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APPLICATION OF THYRISTORS IN CONTROL OF SMALL MOTORS

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I. INTRODUCTION

With the recent progress made in the semiconductor industry, it is now an easy matter to obtain cheaper thyristors of high reliability and thyristor control equipment is gradually becoming practical even for use with small motors.

Two years ago Fuji Electric successfully completed thyristor control equipment for use with the small motors of domestic fan (" Electro 7 " electronic fans) and washing machines (" Ise " electronic washing machines). This equipment is capable of regulating the air or water flow steplessly over a wide range. So far it has been received favorably.

This article will give an outline of several examples of thyristors used to control small motors for general industrial use. These will be static Leonard equipment for general use with dc motors, speed control equipment for use with KS motors (KS speed controllers) and speed controllers for single- and three-phase PS motors (PS speed controllers).

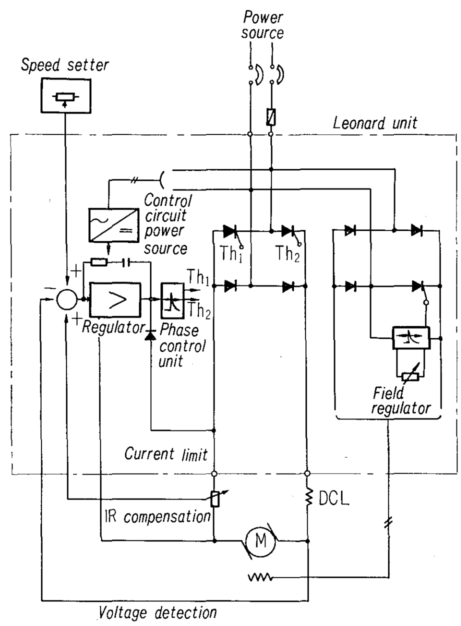

Fig. 1 Schematic circuit of Leonard equipment for single-phase source

II. STATIC LEONARD EQUIPMENT FOR GENERAL USE (DSER, DSR)

Static Leonard equipment has been standardized for general use with ordinary industrial dc motors with outputs of 2 kw or less for single-phase and 41 kw or less for 3-phase.

For economical reasons, the main circuits employ hybrid bridge connections. *Fig. 1* shows a control circuit diagram of this Leonard equipment for a single-phase source, while *Fig. 2* is that for a 3-phase source. For single-phase, voltage control with IR compensation is standard, and for 3-phase, the standard is speed feedback control. The regulator (operational amplifier) is possible the PI and gain adjustment, and has a capability of stable and quick response fitted into the load system. The starting current can be kept constant and any overcurrents limited. For single phase motors, an IR voltage drop method is used for current detection, while in 3-phase motors, an ac side CT detection method is employed. The gate shifter contains a UJT and can perform pulse amplification. The field circuit can be regulated by

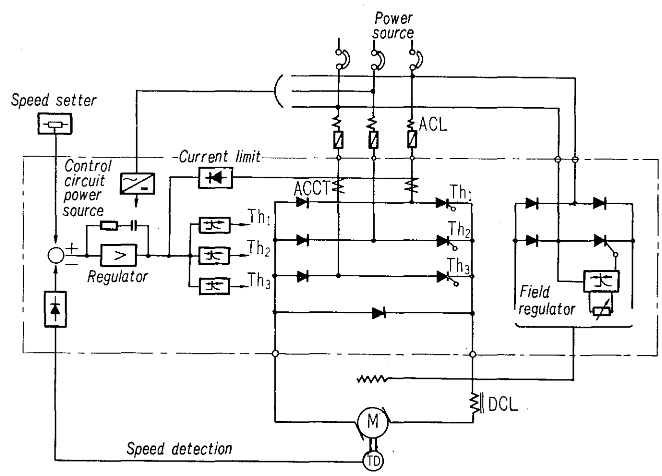

Fig. 2 Schematic diagram of Leonard equipment for 3-phase source

50～100% of the output voltage by means of a hybrid brige connection containing only one thyristor. An ac line reactor is used in 3-phase source to limit the thyristor *di/dt*. Both the PS and KS speed controllers can be used in conjunction with the operator's control

Table 1 Standard Specifications of Leonard Equipment for General Use

Item	Specifications		Remarks
	For single-phase	For three-phase	
Ac voltage	200/200 220 v	50/60 Hz	Source fluctuation are within ±10%
Max. continuous rectifier output (Motor output)	3 kw (2 kw or less)	6~68 kw (4~41 kw)	
Armature voltage	Dc 140 v	Dc 220 v	
Field voltage	Dc 180 v (1φ)	Dc 180 v (1φ)	This value includes series dead resistance voltage drops (or phase control residual angle)
Speed control range	1 : 10 (Torque constant)		The motor is of the forced ventilation type
Base speed	1750 1150 850 rpm		
Speed regulation (Based on base speed)	DVR ±3%		At source fluctuation of ±10%
	ASR ±2%		At load variation of 25~100%
Drive system	Non reversible (with or without DB) Reversible (with DB)		Reversing is performed by a magnetic contactor
External control signal	Dc 0~10 v		Motor controlling adapter (MCA series) can be used
Current limit	IR voltage drop method	ACCT method	
Ambient temperature	−10°C~+40°C		
Construction	Wall mount type	6.5 kw or less: Panel assembly type or self-stand type 11 kw or over: Self-stand type	

station of the "MCA series". *Table 1* lists the specifications. The non-reversible system without dynamic brake is standard for this equipment, but when required, the controllers can be made with dynamic brake or converted into a reversible system by adding a switch.

Since the most suitable commutating diodes are selected for the main circuit hybrid bridge, performance is excellent even when there are heavy starting loads.

III. REVERSIBLE LEONARD EQUIPMENT FOR MACHINE TOOLS

Profiling control and numerical control are now becoming common with machine tools. For example, low inertia motors of 2 kw or less are normally used for feed control in lathes etc. Very rapid response is required in respect to reference change, load fluctuations and stop commands. The speed range must be wide and there must be little speed variation in respect to a wide range of ambient temperature variation. In general, this type of control employs voltage control with IR compensation. When high accuracy is required, speed feedback control is performed. *Fig. 3* shows a schematic diagram of the reversible Leonard equipment. The R_c and series L_c for IR compensation are intended to compensate armature inductance. With this compensation, it is possible to decrease the filter time constant in the detection circuit and also improve the transient response. To make the system reveasible, mutually conjugate dc output is obtained by means of a differential amplifier in the regulator and these outputs are supplied respectively to phase control unit. The loop gain can be regulated, but in order to eliminate

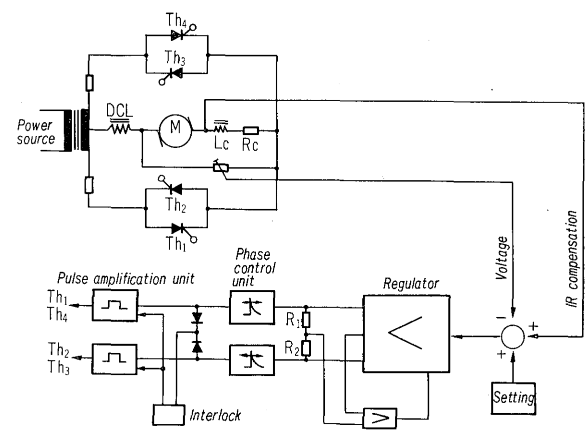

Fig. 3 Schematic circuit of reversible Leonard equipment for machine tools

temperature effects especially in the case of low loop gains, it is essential to maintain temperature drift sufficiently small in the components of the same phase in the regulator output. This equipment employs a unique Fuji Electric method (patent pending) which make feedback of the average values of the same-phase components in the two-output detected by means of R_1 and R_2. The phase control unit also contains a special circuit which keeps temperature variations low. The forward and reverse interlock employs a method by which the pulse from the side which grows first at each half wave stops the pulse from the other side. Offset band adjustment is also possible. With this equipment, the speed regulation is 10% or less at 1/30 of the max. rate speeds and also speed regulation of 10% or less can be maintained for temperature variations in the 0~60°C range at the same speed. The response time differs according to the motor but is generally 0.1 sec. or less.

IV. KS SPEED CONTROLLER (KSR)

Fuji Electric manufactures the KS motor as a ac variable speed motor for general use. This motor has compounded an eddy current coupling (KS coupling) and an ordinary 3-phase squirrel cage induction motor. When the KS coupling exciting current is varied, the transfer torque changes, and this is utilized to control the load speed.

As can be seen from *Fig. 4*, a closed loop is formed to employ a tachodynamo (TD) fixed on the shaft. When automatic control of the KS coupling exciting current is performed by the KS speed regulator, the normal torque characteristics (broken lines in *Fig. 5*) are changed to those shown by the solid lines. Therefore a constant speed can be obtained no matter what the load torque changes.

The KS motor can be applied in many fields of industry and with many types of drive systems. The addition of Motor Controlling Adaptor (MCA series) with capabilities to match the drive system employed serves as a perfect complement to the regulator. Manual setters of the same series can be added when manual drive system are employed.

Control action of regulator differs according to controlled system. KS speed controller ordinarily performs "P-action" but when required "PI-action" it is easily performed by adding an additional component to one part of the circuit.

The regulator consists of the each part of detection, setting, comparing and amplifier as shown in *Fig. 4*.

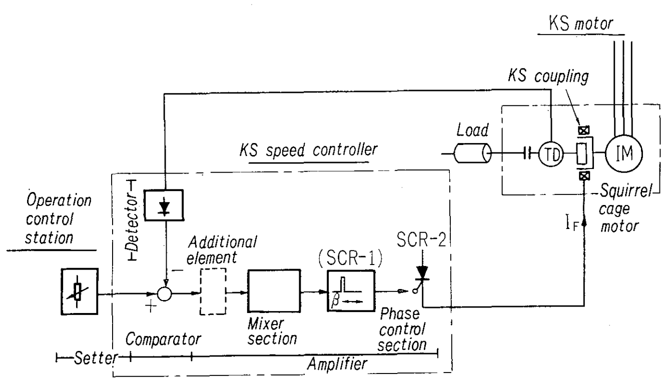

Fig. 4 Block diagram of KS motor control circuit

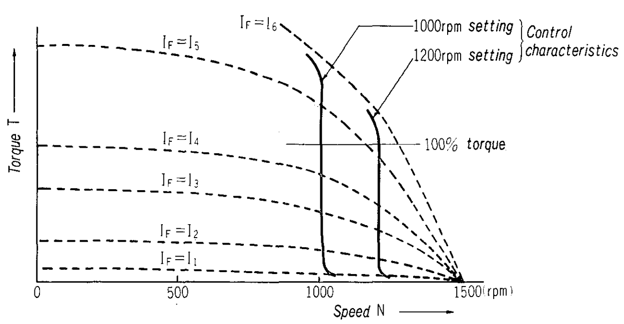

Fig. 5 Torque-speed characteristics of controlled and non-controlled KS motors

The amplifier part are divided into mixing section and phase control section, and the phase control section have one transistor and two thyristors.

The signal mixing unit algebraically adds setting, speed feedback and synchronized signals as currents, while the phase control unit determines the thyristor firing angle β in accordance with the control deviation current. Due to gain up to the output stage thyristor SCR-2, a high sensibility to make a speed variation only 1% can be obtained.

This controller can perform half-wave rectification control of an ac power source (200 v) using a compact thyristor (GTD02) and since the excitation power required for the KS coupling is small, it can be used widely in any device up to the equivalent of the 300 kw KS motor. Beside the simple speed change process, it can also be employed in cascade drive systems receiving very small electrical signals such as those used for various types of process control in measuring plants. With a simple PI regulator, 1% control can be achieved. The speed control range is wide when compared to mechanical speed changer and the use of thyristors makes the equipment compact, lightweight and stout. Because of thyristor half wave control, it is easy to achieve high reliability using only a few electronic components. When combined with the solidity and maintenance-free KS motor, this control equipment proves highly stable.

V. THREE-PHASE SPEED CONTROLLER (PSR)

1. Standard Type

The speed torque characteristics of induction motors vary in proportion to the square of the primary voltage. Similar characteristics are obtained from phase control of the source voltage is applied instead of sinusoidal wave voltage (Refer to *Fig. 7*). If closed loop control is carried out by feeding back the output of the tachodynamo mounted to the shaft of a motor with high slip characteristics as shown in *Fig. 8*, constant speed characteristics can be obtained no matter what the size of the load. This controller operates according to this principle. The control sys-

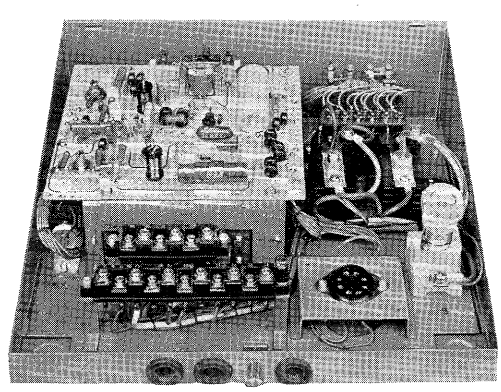

Fig. 6 Internal view of KS controller

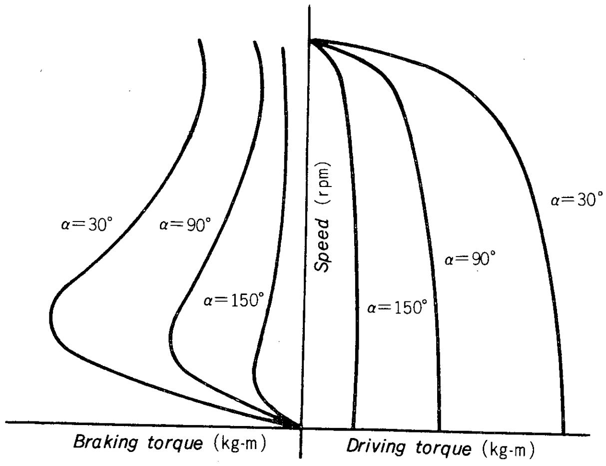

Fig. 7 Speed-torque characteristics of PS motor

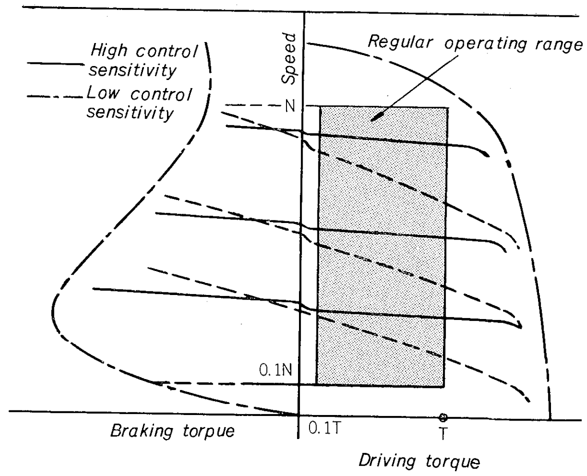

Fig. 9 Controlled characteristics of PS motor

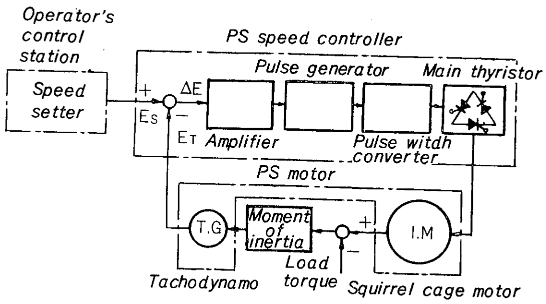

Fig. 8 Block diagram of PS motor

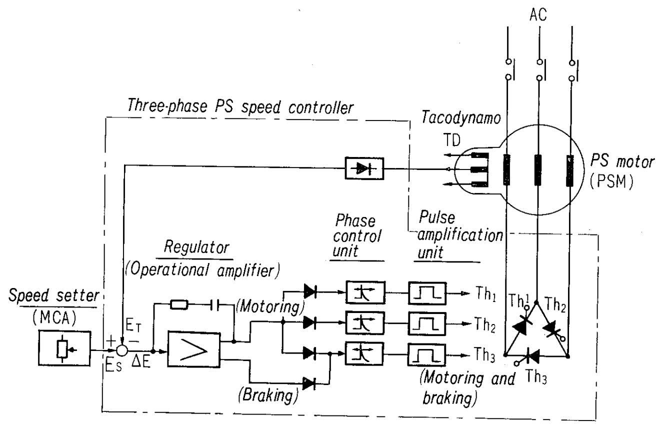

Fig. 10 Schematic diagram of 3-phase PS controller

em is equivalent to a speed control system for a dc hunt motor with high loop gain for low speeds and ɔw loop gain for high speeds. Highly accurate speed ontrol is possible over a wide range just as in the c motor. Efficiency presents a problem in this equip- ıent but the construction is simple and cheap, main- ɜnance is not required since there are no brushes, rake control is possible, inertia of rotor is small nd it can be used in adverse environments. In ad- ition to these features, it also exhibits excellent tran- ent response characteristics. It can be widely em- loyed with medium and small capacity machinery. *ig. 9* shows the control characteristics and *Fig. 10* ıows the schematic circuit diagram of this equipment. he circuit employs a delta connection for the main ıyristors. This controller exhibits the quite equiva- ntly the same voltage control characteristics as the ⁄brid reverse parallel connection shown in *Fig. 12.* ɔmpared with the latter, the thyristor current ratings e 1.5 times greater, but it is cheaper since a mini- um of elements are used. When only one of the ree elements are firing and halfwave dc current is ›wing, good braking characteristics can be obtained. ıe control circuit amplifier is a transistor differential ɪplifier which sends out mutually conjugate dc tput. It posseses PI characteristics and stable, rapid ›ponse fitted to the load system can be obtained. aking is effected by a diode OR logical circuit when ɜ input deviation voltage polarity is reversed, and the firing command voltage is sent to only one of the thyristors. Speed setting is performed by an output signal from an operator's control station of MCA seires and all types of drive are possible includ- ing, cushion starts, the same speed, synchronous and ratio drive. The speed control range is 1 : 10 and the speed variation is 2% or less. The standard equipment is constructed for 0.2~15 kw at ac 200 v and 15~37 kw at 400 v.

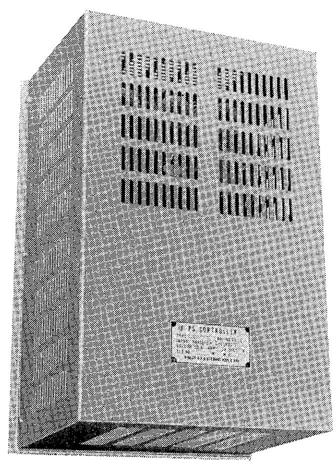

Fig. 11 External view of 3-phase PS controller

2. Reversible Type

This system is ideal for use in the motors of cranes etc. where the environmental conditions are bad and intermittent loads are applied. Such applications require sufficient braking characteristics in respect to frequent reversing. Reverse operation is performed ordinarily by means of magnetic switches to keep low costs but, magnetic switches can effect switching while the current not be flowing by means of thyristor control and therefore magnetic switches keep a long life in this equipment. So for it was common practice to provide a separate rectifier in order to obtain sufficient dynamic brake power. This equipment, however, employs Fuji Electric's newly developed hybrid reverse parallel connection combined with the braking thyristor Th_4 in a unique circuit method as shown in *Fig. 12* (patent pending) which has succeeded in eliminating braking power insufficiences, formerly such a problem in hybrid reverse parallel connections. The reason why the delta connection is not used in this equipment, two reversible switches, one before and one after the motor are necessary. As can be seen from the figure, two control units are used, one for braking and one for motoring. During braking Th_2 and Th_4 are fired. Due to the free wheeling operation of Th_4, the dc component is increased as the pulsation of braking current is decreased and thus effective braking power can be obtained. Four quadrant drive, forward/reverse and motoring/braking can be easily achieved. This equipment is being practically used in 440 v 60 kw auxiliary hoisting crane motors and results have been very good so far.

VI. SINGLE PHASE PS SPEED CONTROLLER (PSER)

Single phase induction motors are the most widely used types. A simple, cheap control method is required even in less efficiency. As was described in the previous section, these type motors almost all employ the primary voltage control system. The use of this type of control equipment in domestic appliances and air conditioners has been increasing recently and will soon also become common with machine tools and other types of machinery.

1. For Fans

Since there are few load torque fluctuations in fans, speed control is possible by means of an open loop. *Fig. 13* shows the control circuit diagram for a fan coil unit. A speed regulation range is 100~70%. The use of a starting compensation circuit composed

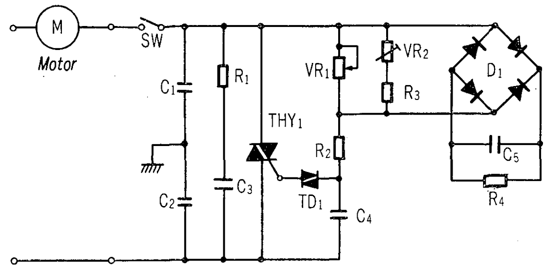

Fig. 13 Circuit diagram of speed controller for fan coil unit motor

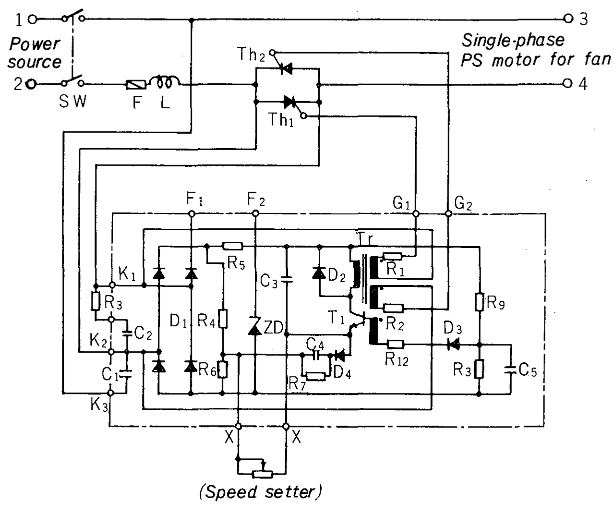

Fig. 14 Circuit diagram for single-phase PS controller for fan

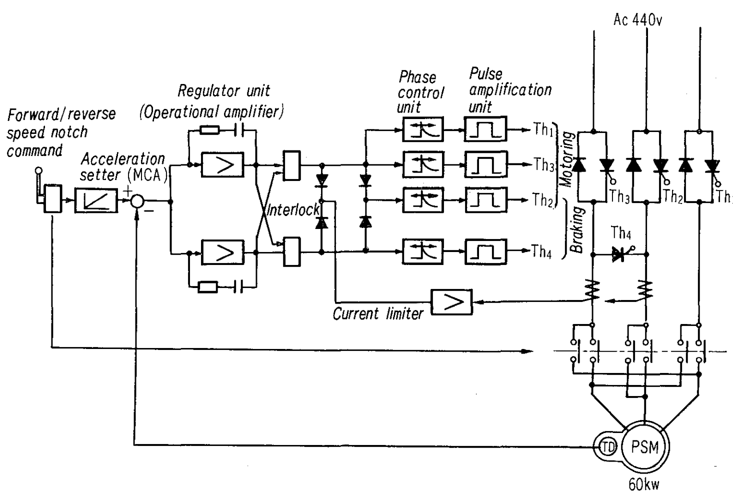

Fig. 12 Schematic circuit diagram of reversible 3-phase PS controller for a crane

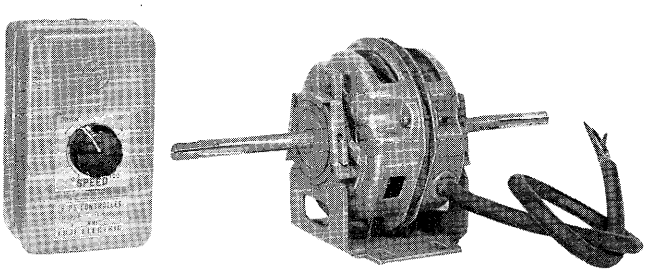

Fig. 15 External view of single-phase PS fan motor

of D_1, C_5 and R_4 guarantees starting at low speed. *Fig. 14* shows control circuit diagram for use with 10~250 w industrial fans. In this circuit, blocking oscillation is performed by a transistor T_1 and an oscillator transformer *Tr* which also serves as a pulse transformer. And trigger pulse which performs phase control is generated (patent pending). In addition to starting compensation, this circuit is also capable of voltage compensation. Therefore, at a speed variation range of 100~30%, speed fluctuations based on power source variations are prevented.

2. For Constant Torque Loads

Fig. 16 shows the control circuit diagram for constant torque loads. The trigger circuit is the same

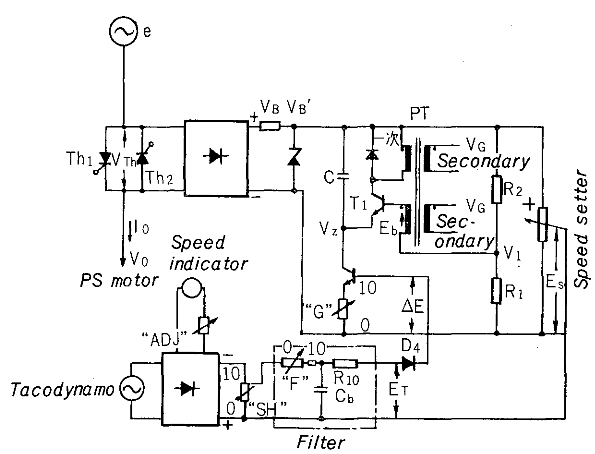

Fig. 16 Circuit diagram of single-phase PS controller for torque constant load

as that in *Fig. 14*. The equivalent resistance of the transistor T_2 connected in series with the capacitor *C* for phase control varies by voltage deviation. The speed control range is 1 : 10 and the speed fluctuation is 5% or less. It can be used with systems between 30 and 400 w.

In applications such as machine tools where high accuracy and stability in respect to load fluctuations are especially need the control circuit diagram as shown in *Fig. 18* is employed. The trigger circuit is the same as that used previously but a ramp and pedestal circuit is formed by means of C_T, R_T, and D_1. A voltage E_1 for gate shifting is supplied from a separate power source. With this equipment PI and gain adjustment are possible. For detection, 3-

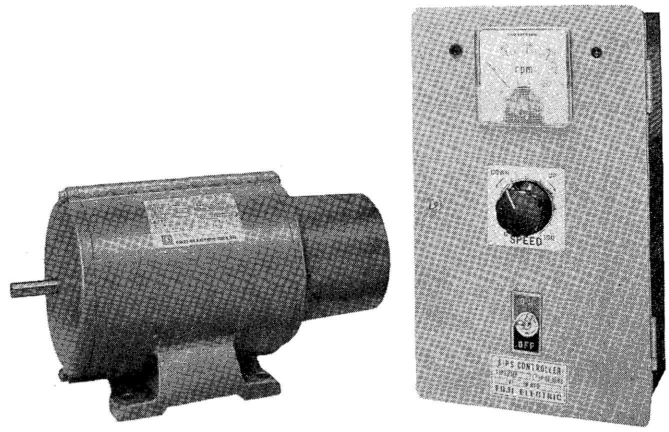

Fig. 17 External vier of single-phase PS motor for torque constant load

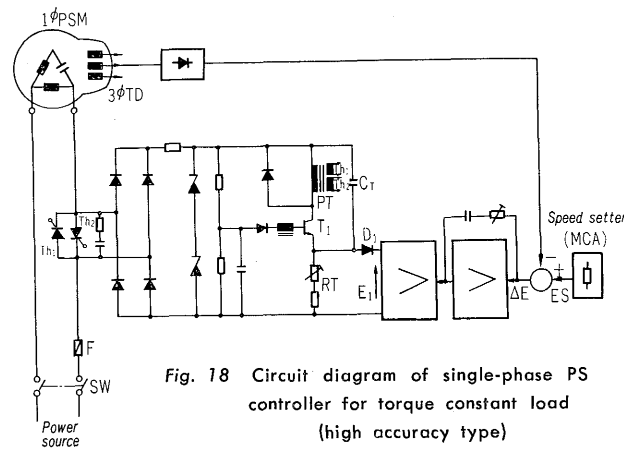

Fig. 18 Circuit diagram of single-phase PS controller for torque constant load (high accuracy type)

phase tacho-dynamo is used and response of 50 ms or less is possible. The speed control range is 1 : 20 and the speed fluctuation is 2% or less. This controller can be used in combination with MCA series equipment for speed setting. The equipment has also been designed so that it is easy to achieve forward/reverse operation and braking by adding an auxiliary control circuis.

VII. CONCLUSION

This article has introduced only examples of standard equipment using thyristors for small motor control. There are, however, also many other special types manufactured.

In recent years, the trend with all types of mechanical equipment has been toward more automation and higher speeds in order to obtain stable quality and higher productivity with the least manpower. The motors used to drive these equipment are required stepless variable speed changing. It is increasing particularly in the small motors. Therefore, we are now concentrating efforts so that the motors and the control equipment can be coupled effectively or made into a single unit, and the high performance, compactness and cheapness as well as to increase the practicality of the motors and control equipment now in existence.