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FUJI PS-MOTOR
A Variable Speed Motor Employing Thyristors

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I. INTRODUCTION

Electric motors are required in every sphere of industry and as this demand increases, motor speed control becomes more important. The industrial expansion and improvement of the living standard will serve to strengthen this tendency. Therefore, as the demand for variable speed motors increases, it becomes necessary to develop improved models of these motors.

Fuji Electric has for some time been conducting extensive research into motor control using thyristors, but until recently the use of thyristors on a general field has been limited in practice because of economic factors. However, since remarkable improvements in semiconductor manufacturing techniques and increases in production quantities have led mass to production, the price of thyristors has decreased and, in conjuction with the progress in thyristor application techniques, the use of thyristors on a general filed is now possible.

Fuji Electric has been producing the KS-motors which employed eddy current coupling, and recently, the company has begun to produce PS-motors (Primary Speed Control Motor : trade name).

This PS-motor employs a very convenient speed control system in which speed variation is achieved by controlling the terminal voltage of a squirrel cage type induction motor. This standard series consists of 3-phase and single-phase PS-motors.

An outline of these PS-motors will be given below.

II. STANDARD SPECIFICATIONS

Squirrel cage induction motors are essentialy constant speed types but the rotational speed could be changed by adjusting the terminal voltage. The PS-motors make use of this property. The squirrel cage induction motor terminal voltage is adjusted by means of thyristor trigger phase angle control and the motor becomes a variable speed motor in which speed control is possible.

Standardization is now complete and production has started. The standard specifications of these 3-phase and single-phase PS-motors are give in *Table 1.*

The 3-phase motor has the capacity to control overspeeds over the entire speed control range and is capable of self speed reduction.

The PS-motor consists of the main motor unit and the PS controller, while the 3-phase PS-motor also contains an operation box.

III. THREE-PHASE PS-MOTOR

1. Main Circuit System

The various types of main circuit systems for the control of 3-phase ac using thyristors are shown in *Fig. 1.* The (c) system in this figure is used in the 3-phase PS-motor. This system possesses the following features in comparison with others.

1) Sufficient 3-phase ac control is possible with the

***Table 1.* Standard Specifications of PS Motor**

Type	Rated Output	Model	Rated Torque	Rated Speed (rpm) 50/60 Hz	Rated Voltage Rated Frequency	Rating	Construction	Motor weight (kg)	Control Device	
									PS controller	Standard operation box
Three-Phase PS Motor	200 W	BRKP 112-4	16/14 kg-cm	120～1200 140～1400	200/220 v 50/60 Hz	Continuous	Drip-proof type	20	PSR-D1	MCA-H1
	400 W	BRKP 412-4	33/28 kg-cm					40	PSR-D1	
	750 W	BRKP 612-4	62/53 kg-cm					65	PSR-E1	
	1.5 kW	BRKP 811-4	1.2/1.1 kg-m					100	PSR-H1	
	2.2 kW	BRKP 812-4	1.8/1.5 kg-m					115	PSR-L1	
Single-Phase PS Motor	30 W	PREKP 10/3.1-4	3/2.7 kg-cm	100～1000 110～1100	100 v 50/60 Hz or 200 v 50/60 Hz	Continuous	Totally enclosed type	7.5	PSER-D1S1	
	50 W	PREKP 10/3.6-4	5/4.5 kg-cm					9.0	PSER-D1S1	
	100 W	PREKP 10/4.0-4	10/9 kg-cm					10.5	PSER-D1S1	
	200 W	BREKP 112-4	20/18 kg-cm				Drip-proof type	20	PSER-D2S1	
	400 W	BREKP 412-4	40/36 kg-cm					40	PSER-E1S1	

(3) Amplifier

The amplifier consists of a multi-stage differential amplifier circuit and is used also as the automatic changer between driving and braking of the PS-motor. *Fig. 9* shows a schematic diagram of the driving and braking auto-changer part as well as its output characteristics.

In *Fig. 9*, V_d is an amplification of the voltage differenec (ΔE).

Thyristor Th_1 is controlled by driving output voltage (E_F) and braking output voltage (E_B), while the other thyristors (Th_2. Th_3) are controlled only by the driving output voltage (E_F)

Therefore, when the load rotational speed becomes larger than the set speed ($E_T < E_S$),

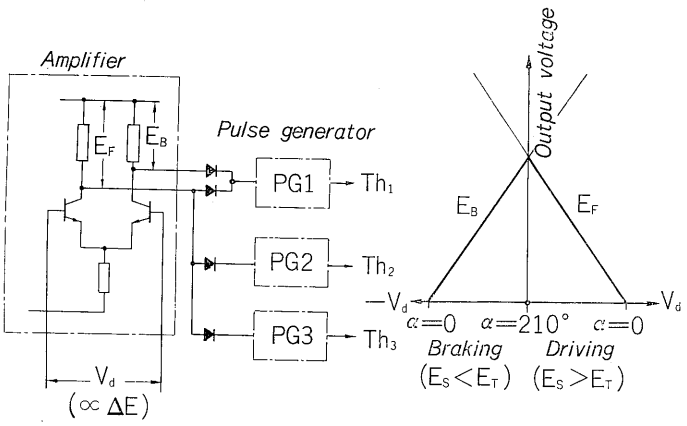


Fig. 9 Auto-changer for driving and braking

thyristors Th_2 and Th_3 cease to conduct and only thyristor Th_1 is controlled by the braking output-put voltage (E_B). Therefore, dc current with its phase angle controlled by $-\Delta E$ flows in the motor winding and braking power generates.

Since the amplifier is provided with the following adjustment functions, simple parallel drive of the PS-motor is possible and highly stable control can be achieved in accordance with the load characteristics.

Speed regulation*) (G): 2–20% (stepless)
Proportional position band (P): 1–100 (stepless)
Reset time (I): 0.01–3 sec. (stepless)
Note: *) Speed regulation when the load torque variation is 10–100% of the rated torque.

2) Construction

The outer case of the PS controller is of the enclosed type and made of iron plates. There is a wall mounting type for from 200 w to 1.5 kw (PSR–D1,–E1,–H1), and self-stand type for 2.2 kw (PSR–L1). *Figs. 10* and *11* show external views of these two types.

The main thyristors are arranged in a stack construction together with the radiation-fin block and protection elements (super-rapid fuse, etc.) and the cooling system is of the self-cooling type. The amplifier, pulse generator, etc. except for the source

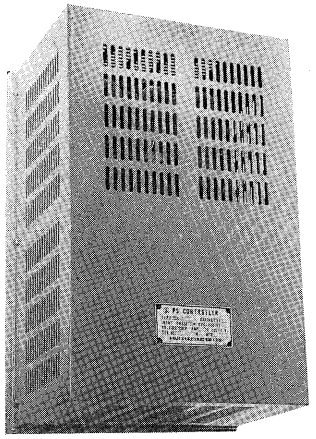


Fig. 10 External view of three-phase PS-controller (wall-mounting type)

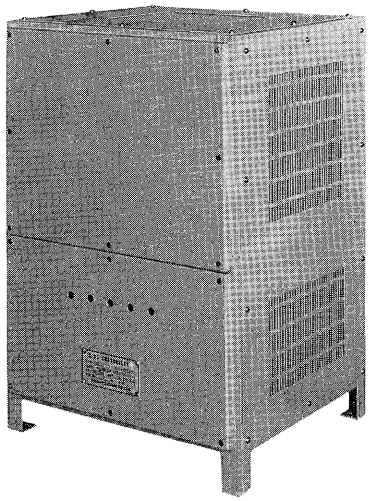


Fig. 11 External view of three-phase PS-controller (self-stand type)

transformer and several circuit components, are of printed-board construction. High reliability is insured by the use of high quality components.

The indicating and operating parts with the source switch, speed indicator, speed setter, etc. are arranged in an "MCA Series" Operation box (MCA–H1,–H2,–H3) as standard, therefore not attached to the surface.

The various adjustable knobs (speed detection voltage, bias proportional position band, reset time and speed regulation) needed for initial running are arranged inside, but can also be operated from the exterior.

3) Application of the MCA series

The MCA series is used for automatic control in PS and KS-motors to simplify such operations as subordinate drive, ratio drive etc.. Besides the operation box (MCA–H1,–H2,–H3), the MCA (Motor Controlling Adaptor)-Series consists of a main setter (MC A–M), ratio setter (MCA–R1,–R2), slow starter (MCA–A), V–I transducer (MCA–V1, V2), buffer am- plifier (MCA–B), etc..

Since the setting signal level of PS controller is made to conform with the MCA series unit signal level 10 v/100%, each panel of the MCA series can be employed by direct coupling. Therefore, by using the various MCA panels, the following drive

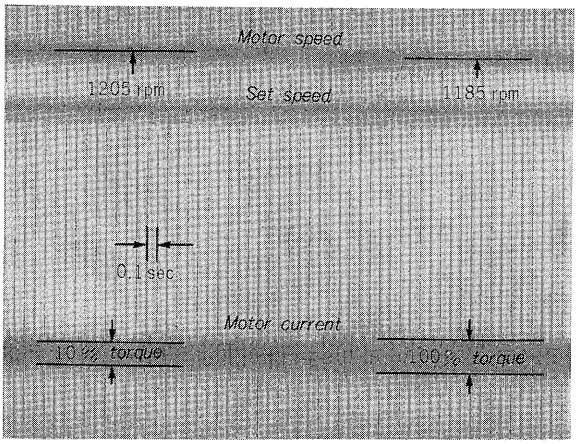
control operations in addition to independent drive are possible in the PS-motor.

(1) subordinate drive (2) ratio drive
(3) synchronous drive (4) program drive
(5) automatic slow acceleration (and deceleration) drive
(6) Cascade drive connected with instrument control system

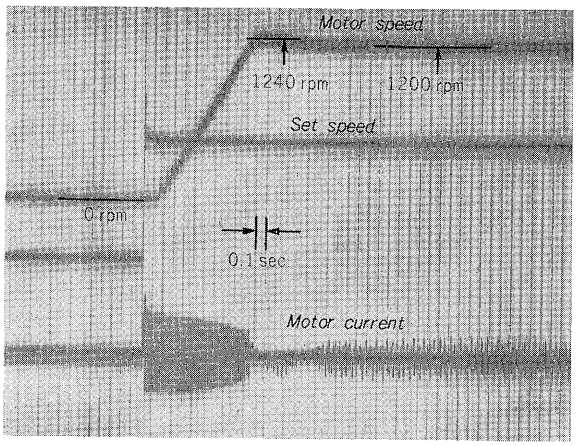
4. Synthetical Characteristics

The 3-phase PS-motor synthetical characteristics are as follows:

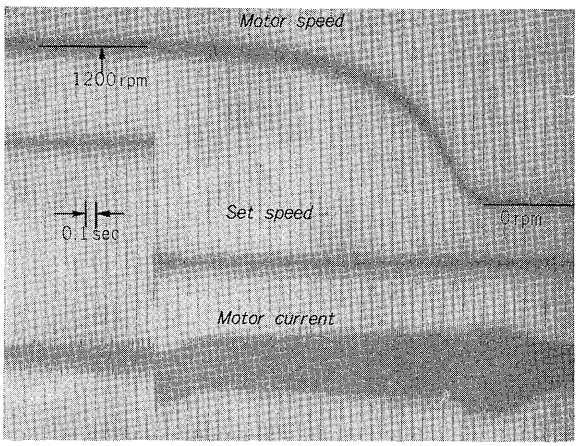
1) Stationary characteristics



(a) Load fluctuation characteristic



(b) Starting characteristics



(c) Stopping characteristics

Fig. 12 Examples of transient characteristics

(1) Speed control range

120–1200 rpm at 50 Hz
140–1400 rpm at 60 Hz (1 : 10)

However, when using for short periods or with light loads, speed control ranges over 1 : 10 are possible.

(2) Speed regulation

The 3-phase PS-motor speed regulation data are given in *Table 2* for the fluctuations of load torque, source voltage, frequency and ambient temperature.

***Table 2.* Speed Regulation of Three-Phase PS-Motor**

Regulated Factor	Condition	Regulation[1)]
Load Torque	10~100% of rated torque	Less than 2% [2)]
Power Source Voltage	±10% of rated value	Less than ±2%
Power Source Frequency	±5% of rated value	Less than ±2%
Ambient Temperature	−10°C~+40°C	Less than 2%

Note: 1) Speed regulation $= \frac{\Delta N}{N_M} \times 100(\%)$

ΔN: Variation in speed (rpm)
N_M: Maximum rated speed (rpm)
2) With the PS speed controller speed regulation adjustment "G" up to 20% (stepless) is possible.

2) Transient characteristics

Transient characteristics vary considerably depending on the control conditions. A sample oscillogram for transient characteristics of load torque regulation, starting and stopping is shown in *Fig. 12.*

IV. SINGLE-PHASE PS MOTOR

1. Main Circuit System

In the single-phase PS-motor as in the 3-phase model, motor terminal voltage is regulated by thyristors, and the motor rotational speed is controled in a variable speed. The single-phase PS-motor employs a condenser motor-type motor and the main circuit system is as shown in *Fig. 13.*

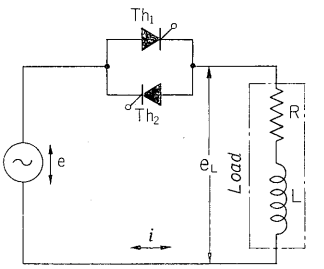


Fig. 13 Main circuit system for single-phase ac control

2. Construction Motor

As mentioned above, a condenser motor type motor is used in the single-phase PS-motor. There are two models available: a 30~100 w totally enclosed self-cooling type and a 200 and 400 w drip-proof

type. *Fig. 14* shows an external view of a totally enclosed single phase PS-motor, while a sectional view of the construction is shown in *Fig. 15*.

In the totally enclosed single phase PS-motor 30～100 w), the complete circumference of the stator is fitted tightly in the frame to enhance the thermal radiation of the losses which present a problem especially at low drive speeds. Therefore, a special cooling fan is not provided but the motor itself is made very compact. With the totally enclosed type, only

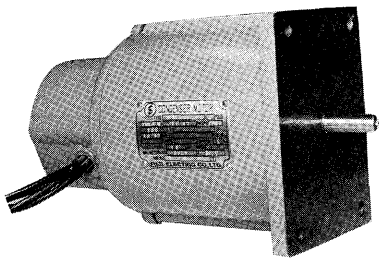


Fig. 14 External view of single-phase PS motor

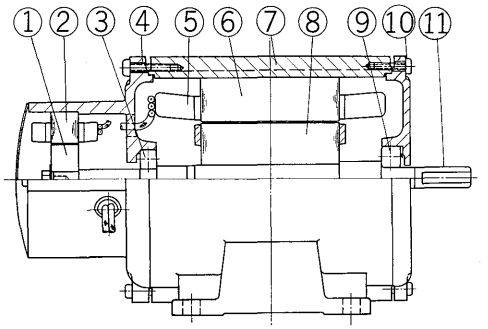


Fig. 15 Sectional view of single-phase PS motor

a few conditions are stipulated in respect of surroundings and therefore it is more convenient than the drip-proof type. For this reason, 200 and 400 w totally enclosed types were considered, but because of external dimension as well as economy, the same drip-proof construction was used as in 3-phase PS motors.

In the usual single-phase induction motors, with few exceptions, the frame is made of steel plates, but in the PS motors, because the influence of magnetic vibrations caused by the high harmonic magnetic field characteristics of the thyristor controlled power source must be kept to a minimum, cast iron with a high degree of hardness is used.

The tacho-generator that is mounted out of the anti-drive end bearing shield is a single phase ac generator with a permanent magnet rotor. As in the 3-phase PS motor, this rotor is mounted on the shaft.

The rotor conductor is made of a diecast alloy with as high resistivity as possible so that reliable control can be carried out against various types of load torque and raise the torque efficiency (torque by apparent power) at low-speed. This results in a decrease in the applicable thyristor capacity.

The motor winding type are a symmetrical 2-phase winding, therefore motor characteristics are the same for forward and reverse drive and changing from forward to reverse drive is easy. The winding insulation uses the class-B material with a high heat resistance.

3. PS Controller

1) Circuit construction

The circuit construction of the single-phase PS controller is shown in *Fig. 16* and the waveforms of the various parts are shown in *Fig. 17*.

When the thyristors in this circuit are not conducting, power source voltage appears at both of the thyristor terminals. This voltage is rectified, clipped by the zener diode, and becomes the source voltage for the trigger phase angle control circuit. For this reason, the thyristors can also be triggered reliably by the impulse signal. As a result, it was possible to simplify the circuit and lower the cost.

The thyristor trigger phase angle is controlled by controlling the base current of transistor T_2 connected in series to condenser C by means of the voltage difference ΔE $(=E_S-E_T)$ of set voltage E_S and detected voltage E_T, and controlling the change rate of the potential V_2 which depends on the charging current of condenser C. In *Fig. 17*, areas I and II show conditions when ΔE is comparatively small, while areas III and IV are for ΔE comparatively large. In areas III and IV of *Fig. 17*, V_B has not attained the value of the power source voltage e, because influence of the PS motor self-excitation voltage is still present. In the waveform G of the PS motor terminal voltage V_0, the voltage present while the thyristors are not conducting also has some influence.

The single-phase PS controller is provided with a filter time constant adjustable resistor "F" and a gain adjustable resistor "G" for adjustments to obtain stable drive in accordance with the load character-

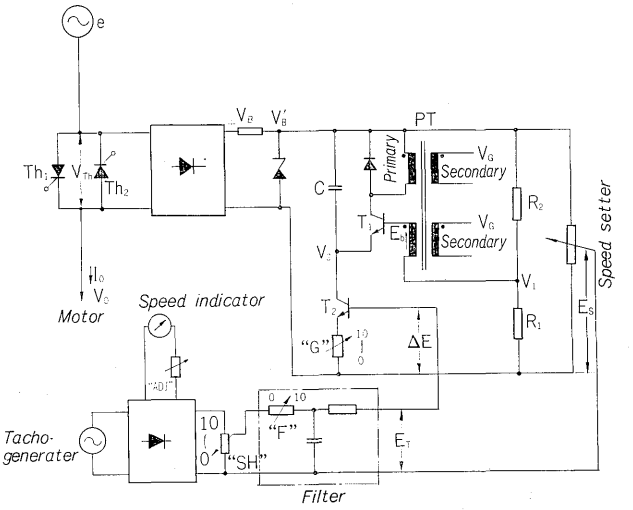


Fig. 16 Circuit diagram of single-phase PS controller

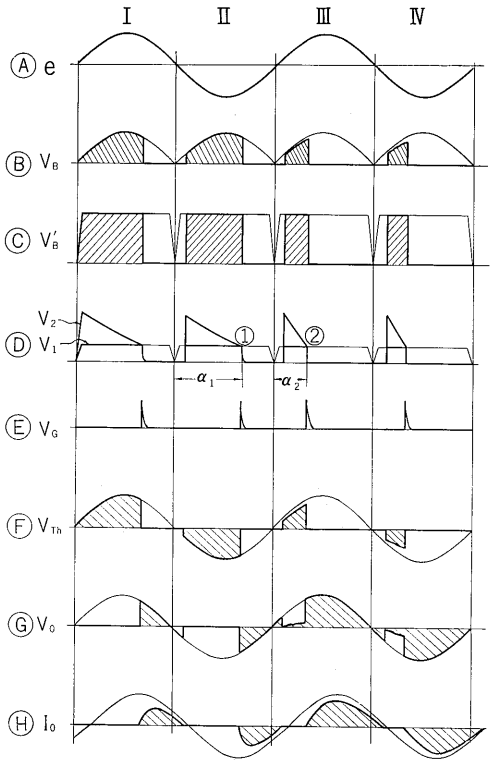


Fig. 17 Waveform of each part

istics of the PS motor. The adjustable resistor "SH" serves to compensate fluctuations in the detected voltage, "ADJ" is an adjustable resistance for compensation of the value shown on the speed indicator.

2) Construction

The power switch, power pilot lamp, speed indicator, and speed setter are located on the front of the single-phase PS controller. It is constructed in a single unit together with the operation section. When used for 30, 50 and 100 w a condenser for motor running is built into the controller but when used for 200 and 400 w, the running condenser is installed separately. The outer case is made of iron plates and is a totally enclosed wall monunting type. An external view is shown in *Fig. 18*. The adjustment knobs ("G", "F", "SH" and "ADJ") needed for initial running of the motor are located inside the controller and of these, only "ADJ" can be operated from the outside.

4. Synthetical Charactristics

The synthetical characteristics of the single-phase PS motor are as follows:

1) Speed control range

100–1000 rpm at 50 Hz

110–1100 rpm at 60 Hz (1 : 10)

When used for a short time or light load driving, control above 1 : 10 is possible.

2) Speed regulation

Single-phase PS motor speed regulation the fluctuation of load torque, source voltage, frequency and ambient temperature are shown in *Table. 3.*

Table 3. **Speed Regulation of Single-Phase PS-Motor**

Regulated Factor	Condition	Regulation *
Load Torque	10~100% of rated torque	Less than 5%
Power Source Voltage	±10% of rated value	Less than ±3%
Power Source Frequency	±5% of rated value	Less than ±3%
Ambient Temperature	−10°C~+40°C	Less than 3%

Note: * Speed regulation $= \frac{\Delta N}{N_M} \times 100(\%)$

ΔN: Variation in speed (rpm)

N_M: Maximum rated speed (rpm)

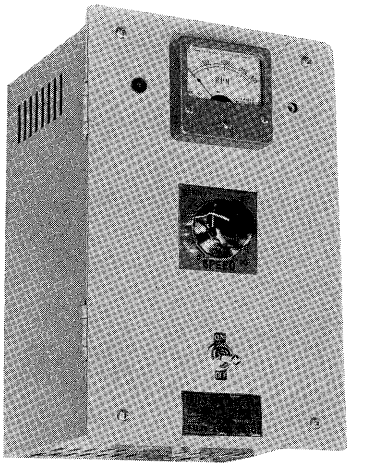


Fig. 18 External view of single-phase PS controller

V. CONCLUSION

Since the PS motors feature a wide range of speed control, simple construction, easy handling and maintenance, they are suitable for every application requiring speed control. The 3-phase PS motor, within its wide range of speed control, has a highly effective braking action and is capable of quick response. For these reasons, 3-phase PS motors can be used in applications which require quick response during retardation, for which KS motors are unsuitable.

Single phase PS motors are applicable not only in cases where only single-phase power sources are available, but they are also cheaper than 3-phase PS motors of the same capacity. Therefore, if phase unbalance does not present a problem even in places with 3-phase power sources, it is advisable to use a single phase motor.

Standardization of 200 w~2.2 kw 3-phase PS motors is now complete and standardization of motors 3.7 kw and above is now in progress. Besides the closed-loop control type single phase PS motors introduced here, an open-loop control system especially for fan load use (10~200 w) has also being standardized.