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Fixed Displacement Solenoid Pumps

1. Introduction

Solenoid pumps have been used in burning appliances such as oil-firing boilers and heaters for use in homes for a long time. This is considered attributable to their longer operating life than comparable motor pumps in addition to the advantages of favorable controllability and compactness.
With their recent widespread applications in fuel batteries, NOx reducing devices to regulate car exhaust fumes, vending machines, cooking devices, chemical feeders, etc., changes in specification requirements for solenoid pumps have become evident.
Under such circumstances, we have developed fixed displacement solenoid pumps as part of our efforts to cope with new applications.

2. Overview of Fixed Displacement Solenoid Pumps

Most of the conventional solenoid pumps used in burning appliances are of the variable displacement type with no fixed displacement operating range on the Discharge Pressure - Discharge Quantity Characteristic Curve (P-Q Characteristic Curve). Accordingly, the discharge quantity undergoes a significant change according to load pressure (back pressure).
On the other hand, the principal characteristic of fixed displacement solenoid pumps is that the discharge quantity is kept fixed without being affected by changes in load pressure (back pressure) in the fixed displacement operating range. In addition, fixed displacement pumps are suitable for applications which involve pressure application and pressure fluctuations such as solution feeding into a tank and automobile use, since the effect of changes in operating conditions (voltage fluctuations, temperature changes, vibrations, etc.) on such pumps is very minor.

3. Operation

In a solenoid pump, fluid is sucked or discharged by reciprocating the electromagnetic plunger (armature) by intermittent electromagnetic and spring reaction forces. In a fixed displacement solenoid pump, the stroke is kept fixed by installing a stopper in both of the top and bottom dead center positions. In many cases, a stopper at either the top or bottom dead center also serves as the operation of a shut-off valve at operation stop time.

The following are the descriptions by use of the Discharge Pressure - Discharge Quantity Characteristic Curve (hereinafter called the “P- Q Characteristic Curve”):

In Fig. 1, fixed solenoid displacement pumps are operated on the curved line connecting a’, b and c. In this line, the range between b and c is the fixed displacement operating range, within which fixed displacement solenoid pumps are normally operated.
The range between a’ and b, which falls in the variable displacement operating range, moves closer to the characteristic of variable displacement solenoid pumps. The discharge quantity is accordingly affected by the discharge pressure (load pressure, back pressure).

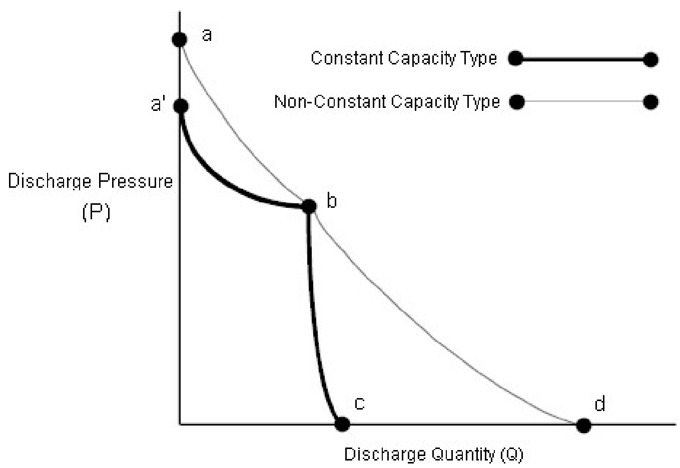

Fig.1 P-Q Characteristic Curve

The curved line connecting a, b and c is the characteristic of variable displacement solenoid pumps.
Since this line has no fixed displacement operating range, the discharge quantity is greatly affected by the discharge pressure.

4. Performance and Characteristic

4.1 Stability and Repeatability of Discharge Quantity

Solenoid pumps, which belong to piston pumps, suck fluid by negative pressure in the suction process. At this time, dissolved air may be separated from the fluid (liquid) according to the condition (cavitation). If this air builds up in the pump, stability and repeatability of the discharge quantity may worsen due to decreased displacement efficiency. With regard to the fixed displacement solenoid pumps recently developed we resolved this problem by increasing the compression ratio to the limit.

4.2 Power Supply Voltage Fluctuations

Fixed displacement solenoid pumps are designed to allow a fixed stroke of the electromagnetic plunger (armature) within the specified working voltage span. Accordingly, the effect of the discharge quantity on power supply voltage fluctuations is minor within this span.
As usage examples, these pumps are suitable for quantitative applications where they are mounted in automobiles with sharp power supply fluctuations. In the case of variable displacement solenoid pumps, the problem of power supply fluctuations is dealt with by compensation from the control point of view. However, this complicates the problem since it is connected to another compensation system.

4.3 Fluid Temperature and Ambient Temperature Variations

If temperature varies, the viscosity of the fluid as well as the DC resistance component of the pump solenoid coil changes. From the pump's point of view, this becomes a change in pressure loss on the output side (load pressure, back pressure) and the change in input energy on the input side. Since fixed displacement solenoid pumps are designed to set the fixed displacement operating range by adding these variable factors to the setting of operating conditions in advance, changes in the discharge quantity are minor.

4.4 Transient Characteristic of Discharge Quantity

Compared with variable displacement solenoid pumps, an overshoot at operation start and an overshoot or undershoot at output switching are extremely minor.

4.5 Self-Priming Performance

Fixed displacement solenoid pumps offer excellent self-priming performance since they are designed to obtain a high compression ratio as stated above.

5. Control of Discharge Quantity

Since fixed displacement solenoid pumps are operated by a fixed stroke, the means of variable discharge quantity becomes the number of strokes per unit time. This is based on pulse-frequency-modulation (PFM) control where the pulse width (PW) of the drive pulse applied to the pump solenoid coil is fixed and the duration time is varied. (See Fig. 2.)
Where the frequency of the drive pulse is f (Hz), the pulse duration time is T (ms) and the pulse width is PW (ms), the following relationship is established:

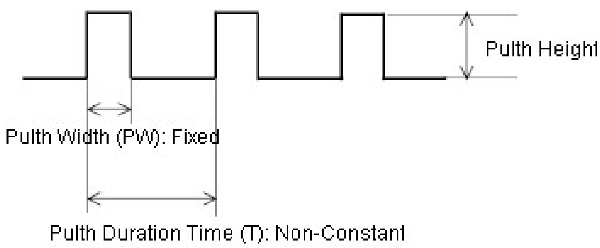

Fig.2: PFM Control

$$F(Hz) = \frac{1000}{T\ (ms)}$$

$$\text{Pulse Duty} = \frac{PW\ (ms)}{T\ (ms)} \times 100(\%)$$

The discharge quantity (Q) is in proportion to the drive frequency (f) which is 10 Hz at maximum. It is difficult to secure the fixed displacement operation for the pump at high frequency bands. The pulse duty becomes approx. 10 - 40% and is determined by pump design parameters.

NOTE:
It is required to protect the driver from the reverse (counter-electromotive) voltage created on the rising edge of the pulse voltage applied to the solenoid coil of a solenoid pump. However, using a flywheel diode alone as shown in Fig. 3 causes an increase in temperature of the solenoid coil or a delay in the current rising edge due to the transfer of the current from the reverse electromotive force to the pump. A slower return time of the electromagnetic plunger (armature) resulting from the above may cause a malfunction.
Since consideration is required to cut the falling edge time of the coil power supply as much as possible, we have prepared the reverse voltage control circuit as shown in Fig. 4. (PAT.)

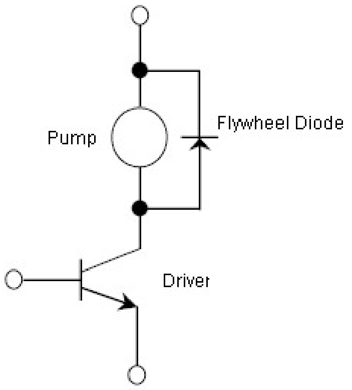

Fig.3: Reverse Voltage Protection Circuit

6. Types and Applications of Fixed Displacement Solenoid Pumps
The fixed displacement solenoid pumps we currently market are shown below. For further information, refer to the catalog.

6.1 Classification by Structure

(1) Piston Type
In the piston type pumps, fluid is pressurized and transferred by the piston according to the methods of pressure application by an electromagnetic force and by a spring force.
It is required to select the component material according to the working fluid since the fluid contacts the metal part of the piston. These pumps cannot be used for inorganic acids.

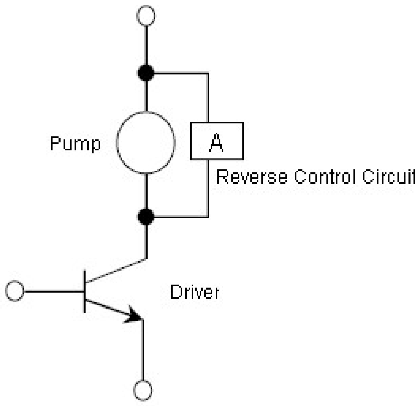

Fig.4: Reverse Voltage Protection Circuit

(2) Diaphragm Type
In the diaphragm type pumps, fluid is pressurized and transferred by the diaphragm. Since these pumps can be used for inorganic acids by selecting the material used in the fluid-contacting part, they are suitable mainly for chemicals.
They structurally have a lower compression ratio than the piston type pumps.

6.2 Classification by Working Fluid

(1)	Water:	The friction part is reduced for applications with pure water etc., to minimize the generation of wear debris due to sliding.
(2)	Oil:	Mainly used for kerosene.
(3)	Chemicals:	The diaphragm type is suitable.

7. Conclusion
In fixed displacement solenoid pumps, the drive frequency which allows fixed displacement operation is as low as 10 Hz at maximum. Accordingly, it is difficult for these pumps to obtain large displacement as is the case with variable displacement solenoid pumps.
Fixed displacement solenoid pumps are useful for applications by which fluid is pressurized and transferred into the tank. The discharge pressure of the P - Q characteristics in such cases refers to the pressure in the tank, that is, the back pressure. Please take note that such characteristics differ from the P - Q characteristics measured by throttling the discharge side in the case of variable displacement solenoid pumps.