393. BEHAVIOUR OF DYNAMIC PROCESSES IN SELF-EXCITING VIBRATION OF A PIPE ROBOT

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Abstract: In this paper, a robot for inpipe inspection of underground urban gas pipeline is presented. The robot is developed for visual and Non-Destructive Testing of the pipeline networks. The dynamic model of an inpipe robot with a self – exciting vibratory drive is presented and the equations of its movement were derived

Keywords: inpipe robot, dynamics, self-exciting vibration, feeder, numerical method

NOTATION

q_i, $\dot{q}_i$, $\ddot{q}_i$ are displacement, velocity and acceleration, respectively (i=1,2).

p_{Ri}, T_{Ri}, V_{Ri} are pressure, temperature and volume of chamber, respectively (i=1,2).

F_{f1} is friction force between pipeline and elastic support.

$F_1(q_1, q_2)$ is friction force between mass m_1 and mass m_2.

$F_{23}(q_2, q_3)$ is contact force between mass m_2 and mass m_3.

G_{in1}, G_{out1} are inlet and outlet discharges of gas mass in the volume V_{R1}, respectively.

G_{in2}, G_{out2} are inlet and outlet discharges of gas mass in the volume V_{R2}, respectively.

R - gas constant.

θ is angle between horizontal plane and center axes of in-pipeline robot.

T is total working time.

INTRODUCTION

Recently natural gas supply has become one of the fundamental public services and its impact on the urban infrastructure is increasing. The urban gas pipelines, as they are buried under the ground, are prone to external corrosion usually derived by moisture and chemical agent in soil, which causes material losses of the pipe wall. Also, cracks in the welded sectors and the damages from third parties such as construction, electricity, sewage works are considered as major reasons for pipeline failures. In the inspection of urban gas pipelines, there is a great need for autonomous inspection equipment that can run through inside the pipelines. However, the inpipe inspection of gas pipelines in field conditions has several aspects difficulty, which are as follows:

1. The urban gas pipelines usually allow restricted access to the test location because they are buried under the ground;
2. Current urban gas pipelines take quite complicated configurations. Straight pipes and welded joints are the most popular ones, and there are also lots of elbows, branches, various valves and other special components. Unlike plain surfaces, there is a highly constrained space of complicated configuration inside the pipelines, which makes difficult to move inside while overcoming intrinsic obstacles;
3. Most of urban gas pipelines are composed of small inner diameter pipes, which make it hardly possible to move the inspection equipment through them. Moreover, the urban gas pipelines have abnormal pipes with gouges and dents obstructing normal maintenance due frequent damages.

Piping systems for the transportation of substances are classified according to the diameters of pipes, length of pipes, transportable substances, radii of pipe bending and so on. Many various robots are developed for the control of inner surface of cylindrical pipes [1,2]

DYNAMIC MODEL OF SELF – EXCITING VIBRATION OF A PIPE ROBOT

The inpipe robot with a self – exciting vibratory drive, consists of the (Fig. 1, 2) body, which mass is m_1 with three supports fitted on it, forming an angle of 120º.

The compressed air is supplied from the pneumatic system all the time via the feeding branch pipe that causes vibrations of the piston m_2 through the elastic element k_3. Therefore, the piston 5 contacts with the mass m_3 fixed in the body through the elastic element k_2.

In order to ensure a reliable movement of the robot along the inner surface of the piping system and in order to reduce the friction on the contact surface between the inner surface of the piping system and the contact surface of the dampers k_0, a roll may be mounted on the end part of the damper. In the end part of the body the elastic element 4 is fixed while the other end is connected to piston 5. The branch pipes are provided in the end and side parts of the body for air supply and release.

The system of equations of inpipe robot is the following [6…9]:

$$(m_1+m_2+m_3)\ddot{q}_1 = -p_{R1}S_1 - p_{R2}S_2 - \\ -(m_1+m_2+m_3)g\sin(\theta) - F_{f1}sign(\dot{q}_1) - F_1(q_1,q_2);$$

$$m_2\ddot{q}_2 = F_1(q_1,q_2) + p_{R1}S_1 - p_{R2}S_2 + F_{23}(q_2,q_3) - \\ - F_3(q_2,q_3) - m_2 g\sin(\theta);$$

$$m_3\ddot{q}_3 = F_4(q_3) + F_{23}(q_2,q_3); \qquad (1)$$

$$\dot{p}_{R1} = \frac{\gamma R(T_{in1}G_{in1} - T_{out1}G_{out1})}{p_{R1}V_{R1}(q_2)} - \frac{\gamma p_{R1}}{V_{R1}(q_2)}\dot{V}_{R1}(q_2);$$

$$\dot{p}_{R2} = \frac{\gamma R(T_{in2}G_{in2} - T_{out2}G_{out2})}{V_{R2}(q_2)} - \frac{\gamma p_{R2}}{V_{R2}(q_2)}\dot{V}_{R2}(q_2);$$

$$\dot{T}_{R1} = \frac{\gamma R T_{R1}(T_{in1}G_{in1} - T_{out1}G_{out1})}{V_{R1}(q_2)} - \frac{RT_{R1}^2}{p_{R1}V_{R1}}(G_{in1} - G_{out1}) - \\ - \frac{(\gamma-1)T_{R1}}{V_{R1}(q_2)}\dot{V}_{R1}(q_2);$$

$$\dot{T}_{R2} = \frac{\gamma R T_{R2}(T_{in2}G_{in2} - T_{out2}G_{out2})}{p_{R2}V_{R2}(q_2)} - \frac{RT_{R2}^2}{p_{R2}V_{R2}}(G_{in2} - G_{out2}) - \\ - \frac{(\gamma-1)T_{R2}}{V_{R2}(q_2)}\dot{V}_{R2}(q_2)$$

The system of differential equations of the in-pipeline robot are integrated by the Runge-Kutta method. Averaged working parameters of in-pipeline robot are obtained by

$$\text{Parameter} = \frac{1}{T}\int_0^T \text{Parameter(t)}dt \cdot \qquad (2)$$

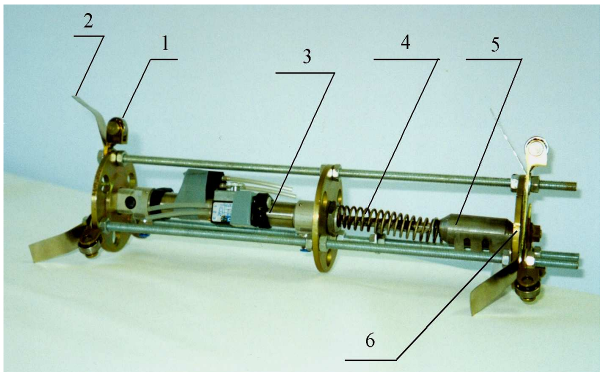


Fig. 1. The design scheme of the original step movement pipe inspection robot with a vibratory impulse drive: 1, 2, 4 – the elastic element, 3 – the movement support, 5 – the piston, 6 – the damper

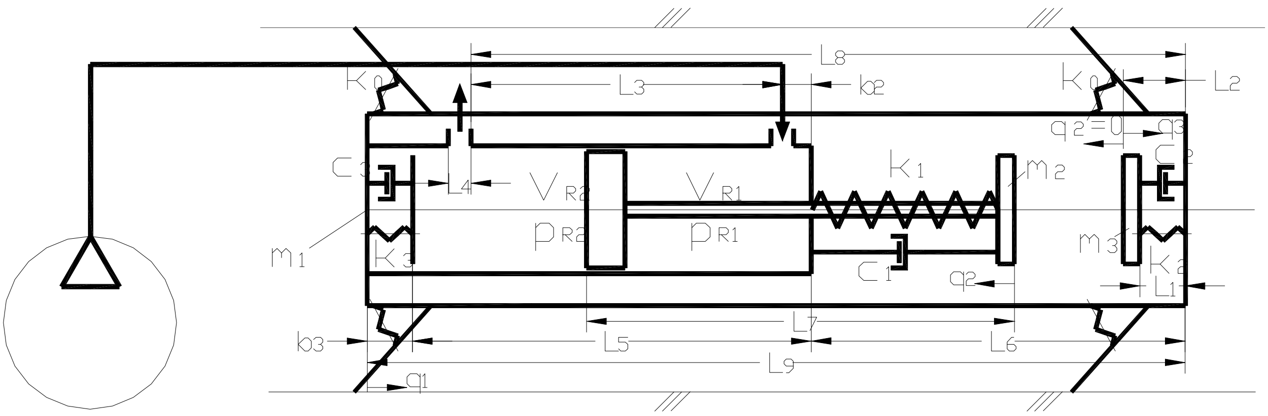
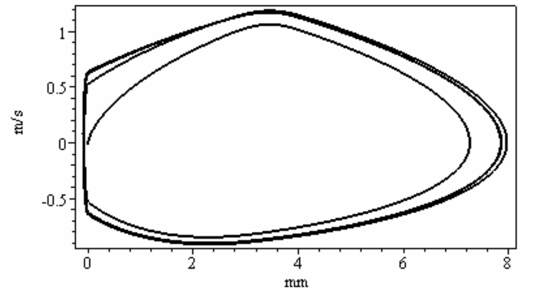


Fig. 2. A circuit of an inpipe robot

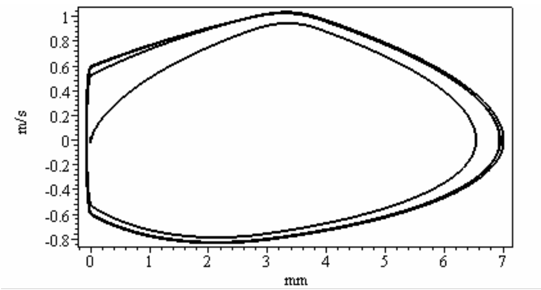
THEORETICAL RESULTS OF SELF – EXCITING VIBRATION OF AN INPIPE ROBOT

As an example of self-exciting vibration in an inpipe robot coefficients of stiffness: $k_1 = 1800\ kN/m$; $k_2 = 10^7, kN/m$; masses: $m_1 = 3.20\ kg$, $m_2 = 0.20\ kg$; inlet pressure $p = 0.3...0.9 MPa$; geometrical parameter: $L_3 = 0.095\ m$.

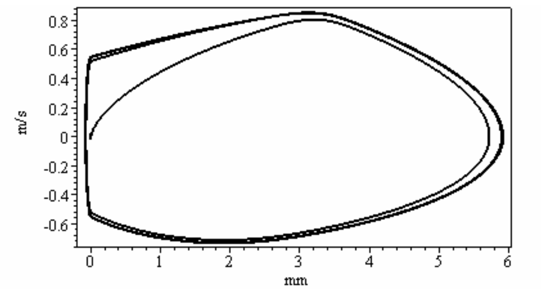
The dependence of speed of second mass on motion are shown in Fig. 3.



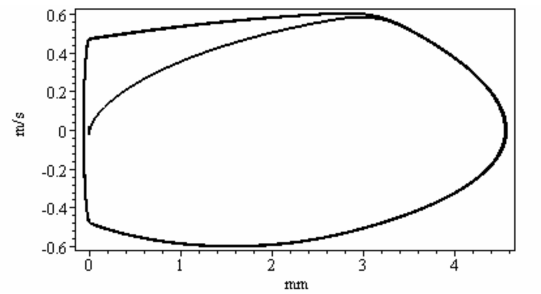
a)



b)



c)



d)

Fig. 3. Phase plot $(q_2, \dot{q}_2)$ for the solution: a – when inlet pressure $p = 0{,}90 MPa$; b – when inlet pressure $p = 0{,}70 MPa$; c – when inlet pressure $p = 0{,}50 MPa$; d – when inlet pressure $p = 0{,}30 MPa$

Dependence of averaged speed of the inpipe robot on a pressure are shown in Fig. 4.

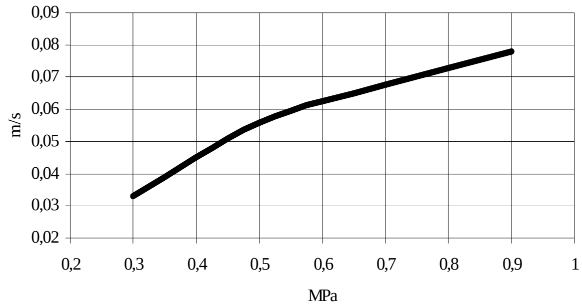


Fig. 4. Dependence of the average speed of inpipe robot on the inlet pressure

CONCLUSIONS

1. The composed mathematical model of an inpipe robot with pneumatic system is presented.
2. The treatment of self-exciting vibratory drive of an inpipe robot is based on generation of self-exciting vibrations in mechanical and pneumatical systems together. The averaged frequency of self-exciting vibrations is 18 Hz.
3. The designed mathematical model of inpipe robot is possible for using for optimization of dynamic characteristics of this robot.

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