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Design and Implementation of a Micro HPU for Nuclear Accident Response Robot

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1. Introduction

Recent research has focused on utilizing robots for initial responses to nuclear accidents. These hazardous environments typically involve confined spaces and demand heavy-duty operations. To meet these requirements, the utilization of a hydraulic drive system and the development of a compact hydraulic power unit, based on an electric motor, are paramount. This paper described the design and application of a micro hydraulic power unit for a nuclear accident response robot.

2. Requirements of micro-Power Units for a Nuclear accidents Response Robot

The ARMstrong robot, which is being developed by the Korea Atomic Energy Research Institute, is powered by a gasoline engine, providing the advantage of outdoor operation and extended runtime. However, this setup is ill-suited for indoor tasks due to emissions and noise issues, and adapting a suitable hydraulic control system for varying work environments proves challenging. This study aims to create an electric-based, miniaturized hydraulic power pack tailored to the ARMstrong robot, designed for high-risk tasks. To this end, we analyze the hydraulic system of the ARMstrong robot to establish the essential requirements for an electrically driven micro hydraulic power unit.

Fig. 1 Nuclear Accident Response robot- ARMstrong robot

- Oil tank Size

To achieve miniaturization, the capacity of the hydraulic oil tank should be selected for the robot drive. The capacity of the tank depends on the frequency of use and control method of the system, but it is recommended to be at least twice the internal volume of the cylinder when heat generation is not likely (below 60℃).

- Hydraulic fluid pressure

A standard hydraulic pressure of 140 bar has been chosen.

- Flow Rate

The flow rate of the system must be selected for pump selection. Based on the current hydraulic valve and hose conditions of the ARMstrong robot and the operating speed of the Target platform, a pump flow rate of 5 LPM or higher is considered adequate.

- Pump type

The hydraulic pump is responsible for providing energy to the hydraulic fluid. Depending on the structure, there are gear pumps, vane pumps, and piston pumps. Since the efficiency of the pump must be high to drive the robot efficiently, and it must be small and light to be mounted on a small power pack, a gear pump with a simple structure and high efficiency was selected.

- Motor power

The power of the motor driving the hydraulic pump was selected based on the torque and speed of the selected pump, and the requirements of the Micro HPU are shown in Table 1.

Table I: Requirements of a Micro HPU

Parameter	Values	Units
Max. Pressure	140	Bar
Max. Flow Rate	5	LPM
Oil tank Size	2~2.5	L
Pump motor Power	1.64	kW
Pump motor Speed	2000	Rpm
Pump motor Torque	7.83	Nm

3. Feasibility test of a Micro Power Unit

Before designing a feasible micro HPU, we checked the applicability of hydraulic power unit for nuclear accident response robots by modifying DC motor-type industrial small hydraulic power packs. The test was conducted under harsh conditions to compare the impact of the bypass leakage on temperature rise, and additional conditions such as heat sinks and robotic arm operation were added to minimize and stabilize the system, and the results are shown below.

① Variable pump drive control to minimize bypass leakage
② Compact heat exchanger for oil temperature management
③ Heat dissipation measures for motor and controller management
④ Highly efficient motor and integrated heat exchanger structure for miniaturization

4. Conceptual design of a micro HPU for maximize thermal efficiency

Conventional industrial hydraulic power units come with various accessories, posing challenges for miniaturization. High-speed pumps, in particular, generate significant heat, necessitating additional heat exchangers to keep hydraulic fluid temperatures below 70℃. This setup is disadvantageous for mobile robot applications. To address these thermal concerns, an integrated heat exchanger is needed within the oil tank structure, utilizing metal 3D printing technology to achieve miniaturization.

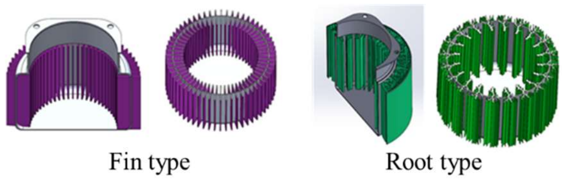

Fig. 2. Heat Exchanger integrated Oil tank

Two geometries are considered, as shown in Figure 2. The fin type, which is a design with many fin structures attached to the inside and outside of the cylinder walls. It is the simplest shape, but it is suitable for increasing the overall contact cross-sectional area to increase heat exchange efficiency. In traditional manufacturing methods, there are methods such as welding around the periphery of the cylinder for development fins, but there are problems such as deformation when the cylinder and fins are very thin, and if they are not completely bonded and have defects, the heat transfer effect may also be reduced. In particular, the outer fins can be bonded, but the inner fins are very difficult to manufacture due to mechanical interference. Additive manufacturing, on the other hand, can be used to make the connection between the cylinder wall and the fins without any problems, and it is also an advantage that it is possible to make fin shapes with very thin thicknesses that are difficult to make by welding or other methods.

The second type, Root type, is a design in which the fins are divided into several strands like the roots of a plant, and the design in 2D is elongated in the Z axis. Compared to the Fin type, the contact cross-sectional area can be much larger, resulting in a greater heat exchange effect. Such a shape is not possible to produce with conventional manufacturing processes. In particular, the root-shaped area is very difficult to realize with other manufacturing processes due to its thin thickness, and the overall height of such a thin complex shape is also a factor that increases the difficulty of manufacturing. On the other hand, in 3D printing, there is no difference in terms of manufacturing difficulty compared to the general pin shape. Therefore, it can be seen as a major design that can judge the utility value of additive manufacturing.

4. Conclusion

In this paper, the design of a micro power unit for a nuclear accidents response robot was discussed. We explained the need for a micro power unit for robots, derived requirements for detailed design, and described a conceptual idea for a heat exchanger-integrated oil tank structure based on feasibility test results. In the future, we will continue research on comparative simulation of heat exchange performance of heat exchanger-integrated oil tank shapes and system configuration, control, and performance verification.

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