# 273. Study of robot actuator operating as a system on air films

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**Abstract.** The paper analyzes the dynamics of a robot pneumatic actuator. The mechanical system motion is described by a differential equation system when the air flow is expressed by a non-dimensional Prandtl formula. The findings of the digital study are presented. The zones of self-exciting vibrations of the vibrotransducer have been determined, as well as the dependences of amplitudes and frequency upon the supply air pressure. The dependence of the linear movement of the actuator's gripper device and its velocity on the geometric parameters of the vibrating transducer of the mechanical system is presented.

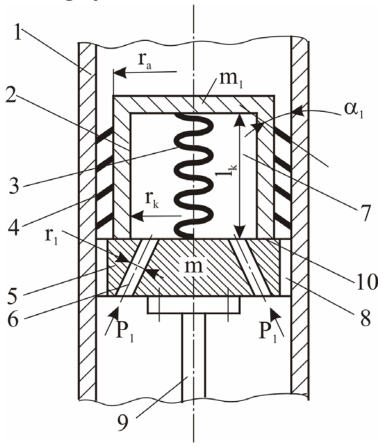
**Keywords:** pneumatic actuator, vibrotransducer, robot.

## Introduction

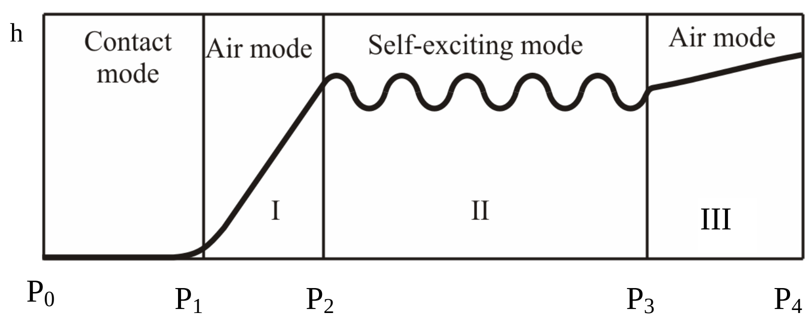
Self-exciting pneumatic vibrations operating in auto-vibration mode have been studied in papers [2-8]. The operation of the actuator under study in the present paper has been described in [1], where the conditions of the actuator's motion, as well as the actuator transducer's amplitude-frequency dependence on the supply pressure, are defined. The aim of the present paper is to determine the dependence of the kinematic parameters of the robot gripper motion at different geometric parameters of the vibrating system.

## Scheme of pneumatic actuator and its operation principle

A scheme of the developed actuator construction is shown in Fig.1a. Its operation is described in smaller detail in paper [1]. The principle of the actuator operation is based on the fact that at certain parameters of the mechanical system, unstable gas outflow through working aperture 10 may be evoked, which causes mass $m_1$ vibrations which, in turn, at certain values of pressing needle 4 to the walls and angle $\alpha_1$, initiate linear motion of the robot gripper 9. The motion of the actuator's gripper 9 can be divided into two modes: the air mode (see Fig. 1b, zone I and zone III) and the vibration mode (zone II).




a)




b)

**Fig. 1.** a - fragment of a robot pneumatic actuator: 1 – body of a robot, 2 – cylindrical chamber of vibrotransducer, 3 – spring, 4 – needle, 5 – support (leg), 6 – supply channel, 7 – pocket, 8 – hole, 9 – operating body (gripper), 10 – circular operating gap, $P_1$ – supply pressure, $\alpha_1$ - fastening angle of a needle, $r_1$ – radius of air supply channel, $r_k$ – radius of chamber, $r_a$ – external radius, $L_k$ – chamber height; b – zones of vibrotransducer modes: h-displacement of an elastic suspension of mass $m_1$, $P_0$, $P_1 \cdots P_4$ - supply pressure

When the robot pneumatic actuator operates in the air mode (zone I and zone III), the actuator pneumatic gripper 9 does not move, therefore this mode cannot be used as a working mode of the actuator. Only the self-exciting vibration mode of the pneumatic actuator vibrotransducer in zone II can be used for robot gripper 9 motion.

## Equations of actuator operating body dynamics

When m>>$m_1$, the motion of cylindrical chamber 2 mass $m_1$ is described by Eq.(1). In this case, air flowing from pocket 7 to outside through gap 10 is described by the simplified San Venam and Vantsel formulas suggested by Prandl [10].
In this case, when the air flow is defined by a dimensionless Prandl formula, a set of differential equations is as follows:

$$\frac{d^2(x^*)}{d(t^*)^2}+\frac{K_1}{m}\left(\frac{m_1 L_k}{\pi r_k^2 P_a}\right)^{1/2}\frac{d(x^*)}{dt^*}+\frac{C_1 L_k}{\pi r_k^2 P_a}(x^*)=P^* \qquad (1)$$

$$\frac{1}{0,76}\frac{r_k^2}{n r_1^2}\frac{L_k}{a_0}\left(\frac{\pi r_k^2 P_a}{m_1 L_k}\right)^{1/2}\left(\frac{d}{dt^*}(P^*)+(1+\alpha+P^*)\frac{d}{dt^*}(x^*)\right)=M(t), \qquad (2)$$

$$M(t)=\begin{cases}\sqrt{(1+\alpha+P^*)\left(\frac{P_1}{P_a}-1-\alpha-P^*\right)}-\\ -\sqrt{\frac{1+\alpha}{\alpha}\left(\frac{P_1}{P_a}-1-\alpha\right)}(\alpha+P^*)-\\ -2\frac{r_k}{n r_1^2}L_k x^*\sqrt{\alpha+P^*}\ , \quad when\ \ P^*\geq\frac{1}{2}\frac{P_1}{P_a}-1-\alpha;\\ \frac{1}{2}\frac{P_1}{P_a}-\frac{1}{2\sqrt{\alpha}}\frac{P_1}{P_a}\sqrt{\alpha+P^*}-2\frac{r_k}{n r_1^2}L_k x^*\sqrt{\alpha+P^*},\\ when\ \ P^*<\frac{1}{2}\frac{P_1}{P_a}-1-\alpha\end{cases}$$

$$\sigma=\left(\frac{m_1 L_k}{\pi r_k^2 P_a}\right)^{1/2};\ \frac{x}{L_k}=x^*,\ \frac{P_k}{P_a}=P^*,\ \frac{L}{\alpha}=L^*,\ n=4;$$

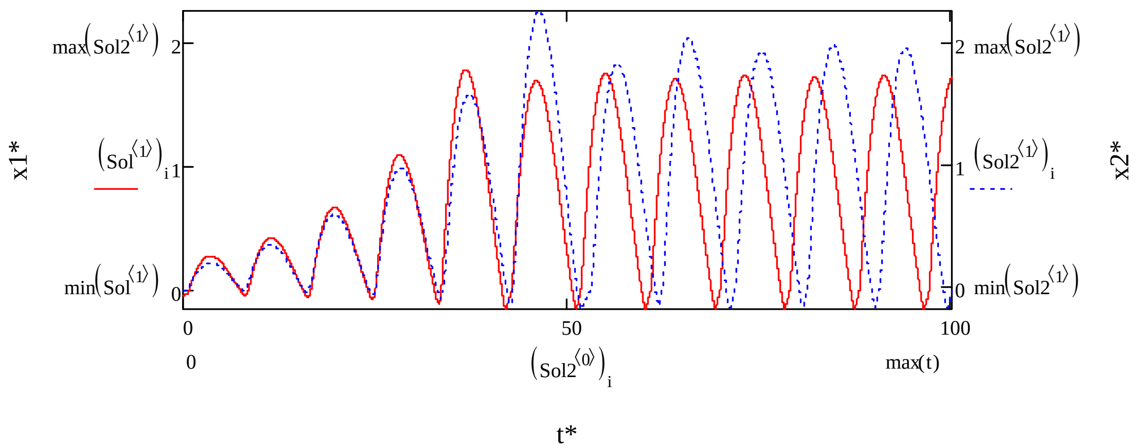
$$h=h_0+x$$

$$x^*=-\frac{h_0}{L_k},\ \frac{dx}{dt}=0,\ \frac{dP}{dt}=0.$$

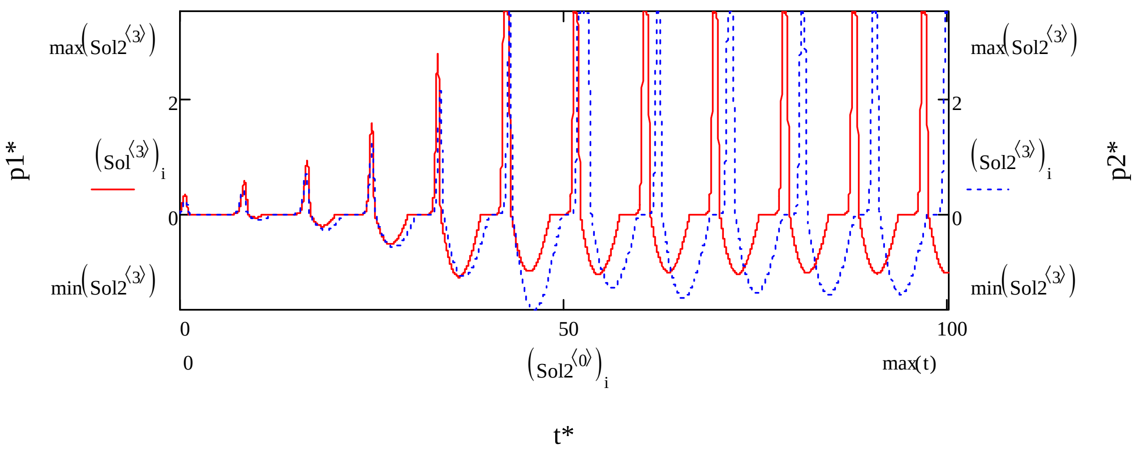
## Findings of theoretical and experimental study

The set of equations (1)-(2) has been solved by the Runge-Kutta method using Mathcad. The results of numerical solution are presented in Figs 2 and 6. Two curves are shown in each of Figs 2,3,5,6. Solid line was received when (conditions A) geometrical parameters were: $r_1=3.1\text{x}10^{-3}$ m; $r_k=$ $10\text{x}10^{-2}$ m; $r_a=12\text{x}10^{-2}$ m; $l_k=15\text{x}10^{-2}$ m; $m_1=2.48$ kg; $K_1=60$ kg/s; C=3.48 N/mm (coefficient of spring stiffness); $H_z=7.0\text{x}10^{-3}$ m (spring strain); α=0.018 (tension). Dotted line was received (conditions B) when parameters were: $r_1=3.1\text{x}10^{-3}$ m; $r_k=12\text{x}10^{-2}$ m; $r_a=14\text{x}10^{-2}$ m; $l_k=20\text{x}10^{-2}$ m; $m_1=2.48$ kg; $K_1=60$ kg/s; C=3.48 N/mm (coefficient of spring stiffness); $H_z=7{,}0\text{x}10^{-3}$ m (spring strain); α=0.018 (tension)

The obtained findings of the theoretical study has shown that the system of equations (1) – (2) provides a sufficiently relevant description of the dynamics of the pneumatic vibroactuator. The results of the study allow us to state that the geometric and dynamic system parameters have an essential impact on the kinematics of the mechanical actuator. When geometric parameter values $r_k$ ir $l_k$ of the actuator's cylindrical glass 2 are decreasing (see Fig. 1a), the zone of the actuator vibrations is narrowing, therefore in this case the kinematic parameters of the robot gripper can be monitored only in a narrower range of parameters.




a)




b)

**Fig. 2.** Transition of mass $m_1$ of the pneumatic vibrotransducer robot gripper to the mode of self-exciting vibrations: a – dependence of mass $m_1$ displacement x* on time t*; b – dependence of pressure pulsations in vibrotransducer pocket 7 on time t* x1* and p1* - conditions A; x2* and p2* - conditions B

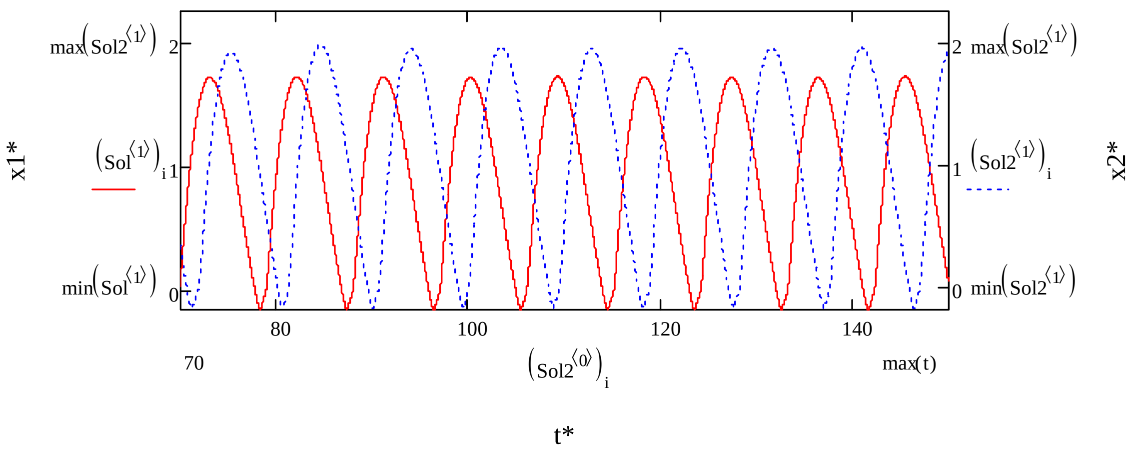



**Fig. 3.** Self-exciting vibration mode of pneumatic vibrotransducer mass $m_1$. Amplitude of self-exciting vibrations h1*=0.972 and frequency f1*=0.109, amplitude h2*=1.225 and frequency f2*=0.098

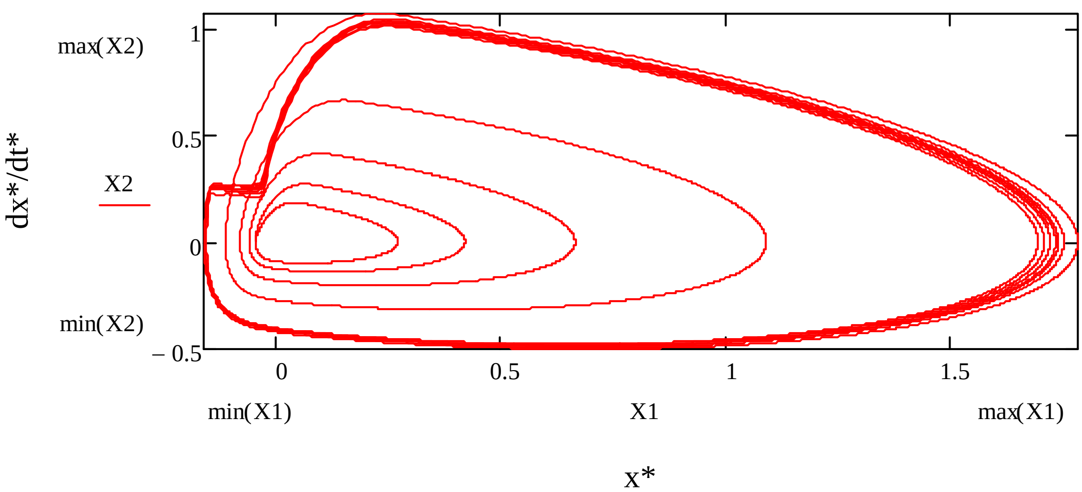



**Fig. 4.** Dependence of actuator mass $m_1$ movement velocity on the displacement at the following actuator parameters (conditions A)

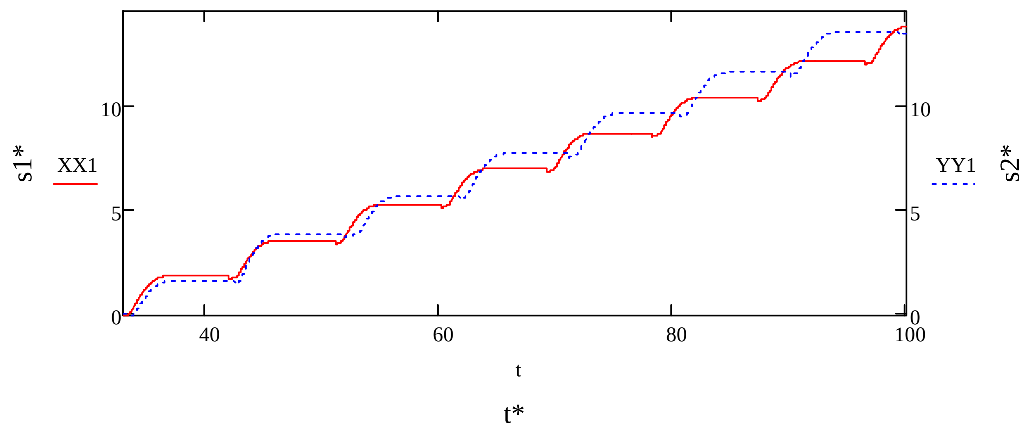



**Fig. 5.** Dependence of robot gripper 9 movement S* on time t*, where: s1* - conditions A; s2* - conditions B

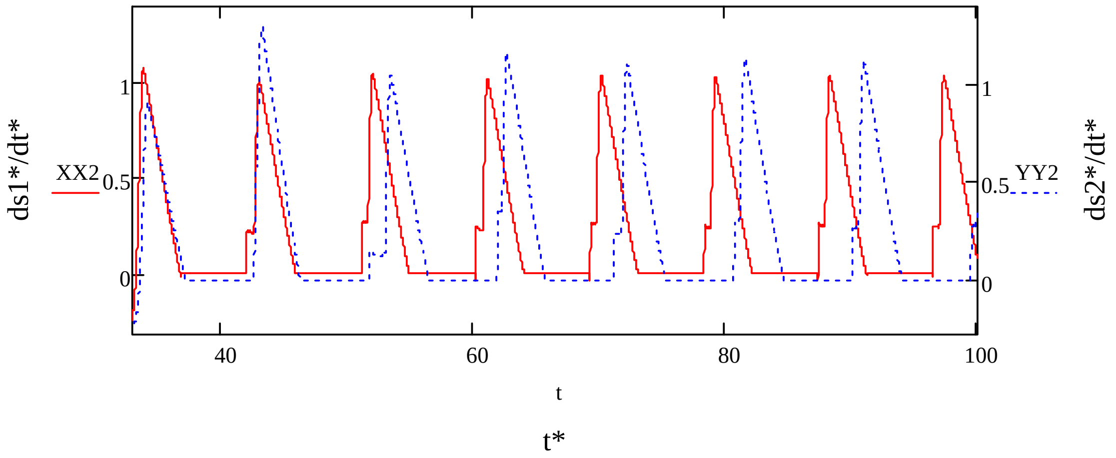



**Fig. 6.** Dependence of robot actuator mass $m_1$ movement velocity on time t*, where ds1*/dt* - conditions A, ds2*/dt* - conditions B

## Conclusions

The vibrotransducer of the pneumatic actuator's gripper operates in the air mode and the self-exciting vibration mode. To ensure the gripper movement, only the actuator's self-exciting vibration mode can be used. Therefore the operation of this actuator can be secure only within a certain range of supply pressure which provides the self-exciting vibration mode of the vibrating system and at certain geometric and dynamic parameters of the actuator.

The kinematic parameters of the robot gripper can be adjusted both by changing the needle fastening angle and the force of pressing them to the inner wall. The specific feature of the robot working organ is that its motion velocity is pulsating, and the pulsation parameters are determined by the characteristics of the vibroactuator's self-exciting vibrations (amplitude and frequency). However, in some technologies this pulsation can be especially useful.

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