

Hydraulic Positioning Unit with Internal Mechanical Position Feedback

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Abstract: The paper presents the actual stage of hydraulic positioning units with external mechanical position feedback and proposes an original design of a hydraulic positioning unit with internal mechanical position feedback, developed by the authors. The design of the positioning unit is discussed in order to obtain a compact system with low sizes, the built experimental model is described and some results of a first set of experimental tests are presented.

Keywords: Hydraulic, positioning unit, position feedback.

1. Introduction

In many industrial applications the actuated load, having translation or rotation movement, must be accurately positioned in different points of the working stroke. In order to increase the productivity, the moving speed must be as high as possible. This is valid especially for industrial robots and CNC machine tools. The accurate positioning depends on the control of the load speed, because the speed must be lowered in the proximity of the stop point. A rigorous control of the load speed can be obtained using electric or hydraulic actuators. When high forces and/or torques are needed along with small dimensions of the system, the only option is the hydraulic actuation.

A classic hydraulic positioning unit is a compact assembly including a hydraulic motor (linear, oscillating or rotational), one or more classic and proportional devices, a position sensor and an electronic control system. The proportional device is usually a flow control device and is mounted on the fixed part of the motor. Often the electronic control system is integrated in the mechanical structure. Such hydraulic positioning units are offered by companies with tradition in the domain of hydraulic proportional equipment (Rexroth, Moog, Atos etc.). The dimensions of such equipment are high, the diameters of the used motors being usually in the range of 20...40 mm.

The positioning systems with mechanical position feedback are often used in industrial applications. Fig. 1 shows the general scheme of such a system.

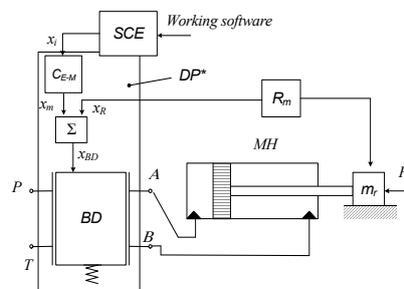


Fig. 1. The general scheme of a positioning system with mechanical position feedback.

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The flow rate into and from the hydraulic motor MH is controlled by a proportional direction control valve DP^* with differential command [1]. The incoming and out coming flow rates depend on the control signal x_c , and, according to the pressures within the chambers of the motor, produce the movement of the mobile assembly of the motor and of the driven load. The position of the load is followed by the mechanical feedback R_m , whose output signal x_R is compared with the output signal x_m of the electro-mechanical converter C_{E-M} ; the output signal x_i of the electronic control system SCE is obtained using a proper software application, according to the type of the converter. As an example, if the converter is an electrical stepping motor, the software application uses the following inputs: the number of programmed steps, the direction of movement, the working frequency or its variation function, the stopover time, etc.

The actuating units may be continuous, when the converter is a d.c. servomotor or a proportional electro-magnet, or incremental, when the converter is an electrical stepping motor.

2. Hydraulic positioning units with external mechanical position feedback

Theoretical and experimental researches were carried out for many years within the Mechatronics and Precision Mechanics Department of "Politehnica" University of Bucharest in the field of hydraulic proportional units with mechanical position feedback. Two experimental models of such units, developed by the authors, are forward presented.

2.1. Model I

Fig. 2 shows the general scheme of a long stroke hydraulic positioning unit with external mechanical position feedback [2]. Fig. 3 shows a view of the built experimental model.

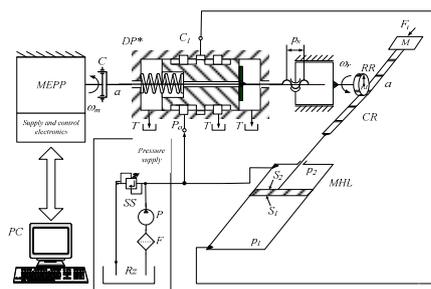


Fig. 2. The general scheme of a long stroke hydraulic positioning unit with external mechanical position feedback.

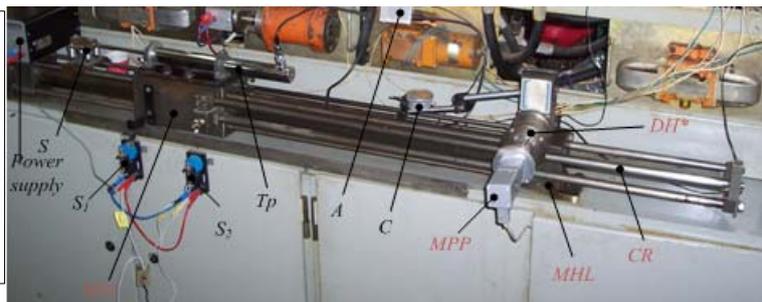


Fig. 3. A view of the built experimental model I.

The unit is a modular system containing a hydraulic linear motor MHL , actuating a mobile mass MM having a translational guided movement and a hydraulic proportional direction control valve with differential control DH^* actuated by a stepping low power electric motor MPP . The position feedback is mechanical and the information on the actual position of the mobile assembly is transmitted to the valve by means of a rack CR , fastened to the mobile mass. The proportional differential direction control valve has only one consumer - the active rodless chamber of the hydraulic motor.

The other chamber is permanently connected to the hydraulic power supply. The mobile assembly moves due to the difference between the active areas S_1 and S_2 of the hydraulic linear motor. The system main characteristics are the following:

- the hydraulic proportional direction control valve is placed with its axis "aa" perpendicular to the axis of the hydraulic motor;
- the actuated load is fastened to the mobile mass, that is guided by four bearing translation guidings fixed on the hydraulic linear motor CH ;
- the feedback rack CR is articulated to the mobile mass MM and is permanently in contact with the feedback gear RR by means of a spring, that also takes over the backlash of the gear;
- the electromechanical converter is a stepping electric motor containing the amplifying and the control electronics.

2.2. Model II

Fig. 4 shows the general scheme of an average stroke hydraulic positioning unit with external mechanical position feedback [3], using a proportional differential direction control valve with two consumers, and fig. 5 shows a view of the experimental model.

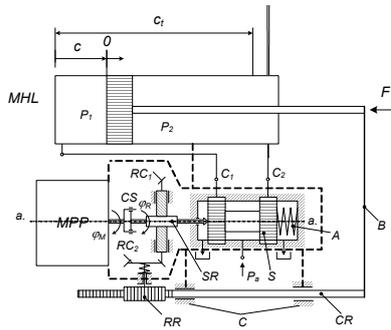


Fig. 4. The general scheme of an average stroke hydraulic positioning unit with external mechanical position feedback.

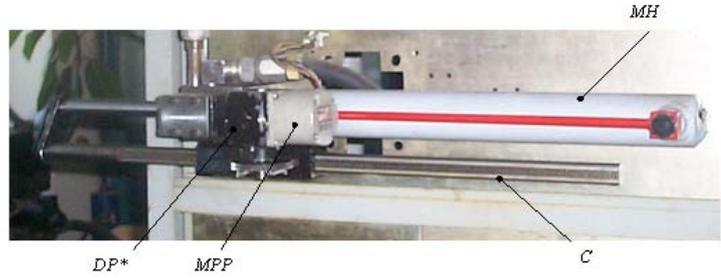


Fig. 5. A view of the built experimental model II.

This system differs from the previous system by the position of its feedback gear axis, that is perpendicular to the "aa" axis of the distributor. In this case the distributor is placed with its axis parallel to the axis of the hydraulic motor and thus the system is more compact. In order to transmit exactly the feedback signal from the mobile assembly of the motor to the mechanical adding system, some measures for backlash takeover were taken for the gear-rack system and also for the conical gear.

3. Hydraulic positioning unit with internal mechanical position feedback

This paper deals with a small size hydraulic positioning unit with internal mechanical position feedback, programmable and controlled by a microcontroller or a PC, developed by the authors, having static and dynamic behavior comparable with the actual commercial systems.

The main characteristics of the unit are: stroke - 150mm; working speed - 0.6 m/s; positioning accuracy - $\pm 0.02\text{mm}$; actuating force: 200N (for a working pressure of 15bar).

Fig. 6 shows the general scheme of the positioning unit with internal mechanical position feedback. The information on the actual position of the load is transmitted directly to the mechanical adding system Σ , consisting of the feedback screw sr and the feedback nut machined into the piston of the hydraulic linear motor MHL . This arrangement makes the system very compact and lowers its sizes.

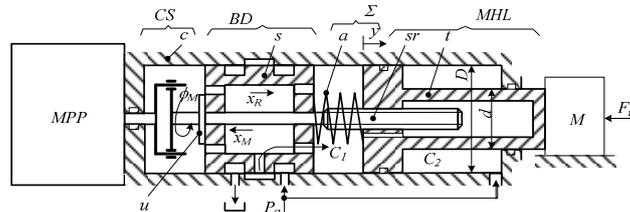


Fig. 6. The general scheme of the positioning unit with internal mechanical position feedback.

The hydraulic distribution unit consists of a mobile slide valve s moving inside the body c . The position of the slide valve depends on the following:

- the position φ_M of the shaft of the command motor:

$$x_M = \frac{p_s}{2 \cdot \pi} \cdot \varphi_M \quad (1)$$

- the system response, y :

$$x_R = y \quad (2)$$

The real movement x of the slide valve is given by:

$$x = x_M - x_R = \frac{p_s}{2 \cdot \pi} \cdot \varphi_M - y \quad (3)$$

where p_s is the pitch of the feedback screw sr .

The angular increment of the stepping motor MPP is given by:

$$\varphi_{M0} = \frac{2 \cdot \pi}{N} \quad (4)$$

where N is the maximum number of steps per one rotation of the motor.

For one angular increment of the motor the unit will move with the increment Δy_0 . In this case, the equation (3) becomes:

$$x = \frac{p_s}{N} - \Delta y_0 = 0 \quad (5)$$

and the main design condition results:

$$p_s = N \cdot \Delta y_0 \quad (6)$$

The link between the shaft of the electric motor MPP and the feedback screw sr is assured by a special coupling CS allowing the translation movement of the screw. The axial position of the screw is followed by the slide valve due to the spring a , that maintains a permanent contact between the fillet u of the screw and the frontal surface s of the slide valve.

In order to assure a high positioning accuracy the following conditions must be achieved:

- the gap “ j ” between the slide valve and the body of the direction control valve must be of $2\div 3\mu\text{m}$;
- the overlap (the contact length between the body and the slide valve when all the orifices are closed) must be in the range $5..10\mu\text{m}$;
- the control signal from the electric motor MPP to the slide valve must be transmitted with high accuracy, so that all backlashes must be eliminated by specific systems.

The limitations in miniaturizing the system are the following:

- the dimensions of the linear motor: the actual commercial hydraulic motors have diameters starting from 25mm;
- the dimensions of the hydraulic proportional differential direction control valve: the actual machining and assembly technologies assure the required values for the gap and the overlap [1] if the diameter of the slide valve is greater then 10mm and its length is under 70...80mm; lowering the diameter of the slide valve must be correlated with its length and new technologies must be used;
- the dimensions of the actuator: the actual commercial offers include actuators with lower sizes without lowering the power.

4. 4. The experimental model

The pre-dimensioning of the unit was accomplished starting from the general scheme (Fig. 6) and the imposed initial data:

- for the hydraulic motor MHL : piston diameter - 20mm and rod diameter - 12mm;
- for the distribution unit BD : nominal diameter - 2mm, slide valve diameter - 20 mm;
- for the actuator: a Phytron stepping motor, ZSS52 type.

The hydraulic distribution unit BD was designed in an original way, inside the body c of the linear hydraulic motor, as shown in Fig. 7. The bore of the body is machined with high accuracy and has a very good quality of the surface. Three equidistant gaps having the length L are cut on the outer surface of the body. The gaps are milled and grinded from the exterior of the body and so the length is obtained and measured with high accuracy. The slide valve s can move inside the body following the position of the feedback screw sr . The orifices for supply pressure and tank are machined in the outer piece ce and the sealing is achieved with the nonmetallic elements g .

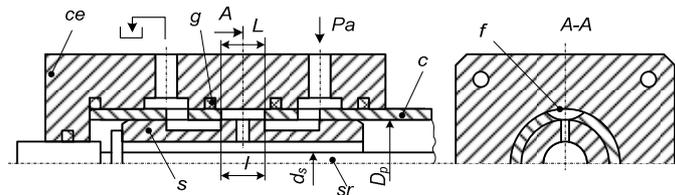


Fig. 7. The hydraulic distribution unit design.

Fig. 8 shows a 3D view of the experimental model designed using SolidWorks programming environment and fig. 9 shows a longitudinal section of the unit. Fig. 10 shows the built experimental model.

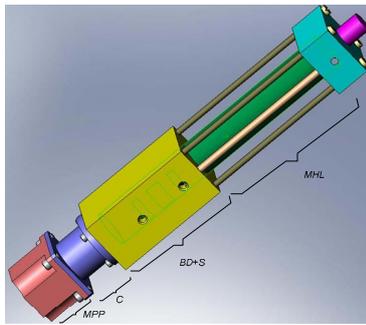


Fig. 8. A 3D view of the experimental model.

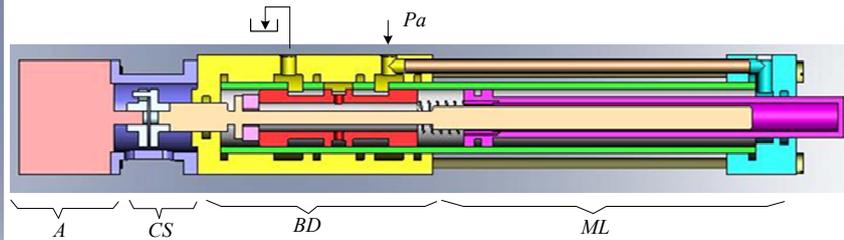


Fig. 9. A longitudinal section of the experimental model.

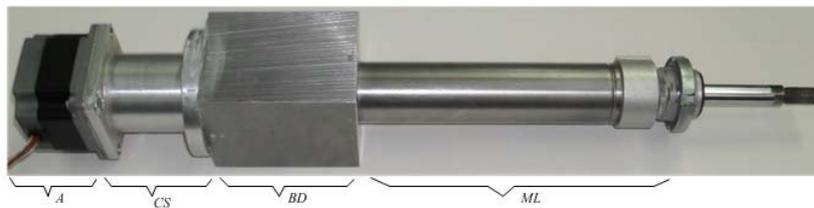


Fig. 10. A view of the built experimental model.

In order to test the built experimental model, an application software was developed using LabView programming environment. The first set of experimental tests revealed the following aspects:

- the built experimental model is functional;
- the positioning accuracy is within the imposed range and it can be improved using more accurate machining and assembly technologies;
- the repeatability of the system was good, with a maximum error of 0.04 mm;
- in certain cases the positioning can be performed using an override.

5. Conclusions

The research revealed that new hydraulic actuating systems can be developed, following the actual trend of improving and miniaturizing the actuators.

6. References

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