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NEW TYPE SINGLE-PHASE PS MOTOR AND ITS APPLICATIONS

Nobuo Nonoyama
Matsumoto Factory

Hiroyuki Kawakita
Development Dept.

I. INTRODUCTION

The field of applications of stepless variable speed motors will undoubtedly increase in the future due to the growth of industry and shortage of labor. This increase is sure to be accompanied by an increase in the demand for higher performance at lower cost. Fuji Electric already manufactured KS motors which employ eddy current coupling and PS motors in which the primary voltage of an induction motor is controlled by thyristors. Both of these motors has won high acclaim in the industrial machine variable speed field. We recently added two new series to meet the demand from general industry. One series is a standard type single phase PS motor having precision and control action as well as self braking function. The other is a reversible type single phase PS motor which is ideally suited for fields demanding high frequency, high speed reversible operation, such as seen in AC power servo motors.

II. STANDARD SINGLE-PHASE PS MOTOR

1. Principles and Features

1) Driving and braking

The braking action of the induction motor when a direct current is applied to the stator is already well known. However, in addition to performing normal driving by controlling the primary voltage of the capacitor motor, the new single-phase PS motor also performs braking employing the above mentioned principle. In driving, an AC voltage is applied to the motor by symmetrically controlling the phase of forward and reverse thyristors Th_1 and Th_2. On the other hand, during braking, Th_1 is turned OFF and a variable braking force is generated by the flow of direct current by controlling the phase of only Th_2. Moreover, since the braking torque will be low when the capacitor is connected into the circuit at braking, a system is used in which this circuit is turned off. In this case, switching to braking is performed by a combination of electronic detection and mechnical contacts considering the cost and braking frequency demanded. A schematic diagram of the main circuit is shown in *Fig. 1*. Torque characteristics are shown in *Fig. 2*.

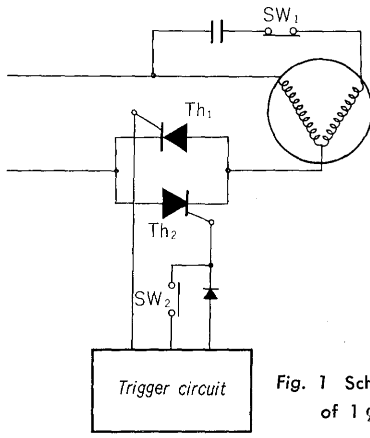

Fig. 1 Schematic diagram of 1 ϕ PS motor

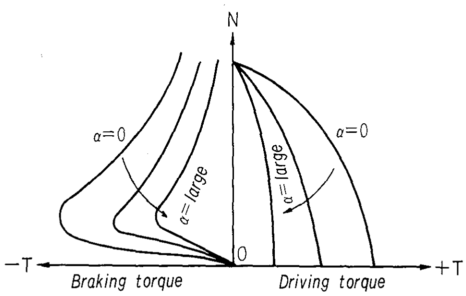

Fig. 2 Torque-speed curve of 1 ϕ PS motor

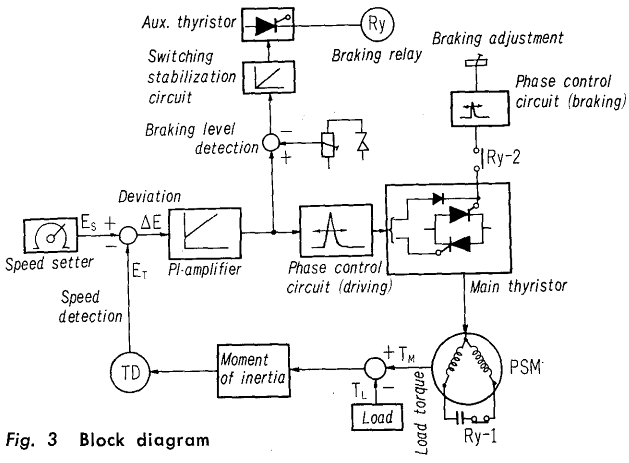

Fig. 3 Block diagram

2) Block diagram

The single-phase PS motor controller is an automatic control device which controls the phase of the motor terminal voltage by means of thyristors to maintain the motor operating speed constant against fluctuations in the load, source, or other conditions. A block diagram of the control system is shown in *Fig. 3.* The motor is operated by comparing the setting voltage E_S with the PS motor speed detection tachometer dynamo voltage E_T, amplifying the difference voltage ΔE with a PI-amplifier, and applying the amplified voltage to the phase control circuit to trigger the thyristors. When $\Delta E>0$, AC control is performed through the drive side phase control circuit and driving force is generated. However, when the rotating speed becomes greater than the set speed, $\Delta E<0$, and the output level of the PI-amplifier rises above the braking level, the output pulse from the drive side phase control circuit is shifted 180°, and at the same time the auxiliary thyristor is triggered through the integrating circuit for stabilized switching and auxiliary relay *Ry* is operated. When the phase splitting capacitor is cut off by the above action, the braking phase control circuit is simultaneously turned ON, only one side of the thyristors is controlled, DC current flows in the PS motor, and braking force is produced. Switching between driving and braking is finally performed by the polarity of the difference voltage ΔE.

3) Features

(1) Single-phase power source (100 V, 200 V) can be easily used.
(2) Possesses braking action and adjustable braking force.
(3) Wide stepless variable speed range.
(4) Very little change in speed due to load or power source voltage fluctuation.
(5) Time lag and overshoot can be adjusted to the minimum for the specific load.
(6) Since there is no commutator or slip ring wear, motor life is extremely long and the motor is maintenance free.
(7) Compact size permits convenient installation at the machine side and incorporation into a control board.

2. Circuit Construction

A schematic diagram of the control circuit is shown in *Fig. 4.*

1) Power source

Since the power source voltage appears across the terminals of the thyristors when main thyristors Th_1 and Th_2 are nonconducting, the source voltage is rectified, clamped by zener diode ZD_1, and used as the phase control circuit power source. At the same time synchronous narrow pulse firing also becomes possible. Consequently, when the thyristors are conducting, the power source voltage drops to almost zero. On the other hand, since the amplifier, setting, braking, and other circuits require a smooth DC power source, the voltage is half-wave rectified from a separate line input, and the rectified voltage clamped by ZD_1 to obtain a constant DC power source without regard to power source fluctuations.

2) Driving

The thyristor trigger angle is controlled by varying the collector potential V_3 of transistor T_1 by means of a base current proportional to the difference voltage $\Delta E(=E_S-E_T)$ of the setting voltage E_S and detected voltege E_T. A trigger pulse is the narrow width one obtaining by suddenly discharging the electric charge stored in capacitor C_0 through the primary winding of pulse transformer PT by turning on of transistor oscillator T_2. Since voltage V_2 is connected to the collector voltage V_3 of T_1, the time constant is extremely small and capacitor C_0 is instantaneously discharged to V_3. However, when $V_3=V_2$, discharging of C_0 is interrupted by D_1 and C_0 is charged at a comparatively long time constant $T_0(=C_0 R_0)$. This time constant is fixed and shifts the phase angle by means of V_3. Proportional band adjustment resistor *P* and reset time adjustment resistor *I* are provided to insure stable operation with various loads. These are used to adjust the feedback characteristics to the base of transistor T_1 by means of *CR*.

3) Braking

When $E_T>E_S$, transistor T_1 is cut-off and V_3 rises (when V_3 is large, the trigger pulse becomes $\alpha=180°$ and the main thyristors are not triggered). When $V_3>V_4$, braking relay *Ry* is operated through relay use auxiliary thyristor Th_B. This turns the braking phase control circuit ON through a triggering diode and since DC current only flows in the one side main thyristor, braking torque is generated in the PS

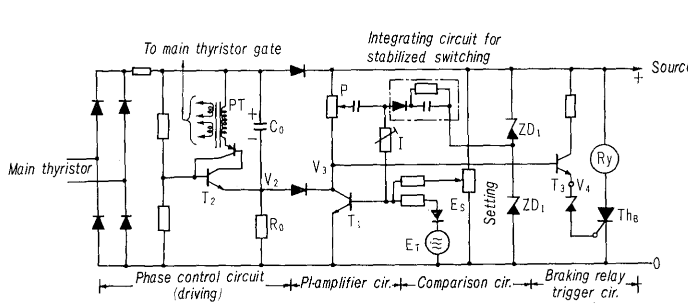

Fig. 4 Schematic diagram of central circuit

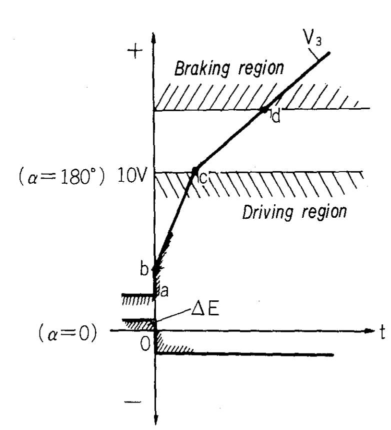

Fig. 5 Response curve of control amplifier

motor. This braking torque can be freely adjusted by varying the trigger phase angle adjustment resistor and differs from the drive side in that the braking force is not automatically controlled.

4) Switching stabilization circuit

Fig. 5 is an example of the change in the collector voltage V_3 of T_1 with respect to the difference voltage ΔE with time. If the setting point is made to suddenly drop at a certain point in time and the difference voltage ΔE is made negative, V_3 is caused to change as shown by the curved line a–b–c by the feedback action of the PI-amplifier, T_1 approaches cut-off, and at the same time the trigger angle is shifted and becomes $\alpha = 180°$ at point *C*. From point *C* the integrating circuit used to stabilize switching is connected between the base and collector of T_1 and V_3 follows a gentle slope and reaches point *d*. At point *d*, auxiliary thyristor Th_B is triggered and braking is performed. In other words, a certain time difference is maintained in drive⇄braking switching and hunting of the relay is prevented even when changes in ΔE are sudden and severe.

3. Standard Specifications

(1) Steady state charcteristics

It is shown in speed regulation of *Table 1.*

(2) Transient characteristics

Transient characteristics differ with the control system composition, but since the standard type single-phase PS motor uses a 3-phase tachometer dynamo in detection and a PI-controller, it displays superb transient characteristics. An oscillogram showing typical response characteristics is given in *Fig. 6.*

4. Construction

1) PS motor proper

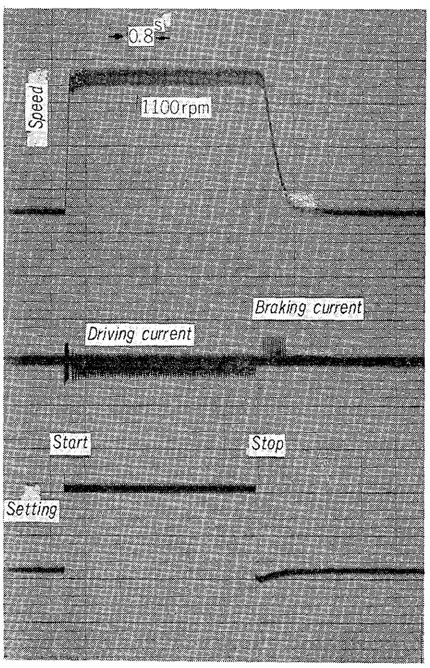

Fig. 6 An example of transient characteristics

***Table 1* Standard specifications of 1 ϕ PS motor**

Type		Standard model	
		Complete type	Separate type
Construction		Enclosed construction wall/flush mounting type	Wall mounting type without case cover
Accessories	Source switch	○	×
	Speed setter	○	○ (Separate)
	Speed indicator	○	○ (Separate)
	Running capacitor	○ (for 200, 400W are separate)	○ (Separate)
Rated voltage		100 V 50/60 Hz or 200 V 50/60 Hz	
Braking action		with	
Ambient temp.		−10∼+40°C	
Adjustable-	Speed detection (SH)	±10%	
	Proportional range (P)	3∼90%	
	Integrating time (I)	0∼500 ms	
	Gain (G)	2∼10%	
	Braking volume (DB)	(0)∼100%	
Outer-	Speed indicator	—	0∼9 V DC/0∼1,500 rpm (1 mA)
	Setting signal	—	0∼10 V DC/0∼1,100 rpm
Speed range	50 Hz	100∼1000 rpm (1 : 10)	
	60 Hz	110∼1100 rpm (1 : 10)	
Speed regulation	Load torque fluctuation (10∼100% of rated load)	2% or less	
	Power source voltage fluctuation (±10% of rated load)	±2% or less	
	Ambient temp. fluctuation (−10∼+40°C, 10 deg span)	2% or less	
Color of finish		Munsell 7.5 BG6/1.5	—
Weight (kg)		4.7	1.4

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

(ΔN: Deviation of speed rpm
N_M: Rated max. speed rpm)

30, 50, 100 W type: Totally enclosed type is standard. A foot mounting type and a flange mounting type are available. Construction is identical to that of general induction motors except for the tachometer dynamo at the anti-driving side.

200, 400 W type: Drip-proof guarded type is standard. A foot mounting type and a flange mounting type are available. A tachometer dynamo is provided at the anti-driving side and a fan rotor is provided at both sides of the main rotor to provide ample cooling by self-ventilation even at low speeds. An exterior view of the 200 W single-phase PS motor is given in *Fig. 7.*

2) Speed controller

(1) Complete type

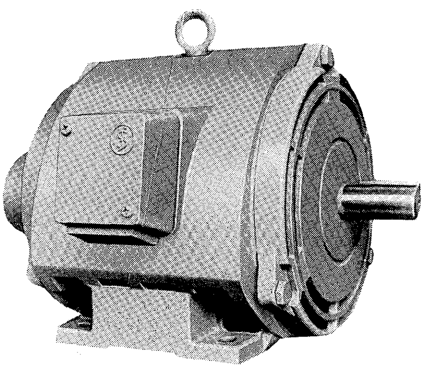

Fig. 7 Outer view of 1 ϕ PS motor

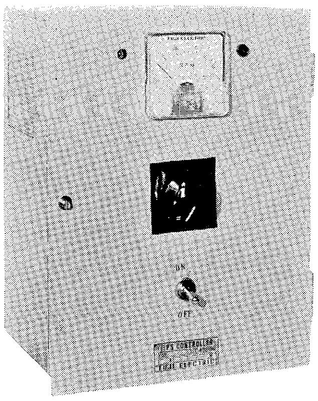

Fig. 8 Outer view 1 ϕ PS controller with case

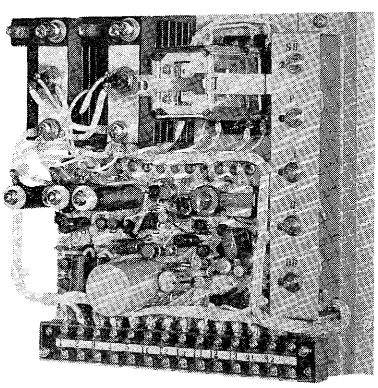

Fig. 9 Outer view of controller without case

The main thyristors and control circuit are enclosed in a steel plate case equipped wiht a source switch, speed setter and speed indicator. Both wall mounting and flush mounting are possible. The running condenser is also housed in the case (the condenser is housed in a separate case in 200 and 400 W units).

(2) Separate type

The main thyristors and control circuit are mounted on a base plate without a case for wall mounting. The source switch, speed setter, speed indicator, and running condenser are separate. An exterior view of the complete type is shown in *Fig. 8* while that of the separate type single-phase PS speed controller is shown in *Fig. 9*.

III. REVERSIBLE TYPE SINGLE-PHASE PS MOTOR

1. Principles

In order to realize an extremely low cost construction in the standard single-phase PS motor, contact switches are used only in the braking circuit. However, when rapid follow-up is required with respect to change of commands, load fluctuations, and such general AC power servo applications as high frequency reverse drive and position determining control, continuous, contactless four quadrant operation is desirable. The reversible type single-phase PS motor has been designed to meet this demand. *Fig. 10* is a schematic diagram of this system. Reverse operation is performed by connecting the power source side through 2-AC control arms consisting of thyristors connected in reverse parallel to terminals 2 and 3 of a single-phase PS motor having a symetrical 2-phase winding. Each thyristor arm is phase controlled by feedback from the DC tachometer dynamo directly coupled to the motor shaft. In other words, when the speed difference $\Delta E(=E_S-E_T)$ is positive, thyristor $Th_{1,2}$ are turned ON and $Th_{3,4}$ are turned OFF. If for any reason the speed rises above the set value, ΔE bocomes negative, $Th_{1,2}$ are immediately turned OFF, $Th_{3,4}$ are turned ON, the motor switches

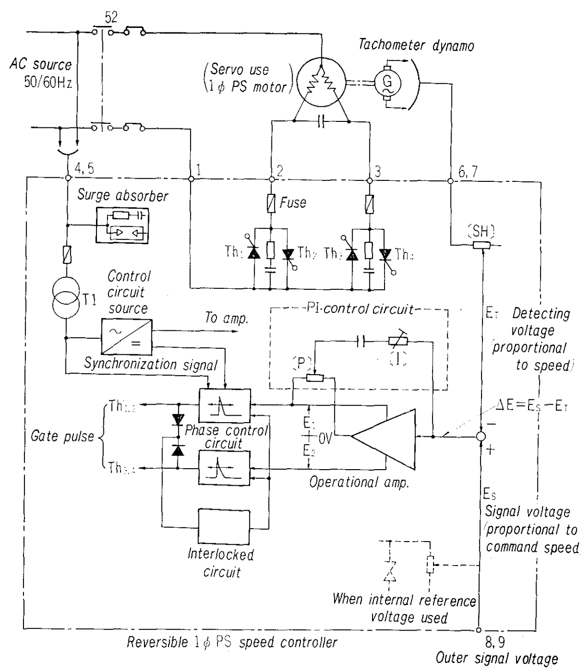

Fig. 10 Schematic diagram of reversible type 1 ϕ PS motor

to the negative torque range, and plugging brake is performed as shown by the dotted lines in *Fig. 11* to maintain a constant speed in the first and fourth quadrants. If the polarity of the setting voltage is inverted, constant speed operation is performed in the third (drive) and second (braking) quadrant. This speed controller uses the rectifier unit of a single-

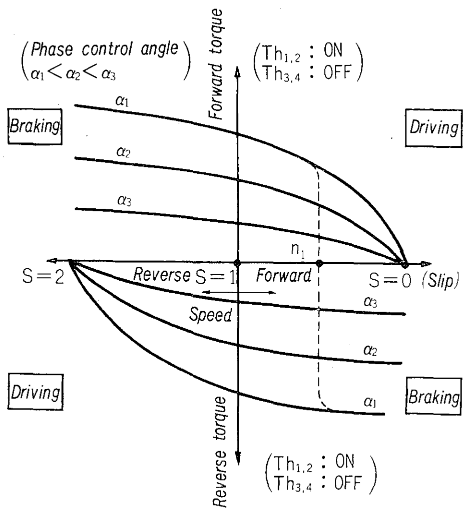

Fig. 11 Torque-speed curve of reversible ype 1 ϕ PS motor

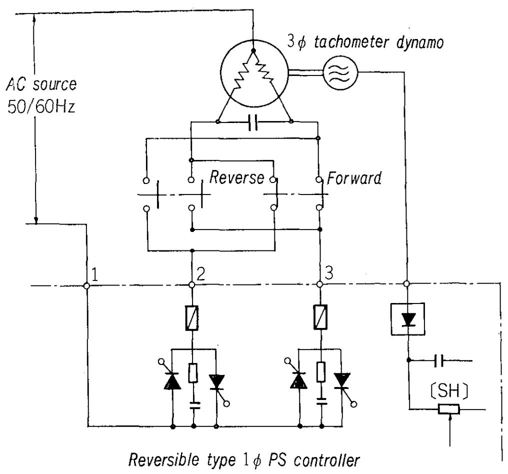

Fig. 12 Combination of reversible type 1 ϕ PS controller and standard PS motor

phase reversible Leonard equipment for DC motor with only the connection of thyristors and the method generating the trigger pulses changed to AC control use. The speed operational amplifier is a PI-amplifier having two mutually conjugate angles output. These outputs apply a phase command voltage to the phase control circuit of the corresponding thyristor arms. The interlock circuit gives priority to the advanced phase pulse within the half-wave of the same power source and makes the operation of the delayed pulse ineffective to prevent short circuiting through simultaneous application of pulses to the thyristors of both arms. *Fig. 12* shows the circuit when the tachometer dynamo of the directly coupled to the motor is a 3-phase AC type the same as the standard type. This is used when only continuous control in both ranges of driving$\rightleftarrows$braking ranges is necessary with operation remaining in the forward or reverse directions. A switch is necessary in forward and reverse switching.

2. Construction

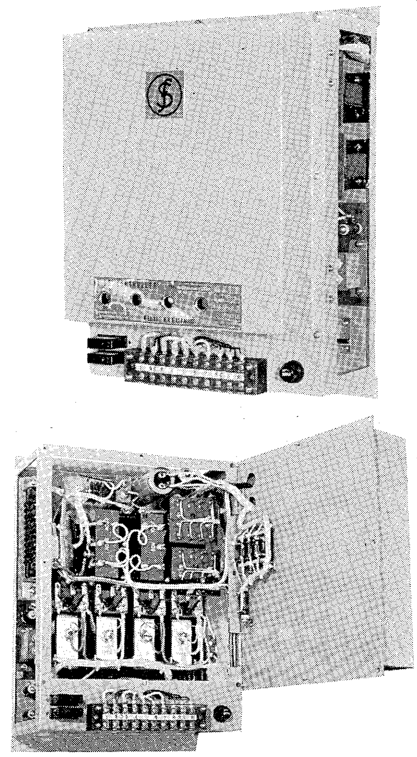

Fig. 13 Reversible type 1 ϕ PS controller

The motor is identical to the standard type except for the DC type tachometer dynamo. As shown in *Fig. 13*, the controller is extremely compact with a thyristor stack, protection circuit, phase control circuit, and control source transformer mounted on the base plate and the printed circuit board (amplifier and phase control circuits) housed in the front of a case with a door and can be easily incorporated into a switchboard or mounted to a wall.

3. Specifications and Characteristics

Standard specifications are given in *Table 2* (*a*) and (*b*). Example dynamic characteristics when an inertial mass is coupled to a 50W motor are shown in *Fig. 14*.

IV. CONCLUSION

The modified standard type and the reversible type single-phase PS motors have been introduced above. These PS motor feature a rotating system having small inertia and rapid response as well as a wide speed range, excellent constant speed characteristics, and control performance identical to that of DC machines. In addition, they also feature easy maintenance and controllable braking torque. They are also superior to DC machines, with their low efficiency at the opposite low speed range, from the viewpoint of low cost construction, and can be widely used in place of a DC machines in the medium and low capacity machine range. This system was first developed in the United States, but has also been widely recognized in Japan recently and are being widely used.

***Table 2* Standard specifications of reversible type 1 ϕ PS motor**

(a) Combined specifications

Rated voltage and frequency	Rated output (W)	1 ϕ PS motor type (with DC tacho.)	Reversible type 1 ϕ PS controller: Type	Reversible type 1 ϕ PS controller: Rated output current	Reversible type 1 ϕ PS controller: Rated output voltage
100 V 50/60 Hz	30	PREKP 10/3.1-4	PSER-D1R	15 A	95 V 50/60 Hz
	50	PREKP 10/3.6-4			
	100	PREKP 10/4.0-4			
	200	BREKP 112-4			
	400	BREKP 412-4	PSER-E1R	22 A	
200 V/220 50/60 Hz	30	PREKP 10/3.1-4	PSER-D2R	15 A	190 V/210 50/60 Hz
	50	PREKP 10/3.6-4			
	100	PREKP 10/4.0-4			
	200	BREKP 112-4			
	400	BREKP 412-4			

(b) Common specifications

Speed range	30～100 W 1 : 50 (1 : 20 by AC tacho.) 200 W, 400 W 1 : 20
Speed regulation	±1% (with respect to rated value)
Adjustable range	Gain (G): 5 : 1 (stepless) Proportional band (P): 1～100 (stepless) Integrating time (I): 5～100 ms (stepless)
Signal and feedback voltage	±10 V/100% (combination with MCA possible) 10 V at ±1000 rpm 50 Hz 10 V at ±1100 rpm 60 Hz
Ambient temp.	−10～40°C

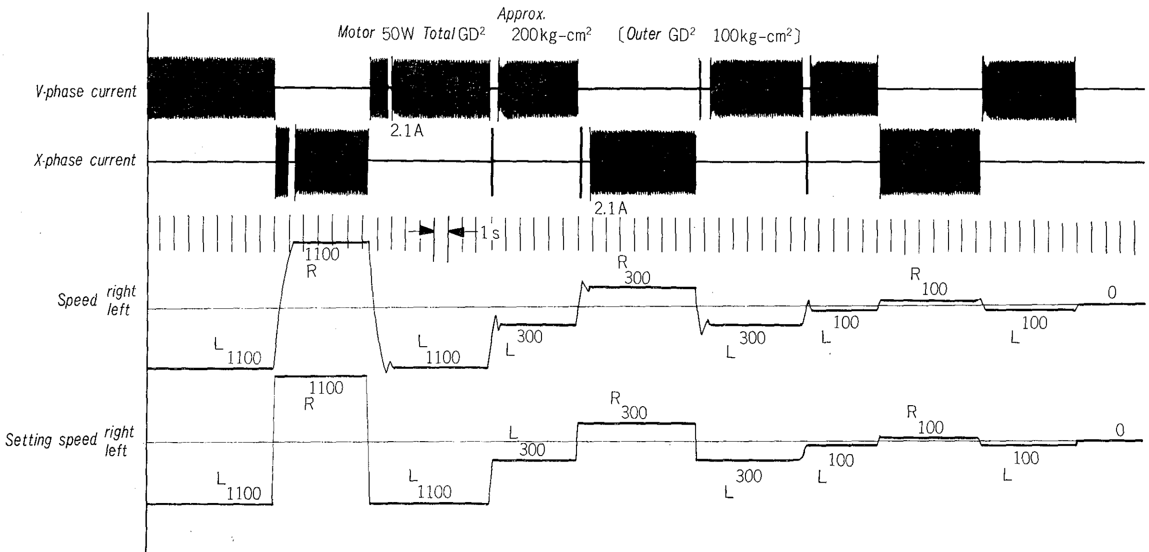

Fig. 14 **An example of dynamic characteristics**