Flow Rate Estimation of Mobile Hydraulic Manipulator

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***Keywords :** Hydraulic, Manipulator, Robot, Flow rate, Efficiency

1. Introduction

Hydraulic Power Units (HPUs) are used as a power source in hydraulic systems. Industrial HPUs can dissipate generated heat easily thanks to the large reservoir capacity and additional cooling devices such as chillers. However, it is not applicable to mobile robot HPUs. Because of smaller reservoirs and lack of chilling devices, fluid temperature can easily rise.

Overheating of fluid accelerates the oxidation and alters the viscosity of hydraulic fluid, therefore degrading dynamic performance of the robot. Most of the heat is generated due to overflow in the HPU.

Overflow loss not only affects the performance of the robot but also reduces the operating time. Therefore, it is important to figure out the required flow rate to actuate.

In this paper, we derive the fluid flow rate of hydraulic robot ARMstrong to prevent overheating and improve energy efficiency. The ARMstrong is being developed by KAERI(Korea Atomic Energy Research Institute) to respond to nuclear accidents.

2. Flow Rate Estimation

To minimize overflow loss, it is essential to accurately determine the required flow rate. It can be obtained by adding the supplied flow rate to actuators Q_{act} to the internal leakage of hydraulic system. This paper mainly addressed the Q_{act}, and internal leakage is going to be addressed in the future work.

2.1. Mechanical structure of ARMstrong

ARMstrong has 6 DOF (Degrees of Freedom) for each arm and 2 DOF for gripper. All of the joints are driven by hydraulic cylinders, excluding wrist rotation driven by hydraulic motor. Reference angles are received as a command signal for each joint.

Q_{act} is summation of supplied flow rate for each actuator. For cylinders, it can be calculated by multiplying the desired speed by the effective area, and for motors, by multiplying the desired angular speed by the volumetric displacement.

Because the controller only gives angular values of joints, it is necessary to calculate the linear values of the cylinder using kinematic equations.

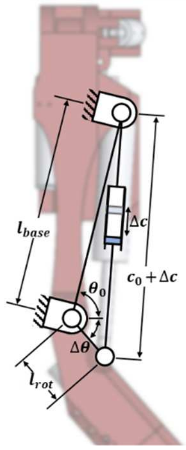

Fig. 1. Elbow joint linkage mechanism

All joints driven by cylinders use a 4-bar linkage mechanism as shown in Fig. 1. Kinematic equations can be expressed as follows:

(1) $l_{base}{}^2 + l_{rot}{}^2 - (c)^2 = 2 l_{base} l_{rot} \cos(\theta)$

(2) $\begin{cases} c = c_0 + \Delta c \\ \theta = \theta_0 + \Delta\theta \end{cases}$

l_{base}, l_{rot} denote the length of the base link and the rotating link and θ, c represent the angle and the total length of the cylinder. c_0 and θ_0 are the values at the original position.

2.2. Flow rate of hydraulic cylinder

Displacement of the cylinder can be expressed as a function of θ by inverting equation (1).

(3) $f(\theta) = \sqrt{l_{base}{}^2 + l_{rot}{}^2 - 2 l_{base} l_{rot} \cos(\theta)} - c_0$

The desired speed is obtained by differentiating $f(\theta)$ with respect to time.

(4) $v_{desired} = f'(\theta)\,\dot{\theta}$

Flow rate of cylinder is determined by the velocity and effective area of the piston. For single-rod cylinders the effective area differs between pull and push.

(5) $Q_{cylinder} = A \cdot v_{desired}$

(6) $$A = \begin{cases} \frac{1}{4}D^2\pi & (if\ v_{desired} > 0) \\ \frac{1}{4}(D^2 - d^2)\pi & (if\ v_{desired} \leq 0) \end{cases}$$

D is inner diameter of cylinder, d is diameter of rod.

2.3. Flow rate of hydraulic motor

Flow rate of hydraulic motor is determined by the angular speed and volumetric displacement. D_{motor} represents the volumetric displacement of motor.

(7) $$Q_{motor} = D_{motor} \cdot \omega_{desire}$$

2.4. Total flow rate of a manipulator

Required total flow rate to actuate joints is obtained by summation of each flow rate.

(8) $$Q_{act} = \sum Q_{cylinder} + \sum Q_{motor}$$

3. Conclusions

In this paper, the required flow rates for each actuator of the hydraulic robot were estimated by solving kinematic equations. Understanding the required flow rate of the hydraulic system is necessary for HPU control.

In the future, we plan to add model for internal leakage to estimate more accurate flow rate. Experiments will be conducted to assess the feasibility of the proposed flow rate model.

ACKNOWLEDGEMENT

This work was supported by the National Research Foundation of Korea(NRF) grant funded by the Korea government(Ministry of Science and ICT)(No. RS-2022-00144468).

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