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A MOBILE VIBRO-ROBOT FOR LOCOMOTION THROUGH PIPELINES

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ABSTRACT

The subject of our work is the creation of different designs of mobile robots for the movement through pipelines and similar technical systems. Using the transversal vibrations of an elastic bristle body, allows us to develop a new crawling vibro-robot. The motion is mainly realized by anisotropic friction forces. For the design process, we use the well-known construction principle of combination of alternative systems. It enables the transfer of structural characteristics (i.e. its kinematics) from one object to another, leading to new desirable characteristics or optimisations of existing technical objects. An analytical model of the motion of the bristles is presented.

Index Terms – elastic bristle body, anisotropy of friction, locomotion

1. INTRODUCTION

In recent years, the research focus has been shifted more and more towards legless (apedal) locomotion systems that are inspired by snakes, worms and similar biological objects. The motivation for this research direction has different perspectives. The analysis of biological objects and alternative technical systems allows creating several new biologically inspired robots.

The known legged robots have several actuators for the movement of each leg. Our robots are based on ideas from HATAZAKI et. al. [1] who built a cilium hair based robot with only one actuator. Instead of the continuous cilia structure, the presented robot moves based on evenly located (separated) “legs” or bristles. Thus, the minimization of the number of actuators is managed [2]. This minimization can be realized by using [3] [4] [6]:

- Periodical change of the robots body shape in the horizontal plane (salamander, snake, lizard)
- Periodical change of the robots body shape in the vertical plane (flying insects)
- **Anisotropic friction and vibrations of the body**
- Traveling waves (holothouria, earthworm)
- Multidimensional vibration of elastic extremities (mosquito)
- Reducing the number of bearing legs (kangaroo, basilisk, birds)

2. DESIGN AND PRINCIPLE OF MOTION OF VIBRO-ROBOT

The pipeline inspection vibro-robot is made by a hollow cylinder with a vibrating actuator inside. On the external surface of the cylinder, there are evenly located elastic short bristles (Figure 1).

Figure 1: Two prototypes of vibro-robots

Due to the operation of the actuator, the prototype begins to move upwards and downwards with respect to the ground. The bristles are excited by the vibration of an unbalanced rotor. Two phases of this process are presented in Figure 2.

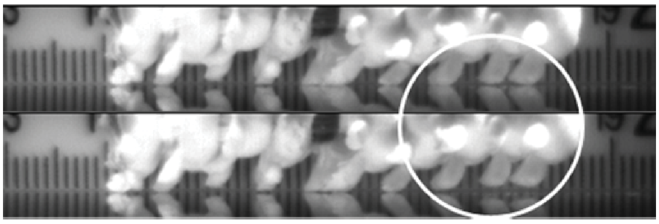

Figure 2: Two phases of the vibration

In the first phase of the vibration, the artificial worm moves downwards as one can see in Figure 3. As the bristles do not change their length, they bend or turn in the hinge, which appears in the motion of the worm, because sliding of bristles is absent. In the second phase, the robot moves upwards and the friction force decreases. The bristles are sliding forward and return to the previous state.

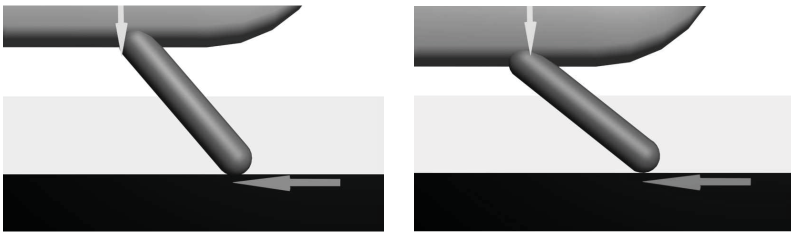

Figure 3: Locomotion of the robot due to the friction force

Due to the asymmetric friction forces, at different phases of oscillation, the motion of the robot through the pipelines is achieved.

3. ANALYTICAL MODEL

To describe the robot motion through the pipeline, a simplified model with only one bristle is used. The bristle is modeled as rigid beam with a mass concentrated on their distal ends (pendulum). The elastic properties of the real bristle are considered to be concentrated in the hinge to the worm body in form of a torsion spring.

3.1. Static analysis

In the static state, the gravity force of the robot, which acts on the bristle in the vertical plane, can be written as $P = Mg$, where M is the mass of the robot and g the constant of the gravity acceleration. The angle ϕ_{st}, between the robot body and the bristle in the static state, is smaller than the angle of the free state ϕ_0 (without deformation). The elastic force in the point B is in direct proportion with the deviation of the bristle. A new coordinate system is introduced, which has origin point intersects with the point B. Along the bristle lies axis $\tilde{z}$ and axis $\tilde{y}$ is perpendicular to it.

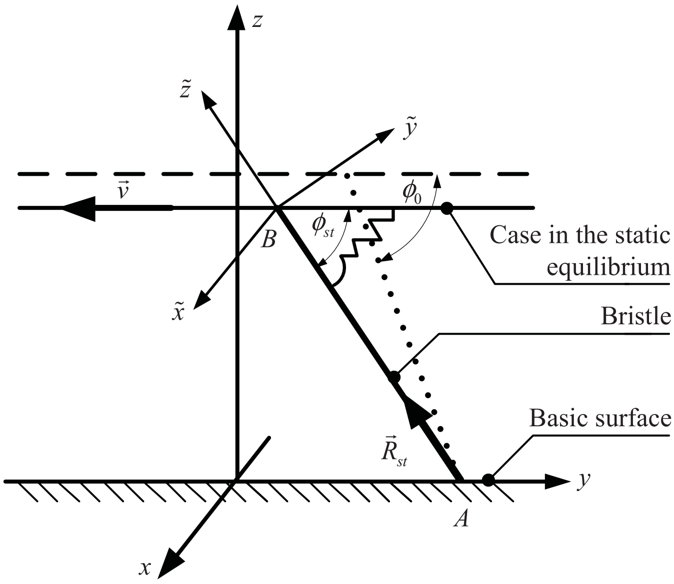

Figure 4: Model with one bristle

Applying the condition of equilibrium, equation (1) is obtained.

$$\cos\phi_0 = \frac{c}{g\left(M+\frac{m}{2}\right)}\left(\phi_0 - \phi_{st}\right) \tag{1}$$

Here c is the stiffness of the torsion spring and m the mass of the bristle. The reaction force can be written as:

$$R_{st} = g\left(M+\frac{m}{2}\right)\sin\phi_{st} \tag{2}$$

From (2) the friction force $F_{r,st} = R_{st}\cos\phi_{st}$ and the reaction force of the surface can be formulated as $N_{r,st} = R_{st}\sin\phi_{st}$. By setting the parameters M, m and l, it is possible to calculate the friction force $F_{r,st}$, depending on the angle ϕ_{st}. The angle ϕ_{st} could be calculated from (1), if the stiffness c is given.

3.2. Dynamic analysis

The vibrated system is activated in the static equilibrium position, which causes the movement of the bristle with the force $P = P_0\cos\omega t = Mg\cos\omega t$. The elasticity force of the spring tries to return the bristle to the static equilibrium position.

An angle ϕ_g of the bristle with a basic surface $\phi_g = \phi_{st} - \phi$ is introduced, where ϕ is the angle between different positions of the bristle during one complete oscillation. The elastic force can be written as (3).

$$\Phi = -c\left(\phi_{st} + \phi\right) \tag{3}$$

Applying the principle of angular momentum relative to point B leads to equation (4).

$$J_x\ddot{\phi} = \left(M+\frac{m}{2}\right)gl\cos\left(\phi_{st}-\phi\right) - cl\left(\phi_{st}-\phi\right) + P_0 l\left(\sin\omega t - 1\right) \tag{4}$$

Here J_x is the mass moment of inertia of the bristle relative to point B.

Because of angle ϕ is relatively small, the linearization $\cos\left(\phi_{st}-\phi\right) \approx \cos\phi_{st} + \sin\phi_{st}\cdot\phi$ could be applied, which leads to the transformation of equation (4) in the form of equation (5).

$$J_x\ddot{\phi} = \left(M + \frac{m}{2}\right) gl \cos\phi_{st} + \left(M + \frac{m}{2}\right) gl \sin\phi_{st} \cdot \phi - c\phi_{st} l + c\phi l + P_0 l \left(\sin\omega t - 1\right). \tag{5}$$

This equation describes the motion of the robot downwards when point A is fixed. The sliding in this phase is supposed to be absent due to the friction force.

In the second phase of the oscillations, the body of the robot moves upwards and passes the static equilibrium position. In this case, the friction force decreases and the bristle moves forward along the base surface. During one complete oscillation, the bristle is displaced one step. Equation (6) gives the speed of a bristle on the base surface.

$$v_A = \left(l^2\phi\right)\dot{\phi} - a_0\omega\cos\omega t \tag{6}$$

Here ϕ can be calculated as the solution of equation (5). ω and a_0 depend on the source of oscillation.

Using the presented equations, it is possible to find the speed of the robot during motion along axis y for the given parameters of oscillation.

4. CONCLUTIONS AND OUTLOOK

We designed a apedal locomotion system "Vibro-worm" for the purpose of inspection of pipelines. As a source of oscillation, an unbalanced rotor with a DC-motor is used. For the motion of the robot through a pipeline, the anisotropy of the friction is used. By merging the transversal vibrations of an unbalanced rotor with a elastic bristle body arises an opportunity to develop a vibro-worm.

Further investigations will be oriented to develop a system of combined vibro-robots. Due to the combination of several parts characteristics, it will be possible to develop new systems with new desired parameters (i.e., achievement of higher speed as well as huge driving force). Furthermore, it is possible to use the resonance effect during the bristles vibration to develop new systems with a controlled direction of motion.

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