Evaluation of dynamic characteristics of water driven stage

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Abstract

The dynamic characteristics of the water driven stage that was developed for the single point diamond turning machine are considered with its static characteristics. The table of the stage is controlled by the flow rate into the piston-cylinder designed in the table structure. The paper aims to evaluate both static and dynamic characteristics of the stage. In order to consider the dynamic characteristics, the time constants of the stage are considered based on the mathematical models. Then an experimental method to identify the time constant is discussed.

1 Introduction

The water driven stage was developed for the machine tool table for single point diamond turning. Speed of the table is basically controlled by the flowrate into the stage. The speed of the stage determines the feed rate in the turning operations. The speed should be thus regulated by an appropriate feedback control system in order to generate uniform surfaces.

In the previous paper [1], a mathematical model of the water driven stage was introduced for designing feedback control system. Then it was indicated that the stage is modelled by a first order system. In the present paper, the static characteristics of the stage are first evaluated theoretically and experimentally. The dynamic characteristics of the stage are then considered using derived mathematical model. The time constant of the stage is thus evaluated via the derived mathematical model. Experimental method to determine the time constant of the system are then discussed and planned.

2 Structure of water driven stage

Figure 1 shows the structure of the water driven stage [2]. The stage has a piston-cylinder mechanism that is made inside the table structure. The piston and cylinder is not circular cross-section but square cross-section. As shown in Fig. 1, the piston is formed on the upper and bottom surfaces of the guide-way, while no piston structures are formed on the side surfaces. The pressure difference of the supplied water can thus be generated, makes table motion along the guide-way. The speed of the stage is controlled by the water flow rate. The table of stage is supported by water hydrostatic bearings in the vertical and horizontal directions, except for the feed direction.

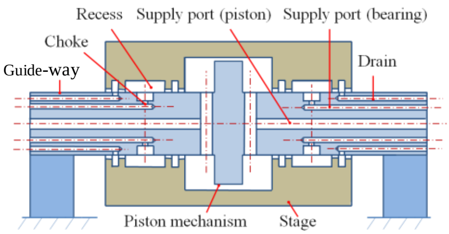

Figure 1 Structure of water driven stage

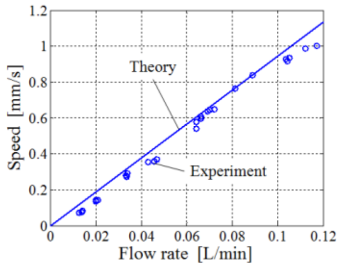

Figure 2 Static characteristics

3 Time constants of water driven stage

The water driven stage can be modelled by a first order system [1]. It is noted that the equation of motion is represented by different forms, depending on the conditions of the water supply system. For instance, if the stage is controlled with constant supply pressure, the equation of motion is represented by Eq. (1).

$$T_{c1}\frac{dv}{dt}+v=\frac{A}{c}p_s-\frac{F_c}{c} \tag{1}$$

Here, c: viscous damping coefficient due to water flow between the table and guide-way, v: speed of table, A: area of piston, p_s: supply pressure, F_c: external forces such as cutting and/or grinding forces. The time constant T_{c1}, if the constant supply pressure can be assumed, is given by Eq. (2).

$$T_{c1}=\frac{M}{c} \tag{2}$$

Here, the mass of table is represented by M.

If the flow rate is controlled, the equation of motion is modified as Eq. (3).

$$T_{c2}\frac{dv}{dt}+v=\frac{AR}{c+A^2R}q_p-\frac{F_c}{c+A^2R} \tag{3}$$

Here, R: flow resistance at the clearance between the piston and cylinder, q_p: supplied flow rate into cylinder. The time constant T_{c2}, if the flow rate is controlled, is given by Eq. (4).

$$T_{c2} = \frac{M}{c + A^2 R} \tag{4}$$

Accordingly, the time constant of the stage changes depending on the control conditions. The static characteristic of the stage is derived from Eq. (3).

$$v = \frac{AR}{c + A^2 R} q_p \tag{5}$$

4 Static characteristics and step respose of water driven stage

The static and dynamic characteristics of the water driven stage are investigated experimentally and theoretically. The relationship between the speed and flow rate is given by Fig. 2. As shown in Fig. 2, the calculation result agrees with the experimental result. In addition, the result shows that the required speed for the feed motion for single point diamond turning is obtained by supplying several ten milli-litters per minutes.

The dynamic characteristics are also considered by the step response method based on the derived mathematical model. The derived mathematical models indicate that the time constants are represented by different forms depending on the control conditions, as indicated by Eqns. (2) and (4). These can be determined via experiments with the constant pressure condition or the flow rate control condition. The constant pressure condition can be easily made compared with the flow rate control. For instance, the constant water pressure can be made using an over-low tank. In this case, the time constant T_{c1} is calculated to be about 10 s using Eq. (2). In contrast, the time constant T_{c2} is about 1 ms using Eq. (4).

An experimental method planned is explained. As shown in Fig. 3, the constant mass is hanged with a thin wire from moving table through pulley so that it works as the external constant force acting on the table. In order to disconnect the mass stepwise from the table, an electromagnet can be used. The step input for the stage can be then applied by falling the mass stepwise by stopping the electric voltage supply to the electromagnet. A preliminary experiment was carried out, the step response has then been measured as given in Fig. 4. The experimental result shows the time constant is about 0.2 s. However, both the constant pressure setting and flow rate control condition were not attained successfully. Thus, the time constant of the stage will be precisely measured with currently prepared experimental setup.

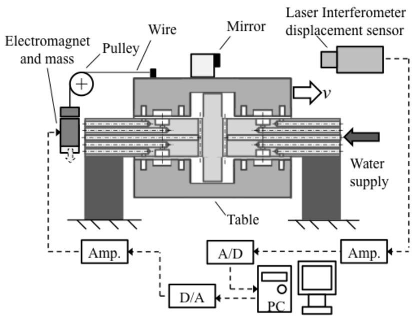

Figure 3 Experimental setup

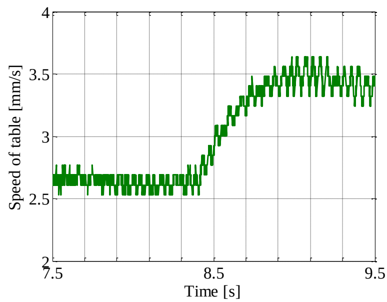

Figure 4 Measured step response

5 Summary

Static characteristic and dynamic characteristic of the water driven stage were considered. In particular, the time constant of the stage was investigated via derived mathematical models. Two different forms of the time constant are compared. The experimental method for evaluating the time constant was also discussed. The experimental evaluation for identifying the time constant based on the considerations in the paper will be carried out.

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References:

[1] Y. Nakao, M. Nagashima, T. Sano and K. Suzuki, Design of feedback control system for water driven stage, Proceedings of 11th International Conference of the European Society for Precision Engineering and Nanotechnology, Vol. 1, pp. 335-338, (Como, 2011-5).

[2] Y. Nakao, M. Kawakami, Design of water driven stage, Proceedings of 9th International Conference of the European Society for Precision Engineering and Nanotechnology, Vol. 1, pp. 200-203, (San Sebastian, 2009-6).