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ENERGY SAVING OF OIL HYDRAULIC PUMP UNIT BY IDLING STOP METHOD USING AN ACCUMULATOR

Katsumasa Suzuki[1], Yoshitaka Niimura[1], Kazutoshi Akitani[1]
and Ken Sugimura[2]

ABSTRACT

In recent years, energy saving has advanced in various fields due to the shortage of energy resources such as oil and the need to protect the earth's environment. Energy saving is also very important in the hydraulic industry field.

If an accumulator is used for a hydraulic pump unit, intermittent operation of the electric motor for the pump drive, called "idling stop type operation," is attained by using the pressure holding function of the accumulator. Consequently, a reduction of useless power consumption can be realized. In this research, a hydraulic pump unit of the intermittent operation with an accumulator (called "ACC pump unit"), a hydraulic pump unit of an inverter control type ("INV pump unit"), and a hydraulic pump unit with a variable displacement pump ("VD pump unit") are tested.

The power consumption, pump output pressure, pump rotation speed, and energy efficiency in one cycle of each pump unit were measured when the same work was done. As a result, the energy efficiency was 40% for the ACC pump unit, 15% for the INV pump unit, and 11% for the VD pump unit. Therefore, the ACC Pump Unit was shown to have the most excellent energy-saving effect.

Keywords: Energy Saving, Oil Hydraulic Pump, Efficiency, Accumulator, Idling Stop

1. INTRODUCTION

In recent years, energy saving has advanced in various fields due to the shortage of energy resources such as oil and the need to protect the earth's environment. Energy saving is an important subject in the hydraulic field. As an example, if an accumulator is used for a hydraulic pump unit, intermittent operation of the electric motor for the pump drive, called "idling stop type operation," is attained by using the pressure holding function of the accumulator, and useless power consumption is reduced.

[1] Department of Mechanical systems Engineering, Tokyo City University (former name: Musashi Institute of Technology), Tamazutsumi, Setagaya, Tokyo 158-8557, Japan, Email:ksuzuki@sc.musashi-tech.ac.jp
[2] Nippon Accumulator CO., LTD.

In this research, a hydraulic pump unit of intermittent operation type with an accumulator (ACC pump unit) is compared with an inverter control type pump unit (INV pump unit) and a variable displacement type pump unit (VD pump unit). Clarifying the energy-saving effect of the intermittent operation hydraulic pump unit with an accumulator is the primary purpose of this research.

Fig. 1 Experimental equipment

2. EXPERIMENTAL DEVICE and EXPERIMENTAL METHOD

A photograph of the experimental device used in this research is shown in Fig. 1. A schematic illustration of the experiment device is shown in Fig. 2. In Fig. 2, ① shows the work portion of the equipment. It is assumed that a workpiece is gripped by a machine tool and cut with exchanging cutting tools. A pressure supply of more than 2.6 MPa is necessary. A hydraulic-pump unit (made by company A) is shown in ②. This unit has an accumulator and a pressure switch. The INV pump unit (made by company B) is shown in ③. The VD pump unit is shown in ④. The working fluid is supplied by ②, ③ or ④ to ①. This figure shows that ① and ② are connected and hence the working fluid is supplied by the ACC pump unit. The parameter values for each pump unit are shown in Table 1. The contents and required time for one cycle of work are shown in Table 2. This one cycle is common to ACC pump units, INV pump units and VD pump unit. The parameters listed and the time required assume that a workpiece is held with a machine tool, cut with exchanging cutting tools, and the control is executed by a micro sequencer.

Table 1 Parameter values

	ACC pump unit VD pump unit	INV pump unit
Displacement volume [cc/rev]	8.0 (Maximum)	5.7 (Fixed)
Maximum operating pressure [MPa]	4.0	4.0
Rated output of electrical motor [kW]	0.75	1.5

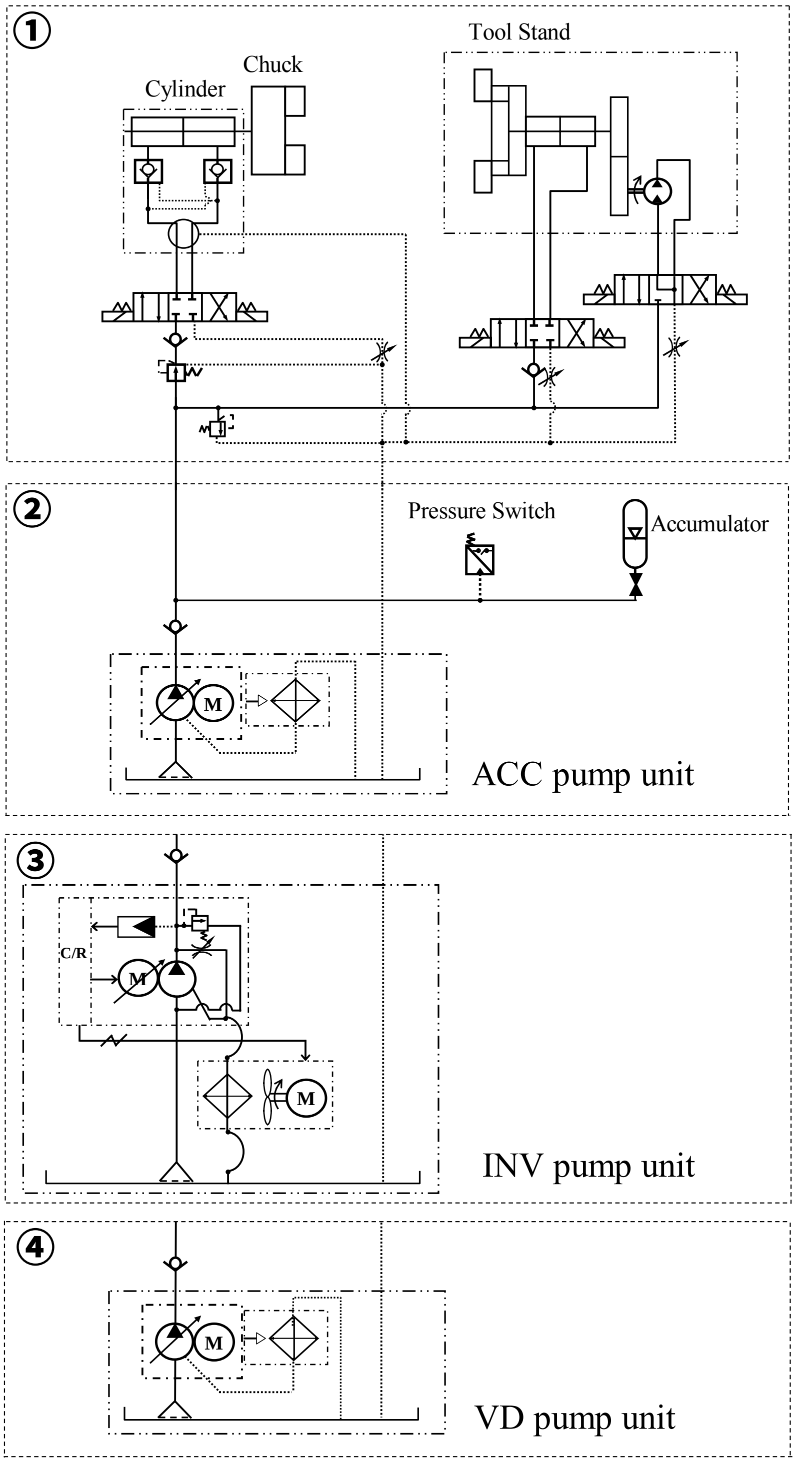

Fig. 2 Experimental circuit

Table 2 Details of one cycle of operation

No.	Contents	Operation time[s]
1	Waiting	5
2	Cylinder progress	1
3	Waiting	5
4	Cylinder regress	1
5	Unclamp of Tool Stand	0.85
6	Rotation of Tool Stand	3.4
7	Clamp of Tool Stand	1
8	Waiting	5
9	Three times repetition from 5 to 8	30.75
Total time of 1 cycle		53

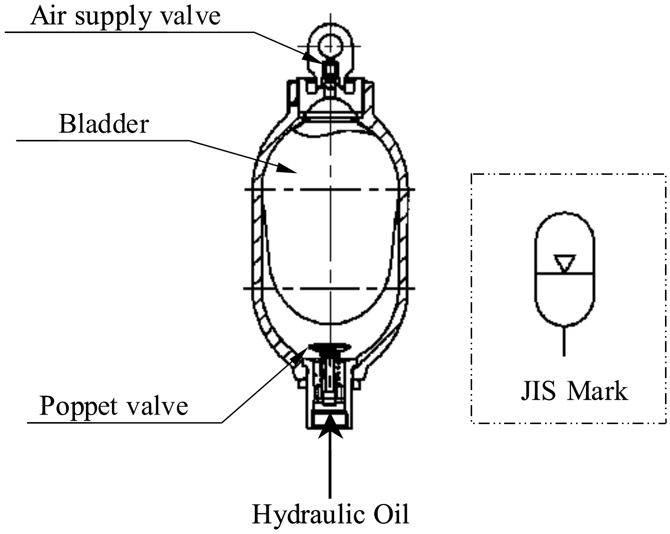

Fig. 3 Accumulator

2.1 ACC Pump Unit

As shown in Fig. 3, a bladder type accumulator with a capacity of 3 L is used in this experiment (Japan Accumulator, 2006). The bladder is filled with nitrogen. If the pump output pressure exceeds 3.0 MPa as the high-limit-setting pressure, the pump drive motor of the ACC pump unit is turned OFF by the pressure switch. If the pump output pressure is less than 2.6 MPa, the pump drive motor is turned ON. The working fluid is discharged or stored by the accumulator according to the pressure change. Although the pump is variable displacement type, it works almost the same as a fixed displacement type in the pressure range of 2.6 - 3.0 MPa, since the cutoff pressure is set at higher value than these.

2.2 INV Pump Unit

Inverter control is widely used for energy saving of the hydraulic pump unit. The load pressure signal detected by the pressure sensor is inputted into the inverter controller. The pressure is kept constant by changing the frequency of the electric power of the electric motor drive, changing the pump rotation speed and adjusting the flow rate. The target output pressure is 2.6 MPa, which is the minimum pressure required for operation.

2.3 VD Pump Unit

The experiment in this study is executed on the condition that the pressure switch of the ACC pump unit is always set to the ON state. In addition, the stop valve at the accumulator entrance is shut and the accumulator does not work in the experiment of this hydraulic pump unit.

3. EXPERIMENTAL RESULTS

3.1 One Cycle of ACC Pump Unit

The measured results of the power consumption, pump rotation speed, and pump output pressure in one cycle of the ACC pump unit are shown in Fig. 4. The pump is driven when the pump output pressure is less than 2.6 MPa. The pump is turned OFF when the pressure exceeds 3.0 MPa. Working fluid is supplied from the accumulator in the interim. The output pressure sometimes shows a spike. This is produced when the oil flow changes instantaneously with the switch of an electromagnetic valve. Electric power is consumed only at the time of pump rotation.

3.2 One Cycle of INV Pump Unit

The measured results of the power consumption, pump rotation speed, and pump output pressure in one cycle of the INV pump unit are shown in Fig. 5. The pump output pressure is constant at the target pressure of 2.6 MPa. Namely, if the pump output pressure is less than 2.6 MPa, the pump rotation speed increases and the flow rate increases. The pump output pressure is held at the target pressure 2.6 MPa by lowering the pump rotation speed and decreasing the flow rate if it exceeds 2.6 MPa. However, the rotation speed does not decrease to less than 400 rpm. The power consumption changes almost proportionally to the pump rotation speed.

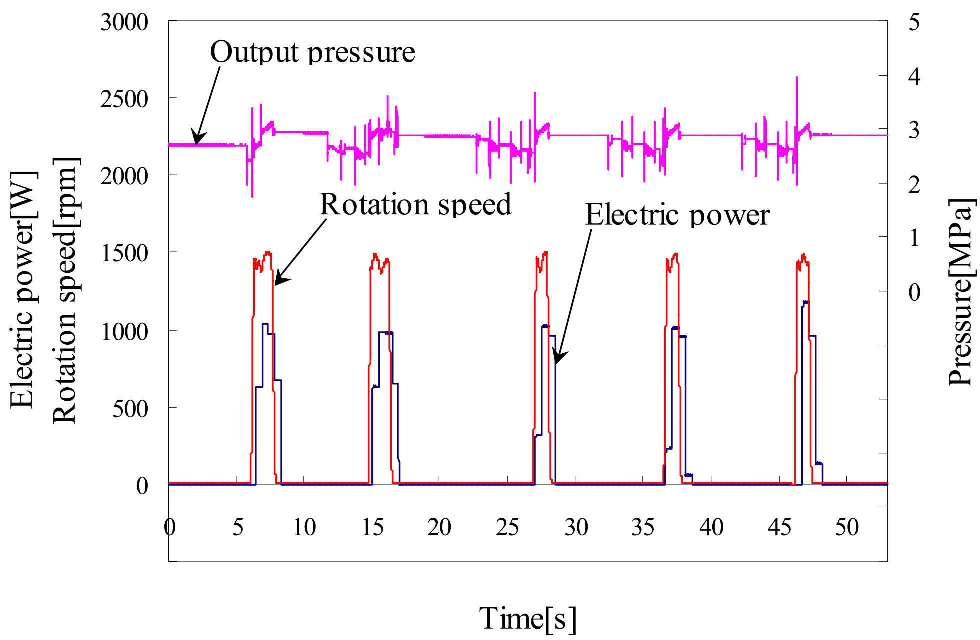

Fig. 4 Electric power, rotation speed and output pressure in one cycle of ACC pump unit

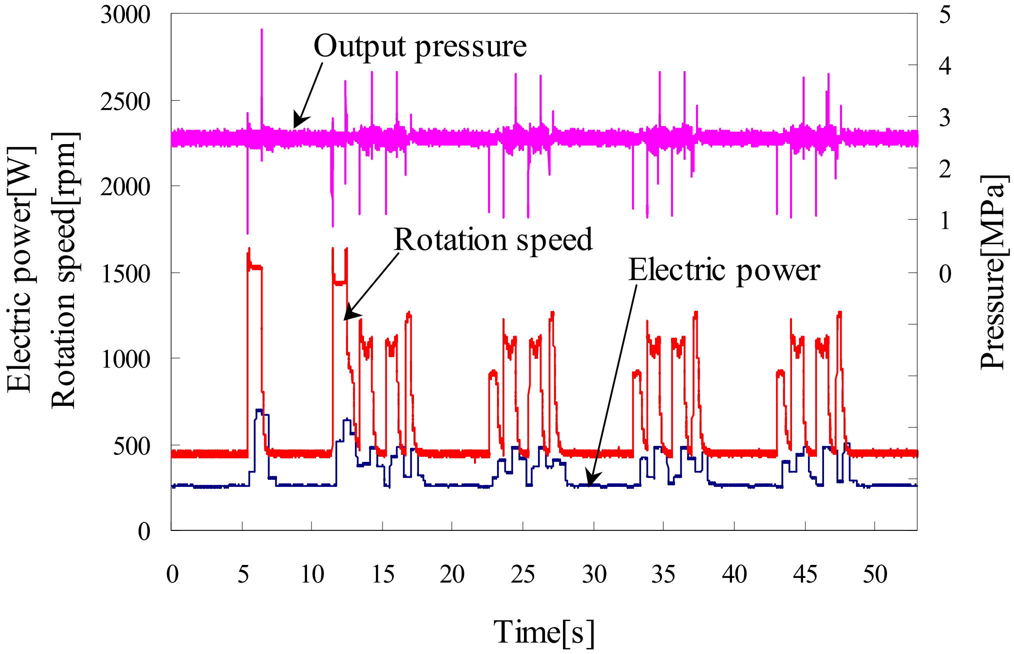

Fig. 5 Electric power, rotation speed and output pressure in one cycle of INV pump unit

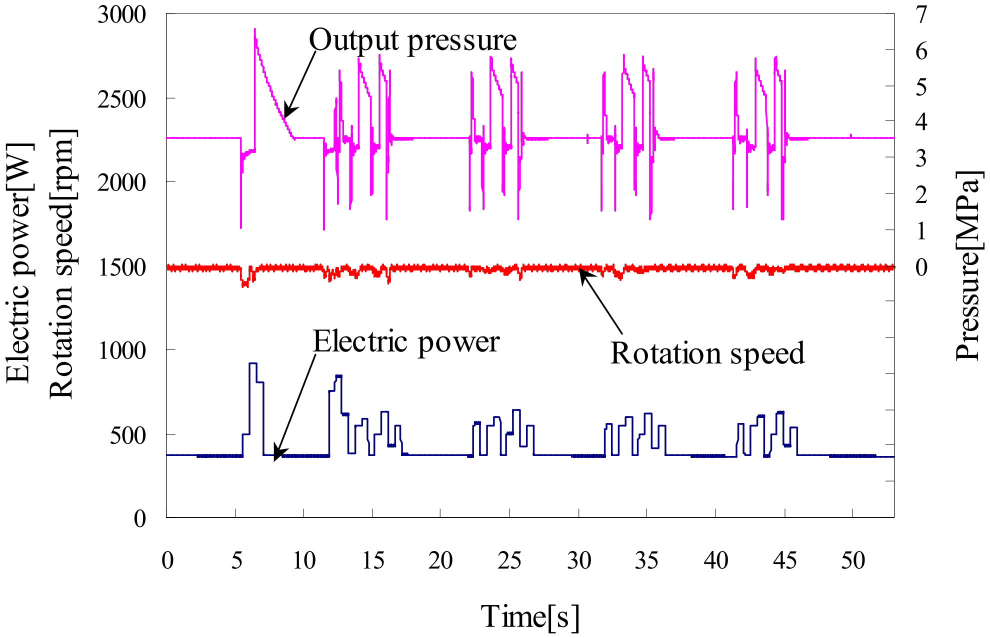

Fig. 6 Electric power, rotation speed and output pressure in one cycle of VD pump unit

3.3 One Cycle of VD Pump Unit

This experiment was conducted by using the ACC pump unit keeping the pressure switch set at the ON state. The measured result is shown in Fig. 6. Since the pressure switch is not turned off in this case, the pressure rises to more than 3 MPa. Because the variable displacement pump is used, the amount of pump discharge decreases when the output pressure becomes more than the set value. Thus, pressure regulation is carried out. The pump full-cutoff pressure is set at 3.8 MPa. The pump rotation speed is approximately 1480 rpm. The power consumption is similar to that of the INV pump unit in Fig. 5. Although this experiment differs in the method of energy saving, both pump units use energy slightly exceeding the necessary work. When the same work is done, the change of power consumption becomes similar in shape.

3.4 Consumed Electricity and Energy Efficiency of Each Hydraulic Pump Unit

The consumed electricity in one cycle of each hydraulic pump unit is shown in Fig. 7. In the idling stop operation of the ACC pump unit, a reduction of approximately 63% of the power consumption is made in comparison with that of the INV pump unit. Next, the energy efficiency in one cycle of each hydraulic pump unit is computed. First, the consumption power of the load side in one cycle is computed by equation (1).

$$E_{1cycle} = P_L \times V_{1cycle} \quad (1)$$

Here, $E_{1\mathrm{cycle}}$ [J] is the consumption energy of the load side in one cycle, P_L [Pa] is the necessary load pressure, and $V_{1\mathrm{cycle}}$ [m^3] is the output flow volume in one cycle. In this experiment, P_L= 2.6x10^6 Pa, $V_{1\mathrm{cycle}}$=1.27x$10^{-3}$$m^3$, and so $E_{1\mathrm{cycle}}$=3.31 kJ.

From the consumed electricity in one cycle of each hydraulic pump unit and the load side consumption energy $E_{1\mathrm{cycle}}$, the energy efficiency of each hydraulic pump unit is computed and shown in Fig. 8. The energy efficiency is 11% in the VD pump unit, 15% in the INV pump unit and 40% in the ACC pump unit.

3.5 Measurement of Static Characteristics of the Hydraulic Pump

3.5.1 Static characteristics of ACC pump unit

To measure the static characteristics of the pump of the ACC pump unit, a flow meter and a flow metering valve are connected to the ACC pump unit, as shown in Fig. 9. The pressure switch is kept ON. This result is also a measurement of the static characteristics of the VD pump unit. The flow metering valve is adjusted, output pressure is changed, and then flow rate Q_0 [m^3/s], electric motor power consumption for pump drive L_N [W] and pump output pressure P_0 [Pa] are measured. Output power L_0 [W] and pump efficiency η [%] are computed from equations (2) and (3) using these values.

$$L_o = Q_o \times P_o \quad (2)$$

$$\eta = \frac{L_0}{L_N} \times 100 \quad (3)$$

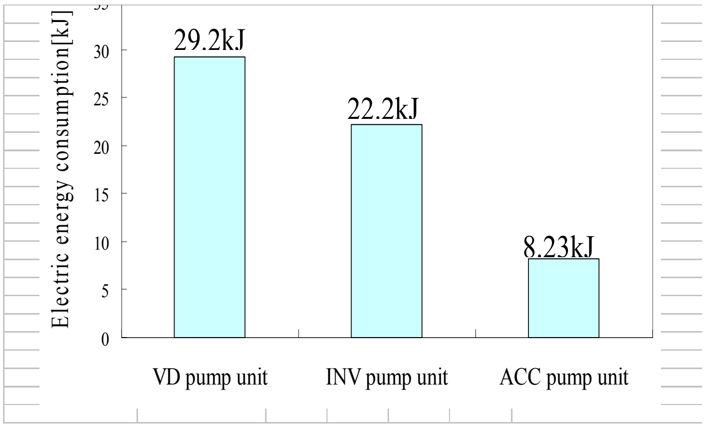

Fig. 7 Electric energy consumption of ACC pump unit, INV pump unit and VD pump unit during one cycle

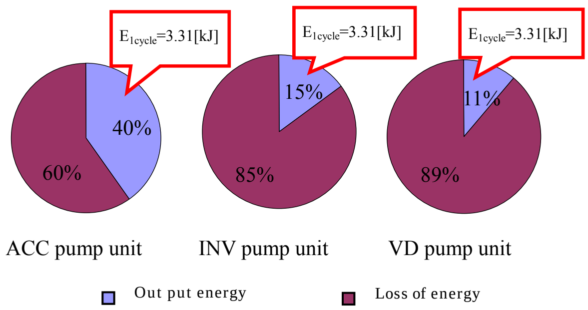

Fig. 8 Energy efficiency during one cycle of ACC pump unit, INV pump unit and VD pump unit

The measured results are shown in Fig. 10. The pump rotation speed is almost constant. The measured flow rate begins to decrease suddenly at approximately 3 MPa and becomes zero at 3.8 MPa. Because the ACC pump unit uses the variable displacement vane pump, the displacement decreases, and the pump discharge changes when the discharge pressure becomes high. However, the pump is turned OFF by the pressure switch if the pressure is more than 3 MPa in the one-cycle test. It is turned ON if the pressure is less than 2.6 MPa. Therefore, it can be regarded as a fixed displacement pump in this operating condition.

The pressure at which the flow rate becomes 0 is called the full-cutoff pressure. The pressure where the flow rate begins to decrease is called the cutoff pressure. The power consumption and output power increase when the output pressure increases until the cutoff pressure, but they decrease with the reduction in flow rate after the cutoff pressure is exceeded. Since the drive range of the ACC pump unit is set to 2.6 – 3 MPa, the pump efficiency is approximately 53% in this range.

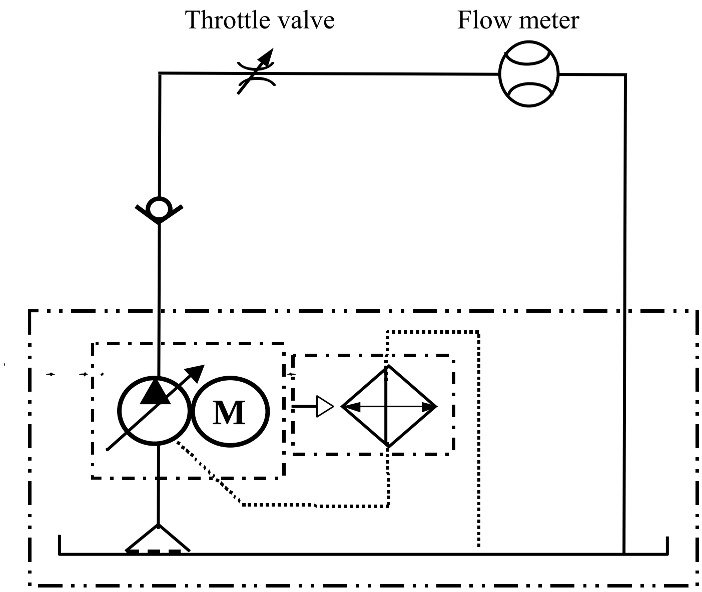

Fig. 9 Measurement circuit for ACC pump unit

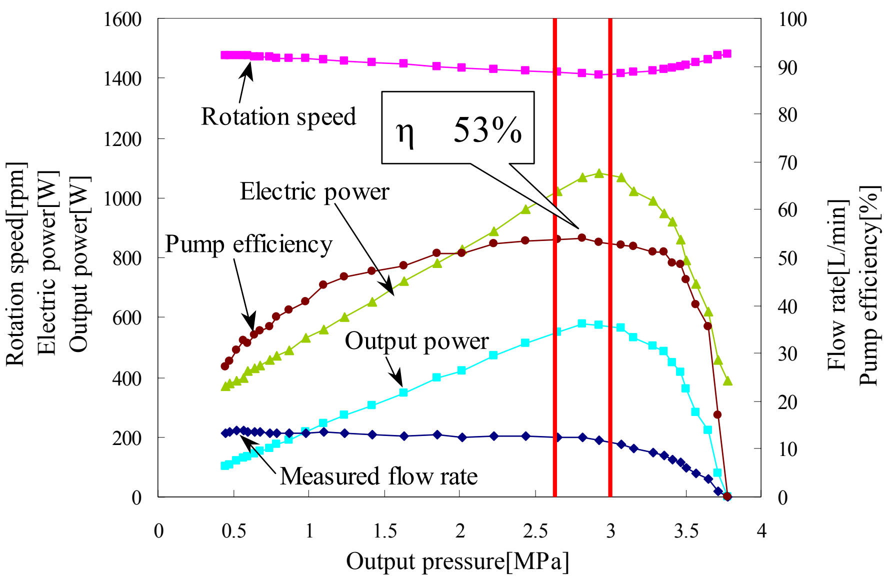

Fig. 10 Static characteristics of ACC pump unit measured by keeping the pressure switch ON

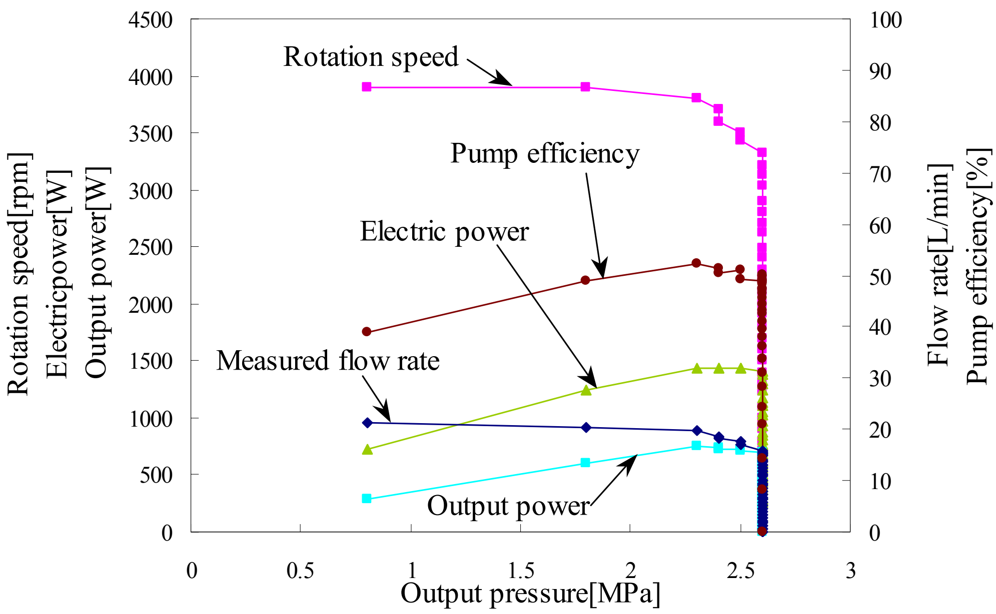

Fig. 11 Static characteristics of INV pump unit ①

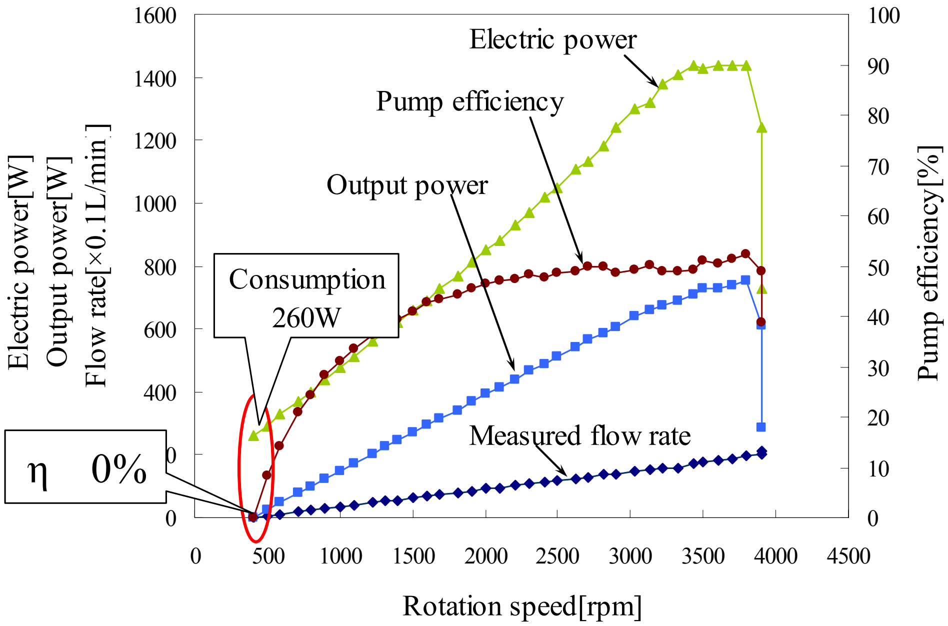

Fig. 12 Static characteristics of INV pump unit ②

3.5.2 Static characteristics of INV pump unit

To measure the static characteristics of the pump of the INV pump unit, the flow metering valve and the flow meter were attached to the INV pump unit and the characteristics were measured in the same way as the ACC pump unit shown in Fig. 9. The measured results of this pump's characteristics are shown in Fig. 11. In this figure, all the curves are perpendicular at 2.6 MPa. This is because the target pressure of the inverter controller is 2.6 MPa. The flow rate and pump rotation speed show similar changes at less than 2.6 MPa. They decrease gently until the target pressure. The electric power consumption, output power, and pump efficiency show similar changes. They increase gently when the output pressure increases. Since the data are concentrated at 2.6 MPa, the details are not understood. Therefore, in Fig. 12, the horizontal axis shows the pump rotation speed and the vertical axis shows the flow rate, power consumption, output power, and pump efficiency.

At the experiment of one cycle, described in Section 3.2, the INV pump unit is driven at a low speed of approximately 400 rpm in 49 seconds, which is 79% of the one-cycle time. At this time, the work of the load side is on standby, as shown in Table 2. The actuator is in the stopping state. This rotation state of 400 rpm is a big problem in the INV pump unit. The electric power of approximately 260 W is always consumed and the efficiency is 0%. This is an example of useless power consumption. In other words, it is shown that electric power is wasted for 79% of the period during one cycle.

4. Conclusion

The relation among the power consumption, pump output pressure and pump rotation speed in one cycle of the ACC pump unit, INV pump unit, and VD pump unit was clarified. From comparisons of the consumed electricity per one cycle of the INV pump unit, it was shown that the ACC pump reduced power consumption by approximately 63%. The energy efficiencies per one cycle were 11% in the VD pump unit, 15% in the INV pump unit and 40% in the ACC pump unit. In addition, the static characteristics of each hydraulic pump unit were measured.

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