Definition of pneumatic artificial muscles operational characteristics

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Abstract. The paper describes the experimental measurements carried out in order to describe the actions taking place in antagonistic involvement of pneumatic artificial muscles (PAMs). Operational capabilities limits of PAMs operation was recorded.

Keywords: Pneumatic artificial muscle, acceleration, pulse-width modulation

1 Introduction

In the field of manufacturing technique is in applications requiring replacement or enhancement of power of the human muscular system, respectively in materials handling, it is possible to consider the use of the pneumatic artificial muscles as the drive for the manipulator. Application of PAM as a drive is possible for example in an environment where the use of conventional drive is disadvantageous or not conceivable. Relevant examples are aggressive or explosive environments. The reason for continuously more intensive research into the characteristics of PAM and their application is their high proportion of the generated power to their weight. For PAM there is characteristic inherent strength and safety. PAM itself have several additional benefits such as clean operation, easy maintenance, low acquisition costs, maintenance costs, high durability and in condition for safe operation, sparking or ignition is not possible. These benefits are the reason why PAM can become an alternative in substitution for traditionally used drives in selected applications. This article deals with an experimental measurements made on experimental device with an installed propulsion drive consisting of two pneumatic artificial muscles located in opposition and connected by chain transmission with shaft for the transmission

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of torque. Opposed involvement of PAM is termed as antagonistic involvement of pneumatic artificial muscles (PAMs). [1 - 5]

A wider range of usability of these drives prevents poor cope with precise position control. PAMs requires accurate positioning control system that would be capable of rapid response to changes taking place in the PAMs. In position control today there are often applied mathematical and statistical methods intended to create the most accurate mathematical model of PAMs with the estimated optimal control parameters. In the case of wider application of PAMs and unforeseen changes in workload, the task of the control system is a control of non-linear system. Therefore, an effort of the measurements referred in this article describes the conditions of PAMs operation ensuring stable operation of the experimental device. [1 - 5]

For potential of mass applications of PAMs manufacturing nodes it is possible to also consider the effectiveness of PAMs use, as well as the effective use of the working media. Therefore there is necessary to fix the limit of the conditions of PAMs operation, for identifying the potential for operation of the device with the lowest consumption of process media. [1,6,7]

2 Static characteristics of artificial muscles

PAM works on the transformation of pneumatic energy into mechanical energy. PAM contraction is the result of the impact of pressure of medium (gas) to the inner layer of the membrane, as performing input labor W_{in}: [2,8,9]

$$dW_{in} = \int_{S_i} (P - P_0) dl_i . ds_i = P` dV \tag{1}$$

where: P – gas absolute pressure inside the PAM, P_0 - ambient gas absolute pressure, P`- relative pressure (P-P_0), Si - total inner surface of the muscle, ds_i – area differential, dl_i - inner surface differential, dV – volume differential. [8,10]

Work output W_{out}, arising when PAM length is reducing is defined as:

$$dW_{out} = -F dL \tag{2}$$

where: F – PAM axial tractive force, dL – displacement in axis direction. [8]

If energy loss caused by the system will be neglected, then under the law of energy conservation the work at the output is equal to input work:

$$dW_{out} = dW_{in} \tag{3}$$

After substituting both equations (1) and (2):

$$F = -P' \frac{dV}{dL} \tag{4}$$

Ratio of dV / dL is intended assuming idealized active part of PAM as an ideal cylinder (Figure 1.), where: L - cylinder height, θ - braid fiber and the cylinder axis angle, D – cylinder diameter, n - fiber encircles around the cylinder, b – fiber length. [8]

With constant parameters n a b, can be expressed L and D as a function of θ:

$$L = b\cos\theta \tag{5}$$

$$D = \frac{b\sin\theta}{n\pi} \tag{6}$$

The volume of cylinder:

$$V = \frac{1}{4}\pi D^2 L = \frac{b^3}{4\pi n^2}\sin^2\theta\cos\theta \tag{7}$$

The output force is defined as a P` and θ function:

$$F = -P'\frac{dV}{dL} = -P'\frac{dV/d\theta}{dL/d\theta} = \frac{P'b^2(3\cos^2\theta - 1)}{4\pi n^2} \tag{8}$$

The output force, developed by pneumatic artificial muscle is thus linearly dependent on the pressure of the working fluid inside the PAM. It is also the function of angle between the braid fiber and the cylinder axis θ. [2, 8]

3 Experimental apparatus

Experimental actuator consists of an antagonistic involvement of PAM, compressed air supply system and the control system. The task of the control system is to measure, process and record informations about the static and dynamic characteristics during operation of actuators. On the basis of the data control, the control system interfere with the operation of experimental assembly. PAMs are mounted on the support structure. Arm serving for attaching a weight is mounted to the drive shaft. [7]

The Figure 2. shows a schematic representation of an experimental assembly where: PAM_L – left pneumatic artificial muscle, PAM_P - right pneumatic artificial muscle, LM – distance of the center of gravity of weight M from the shaft of the arm, SP -potentiometric encoder, α - angle of the arm rotation from the neutral position 0, P_L - left PAM pressure sensor P_P - right PAM pressure sensor, P - pressure, I - electric current, R - electrical resistance P_K - pressure at the compressor outlet, V_{1L} / V_{1P} - left / right inflation electro valve, V_{2L} / V_{2P} - left / right drain electro valve P_{VZD} - vessel pressure, A / B / C - acceleration sensors. By orange are highlighted signals from measuring devices, by red are highligted signals from vibration sensors, By light green are drawn control signals for controlling electro-pneumatic valve and blue color representing transportation routes for the compressed medium. Control of this facility is realized by means of four electro-pneumatic valves. Two electro-pneumatic valves are used to connect the PAM system and the compressed medium. Other electro-pneumatic valves are used for deflation of each PAM. [7]

The Figure 3. shows the experimental assembly in its operation.

4 Experimental measurements

During experimental measurements were monitored characteristics of the device during its operation. Arm was rotated into 4 positions (15°, 30°, 45°, 60°). For this experimental measurement has been set the size of the maximum PAM working pressure to 5.1 bar, tolerance of accuracy of pressure setting in PAM to 0.05 bar. Tolerance of the arm rotational angle size has been set at ± 1,5°. Size of the width-pulse modulation has been set to 20-100%. Measured were pressures in each PAM (PS 016V-504-LI2VPN8X H1141), value of arm rotational angle (potentiometric resistive divider) and arm acceleration (DeltaTron 4514-B).

The control system operates in cycles. During performance of one cycle are measured and recorded data corresponding to one group (cluster) of data from each sensor element and control intervention variable. In this paper are taken into consideration the data about the size of rotation of the carrier arm, its acceleration and the data about size of width-pulse modulation for the opening of electro-pneumatic valves. Position control is performed by using a simple algorithm providing a deflation for one PAM and simultaneous inflation for the second PAM.

In the figures Figure 4. and Figure 5. are drawn only data about the value of PWM for the left PAM whose represent the opening of the electro-pneumatic valve serving for inflation of PAM (plotted in the positive direction) and electro-pneumatic valve for PAM deflation (plotted in a negative direction). Waveforms are arranged one below the other and they represents the values of the angle of the carrier arm rotation, support arm acceleration and informations about opening of the electro-pneumatic valves used to control the left PAM. Measured data are representing processes in PAMs during time when they are holding the desired position.

There is a significant difference between the size of acceleration when positioning the arm to different positions. With an enlarged rotation of the carrier arm there is significant decrease in the value of the measured acceleration. This is caused by increasing the rigidity of the system. Impact emerging in PAMs from the operation of electro-pneumatic valves is responding to fluctuations in the measured acceleration. Waveforms displays a phenomenon occurring within the opening of electro-pneumatic valves on more than one iteration of the control program. If the electro-pneumatic valve is open for more than one iteration occured glimpse of the support arm to the opposite side, even in the smallest size of PWM.

5 Conclusions

At the Department of process technique, Faculty of Manufacturing Technologies with a seat in Prešov was designed an experimental actuator comprising a pneumatic artificial muscles. The article discussed waveforms from the experimental measurements whose describes the behavior of mechanism during its operation. After control of stable and efficient operation of PAMs in compliance with the limits for operation PAMs, can be accessed to the application of mathematical models into experimental facility control system.

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Figure 1. n and b coefficients determination [8]

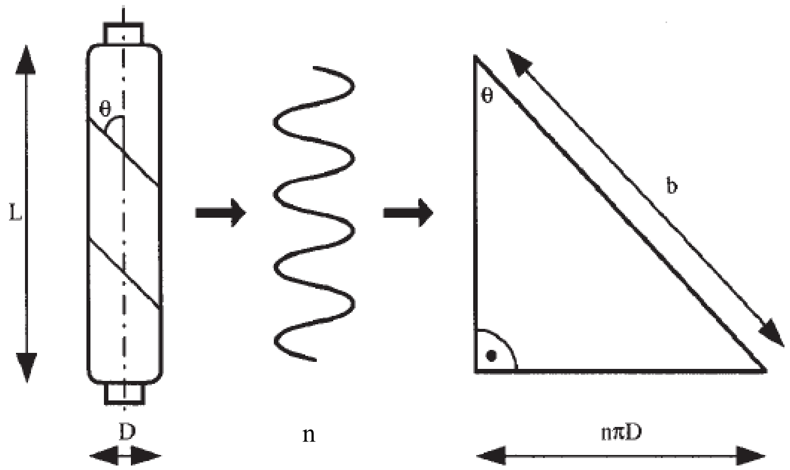

Figure 2. Schematic depiction of experimental involvement with the NI cRIO 9024 [7]

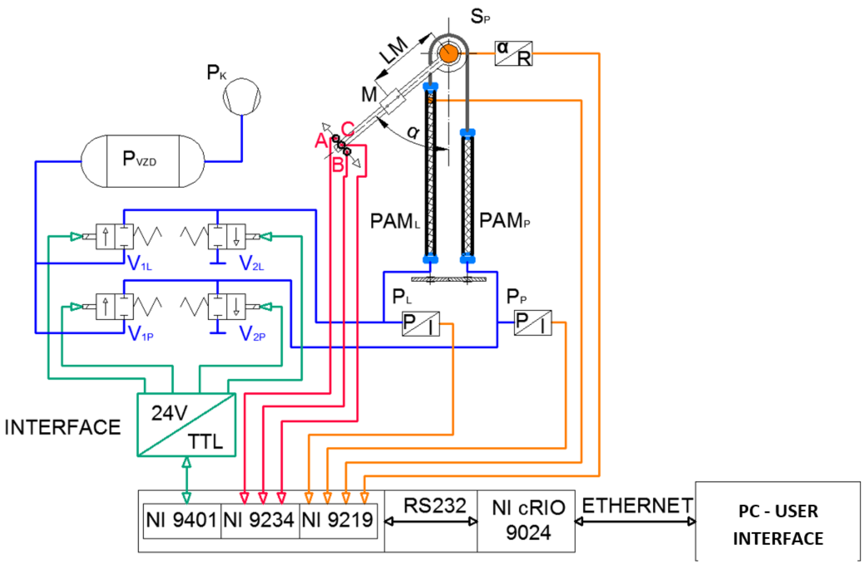

Figure 3. Experimental device with drive based on PAM [7]

Figure 4. Experimental measurements when positioning the arm to 15° and 30° [7]

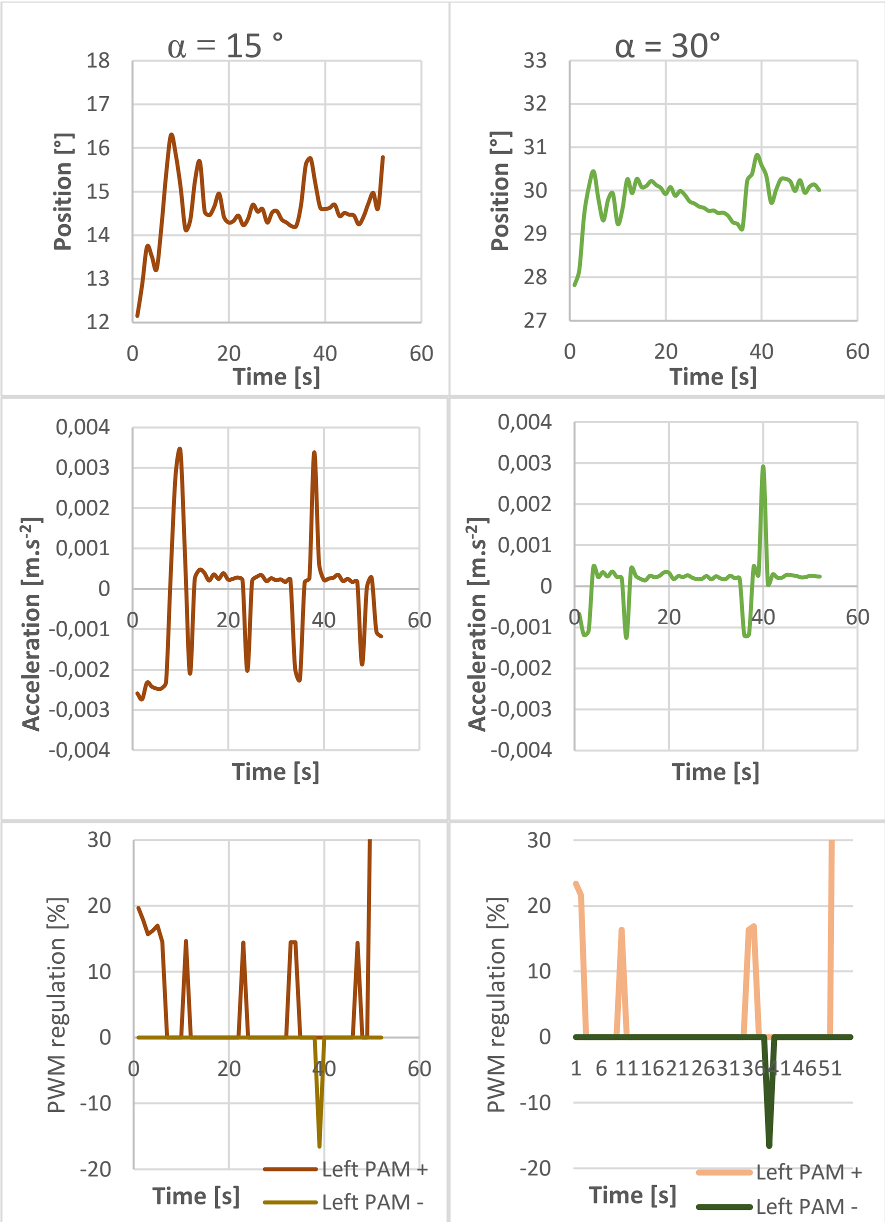

Figure 5. Experimental measurements from arm positioning to 45° and 60° [7]