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Development of a Pneumatic Drives Parametric Model

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ABSTRACT : *The article describes a pneumatic actuators features, as well as their use in robotics (analyzed drive design). A tree of structural elements properties for a pneumatic drive was proposedin order to obtain a comprehensive and accurate analysis. A parametric model for determining the basic pneumatic actuators parameters has been developed on basis of tree. The carried out key parameters of the study determined that the accuracy can be increased by reducing speed of robot movement and drive power is directly dependent on moment.*

KEYWORDS *parametric, model, pneumatic drives, industrial, robots.*

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I. INTRODUCTION

The drive is an important part in robotics. Drives used in works affecting their feasibility and performance [1].Significant indicators of robots in addition to cost are: reliability of drive elements and durability of elements of its design.

There are three main types of actuators that are currently used in robots: pneumatic, hydraulic and electric, as well as different combinations of these three. Every robot is fitted with a system of actuators on the arms or in the joints, constituting a drive system [1-3].

In this paper pneumatic type of drives is considered, since its main advantages are simplicity, high reliability and low cost.

Pneumatic drives (PD) are used mainly in small, simple robots performing "pick-and-place" tasks [2].Pneumatic actuator allows you to get a high movement speed of output manipulator link.

Pneumatic drives feature the use of compressible fluids, usually compressed air. The advantages of these drives are the abundantly available and easily accessed power medium (air) that can be released when the task is finished. Their presser, compared with hydraulic drives, also makes these systems very safe to operate. In addition, unlike all liquids, air has good dynamic properties, no viscosity and low stiffness (high compliance) [2].

When designing a drives, the following requirements should be considered [4-7]:

- minimum drive elements mass with a high efficiency of entire structure;
- minimum drive size with high energy performance, which provide a large ratio value of output power to mass;
- ensuring speed, that is, the movement of actuators works with high speeds and with a minimum positioning error;
- ease of installation, repair, maintenance, changeover and noiseless operation

PD has become widespread, 40-50% of global robots [1, 2].

An important feature of pneumatic actuator is that, as a rule, it is easily combined with the manipulator links, thereby pr
oviding a direct impact on them [2].

II. MATERIALS AND METHODS

2.1 Related work

Pneumatic robots are widely used in the automation and mechanization of a industrial processes number.

Existing works are devoted to design of features consideration, dynamics of drive elements motion, management and modernization of these devices. The solution of drives parametric identification problem is a constant interest, since they affect the overall robot performance.

In [8] study of main parameters characterizing the air motor. The dynamics of pneumatic motor rod movement is considered. Built a mathematical model of work pneumatic drive based on the Bernoulli law and equations of flow continuity, and also equations of cylinder motion according to Newton's second law. A series of experiments with industrial robot, during which a stock transfer schedule was obtained.

In [9] reports the concept, design and development of a pneumatic braided muscle actuator, able to produce bi-directional force and motion. A 3D-finite element model of the actuator is developed and a number of non-linear quasi-static simulations are performed using the explicit dynamic solver LS-Dyna, to measure the blocked force and free displacement of the actuator. Finite element modeling is utilized as a design tool in order to study the feasibility of the concept, where a single braid structure is deformed to produce both contraction and elongation.

Methods of dynamic calculation of actuators of discrete pneumatic actuators are presented in [10]. The work gives the definition time of executive devices cavity's filling that could be used in dynamic calculation of pneumodrive's parts.

Modeling vacuum bellows soft pneumatic actuators with optimal mechanical performance described in [11]. This paper presents the concept and model of "Vacuum Bellows," a cylindrical membrane-reinforced contractile vacuum soft pneumatic actuator (V-SPAs). Presents experimental results highlight the utility of the model and some practical advices for actuator fabrication and use.

The loudspeaker of pneumatic actuators in robots and manipulators is considered in [12]. The features of air motor functioning and mathematical dependencies of its parameters are investigated.

2.2 Analysis of features and robots drives use

Consider the features and use of PD in robotics (Fig. 1) [1, 2].

Fig. 1. Pneumatic drive with spring return

The software includes: engine; switchgear supplying air to the engine; drive speed controller by controlling air flow. The engine can be both rotary and forward movement (pneumatic cylinder).

An example of a single-acting pneumatic cylinder is presented in Fig. 2 [1, 13].

Single-acting pneumatic cylinders are used in cases when it is necessary to transfer power only in one direction, as well as when, for security reasons, the "retracted" rod position should be provided when power is turned off (pressure drop of compressed air in pneumatic network). In such devices, the return occurs unchecked.

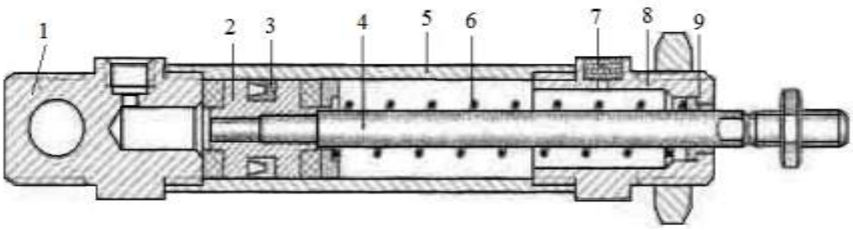


Fig. 2. Single-action pneumatic cylinder

The pneumatic cylinder consists of following elements:
1 - cylindrical body back cover, in which the air inlet;
2 - a piston that divides the inner space of body (sleeves) into two cavities (rod and piston);
3 - a seal that separates the body cavities;
4 - rod rigidly connected to the piston;
5 - cylindrical body;
6 - return spring, which is mounted inside the cylinder and covers the rod;
7 - filter element;
8 - cylindrical body front cover has a decompression opening with an integrated filter element 7;
9 - guide sleeve, which is located on front cover of housing and is a support for sliding the rod, transmits forces from the piston to an external object. There are a large number of single-acting pneumatic cylinders designs, such as diaphragm pneumatic cylinders.

Double-acting pneumatic cylinders are used in cases when it is required to transfer working force during linear movements in both directions, for example, when moving, installing, raising and lowering the working bodies of machines and other production and technological operations.

An example of a double-acting pneumatic cylinder is shown in Fig. 3 [14].

In piston pneumatic cylinders of one-sided and double-sided action, almost all elements, as well as the methods of their fastening, are the same.

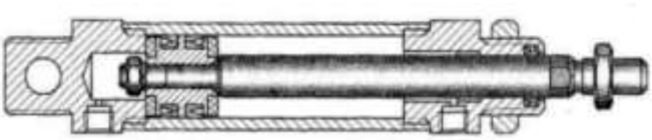


Fig. 3. Double-acting pneumatic cylinder

The movement of rod in any direction is working and can be carried out under load. During the return piston stroke, rod cavity is under excessive pressure, which is due to install additional seals need on piston and in front cover to prevent compressed air from leaking through the rod.

PD is used only in light and medium robots carrying capacity.

PD is used in robots with the number of mobility degrees equal to 2 or 3 [1, 2].

The positioning error in these drives does not exceed ± 0.1 mm.

Advantages of PD: simple construction; low cost; high speed of robots elements movement (dampers are used to reduce the speed in cycle-controlled robots) are quite reliable in operation.

The disadvantage of PD is that they are poorly controlled and therefore are mainly used as unregulated with cyclic controls.

The most common pneumatic cylinders, which can directly connect with the manipulator links without the aid of transmission mechanisms, which simplifies the robot mechanical system.

The most appropriate use of pneumatic drivers in industrial robots with a power consumption of 60 - 800 watts.

Regardless of drive type, criteria for comparative evaluation of drive options in final selection may be drive mass, specific output power, efficiency, the adequacy of mechanical and control system energy sources, possibility of modular-modular construction, ease of maintenance and operational safety.

III. RESULTS

3.1 Parametric model of pneumatic drives for industrial robots

As a result of PD features analysis, it is determined that the most important areas of PD development include the study of pneumatic drives dynamics, as well as the choice of their optimal structure, satisfies the specified criteria of optimality, what are the lowest cost, high accuracy, reliability, noise immunity, constructive compactness , embed ability, etc.

In Fig. 4 shows a structural properties tree of elements for a pneumatic drive.

Taking into account the structural properties, which are shown in Fig. 4 proposed parametric description of the PD, which can be represented in form:

$$PD = < EB_i^j, DB_i^j, CB_i^j >, \quad (1)$$

where PD –pneumatic actuators;

EB_i^j – subset executive block PP; i = 1…N, N –number of subclasses of pneumatic actuators (according to the classification in Fig. 4); j – parameters ПП, j = 1…M, M –number of parameters;

DB_i^j – subset allocation block;

CB_i^j – subset control block.

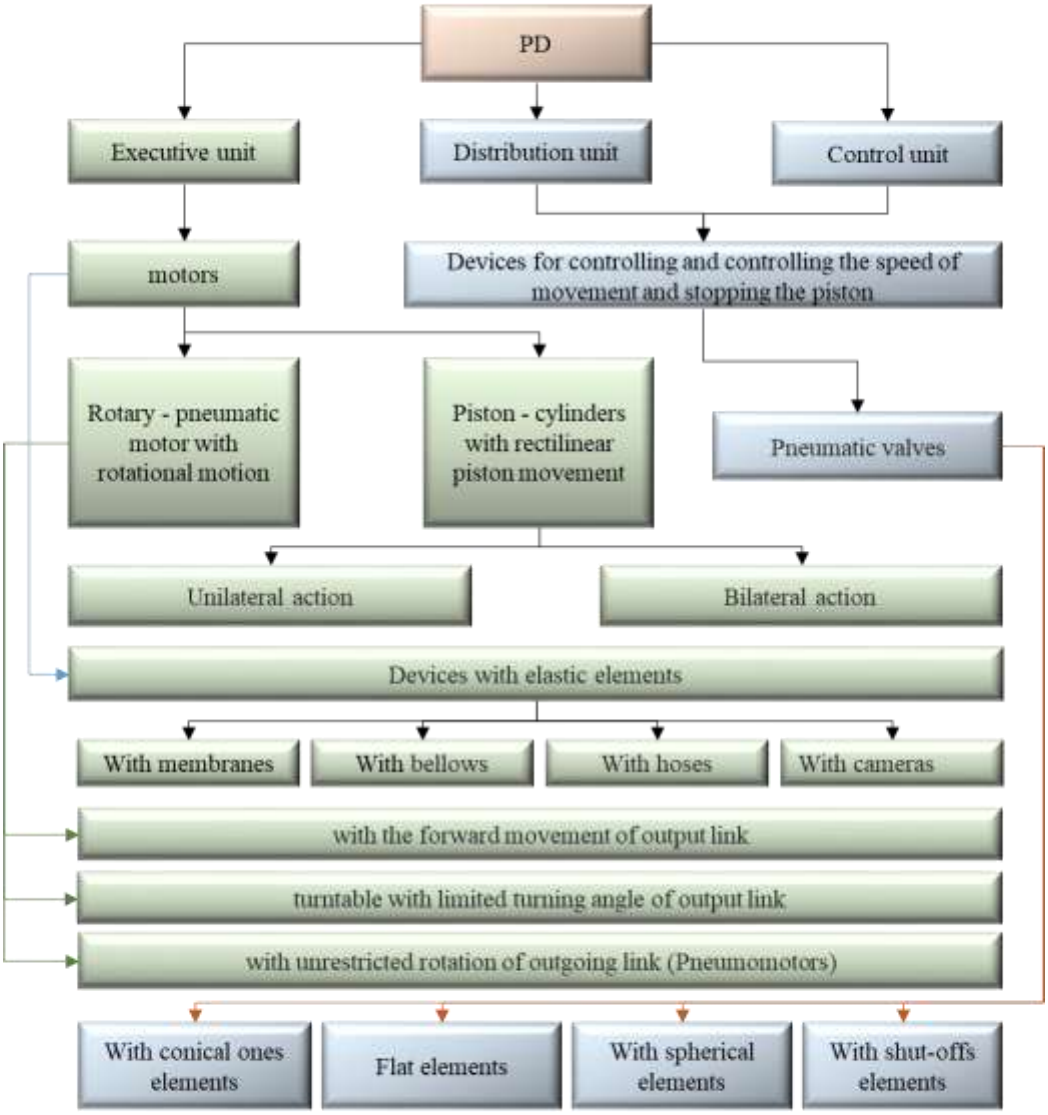


Fig. 4. Tree of structural properties elements for pneumatic drive

Let the subset executive unit of pneumatic actuators consists of structural elements:

$$EB = < RtP_k^r, PCl_k^r >, \qquad (2)$$

where RtP_k^r – "air motor" element during rotational motion (for k = 1 ... K, K is the number of parameters and for r = 1 ... R, R is the number of air motor types);

PCl_k^r – cylinder element with rectilinear piston movement (for k = 1 ... K, K is the number of parameters and for r = 1 ... R, R is the number of cylinders types).

Let us proceed to the second subset consideration - distribution block, which can be described as follows:

$$\text{DB} =< RsM_k^r, RsP_k^r >, \quad (3)$$

where RsM_k^r – an element for regulating the piston speed (for k = 1 ... K, K is the number of parameters and for r = 1 ... R, R is the number of devices types for regulating the piston speed);

RsP_k^r – a piston stop control element (for k = 1 ... K, K is the number of parameters and for r = 1... R, R is the number of piston stop control devices types).

Let us proceed to the third subset consideration - control unit, which can be described as follows:

$$\text{CB} =< CsM_k^r, CsP_k^r >, \quad (4)$$

where CsM_k^r – control element of piston speed (with k = 1 ... K, K is the parameters number and when r = 1 ... R, R is the number of control devices types for the piston speed);

CsP_k^r – piston stop control element (with k = 1 ... K, K is the parameters number and r = 1 ... R, R is the number of piston stop control devices types).

Based on tree structural properties of elements for pneumatic drives shown in Fig. 4 we will offer a parametric description of main parameters for PD key blocks (PD_p):

$$PD_p =< RmO_{nom}, ArO, \text{Im}\,p, Wvm_k, Epa_k, Pss, Psp, Pac,$$

$$Epp_k, Dm_k, Pmv, Lfr_k, Plp_k, Twp, Sm_k, Sz_k, VlT, EfR, PmT_{\max} > \quad (5)$$

where RmO_{nom} – rated torque on output shaft;

ArO – rotation angle of output shaft;

$\text{Im}\,p$ – idling pressure;

Wvm_k – engine displacement when turning to full angle when k = 1 ... K, K is the maximum engine displacement;

Epa_k – effective piston area with k - cavity type, k = 1 ... 2 (1 - working cavity (piston), 2 - exhaust cavity (rod));

Pss – working stroke of air motor piston;

Psp – air motor piston speed;

Pac – acceleration of air motor piston;

Epp_k – effective area of intersection of pipelines (PP) at k = 1 ... 2 (1 - at PPT exit, 2 - at the entrance);

Dm_k – diameter of engine parameters at k = 1 ... 2 (1 - piston, 2 - rod);

Pmv – driving force;

Lfr_k – load force (necessary) with k = 1 ... 3 (1 - friction force, 2 - inertia force, 3 - weight of moving drive parts with the object of manipulation);

Plp_k – arrangement of cylinder piston at k = 1 ... 3 (1 - horizontal arrangement of piston cylinder, 2 - vertical arrangement of cylinder piston);

Twp – time of pneumatic cylinder;

Sm_k – range of piston parameters regulation at k = 1 ... 2 (1 - piston movement speed, 2 - piston stopping);

Sz_k – overall dimensions of PD blocks with k = 1 ... 2 (1 - executive, 2 - distribution, 3 - controls);
VlT – voltage;
EfR –coefficient of performance.
The parameter time of pneumatic cylinder Twp can be described as:

$$Twp =< Tdr, StT, Trn >, \qquad (6)$$

where Tdr – pneumatic cylinder forward stroke time;
StT – downtime of pneumatic cylinder;
Trn – return stroke time of pneumatic cylinder.
The direct hour of pneumatic cylinder can be represented as:

$$Tdr =< Tdo, Tpc, Tip, TmP, TpW >, \qquad (7)$$

where Tdo – valve response time,
Tip – time of air propagation to cylinder;
TmP –time of pressure increase;
Tpc – time of piston movement;
TpW – time during which pressure builds up to working pressure.
The pneumatic cylinder return time can be represented as:

$$Trn =< Tdo, TmP, TpW >. \qquad (8)$$

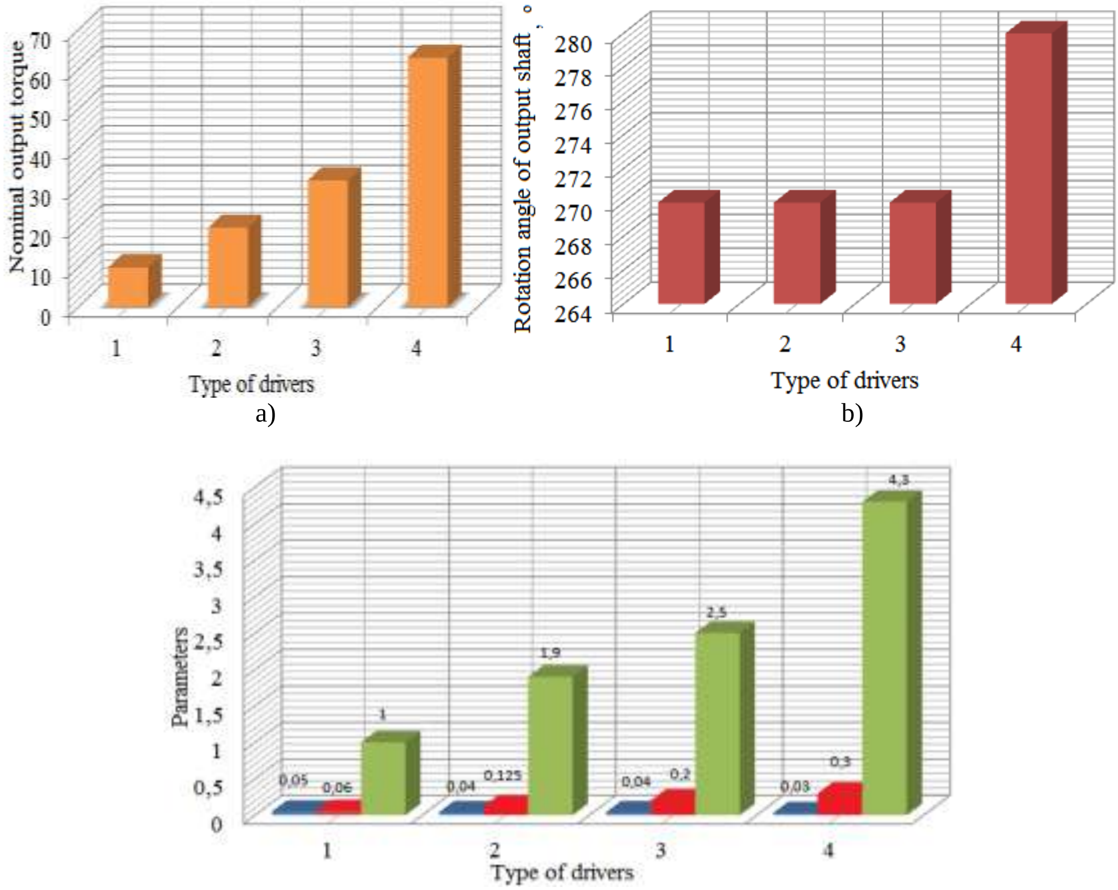
3.2 Discussion of parametric model application results
Having the proposed parametric model (5) to determine the PD key parameters, key parameters in Table 1.

Table 1: Comparison of robot drives

№	PD options	Color chart	PDL1 (1)	PDL2-1 (2)	PDL3-1 (3)	PDL6-1 (4)
1	Nominal output torque, Н·м		10	20	32	63
2	Output shaft rotation angle, °		270	270	270	280
3	Idling pressure, MPa		0,05	0,04	0,04	0,03
4	Engine displacement when turning at full angle, dm^3		0,06	0,125	0,2	0,3
5	Weight, kg		1	1,9	2,5	4,3

Consider the main technical PD parameters PDL type (with modifications 1, 2-1, 3-1 and 6-1). A comparison of 4 types pneumatic motors parameters is shown in Fig. 5a, Fig. 5b and Fig. 5c.

Thus, it is determined that the PD with a large engine displacement and weight, there is a greater nominal torque on the output shaft and a lower no-load pressure. Drive power depends directly on the moment and is in itself a mathematical, calculated value that cannot be measured separately from the moment.



c)

Fig. 5. Comparison diagram of PD parameters

Torque reflects the power that will be available at "incomplete" engine speed. The more torque better power. The more power, more energy you can add work, directly affects the speed. The maximum speed is achieved when power is consumed, will be equal to the power of motor. "Low-speed" motors have large rotating moments.

IV. CONCLUSION

The paper analyzed the structure and characteristics of PD application. A tree of structural elements properties for pneumatic drives is proposed, where the main drives elements are blocks: executive, distribution (regulation), control.

Taking into account the structural properties tree of PD elements, a parametric model has been developed, which, unlike the well-known ones, allows building structural properties trees of basic elements for alternative drives. This model makes it possible to generate a variety of choices for the drive designer.

Thus, the ability to build a parametric model is essential in computer-aided design process and creation of computer-aided design systems, since each design stage of drives can be associated with its own model and thus avoid unreasonable complication of design problem.

A study of drives key parameters on basis of which it was determined that the accuracy can be increased by reducing the robot speed, and drive power directly depends on the moment. As a result of research, it was determined that the PD with a large engine displacement and mass has a higher nominal torque at the output shaft and a lower idling pressure.

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