Chapter 8
Mobile Worm-Like Robots for Pipe Inspection

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ABSTRACT

This chapter describes various designs of multilink mobile robots intended to move inside the confined space of pipelines. The mathematical model that describes robot dynamics and controlled motion, which allows simulating different regimes of robot motion and determining design parameters of the device and its control system, is presented. The chapter contains the results of numerical simulations for different types of worm-like mobile robots. The experimental studies of the in-pipe robots prototypes and their analyses are presented in this chapter.

1. INTRODUCTION

Today, pipelines are the main elements of transportation systems for transferring gaseous, liquid substances and solids in the form of solutions over long distances. In the process of maintaining operating conditions of pipelines monitoring the inner surface of pipe is needed. The use of mobile robots to monitor the internal surface of the pipeline eliminates human labor in difficult-to-reach and dangerous places and increases the efficiency of the operations. A rapidly developing and promising solution for those tasks is the use of a snake - and worm-like principles of locomotion of robots to move in confined spaces of pipelines.

Worm-like robots (WLR) have simple structures and do not need any special actuators such as wheels, caterpillars or legs. Therefore mobile vibration robots can move not only in space, but also in dense materials unlike wheeled or leg-equipped robots. Worm-like motion allows movement on rough surfaces and in liquids. Mobile devices which can move without special movers interacting with the environment

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directly by their frame possess a number of advantages, as compared to wheeled, crawling, and walking systems first of all due to their simple design. This advantage allows one to use these principles to create miniature microrobots capable of moving in narrow channels, slits, and environments inaccessible to other mobile objects.

In the simplest case the robot's body moves in one dimension, in a line or in a pipe. The motion is realized by constantly changing shape (worm-like motion).Typical biological example are insects such as caterpillars and flatworms.

A robot is a complicated mechatronic system, which consists of mechanic, electronic, and control sub-systems. Mechanical influence on the internal masses of the robot, and the robot body is interacting with an environment with some force. Robot can be equipped with an electronic control system with a feedback module, which allows it to carry out an optimal regime of motion and maintain the given parameters of the working element under the influence of different external forces. The most important task in the design of mobile robots is to consider the effects of the device's interaction with the external environment and the dynamic effects of the robot body moving by the electric motor.

The parameters of the working element and regimes of motion depend on robot's task and environmental conditions. For realizing a one-direction motion we need to have an asymmetrical dry friction force between robot bodies and surface. This nonlinear friction force can be realized by special form needles or guidelines on the contact place or by special one-way clutch mechanisms. A large cycle of papers (Chernous'ko, 2000; Figurina, 2003) is devoted to devices which represent a chain of rigid links connected by rotary joints in which drives are situated. These drives create control internal moments for the multi-link robot. Dry friction acts between the multi-link robot and the surface along which it moves. By controlling the moments at the joints, and thus, the friction force applied to the mechanism, its motion from an arbitrary initial state to the given final state can be achieved.

In work of Chernous'ko (2003) controllable rectilinear motion along a rough surface of the system of two bodies interacting with each other via the control force was studied.

In work of Chernous'ko (2006) and Zimmerman (2005) the rectilinear motion along a horizontal rough surface of the body with the moving internal mass which also moves along the straight line parallel to the line of motion of the body was addressed. The asymmetry of the friction force necessary for motion in the given direction is provided by the dependence of the coefficient of friction on the sign of the velocity of the constituent bodies of the system.

In work of Zimmerman (2001) the dynamics of the mobile system including two bodies connected by an elastic element with the linear characteristic were analyzed. The motion was caused by the harmonic force acting between the bodies.

In papers of Yatsun (2007) the dynamics of the motion of worm-like robots for the cases with infinite and finite number of bodies was discussed.

In work of Bolotnik (2006) a mathematical model was developed and the motion of the two-mass system was studied taking into account the characteristics of the electric drive. In this system one mass directly contacted the rough surface, while the second mass moved with respect to the first mass without friction.

In many works (Magnus, 1982; Tatar, 2008; Moghaddam, 2008; Mistinas, 2002; Kothari, 2008; Horodinca, 2008; Robinson, 2008; Gambao, 2008; Dovica, 2001) the dynamics of controlled vibration-driven and vibroimpact motion of a mobile system were addresses.

Some various schemes of multilink snake-like robots are represented in papers of Sapronov (2010), Malchikov, (2012), Hirose (1993), Habib (2007).

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