355. Analysis of mini submarine control based on moiré interferometry

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Abstract. The purpose of this work is to create a new remotely controlled mini submarine used in robotics or in toy industry. To prepare the numerical and mathematical models for identification of the most optimum ratio *alfa1/alfa2* of raster discs, number of raster notches, and a required angle of one disc turn *beta,* for changing the flow direction and, simultaneously, the sailing direction of the mini submarine.

Keywords: Moiré interferometry, Mini submarine, Mini robot, Piezoelectric actuator.

Introduction

Mini submarines [1] or robots [2] with piezoceramic actuators [3, 4] are widely described in scientific and engineering sources. Our goal was to develop a new type of mini submarine, operation of which is based on moiré interference pattern [5, 6].

This article describes the new patented mini submarine which is controlled due to the optical interference effect, based on the moiré interferometry.

Mini submarine examined in this article is composed of housing and control unit with piezoceramic actuator. Ppropeller, which is connected to the motor, is embedded inside the cylinder body. Control device with piezoceramic actuator, comprised of two raster steel disks, fastened with fastening rings, is fixed on the other side of the body. Number of raster notches of one of the disks is *n*, and the same number for the other is (*n*+1) and it has the possibility to rotate in respect of the first disk. One fastening ring with raster steel disk is connected through the metal rods to the multilayer piezoceramic elements, which are interlinked with control unit and generator.
Novelty of this mini submarine is that one of the parts of its control device, i.e. membrane, is comprised of two raster steel disks and the swimming direction of this mini robot is controlled by means of optical interference effect generated between them.

Numerical and mathematical models of the effect of moiré interference occurring in the mini submarine were investigated. The dependence of the membrane permeability on the turn angle *beta* of one of the raster steel disks is established and presented, as well as the dependence of the permeability on the ratio *alfa1/alfa2*. These relationships allow determining and designing of the best possible control strategies for the mini submarine.

Original patented construction and the implementation of control strategies of the mini submarine is the object of analysis of this article.

Construction of the mini submarine

Mini submarine presented in this article has functional possibility to move in three-dimensional space (under water) Mini submarine is comprised of: cylinder body 1 with embedded propeller 2 that is connected to the motor 3; control device, fixed on the other side of the body 1, with piezoceramic actuator, composed of two raster steel disks 4, 5, which are fastened with fastening rings 6, 7; number of raster notches of raster steel disk 4 is *n*; number of raster notches of raster steel disk 5 is *(n+1)* and it has the possibility to rotate in respect of the first disk; one fastening ring with raster steel disk is connected through the metal rods 8, 9 to the multilayer piezoceramic elements 10, 11, which are interlinked with control unit 12 and generator 13.

The structural layout of the underwater mini submarine is shown on Figure 1.

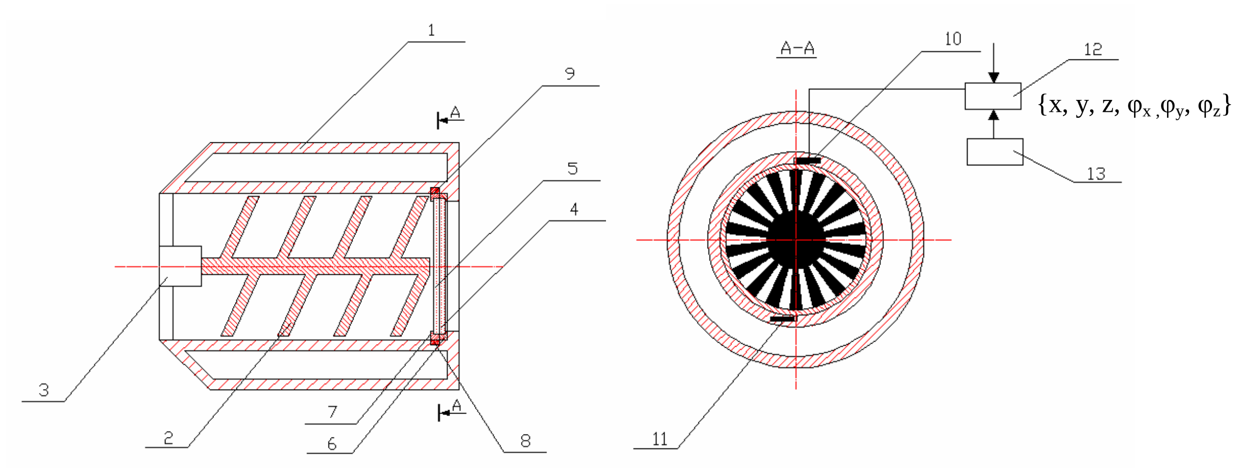

Fig. 1. 1 – Cylinder body, 2 – propeller, 3 – motor, 4, 5 – raster disks, 6, 7 – fastening rings, 8, 9 – metal rods, 10, 11 – multilayer piezoceramic actuators, 12 – control unit, 13 – generator

After the motor 3 is started propeller 2 begins to rotate and to pump the water from the outside creating the water flow inside of the cylinder body 1. Then generator 13 is turned on remotely and passes the signal to the control unit 12, stimulates static and quasistatic shifts in the piezoceramic elements 10, 11, that transmit rotation motion through the metal rods 8, 9 to the raster steel disk 5, fastened in the fastening ring 7. Direction of the water flow through the membrane (composed of two raster steel disks 4 and 5) is controlled by changing the turn angle of raster disk 5 in respect of raster disk 4.

Construction of control membrane

New structural elements (ratio of the raster notches of steel disks *n/n+1*, ratio of angles of open and closed disk areas *alfa1/alfa2*) allow achieving increased mini submarine's maneuverability in comparison with similar devices.

The control membrane is made of two steel disks with raster notches. The number of raster notches of one of these disks is *n* and number of notches for the other is *n+1*. Such ratio is necessary in order to obtain a single interference fringe.

By using ratio *n/n+2* we'll get two interference fringes (fig. 2). And by choosing ratio *n/n+3* we'll get the pattern presented in figure 3, with three interference fringes, and the required control of underwater mini robot we'll not be feasible.

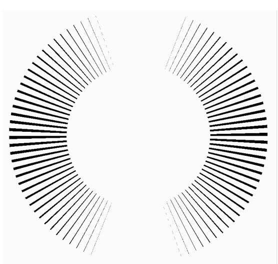

Fig. 2. Effect with two interference fringes

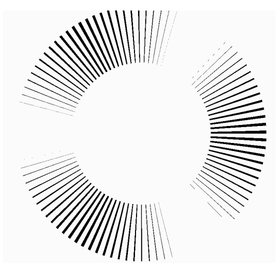

Fig. 3. Effect with three interference fringes

When proper ratio of number of raster notches of the steel disks is chosen and only one interference fringe is obtained it is also necessary to choose proper ratio of angles of open and closed disk areas *alfa1/alfa2* (fig. 4) and the flow would be allowed through only one side of the membrane and the other side would be fully closed.

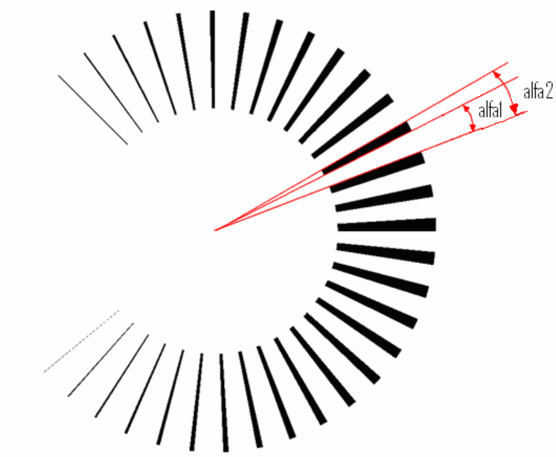

Fig. 4. Ratio *alfa1/alfa2* of open and closed areas of the disk raster notches

After completing mathematical modeling relationship *% (beta)* was determined. This dependence demonstrates how the change of *beta*, the turn angle of one of the raster disks in respect to the other, influences the change in permeability at different membrane sides (left and right) (fig. 5). If maximum permeability is achieved through one side, on the other side permeability is minimal. In intermediate positions similar permeability on both sides can be obtained.

Permeability through the top and the bottom of membrane was not examined, but we could suppose that it should be similar to the results of performed modeling when the flow is allowed to pass through the sides of membrane.

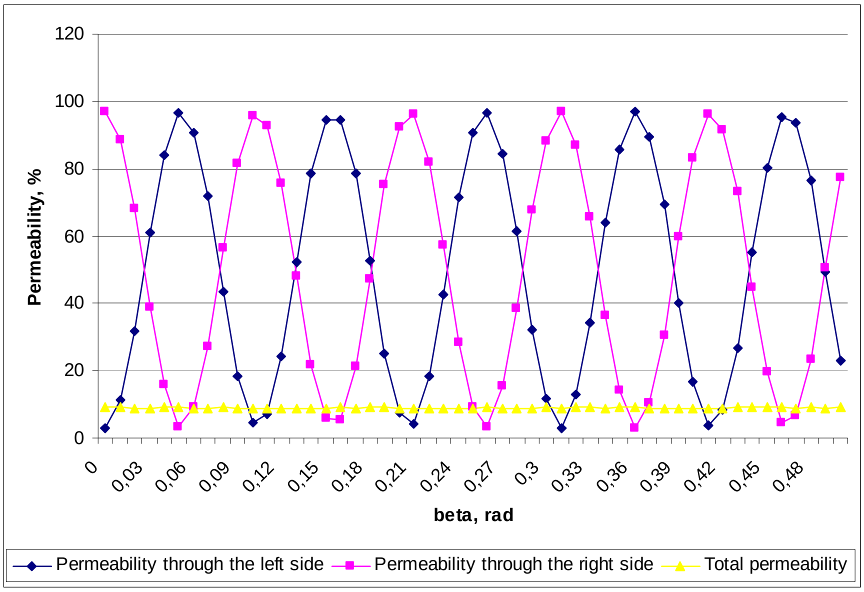

Fig. 5. Relationship *% (beta)*

When one raster steel disk is turned in respect to the other by 0 *rad* angle water flows through the right side of membrane and mini submarine turns to the left. When angle is changed to 0.05 *rad* – water flows through the left side only and the submarine turns to the right. As we see from the graph (fig. 5), cycles repeat if we further vary the angle.

There are also possible transitional positions of swimming direction.

For mathematical modeling ratio *alfa1/alfa2 =0.3* was chosen because only in this case full closure at one side and sufficient total permeability can be obtained. This can be seen from figure 6 where dependence *% (alfa1/alfa2)* is plotted in the bar graph.

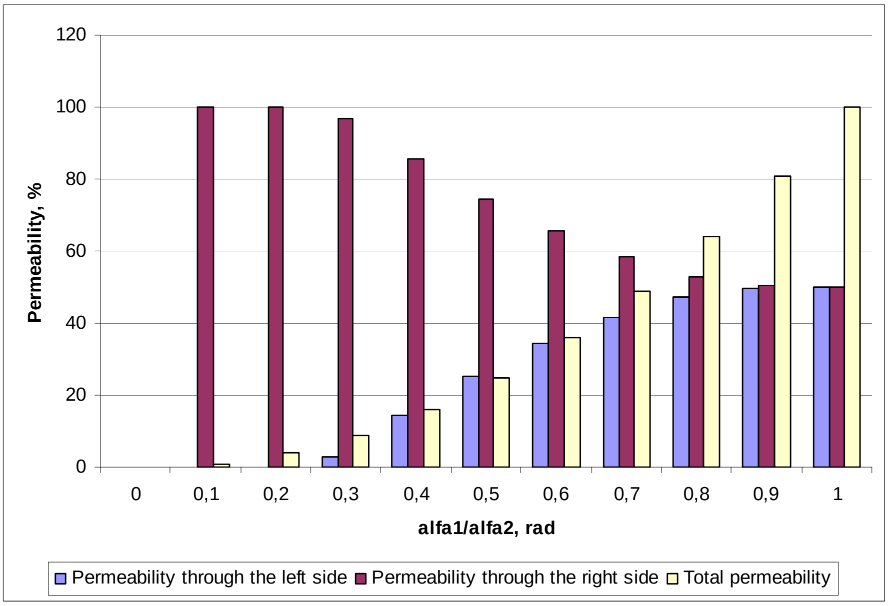

Fig. 6. Dependence *% (alfa1/alfa2)*

As it was mentioned before, one of the raster disks is tightly fastened inside the housing of the robot, and another is fastened to the precise piezoceramic control device and has the possibility to rotate in respect to the first disk.

While the control device does not receive any signal, the flow is passing just through the one side of the membrane (Fig. 7). When the signal is generated and the second disk turns at a required angle, the direction of membrane's permeability, and the submarine swimming direction are changed (Fig. 8). It is also possible that the top or the bottom part of membrane will be opened by changing turn angle and the robot will swim upwards or downwards (Fig. 9, 10).

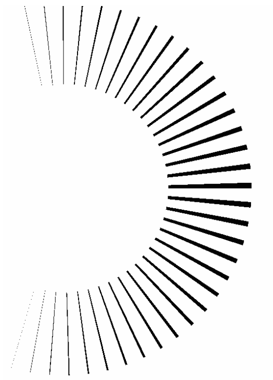

Fig. 7. Flow through the right side

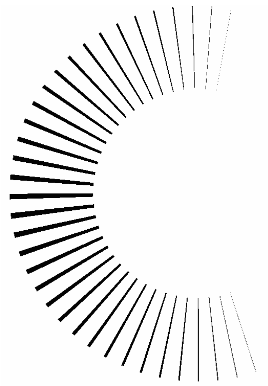

Fig. 8. Flow through the left side

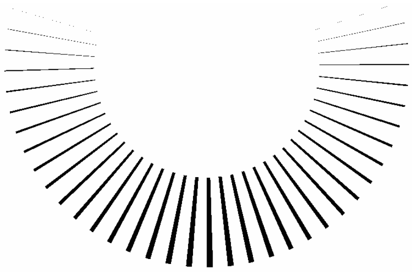

Fig. 9. Flow through the bottom part

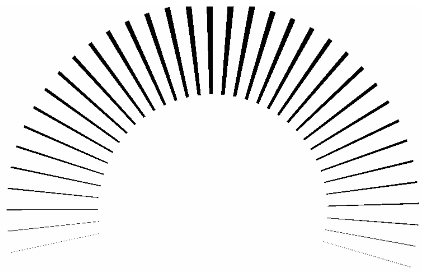

Fig. 10. Flow through the top part

Technology for the production of raster steel disk

Technology for the production of disks is quite complicated as the product is small (about 32 mm diameter), made from very thin 0.3 mm thickness steel sheet, and the laser is used for raster notches to cut out. It is necessary to choose the best possible construction, because cutting width of the laser is constrained, also the sheet is heating and the deformation occurs during the manufacture.

For the construction of control device of this mini submarine considerable precision of raster steel disks is required in order to obtain proper interference effect. A proper ratio of angles of open and closed disk areas α_1/α_2 is particularly important and only when this ratio is equal to 0.3 we can achieve a proper permeability through one side of the membrane and to control swimming direction of mini submarine.

Conclusions

The design and control principles of the mini submarine based on moiré interferometry are described in this article. The mathematical and digital models of moiré interference between the fixed and the rotating disk are developed. These models allow identifying the disk control strategy for changing the swimming direction of the mini submarine. Proper ratio *alfa1/alfa2*, which allows ensuring nearly full closure at one side of the membrane, was determined. Turning angles of one of the raster steel disks *beta*, which allows us to control the swimming direction of mini submarine by, also where determined.

References

[1] Madsen H. Ø., Christensen P. and Lauridsen K. Securing the operational reliability of an autonomous mini-submarine. *Reliability Engineering & System Safety*, *Volume 68, Issue 1, April 2000*, *Pages 7-16*.

[2] Kim B., Lee M. G., Lee Y. P., Kim Y., Ho Lee G. An earthworm-like micro robot using shape memory alloy actuator. *Sensors and Actuators A: Physical*, *Volume 125, Issue 2, 10 January 2006*, *Pages 429-437*.

[3] Lin Ch. and Yang S. Precise positioning of piezo-actuated stages using hysteresis-observer based control. *Mechatronics*, *Volume 16, Issue 7, September 2006*, *Pages 417-426*.

[4] Tönshoff H.-K., Kruse U. and Mahner H.-J. Sensor Systems for Industrial Applications Under Water. *CIRP Annals - Manufacturing Technology*, *Volume 48, Issue 1, 1999*, *Pages 445-448.*

[5] Wiederkehr R. S., Salvadori M. C., Brugger J., Degasperi F. T., Cattani M. The gas flow rate increase obtained by an oscillating piezoelectric actuator on a micronozzle. *Sensors and Actuators A: Physical*, *Volume 144, Issue 1, 28 May 2008*, *Pages 154-160*

[6] Patorski K., Kujawinska M. *The Moire Fringe Technique.* Elsvier science publisher, Netherlans, 1993.

[7] Post D., Han B., Ifju P. High Sensitivity Moire: Experimental Analysis for Mechanics and Materials. *Springer-Verlag, January 1994.*