Editorial

Trend and Outlook of Hydraulic Technology

SAKAMA Sayako*

1. Introduction

"Hydraulics" can deliver higher power with smaller equipment compared to electric, pneumatic or other drive systems. Therefore hydraulic technology finds extensive applications in various industries requiring high power. However from the viewpoint of energy saving, noise reduction and cleanliness, a shift from hydraulic systems to electric (or motor driven) systems has been promoted in all industries. This motorization is expected to be further accelerated in the future. Here arises the question: Is there a possibility that all hydraulic systems will be replaced by electric systems some day? This article compares the trends of technical development between hydraulic and electric equipment to discuss the future direction of hydraulics.

2. Comparison of Characteristics Between Hydraulic and Electric Actuators

Hydraulic actuators can deliver high output (power density) per unit mass. It is well known that even a small hydraulic actuator has relatively high output. But, do you know how much higher the power density of hydraulic actuators is compared to other types of actuators? This article first compares the physical properties between commercial hydraulic and electric actuators based on some performance indexes (i.e., torque, power density and power rate) and then generally describes the characteristics of these actuators.

Note that all research results included in this article are those of rotary actuators and that the data has been extracted from catalogues of commercial actuators. In the comparison, electric actuators are classified into three types: AC, brushless DC and DC motors. Hydraulic motors are classified into three types: bent axis type axial piston motors, swash plate type axial piston motors and radial piston motors.

The first comparison is rated torque relative to the mass of various actuators. Fig. 1 shows the relationship between the mass m [kg] and the rated torque T_r [Nm]. The data of the motors is plotted in the figure with the mass on the horizontal axis and rated torque on the vertical axis. For convenience sake, actuators of 10^3 kg or more are classified into super large size, 10 to 10^3 kg into large size, 10^{-1} to 10 kg into middle size, 10^{-3} to 10^{-1} kg into small size, and 10^{-3} kg or less into super small size for easier comparison. In the mass comparison of the actuators, hydraulic radial piston motors are located in the region of large to super large size and axial piston motors in middle to large size, while electric AC servo motors are found in the region of middle to super large size, and brushless DC and DC servo motors in super small to middle size. The figure indicates that electric actuators are distributed over a wider area than hydraulic actuators.

When looking at the relationship between the mass m [kg] and rated torque T_r [Nm] of actuators, hydraulic and electric motors are likely to be plotted along the line of $T_r \propto m^{4/3}$ respectively. The larger the mass is, the higher the rated torque. The figure also shows that the line along which electric actuators are plotted extends parallel to the line along which hydraulic actuators are plotted at higher levels by nearly one order of magnitude. In other words, hydraulic actuators can deliver a higher torque by nearly ten times that of electric actuators of the same mass.

The next comparison is on the relationship between the mass m [kg] and the power density P_d [W/kg] among actuators. The power density is the result of dividing the rated output of an actuator by the mass. An actuator with a higher power density can be evaluated as being able to delivery higher power even with its small size. Fig. 2 shows the relationship between the mass and power density of actuators.

When comparing the power density between electric and hydraulic motors in the middle to large size region, hydraulic motors show a higher power density by one to nearly two orders of magnitude. However, hydraulic motors of a higher mass are likely to have lower power density. According to the figure, there is no big difference in power density between hydraulic motors and AC motors in the super large size region. The fact that

* Associate Professor, Department of Mechanical Engineering, Faculty of Science and Engineering, Aoyama Gakuin Univ.

hydraulic motors have an almost same level of power density as that of AC motors, in spite of the substantial higher rated torque, is attributable to the difference in motor speed. The motor output is calculated by multiplying torque by speed. Super large size hydraulic motors can generate a ten times higher torque than AC motors of the same size region, but rotate at an about one tenth lower speed than AC motors. Which motor is more suitable depends on which factor has higher priority, torque or speed.

The final comparison is on the indexes representing motor responsivity. Power rate Q [W/s] is used to compare performance between hydraulic and electric motors. The power rate is the result of dividing the square of the motor rated torque by the moment of inertia. A motor with a higher power rate offers superior responsivity. Fig. 3 shows the relationship between motor weight and power rate. According to the figure, hydraulic motors show power rate levels quite different from those of electric motors, implying that the former is superior in responsivity to the latter.

3. Changes in Performance of Hydraulic and Electric Motors and Their Future Outlook

The previous section compared hydraulic motors to electric motors using three indexes: motor rated torque, power density and power rate. The comparison has revealed that hydraulic motors have higher performance than electric motors in all of these indexes. For mechanical systems that require small high-power motors, it is generally difficult to replace all hydraulic motors with electric motors under present circumstances. Then, can you say with assurance that all hydraulic equipment will never be replaced with electric

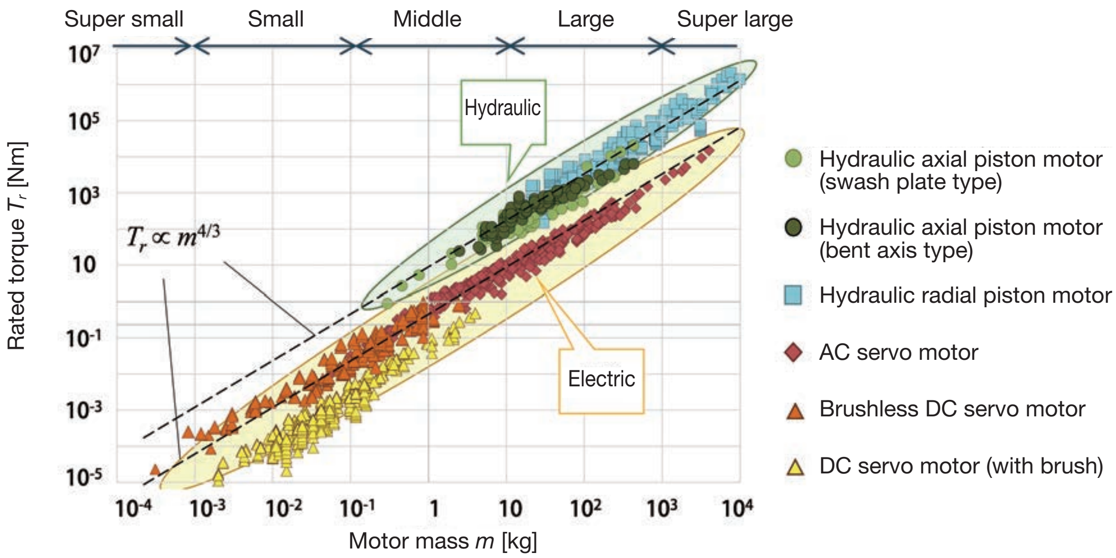


Fig. 1 Comparison of rated torque between hydraulic and electric actuators

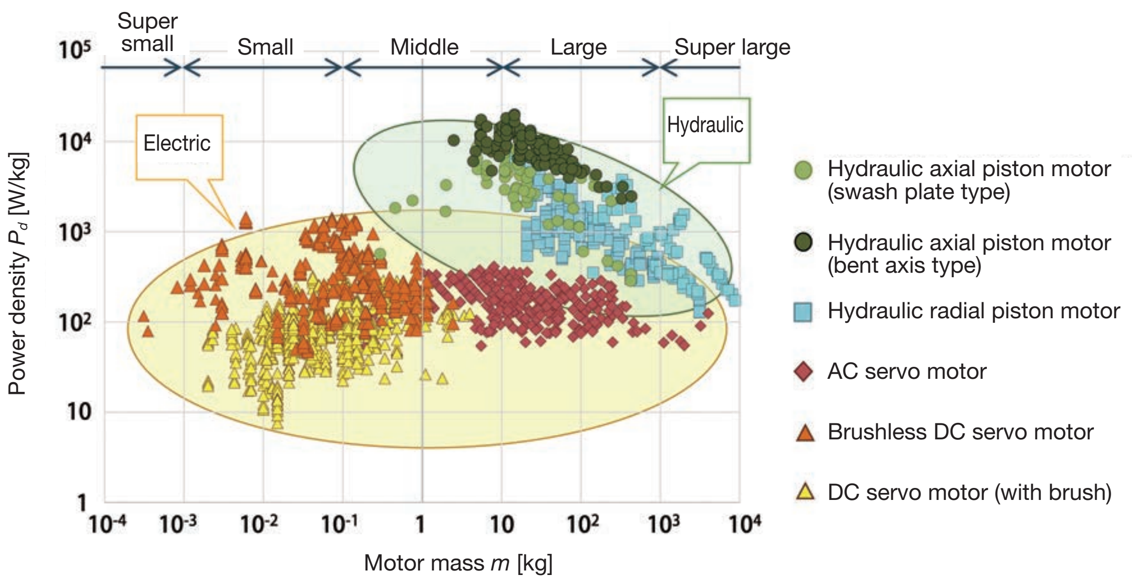


Fig. 2 Comparison of power density between hydraulic and electric actuators

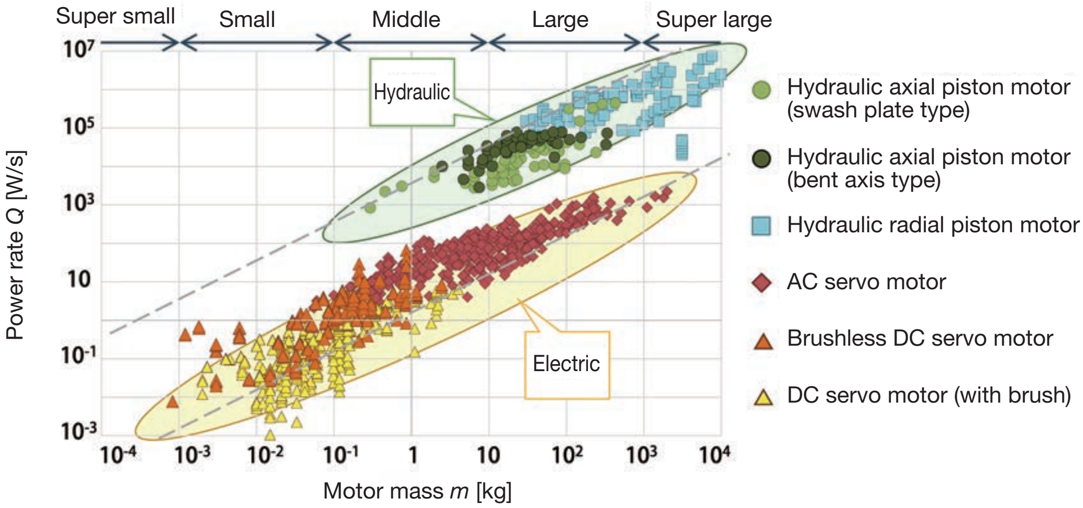


Fig. 3 Comparison of power rate between hydraulic and electric actuators

equipment? Now, in order to predict future changes in performance of hydraulic and electric equipment, the data used for comparison in the previous section should be added to old data to grasp the changes in power density of hydraulic and electric motors.

Fig. 4 shows changes in power density of hydraulic and electric motors. From the time before the 1970s that was the golden age of hydraulic servo to the present, hydraulic motors have shown overwhelmingly higher power density values than electric motors. When comparing the changes in power density, however, electric motors have experienced a steeper increase in power density. Hydraulic motors have also seen a certain increase in power density, but no notable change in recent years. On the other hand, electric motors have continuously increased in power density, resulting in a substantially higher level by one order of magnitude or more than the level of 30 to 40 years ago. If the performance of electric motors continues to grow at this rate, I cannot say that the power density of electric motors will never exceed that of hydraulic motors. Still, when you take a closer look at the data for electric motors, it is brushless DC motors that have recently experienced a rapid increase in power density. That is, super small to middle sized electric motors have seen a substantial increase in power density. With the focus placed on changes in power density of AC motors in the middle to super large size region, no substantial change has occurred since the 2000s. As shown in Fig. 2, current hydraulic motors are mainly used in the middle to super large size regions. It can be thus concluded that the possibility of replacing hydraulic motors with electric motors is low unless AC motors are rapidly improved in performance.

4. Outlook of Hydraulic Technology

Recently the power density of hydraulic motors has not changed a lot as stated in the previous section, but there used to be a trend of growing power density until around 2000. This trend was attributable to the development of higher-pressure hydraulic equipment. Fig. 5 shows changes in power density and rated pressure of hydraulic pumps for construction machinery. The rated pressure increased by 1.5 times in 25 years from the 1975 level. Accordingly, the power density increases two-fold or more. Hydraulic equipment was expected to have even higher pressure in the latter half of the 2000s [1], but in fact they don't. To achieve smaller hydraulic equipment with even higher power, it is necessary to raise the pressure of hydraulic systems. However, a hydraulic system with higher pressure would lead to a higher load on the equipment. It is thus indispensable to actively promote fundamental research for better measures against contamination, air and noise, as well as improved sealing and cooling technology. However, there are no sufficient studies related to hydraulic technology in Japan. Fig. 6 shows the result of a survey on the number of lectures by field presented by the Japan Fluid Power System Society [2] from 1998 to 2010 [3]. The figure shows a trend of a decreasing number of lectures on hydraulics related themes, implying a lower number of universities and research institutes involved in hydraulics related studies in Japan.

Recently, hydraulics has begun to receive attention again from disaster relief and robot engineering fields. Some research and development projects in these fields include studies for the purpose of improving the performance of hydraulic components [4]. To activate hydraulics related studies and develop hydraulic technology, it is also necessary to find some effective applications that can gain the spotlight among many engineers and researchers.

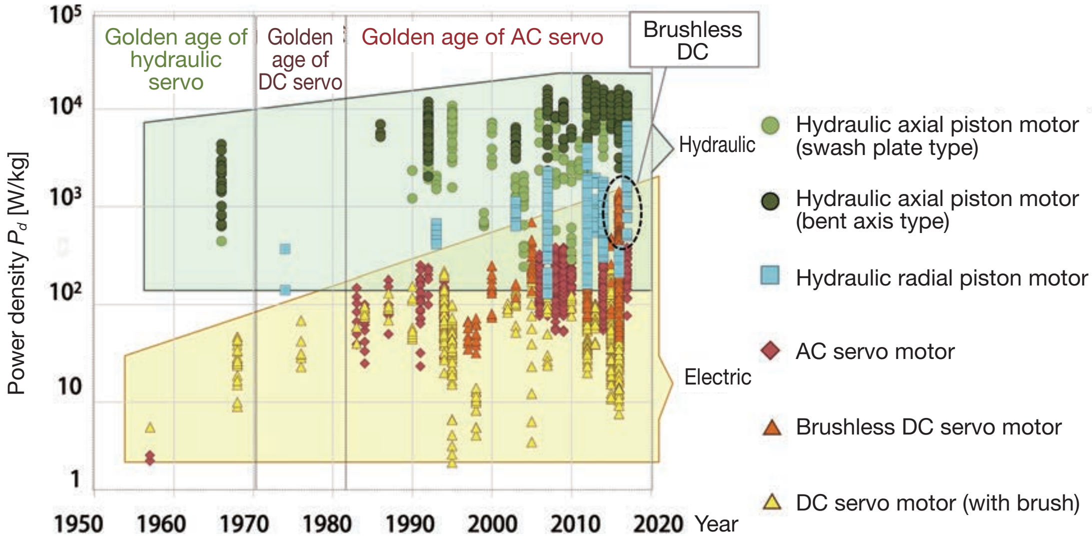


Fig. 4 Changes in power density of hydraulic and electric actuators

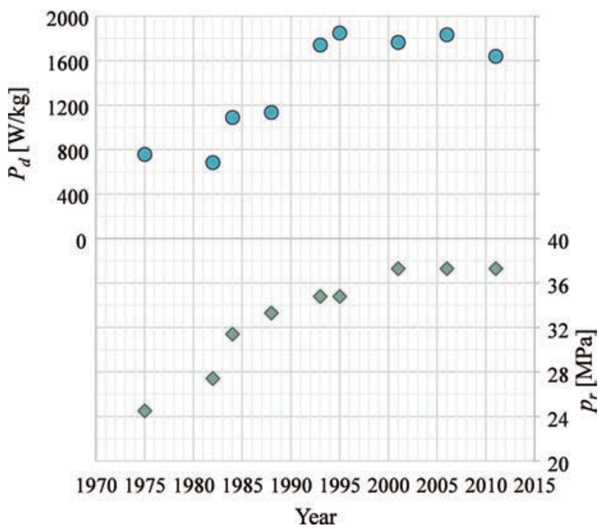
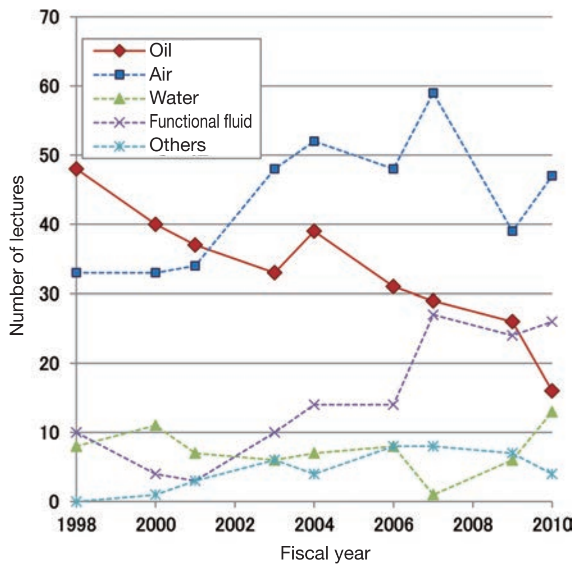


Fig. 5 Power density and rated pressure of hydraulic pumps for construction machinery



Note) Data for the fiscal years in which international conferences were held has been excluded.

Fig. 6 Changes in the number of lectures by field presented by the Japan Fluid Power System Society

5. In Closing

Since it is difficult for electric actuators to generate such a high power that can be delivered by hydraulic actuators, the best current choice to deliver high power under limited size and weight conditions is hydraulic actuators as stated above. To further develop hydraulic technology, universities and research institutes are required to discuss new ways of using hydraulic technology, making use of the strong points of hydraulics, and to propagate the technology. To this end, technical development satisfying the needs of society is required. Industry-university collaboration will become even more important.

References

1) Brendan Casey: Mobile Hydraulic Equipment: Increasing the Pressure, Machinery Lubrication Magazine. (January 2008).
2) http://www.jfps.jp/
3) Yutaka Tanaka, Sayako Sakama: Verification of the 15 Years of Fluid Power Study in Academic Society Theses, Hydraulics & Pneumatics, Vol. 51, No. 11, pp. 104-111 (2012).
4) Koichi Suzumori: Hydraulic Actuators for Tough Robots (Toward Robots with Both "Strength" and "Friendliness"), Hydraulics & Pneumatics, Vol. 55, No. 3, pp. 10-13 (2016).