Transactions of the Korean Nuclear Society Autumn Meeting
Changwon, Korea, October 30-31, 2025

Development of a Compact Hydraulic Power Unit for Robotic Applications in Nuclear Fields

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***Keywords : HPU, Compact HPU, Hydraulic, Robot**

1. Introduction

Hydraulic robots offer high power density and robustness, making them suitable for demanding environments such as nuclear accident response and decommissioning. To enable their use in practice, however, mobile hydraulic systems are required. One of the main challenges in mobilizing hydraulics is the miniaturization of the Hydraulic Power Unit (HPU), which serves as the power source of the system. Conventional HPUs are large, heavy, and designed for stationary applications, which limits their integration into mobile platforms. Research efforts, including those at the Korea Atomic Energy Research Institute (KAERI), have focused on compact HPUs with energy-efficient control, modular structures, and reduced size.

A compact HPU requires a motor driver that is powerful, precise, and small. Such devices are often expensive and limit the feasibility of wider deployment. For hydraulic robots to be applied in real accident or work sites, both cost and reliability must be considered.

To address this limitation, we propose a compact HPU that replaces conventional high-precision motor drivers with a low-cost sensorless speed controller. A control system combining feedforward modeling and feedback regulation is also proposed to compensate for the limitations of such controllers. This paper introduces the design concept and control structure of the HPU, which aim to improve practicality in mobile hydraulic robotics.

2. Design and Control Method

2.1 Design of HPU

The proposed HPU consists of an oil tank, pump, manifold, motor, and motor driver. Among these, the motor and motor driver account for the largest share of the cost. To reduce this, a BLDC motor with a sensorless speed controller was adopted.

A speed controller alone cannot compensate for load changes and therefore cannot maintain constant speed for the same input. To address this limitation, a magnet was attached to the motor shaft and a Hall-effect sensor was used to measure rotational speed, configured as an RPM counter. To keep the HPU compact, an integrated frame was designed that combines the manifold, motor mount, and heat exchanger.

The CAD design of the HPU and the concept of the RPM counter are shown in Fig. 1.

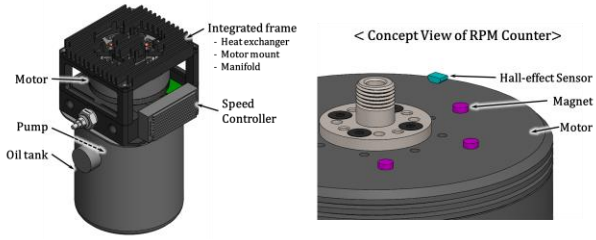

Fig. 1. Design of HPU and concept view of RPM counter

2.2 Control method

Speed control is important in HPUs, since motor speed determines pump flow and directly affects pressure stability. The speed controller does not accept speed input but instead operates with duty-cycle commands. Therefore, a feedforward controller was implemented based on a model of the relationship between duty input and motor speed. This model was constructed as a linearized model based on a look-up table, obtained from experiments measuring motor speed at multiple duty levels under constant system pressure.

During system operation, unexpected pressure fluctuations can occur, and the HPU must maintain pressure through speed control. Since the speed controller alone has difficulty providing a constant output under varying loads, a feedback controller was added. An RPM counter, consisting of an additional magnet and a Hall-effect sensor, was used to measure motor speed, and this feedback was applied to compensate for speed error. The final control structure combines feedforward control based on the LUT with proportional feedback using the measured speed error. Controller parameters were tuned experimentally.

The overall control structure is shown in Fig. 2 and Fig. 3.

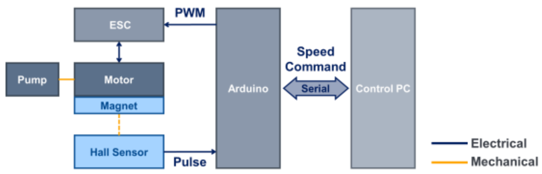

Fig. 2. System diagram

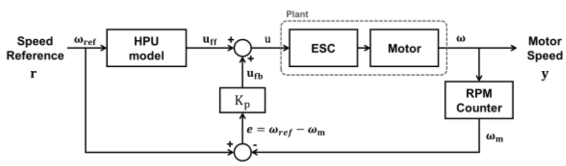

Fig. 3. Control block diagram

3. Conclusion

This paper proposed the design of a compact hydraulic power unit (HPU) for mobile hydraulic robots and outlined a control method suited to the use of a low-cost speed controller. The HPU was designed to maintain a compact form factor while improving economic feasibility, and a control system integrating feedforward and feedback elements was proposed to ensure speed and pressure stability.

Future work will involve experimental validation of the proposed system under detailed operating conditions to verify its performance and further refine the control approach.

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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