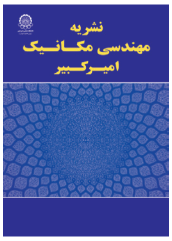

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Modeling and Sliding Mode Control of Rotating Helical Pump

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ABSTRACT: Two-phase fluids transportation is very important in the industry. Rotating helical pump is a special form that can be used to transfer fluid-gas flows and also to generate pulsatile flows. The structure of this pump differs from conventional pumps and its geometry can be changed during operation. In this paper, while demonstrating a fabricated second version of the rotating helical pump, a dynamic analysis is performed for the first time and the governing equations are extracted based on the input control variables (rotational speed and tilt angle of the pump). In the dynamical analysis, a rotating control volume corresponding to a spiral tube is considered. In order to determine the values of the inputs corresponding to the desired outputs, we use the non-dimensional characteristic curves of the pump that was published in the previous study. Then the control is performed on the basis of two input variables to reach the desired pump head and flow rate. A sliding mode controller is implemented. The results include governing equations of the rotating helical pump that can be used in future studies. Moreover, the results show the success of the sliding mode method in control of the pump.

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1- Introduction

There are generally two categories for pumps: displacement pumps and turbomachinery pumps. The positive displacement pumps are suitable when the amount of gas is too high in a very large mixture of multiphase flows. The turbomachinery pumps, are basically used for liquid transportation. The mentioned pumps have been made and used in the industry for a long time. The rotating helical pump, which is the subject of this paper, has a different structure. This pump has been first introduced by Mohseni et al. [1]. The first version of the pump was made and tested empirically, as well as its dimensionless performance characteristics. This pump has special capabilities in addition to the ability to transfer multiphase products which is very important in the industry. It can create pulsatile flow that has some applications in medicine [2] and this kind of flow is effective in increasing heat transfer [3]. Despite the high complexity, many pieces of research have been carried out on the two-phase flow inside the helical tubes. However, the focus of this paper is on the modeling and controlling of the rotating helical pump.

In most applications, pumps operate under steady-state conditions. However, in some cases, it is necessary to control the flow rate and head. For example, when the fluid is pumped into (or from) a variable-height tank, the head should be controlled. Different methods are used to control a pump. For pumps with a fixed geometric structure, the pump speed is usually controlled by the Proportional–Integral–Derivative (PID) method [4]. PID method has many benefits and is easy to implement. However, it has also some drawbacks. For example, it is difficult to set up its parameters, and if some of the operating parameters of the system are changed online, PID control cannot be adapted [5]. As a result, methods such as optimal control [6] and sliding mode control [7] are used to control the pumps.

The rotating helical pump has a variable structure that can affect the operation of the pump. The novelty of the present article is that, in addition to the construction of the second edition, for the first time, dynamic modeling and control are investigated for this variable structured pump. To this end, the dynamical equations governing the behavior of the pump are derived and, due to its nonlinearity, the sliding mode control method is used for control.

2- Methodology

2- 1- Dynamics of rotating the helical pump

The pump of this paper, as shown in Fig. 1, is a rotating helical pump that is used to transport gas-liquid flows. The main structure of this pump consists of a solid cylinder, surrounded by a helical tube. It also passes through a cylinder of a shaft mounted on a bearing. This is a hollow shaft. Bearings are on the chassis. One side of the chassis is on the coupling of the transferring screw and on the other side it is hinged to the bottom of the base. The whole set is inside a reservoir containing a fluid such as water.

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The operation of this pump is summarized as follows; the cylinder is rotated by a permanent magnet that is connected to the shaft by a pin and a belt, and by rotating the spiral tube connected to it. The bottom of the spiral tube, which is the fluid inlet, is filled with air and water alternately with the pump's rotation.

Fig. 1. Rotating helical pump

Dynamic equations consist of two distinct differential equations, one based on the variable of pump rotation speed and its derivatives, and the other according to the variable angle of the inclination of the pump and its derivatives. The objective is to establish a dynamic relationship between the head and flow rate of the pump with two controlled input variables. By applying Newton's second law and considering the dynamics of the DC motor, the differential equation of rotating helical pump in terms of the pump rotational speed is as follows:

$$\ddot{\omega} = \frac{NK_m}{L\,(q+J_e)}V - \frac{N^2K_m^2}{L\,(q+J_e)}\omega - \frac{Rh}{L\,(q+J_e)}\omega^2 - \left(\frac{J_e}{q+J_e}\right)\left(\frac{R}{L}+\frac{Rj}{LJ_e}\right)\dot{\omega} - \frac{m}{(q+J_e)}\omega\dot{\omega} \quad (1)$$

The governing equation of the pump in terms of the pump inclination angle (α) is also as follows:

$$\ddot{\alpha} = \frac{A(\alpha)}{C(\alpha)}\dot{\alpha} + \frac{B(\alpha)}{C(\alpha)}\ddot{\alpha} + \frac{D(\alpha)}{C(\alpha)}\dot{\alpha}^2 + \frac{E(\alpha)}{C(\alpha)}\dot{\alpha}^3 + \frac{F(\alpha)}{C(\alpha)}\dot{\alpha}\ddot{\alpha} + \frac{G(\alpha)}{C(\alpha)} + \frac{H(\alpha)}{C(\alpha)}V \quad (2)$$

3- Control

The purpose of the control is to adjust pump rotational speed and inclination angle given the desired flow rate and head. Sliding Mode Control (SMC) has been used to control the rotating helical pump [8]. Fig. 2 shows schematically the block diagram of the control.

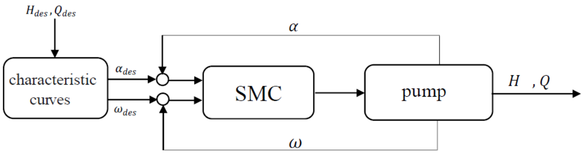

Fig. 2. Block diagram of the control

4- Results and Discussion

Fig. 3, shows the changes in angular velocity and its derivative. The desired value of rotational speed is also depicted in this figure. As seen in Fig. 3, by applying control signal the rotational speed reaches the desired value and also its derivative reaches zero. This implies that after reaching the desired value the control input remains constant.

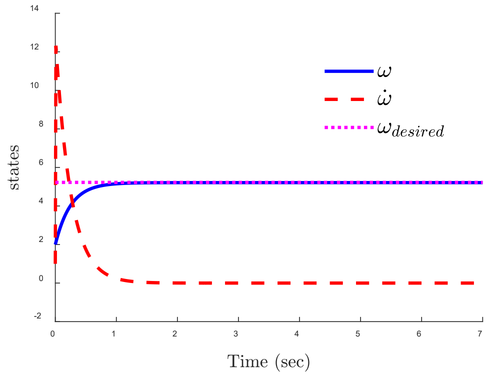

Fig. 3. The variation of rotational speed (rad/sec) with applying sliding mode controller

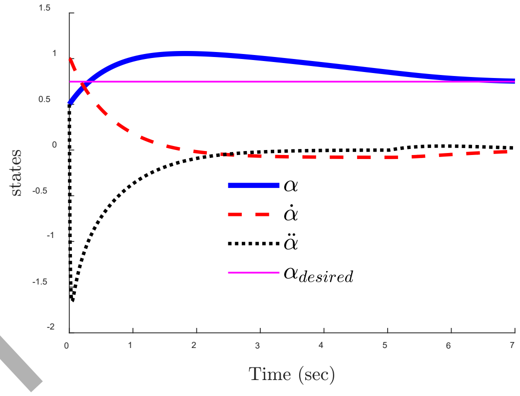

Fig. 4. The variation of inclination angle (rad) with applying sliding mode controller

In Fig. 4, the variation of the inclination angle of the pump, its derivations, and desired value are depicted. As seen, α reaches its desired value under action of the sliding mode control. It should be also mentioned that given a desired set of head-mass flowrate, the corresponding desired values for rotational speed and angle of inclination are obtained using the experimental dimensionless curves from Ref. [1].

5- Conclusions

In this paper, for the first time, the dynamical equations of a rotating helical pump were extracted. A rotating control volume is used to obtain the equations. Derivation of the dynamic equations was done by taking into account the dynamics of the DC motors. A sliding mode controller has been designed to control the performance of the variable structure pump of the current study. Using this controller, it will be possible to control the rotational speed and inclination angle of the pump for the desired set of head and mass flowrate. All the parameters used in the method are based on the built-in model. The results show that the controller has been able to control the pump well and takes the system state variables to their desired values.

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