Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 9-10, 2024

A study on improving cooling efficiency of micro-Hydraulic Power Units (m-HPUs) for mobile manipulators with heavy-duty applications

Jinyi Lee [*], Jongwon Park[*], Ki Hong Im[*], Hyub Lee [+] and Gaeun Shin[*]

[*] *Korea Atomic Energy Research Institute, Daedeok-daero 989-111, Yuseong-gu, Daejeon, 04535, Republic of Korea*
[+] *Korea Institute of Industrial Technology, Republic of Korea*
[*] *Corresponding author: jylee87@kaeri.re.kr*

***Keywords :** Micro-hydraulic power units, Cooling efficiency, Heavy duty application, Mobile manipulator

1. Introduction

Mobile manipulators with hydraulic actuators are specialized for heavy-duty applications. They can be used in nuclear accident response, high-risk work on such as construction sites, and firefighting. The hydraulic power unit (HPU) is the core component of the hydraulic system which supply pressurized hydraulic fluid. In order to utilize hydraulic actuator in mobile systems, the HPU must be embedded in the robot. In contrast to industrial hydraulic systems that utilize external power and have no space limitations, mobile systems with embedded HPU (space limit) need to perform tasks in remote locations with only their own power source (power limit). Therefore, it is essential to develop a compact and efficient HPU that only have core components for supplying hydraulic pressure and cooling elements for actuating. This paper describes the development of a micro hydraulic power unit (m-HPU) for mobile manipulators for heavy-duty operations and strategies to improve cooling efficiency.

2. Embedded design of a micro-hydraulic power unit (m-HPU) for mobile manipulator

2.1 Design concept of a micro-hydraulic power unit (m-HPU)

In order to be utilized as a hydraulic power unit for mobile manipulators, it should be composed of only the core elements, in contrast to industrial HPUs that contain various components. In the case of a conventional HPU, the pump and prime mover are separated from each other and connected by mechanical parts. However, a micro HPU is compactly connected as a pump-motor module. Fig. 1 shows the hydraulic circuit diagram of the proposed micro-HPU. The proposed m-HPU is designed to supply pressurized hydraulic fluid to ARMstrong, a mobile dual-armed manipulator. The ARMstrong robot is driven by hydraulic cylinders and hydraulic motors and each axis has 8-DOF. The m-HPU consists of only the essential elements for hydraulic supply: a pump, filter, prime mover (EM motor), oil tank, and relief valve.

Instead of installing an additional heat exchanger for oil cooling, we developed an oil tank structure with a combined heat exchanger through the additive manufacturing (3d printing technology). This effectively reduced the size of the M-HPU.

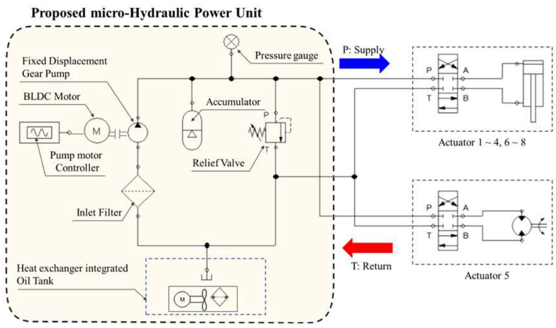

Fig. 1. Schematic diagram of micro-Hydraulic Power Unit

2.2 Heat exchanger integrated Oil Tank for cooling

When operating a hydraulic actuator, the oil temperature rises, which can cause the system to perform poorly. Therefore, it is very important to ensure that the oil temperature is properly maintained. Conventional hydraulic systems use oil coolers such as radiators for this purpose. The oil tank of the proposed m-HPU was designed using additive manufacturing to maximize the cooling efficiency without a separate oil cooler. Two types of oil tanks with integrated heat exchangers were proposed as shown in Fig. 2, and their oil cooling effect was verified through CFD analysis.

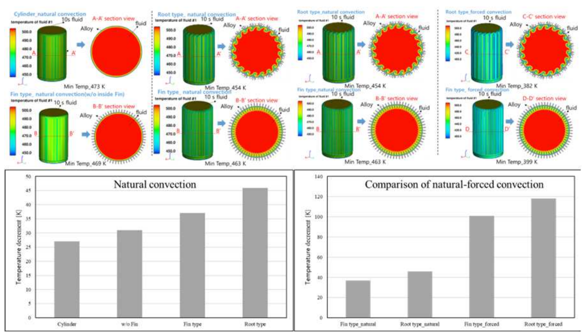

Fig. 2. CFD analysis results of the proposed oil tank

2.3 Control strategies for energy efficiency

Since mobile robotic systems operate with limited battery power, it is necessary to accurately determine the task load and perform variable output control accordingly. In addition, to reduce unnecessary energy loss and accurately control the required flow rate, a flow estimation model was established and a pump speed controller was developed accordingly.

3. Experiments

3.1 Experiment setup

Evaluation of the cooling performance of an oil tank with an integrated heat exchanger developed by additive manufacturing method was conducted. The developed m-HPU was mounted on a mobile dual-arm robot, Armstrong, as shown in Fig. 3. The specifications of the developed m-HPUs are shown in Table 1.

A total of three types of oil tanks (simple cylinder, fin type, and root type) were compared, and the oil cooling effect was compared through all bypass situation and manipulator full operation to compare the effect of the proposed control strategies.

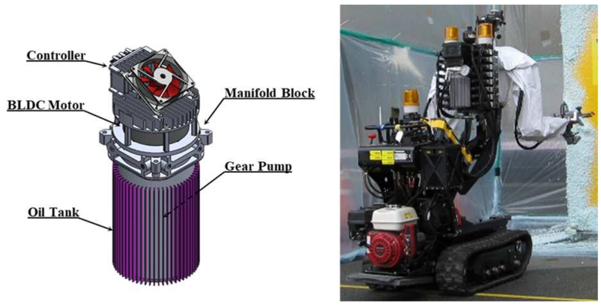

Fig. 3. Micro-hydraulic power unit and ARMstrong robot with m-HPU

Table I: Specification of a Micro HPU

Parameter	Values	Units
Max. Pressure	140	Bar
Oil tank Size	2	L
Power	1.64	kW
Weight	7	kg

3.2 Test results

The experimental results of the heat exchanger integrated oil tank manufactured through 3d printing custom design showed effective cooling performance compared to the existing commercial tank as shown in Fig. 4. In the case of the all bypass experiment, the temperature immediately after the experiment was reduced from 122℃ to 100℃ (straight fin) and 95℃ (root), and in the case of the robot-driven experiment, the temperature was reduced from 76℃ to 67℃ (straight fin) and 71℃ (root). It is concluded that the m-HPU is expected to show significant cooling performance by applying fin type or root type heat exchanger integrated oil tank.

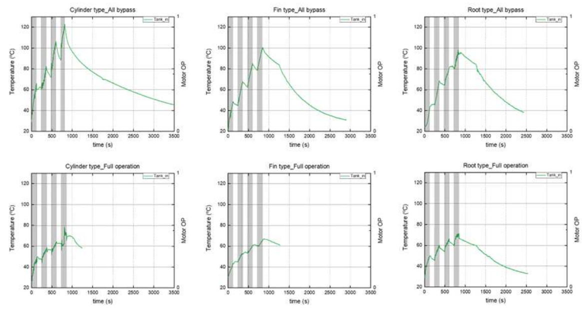

Fig. 4. Temperature test results by oil tank type and operation conditions of m-HPU

4. Conclusion

In this paper, an embedded design of a micro-hydraulic power unit for a mobile manipulator was discussed, as well as strategies to improve cooling efficiency. For a compact design, a heat exchanger integrated oil tank using additive manufacturing method was proposed and verified. The necessity of control strategies to reduce energy losses were also discussed. In future research, a predictive model-based controller to maximize energy efficiency will be applied and verified.

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).

REFERENCES

[1] Cho, B., Kim, S. W., Shin, S., Kim, M. S., Oh, J. H., & Park, H. W. (2021). Energy Efficient Control of Onboard Hydraulic Power Unit for Hydraulic Bipedal Robots. The Journal of Korea Robotics Society, 16(2), 86-93.

[2] Cho, B., Kim, M. S., Kim, S. W., Shin, S., Jeong, Y., Oh, J. H., & Park, H. W. (2021). Design of a compact embedded hydraulic power unit for bipedal robots. IEEE Robotics and Automation Letters, 6(2), 3631-3638.

[3] Lee, J., Park, J., Im, K. H., Shin, G. (2023). Design and implementation of a micro HPU for nuclear accident response robot. Transactions of the Korean Nuclear Society Autumn Meeting, 2023.

[4] Park, J., Lee, J., Im, K. H., (2022). Design of a micro hydraulic power unit for nuclear accident response robot. Transactions of the Korean Nuclear Society Spring Meeting, 2022.