Flow Control Strategy for High Speed Motion of Hydraulic Manipulator

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1. Introduction

The performance of a hydraulic manipulator is primarily determined by the supplied flow rate and hydraulic pressure. In mobile systems, compared to industrial applications, a more compact and simplified hydraulic power unit is utilized to enhance mobility. However, the simplified power pack can lead to reduced performance and stability of the manipulator due to insufficient flow and pressure fluctuations. Therefore, integrating auxiliary control devices or support systems is essential to ensure consistent performance and reliability.

Efficiency in mobile systems is also crucial for ensuring sufficient operating time. Overflowing, which supplies excess flow, results in bypass flow that generates heat. This heat degrades system stability and reduces energy efficiency. To prevent this, it is essential to supply only the necessary amount of flow required for the system's operation.

In this study, we propose a strategy to improve the performance of the manipulator by using an accumulator as an additional source of flow. Energy efficiency is improved through variable pump control, while any resulting pressure fluctuations are mitigated by incorporating an accumulator. Additionally, during operations that exceed the pump's capacity, the accumulator supplements the required flow, thereby enhancing the manipulator's overall performance.

The control strategy will be applied to the hydraulic dual-arm manipulator ARMstrong and micro hydraulic power unit m-HPU, currently under development at KAERI(Korea Atomic Energy Research Institute).

2. Flow Rate Models

In this section flow rate models of m-HPU and manipulator are driven to obtain required flow rate for operating the manipulator. Fig. 1 shows the hydraulic schematic of the m-HPU.

2.1. Fixed displacement pump

A fixed displacement pump is used in the m-HPU and its flow rate can be calculated by multiplying its volumetric displacement by the speed of the shaft.

(1) $Q_{pump} = D_{pump} \cdot \omega_{pump}$

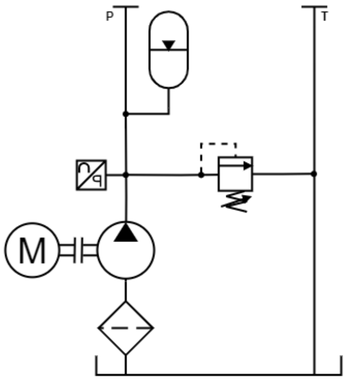

Fig. 1. Hydraulic schematic of the m-HPU

2.2. Diaphragm accumulator

A nitrogen-charged diaphragm accumulator is used, and assuming that the gas undergoes a polytropic process, the flow rate model can be derived as follows.

(2) $P_g V_g^n = P_{g,pre} V_{g,pre}^n$

(3) $\dot{V}_g = -\frac{\dot{P}_g V_g}{n P_g}$

(4) $Q_{accumulator} = \frac{1}{n} \frac{V_{g,pre}}{P_o} \left(\frac{P_{g,pre}}{P_o} \right)^{\left(\frac{1}{n}\right)} \dot{P}_o$

2.3. Required flow rate of the manipulator

The manipulator has 6 joints for each arm and 2 joints for gripper. All of the joints are driven by hydraulic cylinders, except for the wrist rotation, which is driven by a hydraulic motor. Thus, the total flow rate required to actuate the joints is obtained by summing the flow rates for each joint.

(5) $Q_{actuators} = \sum_{k=1}^{N} A_k \cdot v_{k,des} + \sum_{k=1}^{M} D_k \cdot \omega_{k,des}$

3. Control Strategy

To optimize energy efficiency while maintaining consistent system performance, the flow rate supplied by the power pack must match the robot's consumption. The inlet flow rate is provided by the pump, while the outlet flow rate includes the flow to both the accumulator and the manipulator.

(6) $Q_{in} = Q_{pump}$
(7) $Q_{out} = Q_{accumulator} + Q_{actuators}$

By adjusting the speed of the gear pump, it is possible to match the supplied flow rate to the system's demand.

(8) $\omega_{pump} = \frac{Q_{accumulator} + Q_{actuators}}{D_{pump}}$

In the m-HPU, a relatively small-capacity gear pump is used, which can lead to insufficient supply flow during high-speed motion. This flow shortage causes a drop in system pressure, prompting the accumulator to release oil to compensate for the deficit. The accumulator's discharge flow is estimated based on pressure feedback from the sensor installed in the HPU.

4. Conclusions

This study discusses the application of an accumulator to the hydraulic power unit to improve the manipulator's performance. The accumulator’s flow, estimated through pressure feedback, is used for controlling the HPU. Additionally, the damping function of the accumulator is expected to enhance system stability.

Future work will experimentally verify the effectiveness of this approach. Furthermore, the accumulator flow will be actively utilized to maximize the efficiency of the HPU, not just to compensate for flow shortages.

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