272. Development of Smart Membrane Valve Based on Geometric Moiré Interferometry

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Abstract. Novel smart membrane valve which functionality is based on optical interference effects caused by moiré interferometry is proposed in this paper. The membrane is comprised from two steel gratings. Geometrical adjustment between adjacent holes in both membranes results in zero flow rate through the valve when no control signal is activated. Rotation of the control membrane generates moiré interference effects which are exploited for flow control. Relationships between the shape and geometric locations of the moiré circles and the control parameters of the second membrane are determined what helps to implement optimal valve control strategies.

Keywords: Moiré interferometry, flow control, piezoelectric ceramics.

1. Introduction

Valves with piezoelectric actuator control can be found in many different scientific and engineering applications. Typical examples are piezoelectric direct drive servo valves [1, 2, 3]. Many different constructions of piezoelectrically actuated valves are presently commercially available and can be purchased from industrial sub suppliers like PI (Physik Instrumente) L.P., Farmington Engineering, Inc., EDO Electro-Ceramic Products, etc.. Our goal was to develop a new valve with piezoelectric actuation based on the interference of moiré gratings.

Novel smart membrane valve which functionality is based on optical interference effects caused by moiré interferometry [4, 5, 6] is proposed in this paper. The membrane is comprised from two steel gratings. Each of the composite membranes is formed as an array of small round holes evenly distributed throughout the valve cross-section. One membrane is fixed motionlessly inside the valve. The other membrane is mounted on a precision control mechanism which can perform rotational and / or longitudinal micro motions.

Both membranes are geometrically adjusted in such a way that adjacent holes in both membranes do not coincide when no control signal is activated in the control mechanism of the second membrane what results into minimum flow rate through the valve. Microscopic angular deflections of the second membrane result into optical moiré interference between the gratings of the membrane pair. Piezoelectric mechanism for the rotation of the control membrane comprises a piezocylinder and steel disk with holes corresponding to the generated moiré pattern at certain angle mismatch between the membrane pair. An interference pattern of circles (not a pattern of interference fringes) is formed due to the fact that the moiré grating is comprised not from a conventional array of parallel lines but from a mesh of holes.

Numerical and mathematical models of the effect of moiré interference occurring in the membrane valve are investigated. Relationships between the shape and geometric locations of the moiré interference circles and the control parameters of the second membrane are determined what helps to implement optimal valve control strategies. Original patented constructions and implementations of the smart valve control strategies is the object of analysis in this paper.

2. Construction of the piezoelectric valve actuator

Smart membrane valves can be applied in automatic fluid regulation systems for micro flow quantity control in different mechatronics systems in medicine, alimentary industry, etc.

The membrane is comprised from two steel gratings. Each of the composite membranes is formed as an array of small round holes evenly distributed throughout the valve cross-section. One membrane is fixed motionlessly inside the valve. The other membrane is mounted on a precision control mechanism which can perform rotational and / or longitudinal micro motions. The schematic structure of the valve is presented in Figure 1.

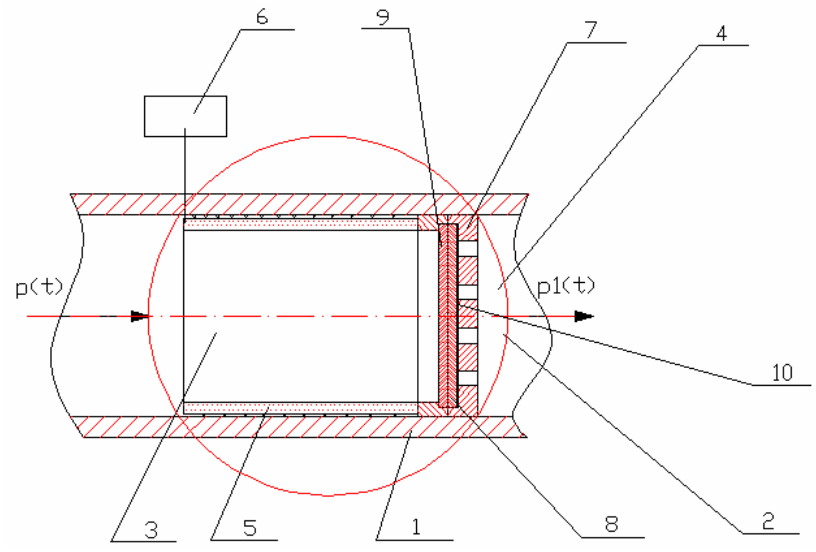

Fig. 1. 1-cylindrical valve body, 2-control actuator, 3-incoming cavity, 4-output cavity, 5-piezocylinder, 6-power supply, 7-steel disc with holes, 8-motionlessly fixed membrane, 9-control membrane, 10-layer of teflon

Smart membrane valve consist of cylindrical body 1 with control actuator 2 mounted inside it. Actuator 2 divides the body into incoming 3 and output 4 cavities. Piezocylinder 5 is connected to the power supply 6. Control actuator 2 consists of steel disc 7 with holes, which is rigidly fixed in the body 1. Two identical membranes with micro pores 8 and 9 are placed before the steel disk 7. Membrane 8 is fixed motionlessly, while membrane 9 can rotate in respect to membrane 8 and is fixed to the piezocylinder 5. Steel disk 7 is coated with teflon 10 which prevents the membrane 8 of wearing.

The principle of operation can be explained as follows. Traveling deformation waves are generated in the pjezocylinder 5 when the power source 6 is connected to it. These traveling waves bring the control membrane into rotational motion in respect to membrane 8. Optical moiré interference pattern is generated as the geometric location of the adjacent micro pores of the two membranes change when the control membrane rotates. This interference effect alters the flow transmissibility. The adaptive actuator can control the rotation of the membrane 9 and thus the flow rate through the valve. Moreover, a steel plate 7 with wholes corresponding to the geometrical shape of moiré patterns generated in the membrane pair at specific angle is placed after the membrane pair. The membrane pair is calibrated in the way that the valve is fully closed when the angle of rotation of the control membrane is zero. When the membrane 9 is gradually rotated, moiré patterns start to form. When the interference moiré pattern coincides with the holes of the steel plate 7, the smart valve lets through the maximum flow.

3. Formation of the moiré interference pattern

Modeling was performed with two identical membranes (Figure 2), which micro pores are of the same diameter $r=0.05$ and are located by the same distance $d=0.2$ (Figure 8). When piezocylinder is not generating deformations waves, the membranes do not form any moiré patterns and the flow through the valve is zero (Figure 3). When the power source is connected to piezocylinder, it turns one membrane by angles *alfa* (Figure 9). Different moiré patterns are generated what corresponds to variable flow through the valve.

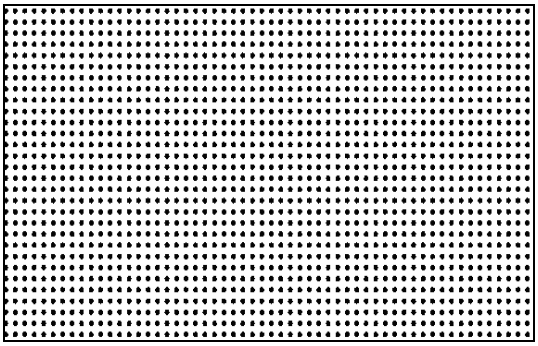

Fig. 2. Geometric locations of micro pores when *alfa=0*

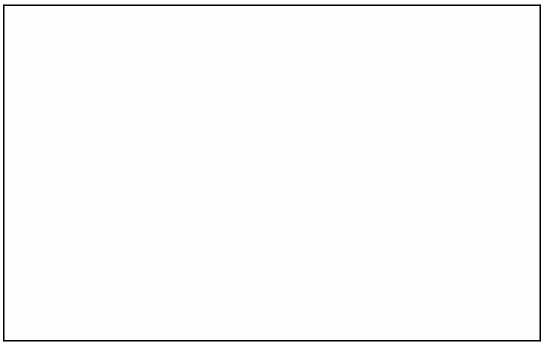

Fig. 3. Geometric location of micro pores when the flow through the valve is zero

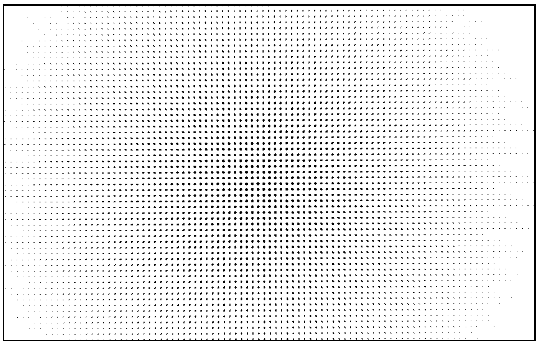

Fig. 4. Geometric locations of the moiré circles when *alfa=0.01*

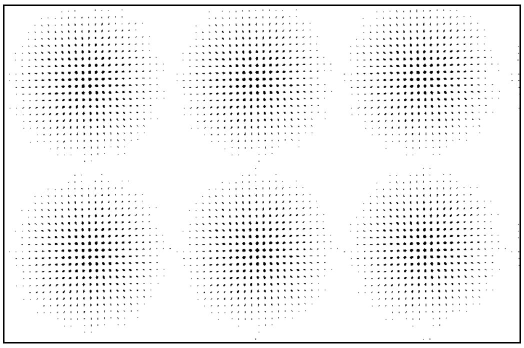

Fig. 5. Geometric locations of the moiré circles when *alfa=0.05*

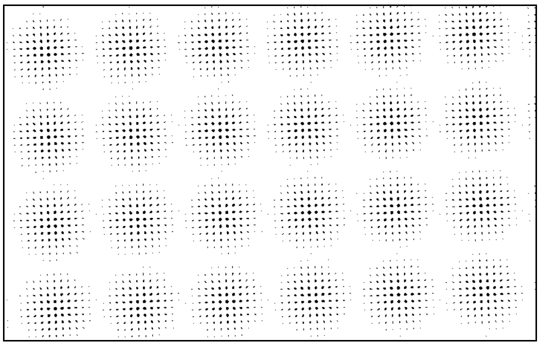

Fig. 6. Geometric locations of the moiré circles when *alfa=0.1*

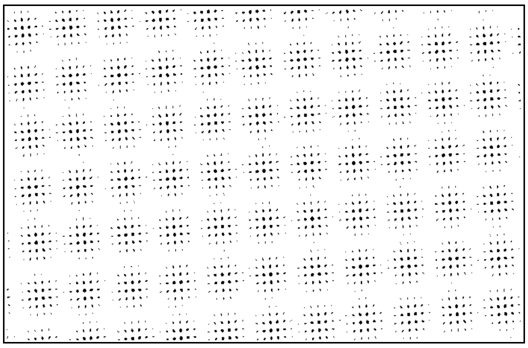

Fig. 7. Geometric locations of the moiré circles when *alfa=0.2*

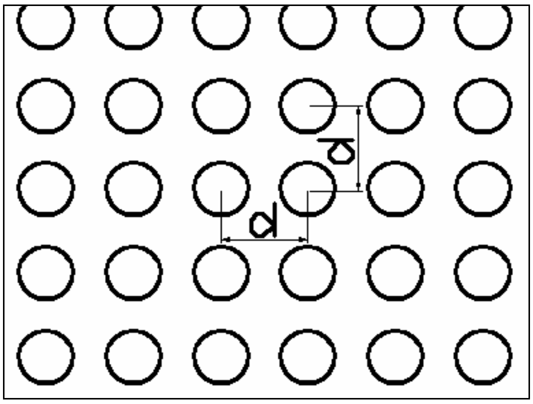

Fig. 8. Location of micro pores in membrane

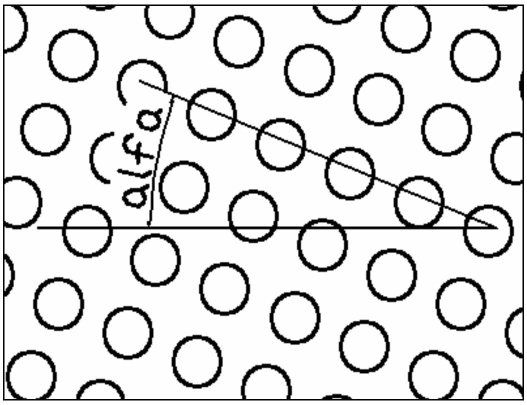

Fig. 9. Micro pores location when membrane turns by angles *alfa*

Detailed investigations of the moiré patters are necessary for development of flow control algorithms. The diameters of the moiré circles *D* distance between the circles' centres *L* and the alignment angle *beta* (Fig. 10) were measured for different control angles *alfa*.

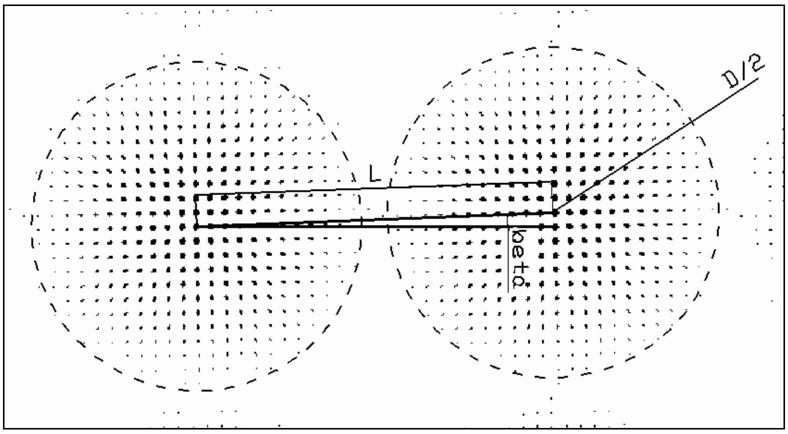

Fig. 10. The position of moiré circles when membrane turn by angle *alfa*

All described measurements are performed at the radius of micro pores $r = 0.05$. The relationships between *D, L* and *beta* from control angle *alfa* are presented in Figures 11-13.

The relationship between *D* and *alfa* (Figure 11) shows, that the diameter of moiré circles *D* decreases when angle *alfa* is increased. When *alfa* reaches 0.12 this relationship becomes almost linear and varies very slow. It was impossible to measure the diameters of moiré circles when the values of *alfa* where higher than 0.34. This relationship is almost invariant to the distance *d* between centers of micro pores.

The relationship between *L* and *alfa* (Figure 12) shows, that when the distance between the centres of micro pores and angle *alfa* increases more than one moiré circle is generated and it is possible to measure the distance between centres of moiré circles *L*. Distance *L* between centres of the moiré circles gradually declines when angle *alfa* is increased. This relationship becomes almost linear when the value of angle is larger than 0.16 for all values of *d*.

The relationship between *beta* and *alfa* (Figure 13) is almost linear. It can be noted that the angle *beta* grows when *alfa* is increased.

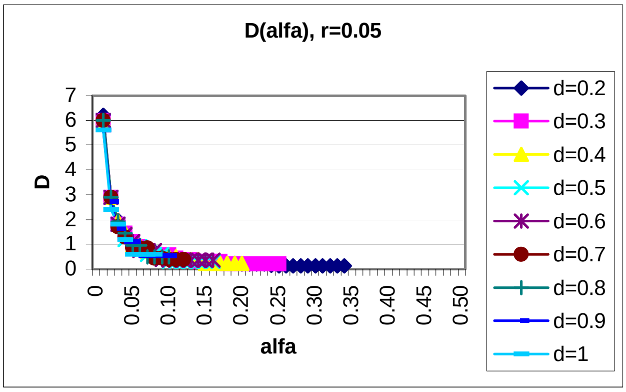

Fig. 11. The relationship *D(alfa)* when *r=0.05*

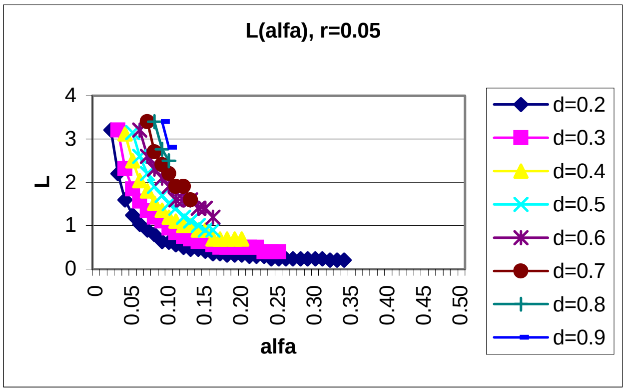

Fig. 12. The relationship *L(alfa)* when *r=0.05*

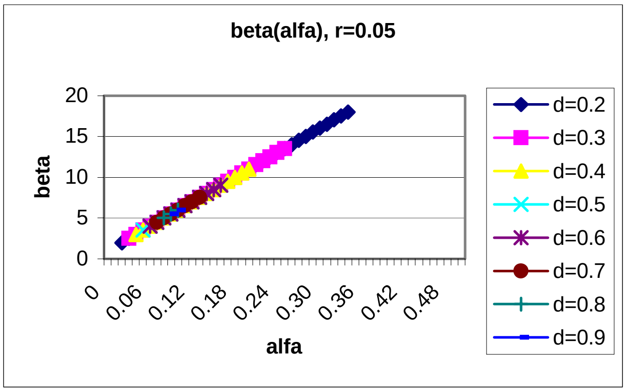

Fig. 13. The relationship *beta (alfa)* when *r=0.05*

Analogous relationships are produced for fixed value of $d = 0.2$ and variable *r* (Figures 14-16) what forms the theoretical background for the development and design of smart membrane valves based on geometric moiré interference patterns.

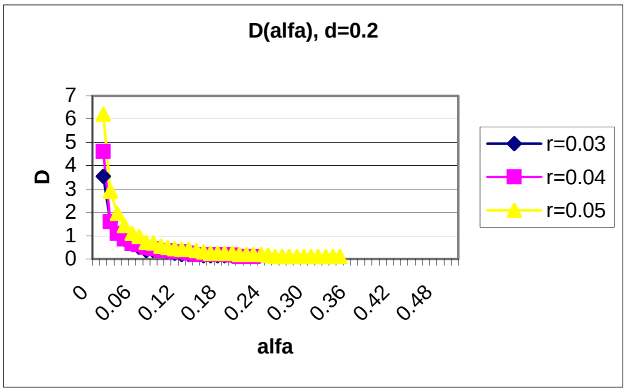

Fig. 14. The relationship *D(alfa)* when *d=0.2*

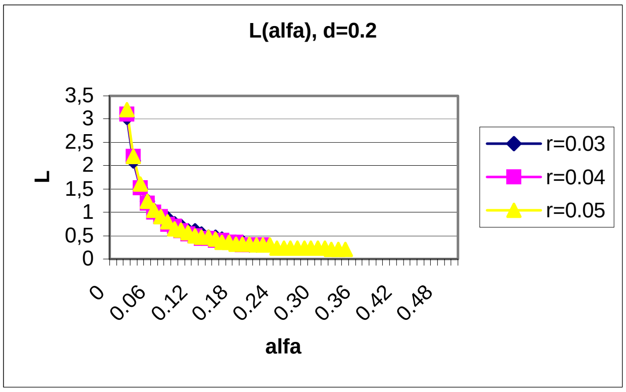

Fig. 15. The relationship *L(alfa)* when *d=0.2*

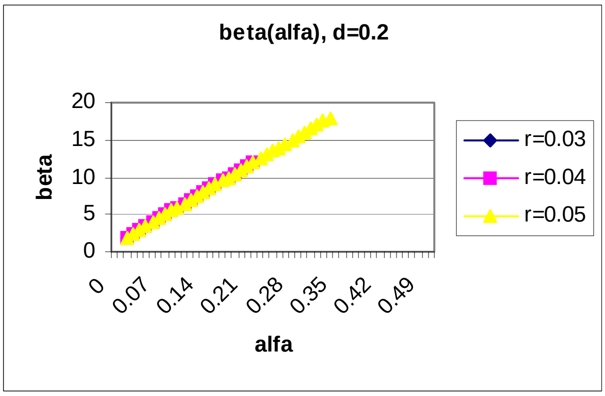

Fig. 16. The relationship *beta (alfa)* when *d=0.2*

Conclusions

Construction and principle of operation of membrane valve which functionality is based on the formation of moiré patterns is proposed in this paper. Numerical model of the moiré interference between the static and controllable membranes is developed. Analysis of the effect of moiré interference enables the construction of an effective flow control strategy.

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