston 5 with a rod 7, condensed by internal 6 and external 8 sealants. The difference between full  $S$  and ring  $S'$  areas of the piston conducts to distinction in using pressure  $p$  at moving to the left and to the right if overcoming external force  $F$  is constant. If constant consumption  $Q$  is brought to the cylinder, the difference of

the areas results in distinction of speeds of movement of the piston depending on a direction of moving.

In order to eliminate these effects when they are undesirable, such hydraulic cylinders are included by means of a valve under the differential circuit (position I and II of the valve) at which the rod's cavity 10 is continuously connected to a supply circuit 11. If  $S' = S/2$ , at the movement to the right (position I of the valve) and to the left (position II of the valve) speed  $v = Q/S'$  and force  $F$  will be identical.

To get the full symmetry of forces and speeds we apply hydraulic cylinders with a double-sided rod with one internal 1 and two external condensations 3 and 4. In this case the design with the fixed rod is shorter in 1,5 times, than a design with the fixed hydraulic cylinder and a control valve.

The number of consolidations which are the sources of friction and places of external and internal outflows, defines volumetric and mechanical efficiency of the hydraulic cylinder, and also its reliability. From this point of view the hydraulic cylinder with a double-sided rod has the smaller efficiency in comparison with the considered cylinders under other equal conditions.

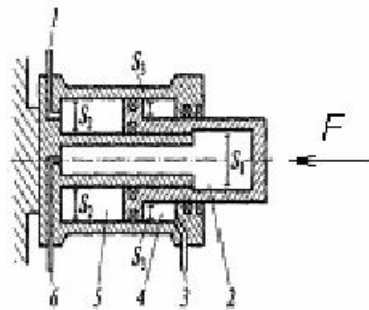


Figure 12: The three-high-speed hydraulic cylinder

The scheme of the three-high-speed hydraulic cylinder with two levels of developed force is shown in fig. 12. Such hydraulic cylinders are used in the pressing equipment. The fast course of approaching with the speed  $V_1 = Q/S_1$  is carried out by filling of a cavity through a supply 6 at hydrolines 1 and 3, connected with a plum area. The working course with small speed  $v_2 = Q / (S_1+S_2)$  on a short way is carried out at a feeding of cavities 4 and 5 through supplies 1 and 3. Thus the hydraulic cylinder used at the maximum working area, develops the maximum force  $F = p (S_1+S_2)$  at the least pressure  $p$ . The fast returnable course with the speed  $v_3 = Q/S_3$  is made at filling a cavity 4 through a line 3, thus lines 1 and 6 are connected to a plum area.

In many cases hydraulic cylinders work in severe conditions when suddenly changing loadings and adverse climatic conditions. For protection against the hit of moisture and dirt provide double external consolidations (for example, 3 and 4) antisplash consolidations 2 and 5, and sometimes rubber sylphon 4 (fig. 13), entirely closing a rod at promotion. Ending brake devices are established for protection against impacts of the piston against a cover of the hydraulic cylinder at the end of a course. Sockets 2 and 3 are realized in covers of the hydraulic cylinder, and corresponding to them there are cylindrical ledges 7 and 6 on the piston, forming with jacks small backlashes. At the end of a course the ring volume 8 will be squeezed out through a throttle 1 and a ring crack, whose resistance is great, and speed of the piston will decrease. Return valves 5 are stipulated for fast filling of the cylinder in the beginning of a course around of a throttle 1 and of the socket.

Telescopic hydraulic cylinders (fig. 14) are applied in the cases when the desirable course exceeds the allowable adjusting length of the hydraulic cylinder. Promotion of the sections of

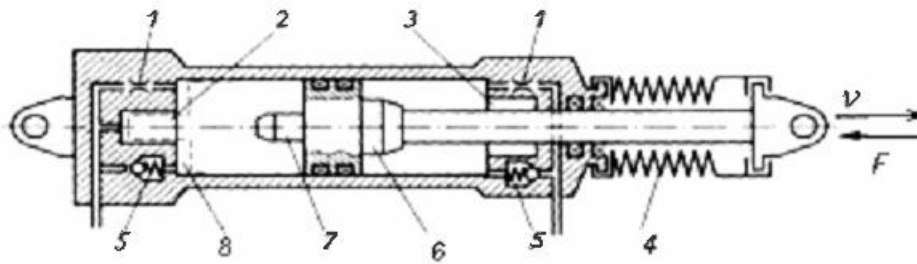


Figure 13: The hydraulic cylinder with trailer throttle brakes and the protected rod

the hydraulic cylinder if it feeds through the line 7 from a source of constant charge  $Q$  (for example, the volumetric pump), will occur at different speed value and if overcoming force  $F$  is constant, at different pressures.

At promotion the piston 1 displaces the first against the stop with the small speed  $V_1 = Q/S_1$  at the smaller pressure  $p_1 = F/S_1$ . After the full promotion of the piston 1 the piston 6, whose area  $S_2$  starts to move till full promotion. At the same time, the speed increases up to  $V_2 = Q/S_2$  and the pressure grows up to  $p_2 = F/S_2$ . The promotion of sections is made under action of force  $F$ , or by submission of charge  $Q$  through the line 5 in the cavities 2 and 3 through the sleeve 4.

Application of the telescopic cylinders having up to six sections is known.

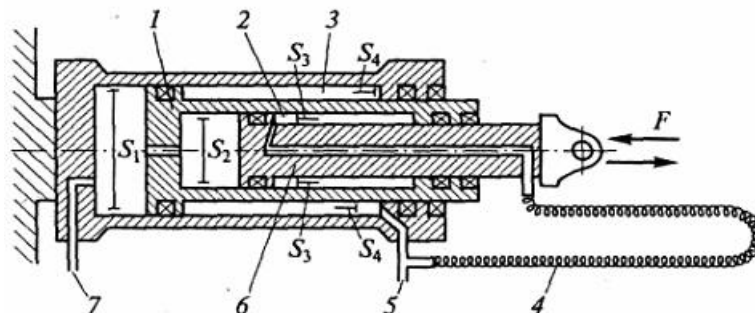


Figure 14: The telescopic hydraulic cylinder

### 3.2.2 Volumetric hydraulic actuator

Volumetric hydraulic actuator is the set of volumetric hydromachines, hydroequipments, hydrolines (pipelines) and the auxiliary devices, intended to transfer energy and transformation of movement by means of liquid.

There are several types of pumps and hydraulic engines, which can be considered as hydromashines. The hydroequipment are devices which control a hydraulic actuator. These devices adjust the hydraulic actuator and protect it from excessively high and low pressure of liquid. Throttles, flaps of different assignment and hydraulic control valves are concerned to the hydroequipment - devices for changing direction of a liquid stream. As auxiliary devices the so-called conditioners of working liquid providing its quality and condition serve: various separators of firm particles, including filters, heat-exchangers (heaters and coolers of liquid),



hydrotanks, and also hydroaccumulators. The listed elements are connected with each other by hydrolines where working liquid goes.

The principle of action of a volumetric hydrodrive is based on small compressibility of drop liquid and transfer of pressure to them under Pascal's law. Pascal's law can be formulated as follows: any change of pressure in any point of the based liquid, without breaking its balance, is transferred in its other points without change. Pascal's law specifies ability of liquid to transfer effort to distance that is widely used in technics(technical equipment). Work of hydraulic jacks, presses, multiplies, brakes, a volumetric hydrodrive, systems hydropneumoautomatics, etc. is based on Pascal's law.

Let's consider the elementary hydrodrive - Hydraulic Jack.

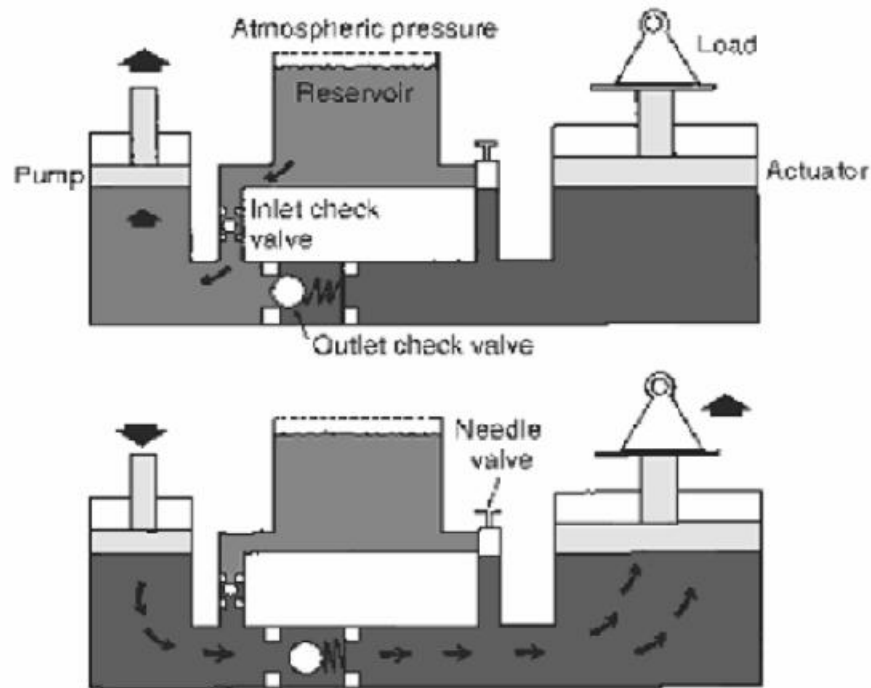


Figure 15: Hydraulic Jack

In this system , a reservoir and a system of valves has been added to a simple hydraulic lever to stroke a small cylinder or pump continuously and raise a large piston or an actuator a notch with each stroke. The top view of within the diagram below shows an intake stroke. An outlet check valve closes by pressure under a load, and an inlet check valve opens so that liquid from the reservoir fills the pumping chamber. The lower view of the diagram shows the pump stroking downward. An inlet check valve closes by pressure and an outlet valve opens. More liquid is pumped under a large piston to raise it. To lower a load, a third valve (needle valve) opens, which opens an area under a large piston to the reservoir. The load then pushes the piston down and forces the liquid into the reservoir.

#### STABILIZATION AND SYNCHRONIZATION OF MOVEMENT OF TARGET PARTS OF HYDRAULIC ACTUATORS

In hydraulic actuators of metal-cutting machine tools and other machines it is frequently applied throttle regulation with the device for stabilization of speed of an output link with the purpose of improvement of loading characteristics. The regulator of the stream that provides stability of established speed irrespective from the change of loading serves as such device.

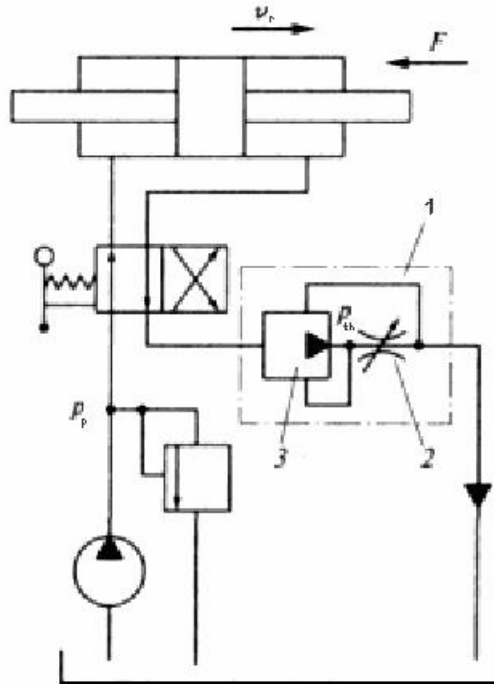


Figure 16: The scheme of a hydraulic actuator with a regulator of a stream

The scheme of a hydraulic actuator of linear motion with the regulator of a stream established consistently on an output from the hydraulic cylinder is shown in fig. 16. The regulator 7 consists of an adjustable throttle 2 and a reducing valve 3. The last supports the constant pressure  $P_{th}$  upon the input in a throttle. Pressure is believed to be constant and equal to atmospheric on the output from the throttle at small resistance of a removing hydroline.

Hence, the charge of liquid through a throttle will be steady. Submission of liquid in hydraulic engine  $Q_{he} = Q_p - Q_{th}$  is steady when the submission of the pump is steady and does not depend on loading, so speed of an output link will also be steady. Actually speed  $V_p$  with increase in loading decreases owing to outflow in the pump, growing with increase in pressure, and also due to discrepancy of work of a reducing valve.

Hydraulic actuator with a steady output frequency of rotation when frequency of rotation of a shaft of the pump is variable and when loading on a shaft of the hydraulic motor is variable is called stabilized.

Stabilization of output frequency of rotation is usually carried out on a signal of the centrifugal or electrohydraulic regulator influencing through an intensifying part on the mechanism of change of working volume of the pump. The hydromotor in such circuit usually uncontrollable.

The scheme of the elementary hydraulic actuator for stabilization of rotation frequencies of the alternating current stable frequencies electrogenerator with a centrifugal regulator of speed is shown in fig. 17. The hydraulic actuator consists of the pump 1 connected to the reducing engine, and the hydromotor 2, the shaft 3 which is connected to the electrogenerator and results in rotation of a centrifugal regulator 4 which moves the valve 5 of hydraulic control valves of a control system with changing of rotation frequency of the hydromotor 2. The last, submitting liquid into the hydraulic cylinder 6 of the mechanism of regulation (the inclination angle of the disk) the pump 7, restores mismatch, supporting output rotation frequency of the hydromotor at constant value.

When one pump actuates two or more hydraulic engines, sometimes it is necessary to

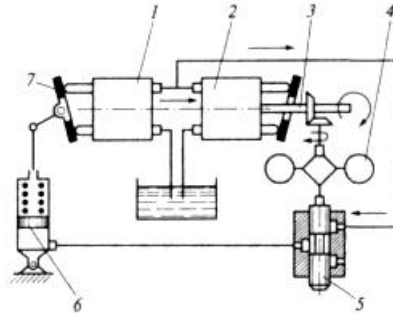


Figure 17: The scheme of a hydraulic actuator with steady output rotation frequency

provide identical speed of their target parts, despite of some distinction of loadings. Such requirement arises, for example, in a hydraulic actuator of the load-lifting machine in which the cargo is risen up by several parallel-connected hydraulic cylinders without skews.

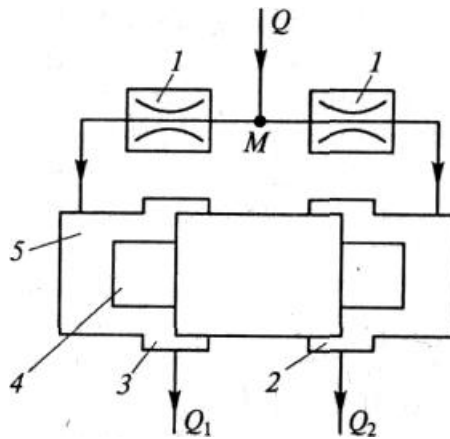


Figure 18: The scheme of a stream divider

Synchronization of movement of hydraulic engines is carried out by means of a so-called divider of a stream (fig. 18) which principle of action is based on throttling. At point M the stream branches into two ones, each of which passes through a constant throttle 7, and then is brought to a sleeve 5 with the floating piston 4. The floating piston plays a role of a valve, moving in one or other side depending on difference of working pressure. The difference of pressure arises when the charge of liquid in one branch is distinct from the charge in another one owing to different loadings and, hence, loss of pressure in one throttle more, than in the other one. Moving aside smaller pressure, for example to the right, the piston 4 reduces the area of an aperture 2 and increases the area of an aperture 3. The piston will stop when pressure in the right and left cavities of a sleeve and consequently, the charge through these cavities will be equal.

### 3.3 Advantages and disadvantages of Hydraulic Actuators

Variable hydraulic actuators are widely used as drives of machine tools, rolling mills, pressing and the foundry equipment, road and building machines, transport and agricultural machines, etc. A number of advantages in comparison with mechanical and electric transfers explains such their wide application:

- infinitely variable control of gear-ratio in a wide range and an opportunity to create the big reduction ratio;
- small specific weight, i.e. the weight of a hydroactuator is in ratio to transmitted capacity (0,2...0,3 kg / kWt);
- opportunity of simple and reliable protection of the engine from overloads;
- small sluggishness of the rotating parts, providing fast change of operating modes (start-up, dispersal, a reverser, a stop);
- simplicity of transformation of rotary movement into reciprocating one;
- opportunity of positioning a hydraulic engine on removal(distance) from an energy source and freedom in making configuration.

It is also necessary to reckon with disadvantages of hydraulic actuators:

- efficiency of a volumetric hydraulic actuator is a little bit lower, than efficiency of mechanical and electric transfers, and during regulation it is reduced;
- conditions of operation of a hydraulic actuator (temperature) influence its characteristics;
- efficiency of a hydraulic actuator is a little reduced in the process of exhaustion of its resource owing to the increase in backlashes and the increase of outflow of liquid (falling of volumetric efficiency);
- sensitivity to pollution of working liquid and necessity of high culture service.

## 4 Application Areas of Pneumatic and Hydraulic Actuators

### 4.1 Pneumatic processing centers

The scheme of the pneumatic processing center with a rotary table is submitted in figure 19.

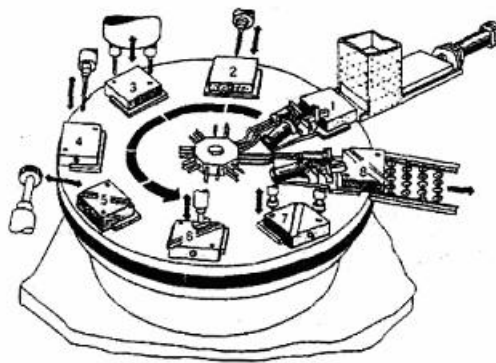


Figure 19: The scheme of the pneumatic machining center

The pneumatic processing center carries out the following functions: - step-by-step rotation with the help of a rotary table - parts cutting with the help of tools 2-7 (drilling, grinding, milling); - reception, positioning and fixing a detail with the help of the block 1; - delivery of a detail with the help of the block 8. On the rotary table various processes of serial part cutting can be carried out. Thus, only once the detail goes into the center and is established

for processing and only once removed and given out from the pneumatic processing center center.

The scheme of the pneumatic processing center for sawing material's is submitted in figure 20.

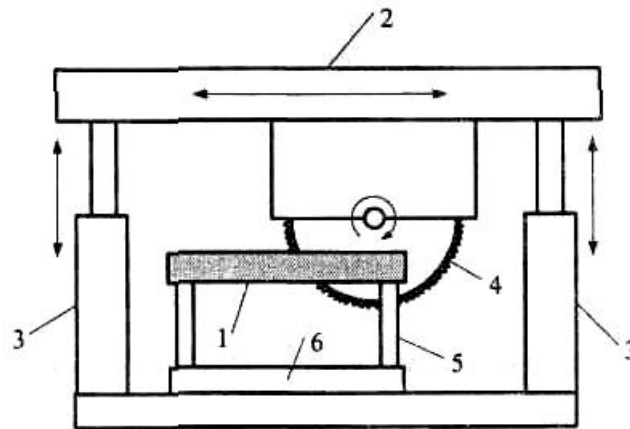


Figure 20: The scheme of the pneumatic processing center for sawing materials

All actuators of the center, including a drive of the tool are pneumatic. Simultaneous movement of several drives achieves any trajectory of sawing material.

## 4.2 Batching

Batching of liquids and the fused metals, for example, in foundry manufacture can be made by system which circuit is shown in figure 21.

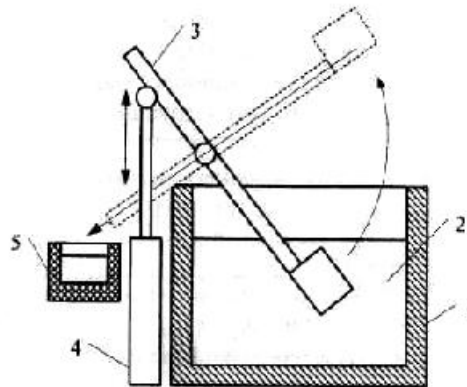


Figure 21: The scheme of batching

The lever with a ladle is actuated by the power cylinder. The volume of a ladle corresponds to a required doze of liquid which gets in the top position of a rod of the power cylinder. With the rod moving to the bottom position the liquid from the ladle is automatically poured in accepting chamber.

### 4.3 Robotics

On the basis of pneumatic actuators stationary and mobile robots with wide functionalities can be created.

One of the first stationary Russian serial pneumatic industrial robots is МІ - 9Ñ.

The robot has four degrees of mobility provided by horizontal and vertical power cylinders, and also by a turning drive of gripping device and a drive of fingers.

Mobile pneumatic robots allow to realize walking type of moving. The example scheme of such robot for automation of mine clearing is shown in figure 22.

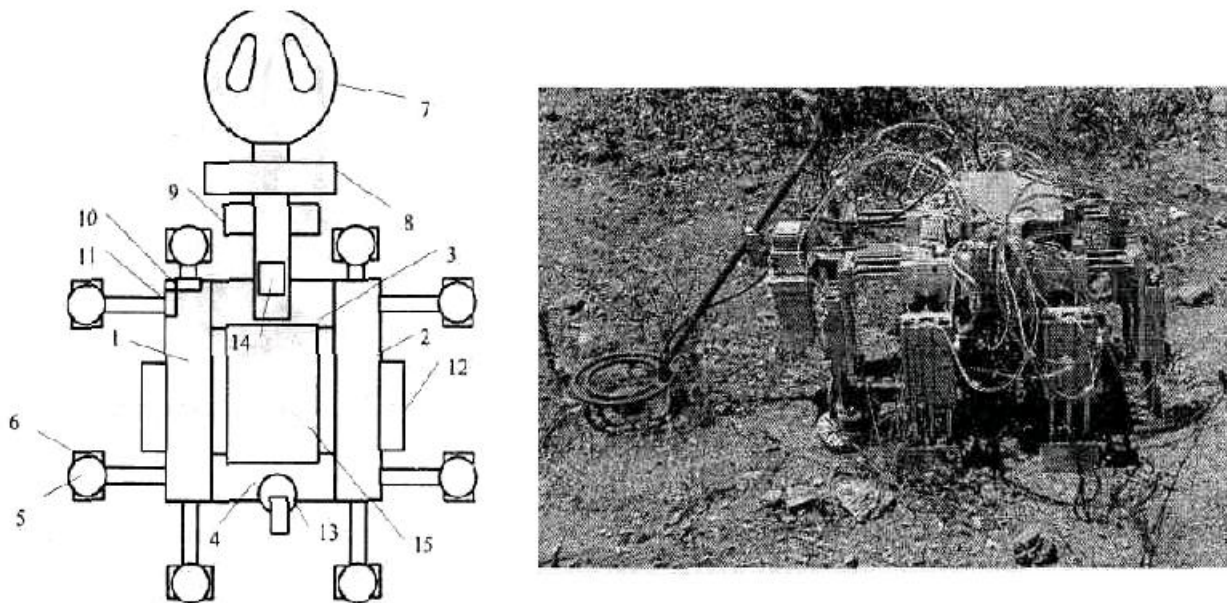


Figure 22: The scheme of the mobile robot

The transport module consists of longitudinal and cross-section pneumatic cylinders which cases are connected symmetrically. Each transport cylinder has two manipulators which are established at end-walls of rods of the cylinder.

Manipulator consists of the elevating cylinder with a course, allowing to overcome the set sizes of obstacles, and supports with a gear working surface to improve coupling with a surface when it makes along on slopes. The block of mines detection consists of metal detector, the infra-red sensor and a chemical sensor control. This block is established on a forward part on a course of the robot. The sensor of longitudinal position movement is placed on the case of the longitudinal cylinder. The sensor of cross-section position movement and the block of detection is, accordingly, on the case of the cross-section cylinder.

The block of valves settles down from both sides of the robot that provides the minimal length of onboard feeding lines. They submit compressed air from the site of the feed component connected to the main feeding line on to managing valves.

The feed component provides robot rotation concerning the main feeding line without creation of the counter torque at the expense of sliding pneumatic condensation. The onboard computer and an electronic compass are established on the top part of the platform.

The robot has two control modes. The first one is a transport mode. In this case longitudinal cylinders move the manipulators which are in the top position, at the maximum speed, and full length of a working course.

During this movement the robot leans on the moving surface by means of manipulators of the cross-section cylinder. On the following step manipulators of longitudinal cylinders carries

out this role and so on. The robot has an opportunity to change a direction of movement on a required angle. Simultaneous movement of longitudinal cylinders in opposite directions carries out rotation of the robot when their manipulators contact with the surface of movement. The second control mode is the mode of mines detection. In this mode the block of detection scans a zone in front of the robot. The trajectory of scanning is realized by cross-section and longitudinal cylinders, which are actuated with the rated speed corresponding to parameters of the block of detection.

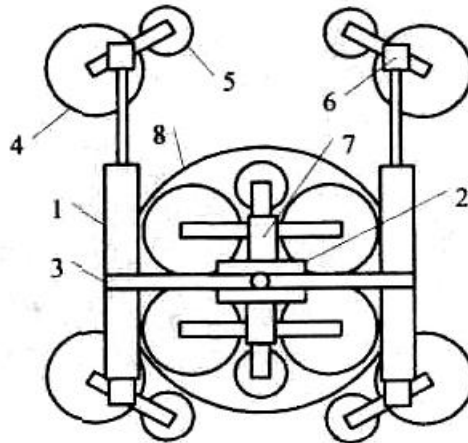


Figure 23: The scheme of the mobile robot with vertical displacement

Creation of robots of vertical moving is rather new direction in the development of mobile robots. These robots are capable to move and carry out technological operations on surfaces inclined at any corner of an that determines the efficiency of their use at big heights in construction, in radioactive zones at nuclear reactors service and in other extreme situations.

The example of a construction of the pneumatic robot of vertical moving is shown on figure 23.

The robot consists of the longitudinal movement module and the rotating movement module. These modules are connected with each other along its rotation axis. The longitudinal movement module consists of two pneumatic cylinders.

Manipulators of longitudinal movement are established at end-walls of cylinders rods. They have vacuum gripping devices which can move concerning the case of the robot by using elevating cylinders.

The rotation module contains the pneumatic drive of rotation connected rigidly with manipulators, having the same combination of gripping devices and elevating cylinders, as the longitudinal movement module.

The robot has nine degrees of freedom.

Movements of the robot are carried out by using step-by-step vacuum fixing of the longitudinal movement module and the rotation module to a surface of movement and serial moving of cylinder rods and their cases to a direction of movement with an opportunity of turn with the help of a drive of rotation on a required angle. Longitudinal movement and rotary movement modules are equipped with elevating cylinders 5. Elevating cylinder rods are connected with concentric gripping devices and sealing gripping devices. This connection is elastic in the direction of the cylinders action. Such connection enables all working surface of gripping devices to enter contact with a rough surface of movement.

## 5 Conclusions

In this report we've discussed pneumatic and hydraulic actuators, their advantages and disadvantages, their types and variants of design.

## 6 Literature

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