◉ 研究論文

A Study on Automation of Hydraulic Motor Performance Test

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유압모터 성능 시험의 자동화에 관한 연구

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Key words : Hydraulic motor(유압 모터), Automatic performance test(자동 성능 시험), Isoefficiency curves(등 효율 곡선).

요 약

본 연구에서는 유압 모터의 기본 성능을 시험하고, 시험 결과를 성능 곡선으로 제시하는 전 과정을 자동적으로 수행하는 유압 모터 성능 시험 시스템을 개발하였다. 이 시스템에서 사용하는 소프트웨어는 컴퓨터와 시험자 사이에서 대화식으로 작동하기 때문에 컴퓨터 및 유압 시스템에 대한 지식이 부족한 초보자라 하드라도 쉽게 사용할 수 있게 되어 있다. 실제 시험 과정에서는 한정된 수의 시험 포인트에서의 유압 모터 효율 값들만을 취하고, 성능 곡선 특히 등효율 곡선 작성에 필요한 부가적인 효율 값들로는 이웃하는 각 테스트 포인트 사이에서 내삽에 의하여 구한 효율 값을 사용하였다. 성능 곡선을 부드러운 곡선으로 나타내는 데는 B 스플라인 함수를 사용하였다.

1. Introduction

It is generally considered that a hydraulic motor undergoes a broader spectrum of operation than any other component in a hydraulic system. Starting under load, acceleration of various types of loads(inertia, viscous, fluctuating, constant) up to speed, operating at various load and speed requirements, decelerating or braking the load, reversal of rotation with various types of loads ; all of these are characteristic and in many cases the advantages of the hydraulic motor in application. With this diversity of requirements in applications, the same diversity is required in hydraulic motor performance test procedure and also complicated test

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equipments and long test time is needed.[1] So, for the purpose of man-hour economizing, the automation of performance test for hydraulic motor(including hydraulic pump) has been studied by some researchers.[2-4] However, there is still much left to be studied hereafter to make such an automatic test system as satisfies the most part of user's requirements.

In this study we focus on "basic performance test" which is the most extensive test from a data standpoint and certainly the most important since the results are published as characteristics curves. These curves usally take the form of the values of volumetric efficiency, torque efficiency and overall efficienev plotted versus pressure differential : at various constant shaft speed. And the results of basic performance test may also be plotted as isoefficiency curves on a plane with the indications of all the related variables such as moter speed, flowrate, torque and pressure differential.

In this study, a new type hydraulic motor performance test system which automatically accomplishes the procedure of basic performance test and represents the data obtained in the test as performance curves is developed. The software of the test system is made as interactive style between a computer and a user, so even to novices it is very easy to use.

It is a marked feature of the software of the new test system that the system can generate desirable isoefficiency curves with not enough numbers of the data got at some confined test points. Additional data necessary for generating isoefficiency curves are generated between every increments of data points by interpolation and Basis spline function is used to get more smooth representative curves with comparatively small data numbers.[5]

2. Basic Equations

Physical parameters related to the performance of a hydraulic motor are shown in Fig.1. The symbol P_1, Q_1 indicate pressure and flowrate at entrance side of the hydrulic motor. P_2, Q_2 are pressure and flowrate at outlet side of the hydraulic motor. Q_l shows case drain flowrate from the hydraulic motor. T and N show torque and revolution speed measured on the motor shaft.

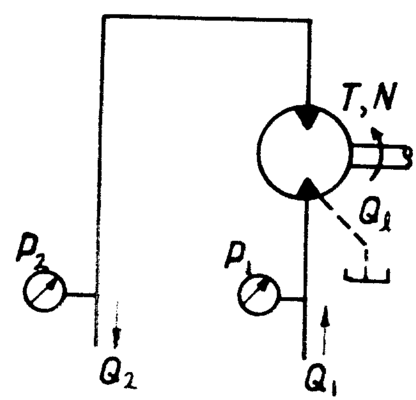

Fig. 1 Physical parameters related to the basic performance of a hydraulic motor

Volumetric efficiency(η_v), mechanical efficiency(η_m) and overall efficiency(η_o) are used as a measure estimating basic performance of a hydraulic motor and defined as follows :

2.1 Volumetric Efficiency(η_v)

η_v is defined as equation (1). Q_{th} in equation (1) is denoted as multiplication between displacement of a hydraulic motor(q) and motor speed(N).

$$\eta_v = \frac{\text{effective flowrate}(Q_{th})}{\text{motor inlet flowrate}(Q_1)} \times 100[\%] \qquad (1)$$

Q_1 in equation(1) can be expressed as $Q_{th} + Q_s$, where Q_s means the sum of case drain flowrate, internal leakage and external leakage. In this case, internal leakage means flowrate of oil from inlet to outlet, which does not contribute to rotation of the motor. Also, external leakage means any leakage from the motor other than case drain and internal leakage. So, eq.(1) may be rewritten as following equation.

$$\eta_v = \frac{q \times N}{Q_1 \times 1000} \times 100[\%] \quad (2)$$

The variables in equation(2) have following units ; $Q_1[l/\text{min}]$, q[cc/rev], N[rpm].

2.2 Mechanical Efficiency(η_m)

Mechanical(or torque) efficiency is defined as

$$\eta_m = \frac{\text{measured torque}(T)}{\text{theoretical toque}(T_{th})} \times 100[\%] \quad (3)$$

Theoretical toque can be computed from following equation (4).

$$T_{th} = \frac{10 \times \Delta P \times Q_{th}}{2\pi N} = \frac{\Delta P \times q}{200\pi} \times 100[\%] \quad (4)$$

Substituting eq.(4) into eq.(3), η_m can be rewritten as following equation.

$$\eta_m = \frac{200\pi \times T}{\Delta P \times q} \times 100[\%] \quad (5)$$

where units of the variables are denoted as ; T and T_{th}[kgf · m], $\Delta P = (P_1 - P_2)$[kgf/cm^2], Q_{th} [l/min].

2.3 Overall Efficiency(η_o)

Overall efficiency is defined as following equation.

$$\eta_o = \frac{\text{mechanical power output}}{\text{hydraulic power input}} \times 100[\%] \quad (6)$$

Equation (6) have the same physical meaning with following equation (7) denoted as multiplication η_v by η_m

$$\eta_o = \eta_v \times \eta_m / 100[\%] \quad (7)$$

3. Composition of Test Setup

Fig.2 shows composition of the test system for automation of hydraulic motor performance test. This test system is mainly composed of oil hydraulic power generation part(A), load generation part(B), motor speed control part(C), sensors part(①, ②, ③, ④, ⑤, ⑥, ⑦), signal transformation part(E), data processing part (F) and data display part(G).

3.1 Oil Hydraulic Power Generation Part

Oil hydraulic power generation part is composed of ① hydraulic pump(bent axis type piston pump, max. press. : 350 bar), ② relief valve, ③ line filter(element pore size : 10μm), ④ return filter(element pore size : 5μm) and ⑤ oil cooler. The relief valve in this test system is used only for safety purpose, because actual circuit pressure is determined by the operation of proportional pressure control valve at the load side.

3.2 Load Generation Part

A hydraulic pump/motor is used for simulating load on the shaft of a test hydraulic motor. Magnitude of load is held to target value by closed loop control of a proportional pressure control value at outlet side of the load simulating pump/motor.

3.3 Motor Speed Control Part

At the inlet side of the test motor, a proportional flow control valve is used to control the revolution speed of the test motor. Motor speed can be set to a target value by closed loop control of the proportional flow control valve.

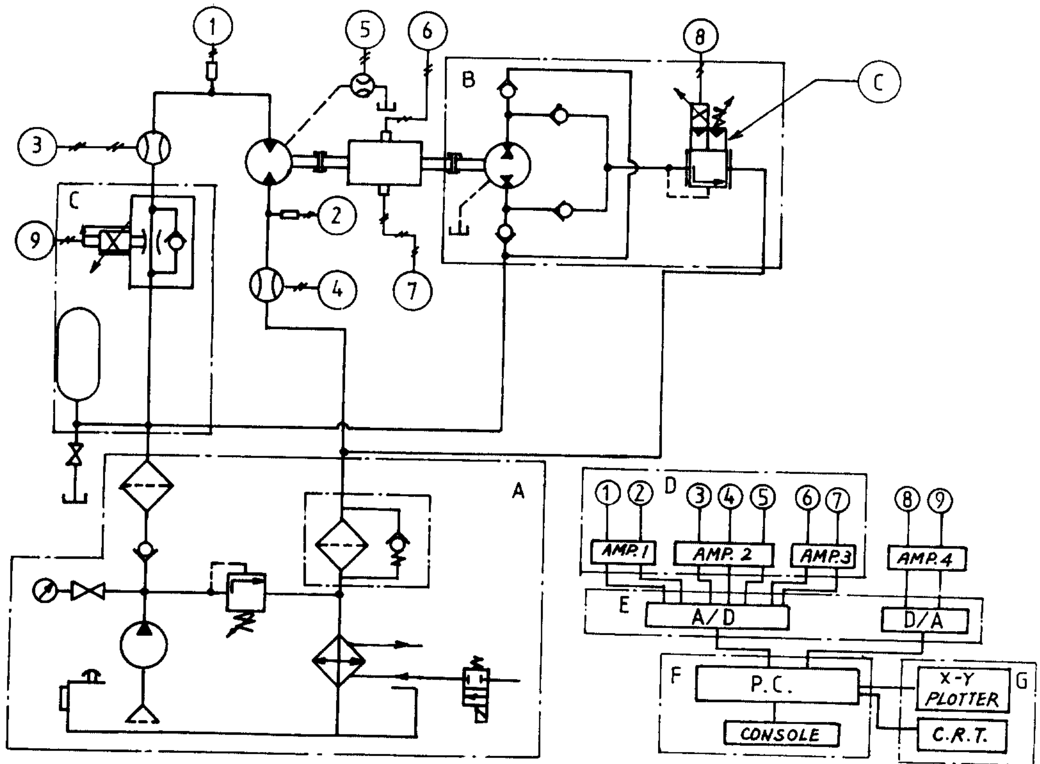

Fig. 2 Composition of the test system

3.4 Sensors Part

In Fig.2, pressure transducers ① and ② are used for measuring the pressure at inlet and outlet side of the test motor. Flow meters ③, ④ and ⑤ are used for measuring the flowrate at inlet side, outlet side of the test motor and case drain flowrate respectively. ⑥ and ⑦ are torque meter and revolution speed sensor of the test motor.

3.5 Signal Transformation Part

This part is composed of various signal amplifiers and A/D, D/A converters. The signals from various sensors are amplified to a few Volts D.C. signals and transported to the personal computer through A/D converter. Also, the signals for driving proportional valves are transported from the personal computer to valve driving amplifiers through D/A converter.

3.6 Data Processing and Data Display Part

16 bit personal computer(IBM PC AT compatible) is used as computer hardware. Processed results(data) are saved at data files. The saved data can be displayed as data itself or represented as performance curves on CRT or X Y plotter.

4. Structure of the Software

Compiled BASIC language is adopted for the software. This software is made as interactive style between a computer and a user, so even to novices it is very easy to use. This software is mainly composed of data acquisition part, data

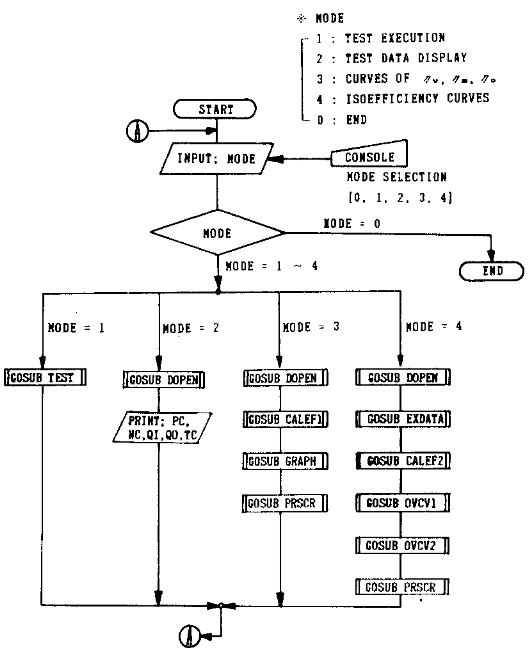

Fig. 3 Flow chart summarizing the software

processing part and graphic display part. Fig.3 shows the flow chart summarizing the software.

4.1 Data Acquisition Part

If we select Mode 1 of the main menu shown in Fig.3, we can start the test proceduce. The test proceeds according to following order.

(a) According to prompt on CRT, user must feed some informations such as the hydraulic motor specifications, speed(rpm) and pressure differential.

(b) At the first step of the test, the pressure differential and revolution speed is respectively set to minimum level(first step of several equally spaced level) by closed loop control of proportional control valves through D/A converter.

(c) Through each A/D channels 5 times repeated data acquisition at a fixed test point are done with constant time interval.

(d) Arithmetic mean value of 5 times data is allocated to array specified for each physical variables.

(e) Only increasing revolution speed one step (increment) by one step without changing the pressure differential as step(b), repeat the test step(c) and (d).

(f) When all the test step over full range of revolution speed under the same pressure differential value is terminated, increase the pressure differential to one step higher value and repeat the test with changing the revolution speed as the same manner at the test step (e).

(g) When all the test procedure is terminated, save data by inserting file name for test data to be saved.

After that, the flow of the program returns to mode selection, that is, the starting point of the program.

4.2 Data Display Part

By selecting mode 2 of the main menu, user can identify the saved data on CRT or printer.

4.3 Computation of Efficiencies and Graphic Representation Part

This part is performed by selecting mode 3 of the main menu. After opening the data file and taking necessary data, computes efficiencies η_v, η_m and η_o and then allocates each computed value to specified array. In the subroutine "GRAPH", curves representing efficiency change versus pressure differential and shaft revolution speed are drawn on CRT. In the subroutine "PRTSCR", the performance curves are plotted on X - Y plotter or printer. In the curve fitting of the data points of efficiency versus pressure differential, smooth curves can be achieved with the aid of Basis spline function.

4.4 Isoefficiency Curves of Overall Efficiency

We can get isoefficiency curves for a hydraulic motor by selecting mode 4 of the main menu.

Very many numbers of data got at very many test points are necessary to get desirable isoefficiency curves.

But very long time would be required for the test to obtain necessary all data from actual test procedure. So, in this study, data are taken at some confined test points and necessary additional data between every neighboring test points are numerically generated by 2nd order interpolation.

Overall efficiencies computed at every data points including numerically enriched points are used as basic materials for the graphic representation of isoefficiency curves.

Graphic represntation step of isoefficiency curves are described as follows ;

(a) Searchs the largest value of overall efficiency data by the program execution.

(b) Starts to draw isoefficiency curve for some predetermined efficiency value at the vicinity of the largest efficiency value.

(c) The second curve with overall efficiency value lower than that of the first curve by some predetermined interval is drawn.

(d) The third and successive curves are drawn by lowering efficiency value step by step by some predetermined intervals.

For example, curves might be drawn from the first curve to the fourth curve with 1% intervals of overall efficiency value, 2% interval between the fourth and the fifth, 3% interval between the sixth and the seventh. These intervals can be determined and changed arbitrarily by user.

5. Test Procedure and Test Results

5.1 Test Procedure

Basic performance test is performed by the following test procedure.

(a) A hydraulic motor to be tested is installed in the test stand.

(b) The hydraulic motor is operated without load until temperature of the hydraulic oil in the system is settled to rated value. The oil temperature is automatically controlled to a set point with ±2℃ deviation by oil temperature controller.

(c) Personal computer is turned on and software is loaded.

(d) According to the software execution, the test system make demands to a user to feed answers.

When the user finished feeding answers, the test system starts to carry out the established test steps.

5.2 Test Results

To verify the effectiveness of the basic performance test system developed in this study, practical test was carried out using a hydraulic motor (model : UMRH 200) made by Uchida co. in Japan.

After starting the program, select mode 1 to perform test procedure. According to the progress of the interactive style program, user is requested to answer. In this case, following values were answered : displacement of the hydraulic motor : 208 cc/rev, maximum pressure : 200 kgf/cm^2, maximum revolution speed : 600 rpm, maxium output torque : 60 kgf · m, division number of pressure differential : 5, division number of revolution speed : 3 and oil temperature : 50℃

By inserting data disk and operating return

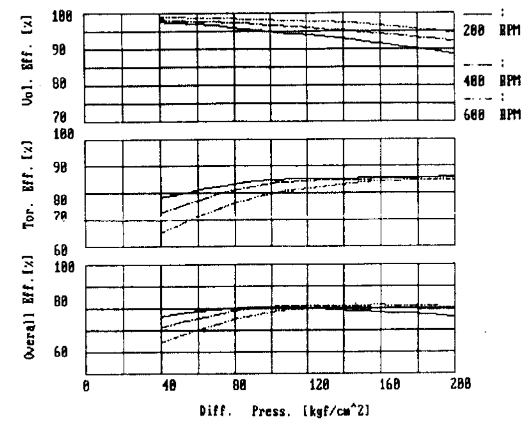

Fig. 4 Test results showing efficiency curves of a hydraulic motor

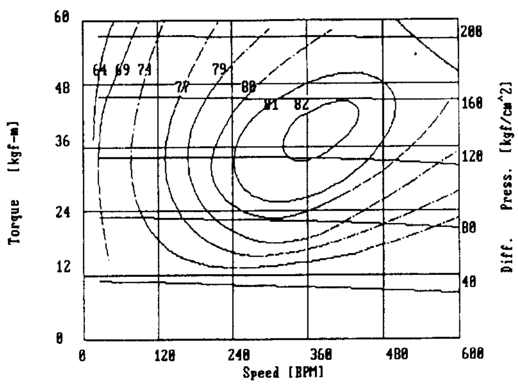

Fig. 5 Test results showing isoefficiency curves of a hydraulic motor

key, test is performed automatically and obtained data are saved on data disk.

When the test proceduce is terminated, program flow returns to the input mode shown at Fig.3. At this point we can select mode 2, mode 3 or mode 4 to represent test results on CRT, printer or X - Y plotter. Obtained test results are shown at Fig.4 and Fig.5.

6. Conclusions

In this study an automatic test system for hydraulic motor basic performance test was developed. To confirm the effectiveness of the test system, practial test was carried out using a hydraulic motor.

Representative results obtained in this study are summarized as follows :

1. Developed test system is very easy to use, because user can carry out the test by only inputing some physical values according to the progress of interactive style program.
2. Time required for the test is reduced on a large scale, which is caused by (a) prompt setting of motor speed and motor load, (b) a through processing of data acquisition, data processing and data display on a computer.
3. Desirable isoefficiency curves can be drawn with confined numbers of data got at not so many test points, which is possible by generating additional data between every neighboring test points numerically.

References

1) Johnson, K.L., "Testing method for Hydraulic Pumps and Motors", National Conference on Fluid Power (1974), 331 - 370.
2) Munt, T. M., Barker, D. J. and Prest, P. H., "The Utilization of a Micro - Computer Monitering of a Hydraulic Pump ", I Mech E (1984), 111 - 119.
3) Prest, P. H. and Barker, D.J., "A Modular Micro - processor Data Acquisition System for Hydraulic Pump Research", I Mech E (1984), 129 - 137.
4) Sato, Y., "Graphics Practice", ASCII publishing Co.(1986), Tokyo, Japan, 143 - 158.