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# BRUSHLESS KS MOTOR AND CONTROL DEVICE

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## I. INTRODUCTION

The KS motor is an ac variable speed motor constructed by combining a KS coupling (trade mark of Fuji Electric for a type of magnetic coupling utilizing eddy currents) with a squirrel-cage induction motor.

Even since production began, KS motors have been widely employed for all types of industrial applications. Because of the built-in advantages they offer, such as simple construction, ease of handling, low cost, etc., over other types of variable speed motors the demand has been increasing constantly year by year. Meanwhile, they are constantly being improved with greater stability, expansion of the standard series, etc., as objectives. A standard series of brushless KS motors has recently been perfected in which both slip-rings and brushes (which are the cause of undesirable wear and sparking) have been eliminated. This not only insures a considerable reduction in the labor involved in maintenance and inspection but also increases the reliability of the equipment itself.

Mass production of brushless KS motors in the 0.75～15 kw range began last year. Many KS motors have already been delivered and are gaining an excellent reputation. In order to achieve automatic speed, KS motors are normally operated by KS speed controllers. In the past several different types of KS speed controllers were being manufactured. These employed either a magnetic amplifier, transistor, or thyristor as an amplifier. Lately, however, a new type of KS speed controller employing thyristors has been perfected. In addition to assuring excellent matching with the Motor Controlling Adapter, which will be described later, improved control characteristics are also provided. Moreover, Motor Controlling Adapters have been standardized for use as auxiliary controllers of the KS speed controllers. This has been done to insure ease of performing all types of automatic control of the KS motor.

On this article, a comprehensive introduction of brushless KS motors including the new thyristor type KS speed controller and various other types of Motor Controlling Adapters, will be given.

## II. BRUSHLESS KS MOTORS

### 1. Principle of Operation

*Fig. 1* is a schematic diagram of the KS motor. The motor consists mainly of fixed magnetic poles with exciting coils, spider, and drum. The drum is directly coupled to a squirrel-cage induction motor and rotates at a fairly constant speed, while the spider is coupled to the load and rotates at variable speeds. When direct current is made to flow through the exciting coils mounted within the fixed magnetic poles, a magnetic flux will be generated. The spider construction is in a multipolar arrangement, so that, when a difference in the speed of the drum exists relative to that of the spider, the magnetic flux interlinking the inside surface of the drum will also move relatively causing the production of eddy currents on the inside surface of the drum. The interaction of these eddy currents with the magnetic flux produces a torque which tends to rotate both the spider and the drum in the same direction. This torque is a function of the relative speed between the spider and the drum, and the exciting current.

An example of the speed-torque characteristics for various exciting currents is shown in *Fig. 2*. Because the KS motor does not provide for the generation of a retarding torque when operated within the normal speed control range, care should be given to this point when considering its applications.

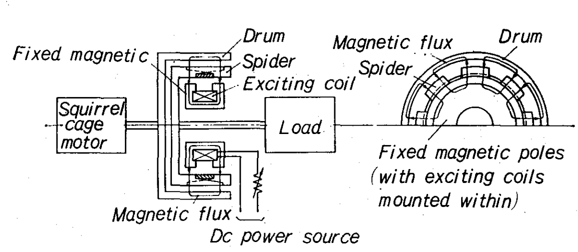



Fig. 1 Schematic diagram of KS motor

### 2. Construction

*Fig. 3* is a cross-sectional diagram of the KS motor, while *Figs. 4* and *5* are external and explod-

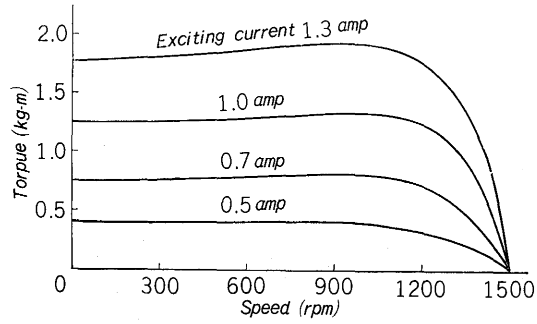



*Fig. 2* **An example of the speed-torque characteristics for various exciting currents**

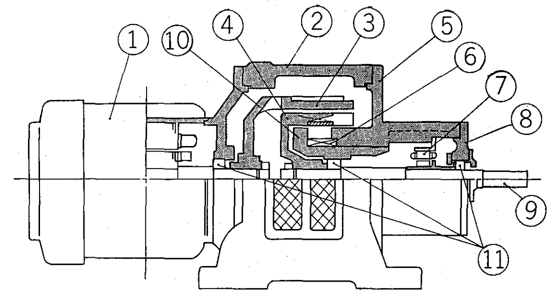



*Fig. 3* **Cross-sectional diagram of KS motor**

① Squirrel-cage motor
② Frame
③ Drum
④ Spider
⑤ Intermediate shield
⑥ Exciting coils
⑦ Tachodynamo
⑧ Shield
⑨ Shaft
⑩ Fixed magnetic poles
⑪ Bearings

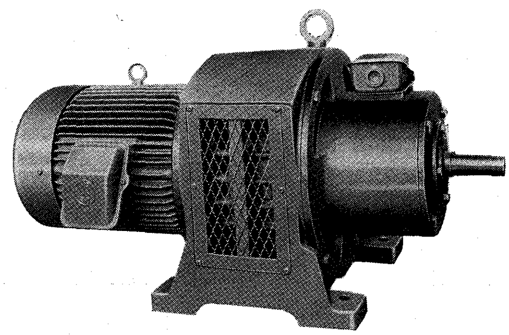


*Fig. 4* **External view of KS motor**

ed views. The construction of the squirrel-cage induction motor is based on IEC dimensions. It is a totally-enclosed, fan-cooled type employing class E insulation. Its construction is similar to that of conventional, flange-equipped, squirrel-cage induction motors.

The KS coupling is the self-cooling type with both heat dissipation ribs and a cooling fan mounted on the drum to insure excellent heat dissipation. Fixed magnetic poles are mounted on the intermediate shield and the exciting coil is placed within the poles. The shafts of both the squirrel-cage motor and the KS coupling are supported by separate bearings thus insuring long life. The tachodynamo is an ac generator employing a permanent magnet for its rotor and is built into the KS coupling shaft.

Listed below are some of the built-in advantages that brushless KS motors have over brush-equipped KS motors.

(1) Because the exciting coils are installed within the fixed poles, thereby eliminating the brushes and slip-rings, troublesome maintenance and inspection procedures are eliminated.
(2) Both size and weight have been considerably reduced by the use of improved design and manufacturing techniques.
(3) Starting and stopping times have been greatly shortened because of the reductions of $GD^2$ of the output shaft.
(4) Construction has been made more durable by independently supporting the shafts of both the drum and spider at two points by means of bearings.
(5) Ease of both maintenance and inspection has been insured by the use of either grease prelubricated shielded ball bearings, which can be used on a semipermanent basis, or those constructed to provide means for supplying lubrication even during operation.

### 3. Standard Specifications

*Table 1* shows the standard specifications for brushless KS motors.

## III. KS SPEED CONTROLLER

### 1. Automatic Speed Control

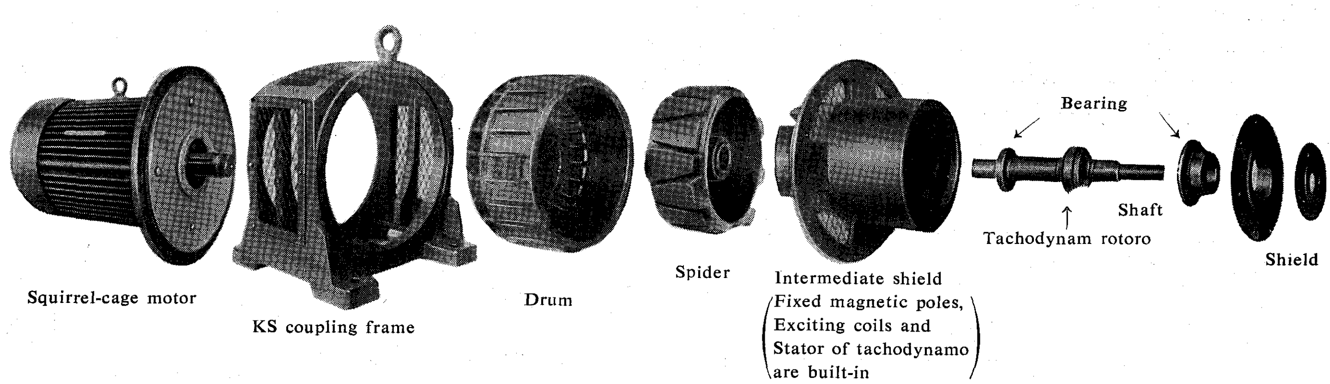



*Fig. 5* **Exploded view of KS motor**

*Table 1* **Standard Specifications for Brushless KS Motor**

| Model of KS Motor / KS Coupling Squirrel-Cage Motor | Rated Output (kw) | Rated Torque kg・m | | Rated Speed (rpm) | Speed Control Range | Weight (ca) (kg) | Model of KS Speed Controller |
|---|---|---|---|---|---|---|---|
| | | 50 cps | 60 cps | | | | |
| KS 18/6P+SORK 81L-4 | 0.75 | 0.48 | 0.4 | 50 cps : 120∼1200<br>60 cps : 150∼1500 | 1 : 10 | 77 | KSR-S2 |
| KS 18/6P+SORK 91L-4 | 1.5 | 0.97 | 0.81 | | | 85 | |
| KS 23/7P+SORK 112-4 | 2.2 | 1.4 | 1.2 | | | 135 | |
| KS 23/7P+SORK 312-4 | 3.7 | 3.4 | 2.0 | | | 150 | |
| KS 26/9P+SORK 411-4 | 5.5 | 3.6 | 3.0 | | | 245 | |
| KS 26/9P+SORK 412-4 | 7.5 | 4.8 | 4.0 | | | 260 | |
| KS 35/11P+SORK 611-4 | 11 | 7.1 | 5.9 | | | 400 | |
| KS 35/11P+SORK 612-4 | 15 | 9.7 | 8.1 | | | 420 | |
| KS 45/19P+SORK 811-4 | 18.5 | 10.9 | 9.1 | | | 710 | |
| KS 45/19P+SORK 812-4 | 22 | 13 | 10.8 | | | 725 | |
| KS 53/22P+SORK 1012-4 | 30 | 17.2 | 14.3 | | | 1200 | |
| KS 53/22P+SORK 1211-4 | 37 | 21.3 | 17.7 | | | 1260 | |
| KS 53/22P+SORK 1212-4 | 45 | 25.8 | 21.5 | 50 cps : 400∼1200<br>60 cps : 500∼1500 | 1 : 3 | 1300 | |

It is evident from the speed-torque characteristics shown previously that operation of the KS motor is possible in cases where the load torque increases with the speed up (as in the case of a generator load) by manually adjusting the exciting current. However, in actual operation, fluctuations, no matter how small they may be, in load torque, power source voltage, etc., will cause large variations in speed. In order to maintain a constant speed in such cases, automatic speed control is usually required. The KS speed controller is a high performance automatic type designed specifically for this purpose.

*Fig. 6* shows a block diagram of the KS motor automatic control system. The process involved in maintaining a constant speed is as follows:

The difference voltage between the voltage divided at the speed setter (preset voltage) and the tachodynamo output voltage (sensing voltage: proprotional to actual speed) is taken, amplified, and subsequently applied to the KS coupling. The control system operates in such a manner that this difference voltage is reduced to a minimum. For example, assume that the load torque has decreased; the torque ($T_M$) generated by the KS motor will overcome the load torque ($T_L$) and tend to increase the speed. However, the tachodynamo voltage is being fed back so there will be no resultant change in speed. The same holds true if the torque generated by the KS motor has fluctuated as a result of power supply voltage variations.

*Fig. 7* shows the torque curve (bold line) obtained when the KS motor is controlled using a preset $N_1$. This shows that, for a certain range, the speed is constant and independent of the load torque. The curvature of the lower end indicates that control cannot be achieved when the load is too light, because of the residual flux on the KS coupling. The curvature of the upper end indicates saturation of the amplifier. Normally, when the load torque range falls between 10∼100% a speed control range of 1 : 10 is guaranteed for the KS motor.

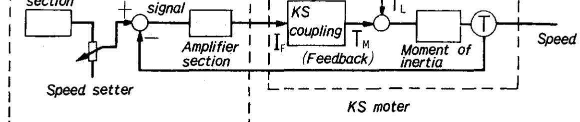



*Fig. 6* **Block diagram of automatic control system for KS motor**

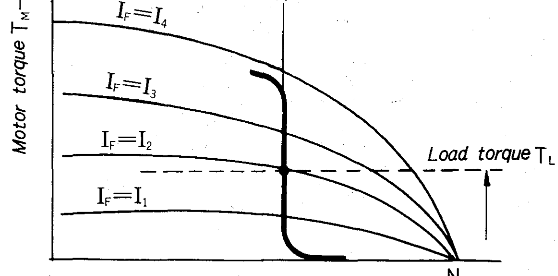



*Fig. 7* **Torque character of KS motor on automatic control system**

## 2. Construction Features

The Model KSR–S2 is a new type KS speed controller employing thyristors for its main portion (i. e., its power amplifier section) and transistors for its phase control circuit. A list of the features of the Model KSR–S2 follows:

(1) Small and light
(2) Neat circuit system
(3) Several types of control can be conducted by using the KSR–S2 in conjuction with Motor Controlling Adapters.
(4) Because the input level is low, cascaded control can be easily performed by direct coupling to instrument controllers.
(5) Stabilized control most suited to the load can be attained by proper adjustment of the control gain.
(6) Although P-action is provided as a standard feature, PI-action can also be obtained by the substitution of plug-in components.
(7) Its fast response makes it excellent for application to short duration signals, such as "inching".

The Model KSR–S2 KS speed controller is enclosed in a wall-mounting sheet metal case. *Fig. 8* shows an external view. The knobs necessary for making adjustments during initial operation (gain adjusting knob "P", bias adjusting knob "B", and speed sensing voltage adjusting knob "SH") are arranged, along with their scale plates, inside the case. The parts have been arranged within the case in such a manner so as to insure ease of adjustment, inspection, and the making of outside connections. For easy substitution, components vital to the P or PI actions have been constructed as plug-in units employing sockets and bases for vacuum tubes.

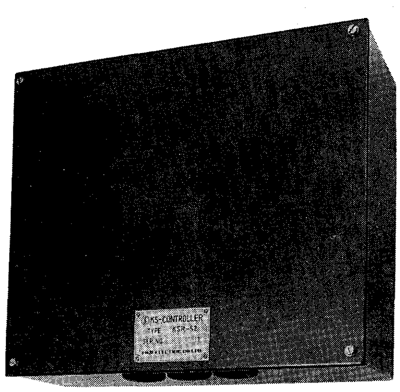


Fig. 8 External view of KS speed controller

## 3. Principle of Operation

*Fig. 9* is a schematic diagram of the Model KSR–S2 KS controller. As has been previously described, the load speed is fed back as the output voltage of the tachodynamo. In *Fig. 9,* control is accomplished by keeping the difference voltage between the preset voltage ($E_s$) on the speed setter and the sensing voltage ($E_T$), which is proportional to the actual speed, at a minimum. To control the output of the output stage thyristor ($SCR_2$), a pulse synchronized with the power supply voltage (e) is applied and the phase made to vary. Hence, the characteristics of the amplifier section should provide a means of converting the difference voltage ($V_d$) into pulse phase variations. *Fig. 10* shows the amplifier section, while *Fig. 11* shows the waveforms associated with each section. When $V_d$ is $0v$ (input is zero), a current $Ic$ has flowed into $T_1$ from $V_B$ through capacitor C. Exciting current does not flow in the KS coupling because $T_1$ is in the ON state i. e. $V_{CE} \doteqdot 0$.

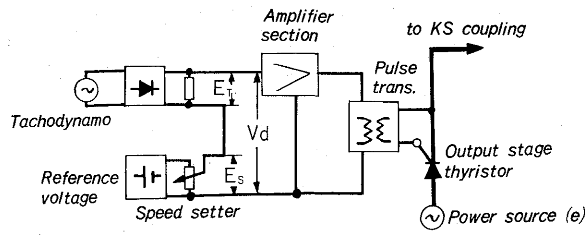



Fig. 9 Schematic diagram of KS speed controller

If an input of $Vd_1$ is now applied, $Id_1$ will flow opposite the direction of $Ic$ and the potential on the base of $T_1$ will drop to zero at the point ① where the magnitudes of these two currents are equal. And $T_1$ will revert to the OFF state and $V_{CE}$ will be appled to the gate of $SCR_1$. Consequently, voltage $V_{R1}$, $V_{PT\text{-}P}$ will appear across $R_1$ and the primary side of pulse transformer $PT$ while at the same time pulses of magnitude $V_{PT\text{-}S}$ will appear across the secondary side of $PT$ so that thyristor $SCR_2$ is turned ON at a firing angle $\theta_{f1}$. The same is true for regions III and IV of *Fig. 11* ; i.e., when the input has increased so that the control current is changed to $Id_2$ the firing angle will also change from $\theta_{f1}$ to $\theta_{f2}$ signifying an increase in output voltage. However, for excessively large inputs, there will be no point of intersection with $Ic$ and, hence, maximum output will be obtained when $\theta_f$ approaches 180°. In *Fig. 11* (J) the current flowing through the KS coupling has

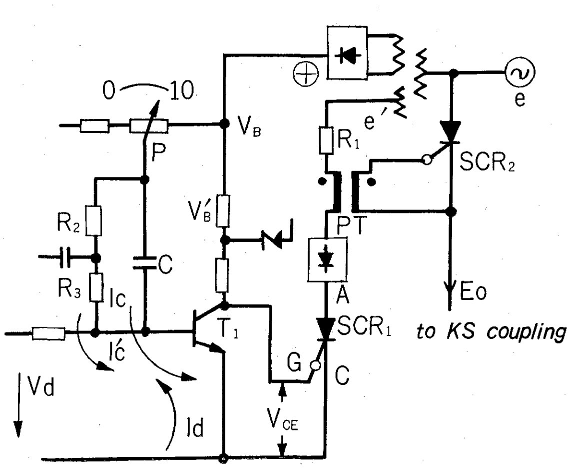



Fig. 10 Schematic diagram of amplification Part

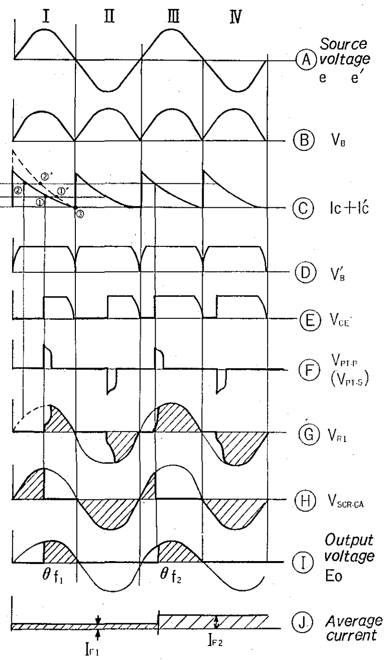



*Fig. 11* Wave forms of each part

been expressed by an ideal average current.

Maximum gain is obtained when " *G* " in *Fig. 10* is set at the " 0 " position and minimum gain is obtained when it is set at the " 10 " position. This is because when " *G* ", in *Fig. 10*, is set at the " 10 " position both the voltage applied across capacitor C and the dc bias current Ic (obtained through the $R_2$, $R_3$ combination), for fixing point ③ in *Fig. 11* (C), will increase. Ic+Ic′ will consequently increase to the value shown by the broken line in *Fig. 11* (C). As a result, the points of intersection for the same $Id_1$ or $Id_2$ will shift from ①→①′ and ②→②′ and the output will decrease. In effect, this signifies a drop in gain.

### 4. Standard Specifications

The standard specifications for the Model KSR-S2 KS speed controller are shown in *Table 2.*

## IV. COMBINATION PERFORMANCE OF KS MOTOR AND KS SPEED CONTROLLER

***Table 2*** **Standardized Specifications for KSR-S2**

| | | | |
|---|---|---|---|
| Input Signal | Constant value control | Manual station of MCA used | |
| | Cascade control | 0~10 v/0~1500 rpm (4 poles 60 cps) } Ripple voltage 0.1% or less | |
| | Ratio control | 0~8 v/0~1200 rpm (4 poles 50 cps) | |
| Input Impedance | | 2.5 kΩ | |
| Output | | Dc 80 v 4.5 amp (Maximum 94 v) | |
| Power Source | | 1φ 200 v or 220 v ±10% 50/60 cps | |
| Power Consumption | | Ca. 650 va | |
| Control Action | | P | PI※1 |
| Adjustable Element | Proportional band | 1~20% | 5~100% Static gain 40 db |
| | Reset time | — | 2, 3, 5 seconds (by switching) |
| | Speed sensing voltage (SH) | ±15% rpm | |
| | Bias (B) | 0 rpm (±1.5 v) | |
| Reference Section Source | | −12 v | |
| External Setting Resistor | | 1 kΩ (variable)+220 Ω (fixed) between terminal ⑩~⑬ | |
| External Setting Voltage | | −10 v[−75 v permissible, output impedance (Rs)※2 250 Ω or less] | |
| Speed Sensing Voltage | | 1 φ 60 v ±15%/1800 rpm (4 poles) | |
| Ambient temperature | | 0~50°C | |
| Case | | Sheet metal enclosed type, surface mounting | |
| Dimensions | | 300×250×120 mm | |
| Weight | | Approx. 6 kg | |
| Dielectric Strength | | Ac 2000 v 1 minute | |
| Applied KS Motors | | 0.7~45 kw self-cooled type, 15~300 kw water-cooled type | |

※1 Plug-in components are replaced with those provided for PI action

※2 When output impedance exceed this value, accuracy is $k\left(1+\frac{R_s}{2500}\right)\%$ ($k$: guaranteed accuracy)

## 1. Steady-Static Characteristics

The following shows static characteristics obtained when the KS speed controller is employed for automatic speed control of KS motors:

(1) Speed control range

The standard speed control ranges for KS motors are as follows:

| | | |
|---|---|---|
| 0.75～37 kw | 1 : 10 | 120～1200 rpm 50 cps<br>150～1500 rpm 60 cps |
| 45 kw | 1 : 3 | 400～1200 rpm 50 cps<br>500～1500 rpm 60 cps |

A speed control range of

1 : 50 { 24～1200 rpm 50 cps; 30～1500 rpm 60 cps }

is also possible, provided that the KS motor is operated at low speeds for short periods of time or low speed operation is confined to light loads (under loads above 10%).

(2) Speed regulation

Speed regulation of the KS motor with respect to fluctuations of load, power source voltage, and ambient temperature are as follows:

- At load torque fluctuations of 10～100% : 1% or less of rated maximum speed.
- At power source voltage fluctuations of ±10% of rated value: ±1% or less of rated maximum speed.
- At power source frequency fluctuations of ±5% or less of rated value: No effect.
- At ambient temperature of 25°C±25°C: ±1% or less of rated maximum speed.

## 2. Dynamic Characteristics

Dynamic characteristics change considerably depending on the loading conditions. The oscilloscope-traces in *Fig. 12* show typical examples for cases of load torque fluctuation, power source voltage fluctuation, and shift in speed setting.

# V. MOTOR CONTROLLING ADAPTER

## 1. Outline

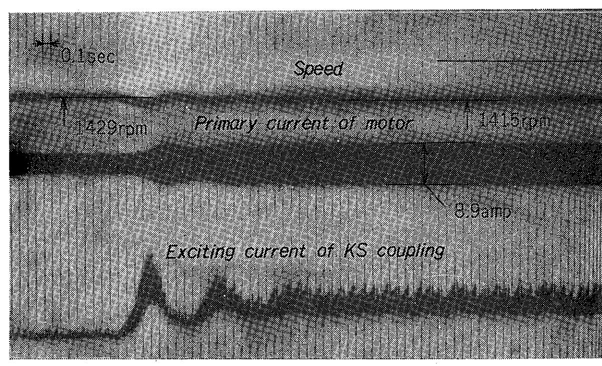
When KS motors are operated in conjunction with other equipment, or when several KS motors are operated so that a particular relationship is maintained between them, it becomes necessary to convert the signal that is to be applied to the KS speed controller into a signal that matches the controller or into one that is best suited to the control objective. To accomplish this, the Motor Controlling Adapter has been incorporated into a unit based on the idea of standardizing various control elements possessing specific functions. Standardization of the Motor Controlling Adapter is based on the following fundamental considerations:

(1) Standardized signal level

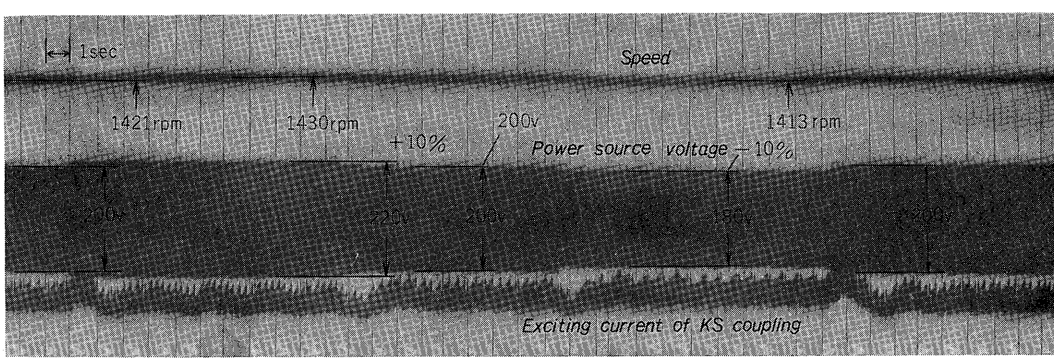
Input/output signals on the Motor Controlling Adapter have all been standardized at 0～10 v/0～100%. Because the control signal level of the KS speed controller has also been set to this value, direct coupling between them is possible. Coupling to instrument controllers can also be easily done.

(2) Standardized external dimensions

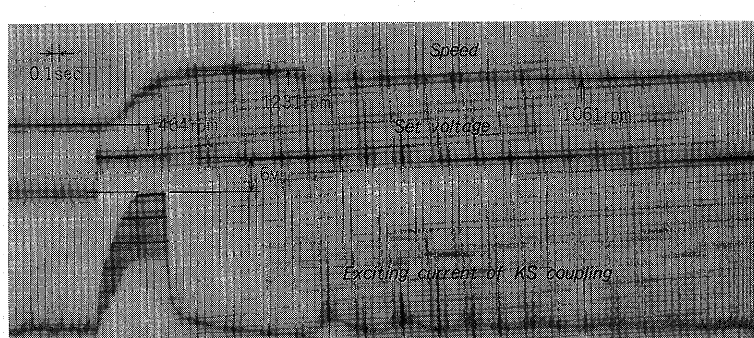
The external dimensions of the Motor Con-




(a) Load torque fluctuation KS: 2.2 kw load 10～100%




(b) Power source voltage fluctuation KS: 2.2kw load 100%




(c) Set speed shift KS: 2.2 kw load 50% $GL^2$=1.0 kg·m$^2$

*Fig. 12* Oscillograms of dynamic characteristics trolling Adapter have been standardized at 110 mm or 150 mm (W) × 250 mm (H) × 120 mm (D). Hence, whenever the application requires a combination of several of these units, they can be mounted side by side following a building block system.

At present, standardization of Manual Station (MCA–H1, –H2, –H3), Main Setter (MCA–M), Ratio Setter (MCA–R1, –R2), and Slow Starter MCA–A) has been completed. Development of the displacement detector, Torque Detector, I–V transducer, and other units is also being pursued.

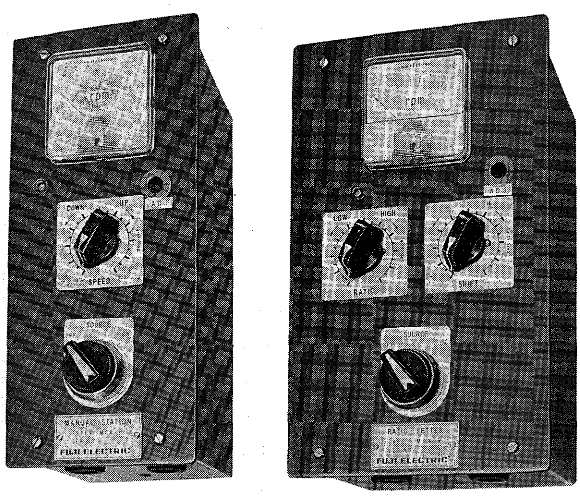


*Fig. 13* External view of Motor Controlling Adapters

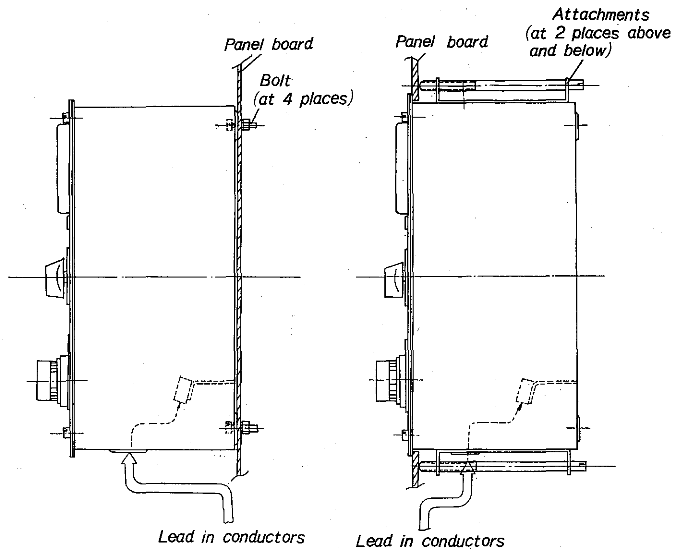
## 2. Construction

As mentioned previously, the Motor Controlling Adapter is housed in a case with standardized dimensions. The case of enclosed type construction by means of sheet metal, is the surface mounting type; however, it can also be mounted flush with the panel. All the components (except the terminal block for making external connections) are mounted behind the front board. The speed indicator, setting (or adjusting) knobs, power switch, etc., are all mounted on the surface so that no adjustments need be made within the case itself. The example of the Motor Controlling Adapters are shown in *Fig. 13.*

Diagrams illustrating the methods of mounting the Motor Controlling Adapter are shown in *Fig. 14.* Mounting flush with the panel, shown in *Fig. 14* (b), is easily accomplished with the aid of metal attachments. Furthermore, regardless of whether the adapter has been surface mounted or flush mounted, the front board of the adapter can be opened to insure ease in making external circuit connection or the checking of components mounted inside.

## 3. Specifications and Capabilities

The standard specifications for all types of Motor Controlling Adapters are shown in *Table 3.* Capabilities are described below.




(a) Surface-mounting (b) Flush mounting on panel

*Fig. 14* Mounting method

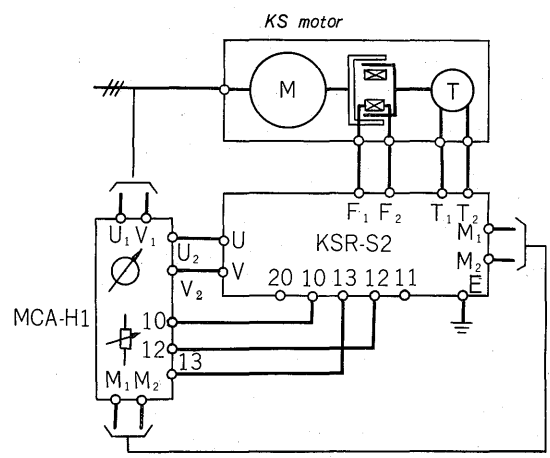



*Fig. 15* Interconnection diagram of KS controller and manual station

(1) Manual station
The MCA–H1 is a master control unit for use when the KS motor is operated alone. It has an ON-OFF switch for the KS speed controller, a power supply indicating lamp, a speed setting resistor, and a speed indicator. In addition to all of the above components, the MCA–H2 also has an AUTO-MANUAL changeover switch. This switch chooses a means of setting the speed either directly through the MCA–H2 or by means of an external control signal. The MCA–H3 has an ON-OFF switch for the KS speed controller, a power supply indicating lamp, and a speed indicator. Speed setting is not possible with the MCA–H3. Power for the speed setters, on both the MCA–H1 and MCA–H2, is obtained from external sources (usually the KS speed controller). *Fig. 15* is the interconnection diagram for the KS motor, KS speed controller, and manual station Model MCA–H1 for independent drive of the KS motor.

***Table 3*** **Standard Specifications for Motor Controlling Adapters (MCA-Series)**

| Unit Name | | Manual Station | | | Main Setter | Ratio Setter | | Slow Starter |
|---|---|---|---|---|---|---|---|---|
| Model | | MCA-H1 | MCA-H2 | MCA-H3 | MCA-M | MCA-R1 | MCA-R2 | MCA-A |
| Surface mounted Components | | Speed indicator and span adjusting resistor, speed setter, power source switch, power source lamp indicator | Speed indicator and span adjusting resistor, speed setter, power source switch, power source lamp indicator, Auto-Man changeover switch | Speed indicator and span adjusting resistor, power source switch, power source lamp indicator | Speed setter, power source switch, power source lamp indicator | Speed indicator and span adjusting resistor, ratio setter, reference point adjustment, power source switch, power source lamp indicator, Out-In changeover switch | Speed indicator and span adjusting resistor, ratio setter, reference point adjustment, power source switch, power source lamp indicator | Time limit fine adjustment, time limit changeover switch, power source switch, power source lamp indicator |
| Case Width | | 110 | 150 | 110 | 150 | 150 | 150 | 150 |
| Input ($V_i$) | | Setting source voltage: 10 (or 12) v | | — | — | 0∼−10 v | | |
| Input Impedance | | Setting circuit resistor: 1 (or 1.2) kΩ | | — | — | 2.4 kΩ | 2.4 kΩ | 2.2 kΩ |
| Output ($V_0$) | | Setting output voltage: 0∼10 (or 2∼12) v | | — | 0∼−10 v | | | |
| Permissible Impedance | | — | | — | 800 Ω | | | |
| Power Source | Voltage | — | | | 1 ϕ 200 or 220 v | | | |
| | Frequency | — | | | 50/60 cps | | | |
| Power Consumption | | — | | | Ca. 4 va | | | |
| Computing Formula of Output | | — | | | $V_0=K\times10$ (v) | $V_0=AV_i+B$ (v) | | $V_0=\frac{10}{T}\cdot t$ (v) $\left(0<t<\frac{V_i}{10}T\right)$ $V_0=V_i$ (v) $\left(t\geqq\frac{V_i}{10}T\right)$ |
| Adjustable Range | | — | | | K: 0∼1 | A: 0.2∼2, B: ±3 | | T: 0, 1∼10, 3∼30 sec |
| Rating of Speed Indicator | | 0∼10±1 v/0∼100% rpm | | | — | 0∼10±1 v/0∼100% rpm | | — |
| Ambient Temperature | | 0∼50°C | | | 0∼50°C | | | |
| Capabilities | At power source voltage fluctuation of ±10% | — | | | Output voltage fluctuation: ±0.1 v or less | | | |
| | At frequency fluctuation of ±5% | — | | | No effect | | | |
| | At load variations of 800 Ω∼∞ | — | | | Output voltage fluctuation: 0.1 v or less | | | |
| | At temperature variations of 0∼50°C | — | | | Output voltage fluctuation: 0.1 v or less | | | |

*Fig. 16* shows an example of the KS motor being used to control the steam pressure of a boiler by regulating its fuel supply.

When the changeover switch on the MCA-H2 is turned to AUTO, speed control of the KS motor can be accomplished by means of control signals from the instrument controller. When the switch is placed in the MANUAL position, independent operation can be performed with the speed setter inside the unit.

(2) Main setter

When conducting either tuning drive or ratio drive of the motor, a master signal for setting the reference speed is required. In the main setter MCA-M output voltages of 0∼10 v, with the setting resistors located within the unit can be obtained. This provides the signal source (master signal source) for the reference speed. The unit employs a transistorized amplifier with a low output impedance; hence, it provides a stabilized signal source.

(3) Ratio setter

This unit is capable of adjusting the output to input voltage ratio. When used with the main setter previously decribed, it is possible to operate several KS motors simultaneously, maintaining a

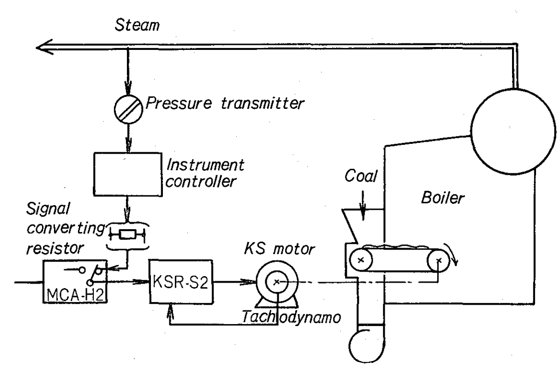



*Fig. 16* **Boiler steam pressure control**

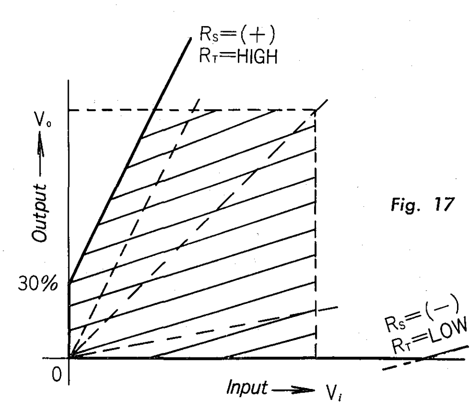



*Fig. 17* **Adjustment range on ratio setter**

certain ratio between their speeds. Moreover, it is also possible to change this ratio any time the necessity arises. The relation between the input voltage ($V_i$) and the output voltage ($V_0$) of this unit is expressed by the following equation:

$$V_0 = A \cdot V_i + B$$

where A=0.2∼2 and B=±3.

The MCA–R1 is equipped with a switch which offers a choice of either ratio drive or independent drive. However, this switch is not provided in the MCA–R2. *Fig. 18* shows an example of this unit being used with a group of conveyors in a system for combining raw materials.

(4) Slow starter

In order to prevent damaging shock imparted to the associated equipment whenever the KS motors are being started (or their speed settings are abruptly changed), acceleration (or deceleration) should be made smoothly and gradually. The same holds true in cases where several KS motors are being started (or their speed settings are abruptly changed), or acceleration (or deceleration) is to be equalized. In order to accomplish this, the speed setting signal change should be gradual. This unit has been designed for precisely this purpose by causing the output to change gradually, even for step voltage inputs.

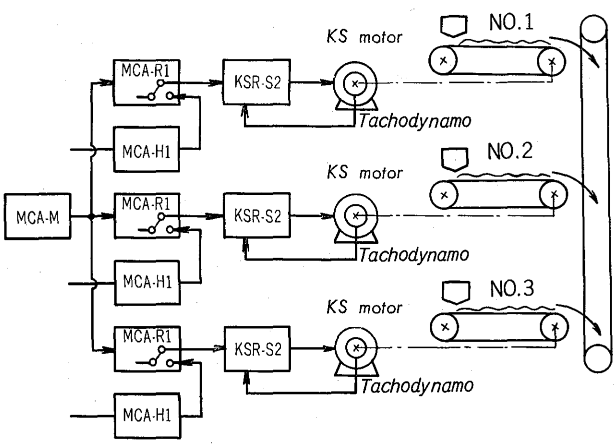



*Fig. 18* Ratio drive employed for a conveyor syestem

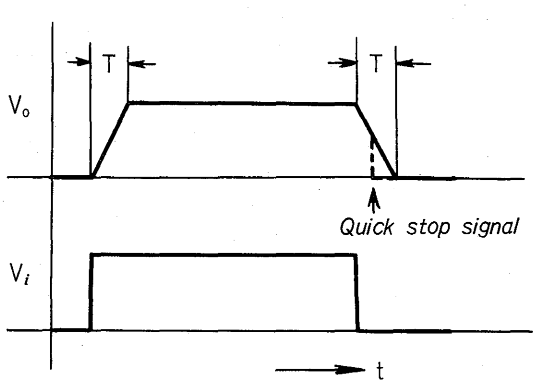



*Fig. 19* Input-output characteristics of slow starter

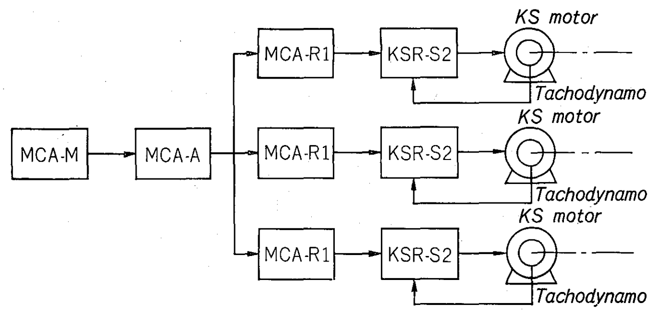



*Fig. 20* Ratio drive of conveyors

The unit consists of a transistorized constant current circuit, capacitor, and a transistorized amplifier. It makes use of the linear increase in the terminal voltage of the capacitor when charged by a constant current. *Fig. 19* shows the characteristics of output to input voltage. To accomplish symmetrical operation during the discharge process, the constant current circuit is combined with a diode bridge. Thus, the slope charactristic obtained during deceleration will be the same as that obtained during acceleration. Quick stop (shown by the broken line in *Fig. 19*) is also possible by making the appropriate connections to the external terminals.

Setting of the time limit for the MCA–A is based on the nominal time it takes the output voltage to change by 10 v.

Rough setting of this time limit can be accomplished by means of a switch (which changes the value of the capacitor). Fine adjustment is made by the proper setting of the constant current value. Arbitrary adjustments from 1 to 30 seconds are possible.

*Fig. 20* shows an example of combination of MCA–A and other items.

## VI. CONCLUSION

With development of the described 0.75∼45 kw brushless KS motors, all KS motors (including the water-cooled 15∼300 kw motors which already had brushless construction) now have brushless construction. As a result, KS motors are now provided as ac variable speed motors offering not only more durable construction, but also higher reliability and ease of maintenance and inspection. Moreover, both the development of a thyristor type KS speed controller and the standardization of the various Motor Controlling Adapters have made KS motors easier to handle; therefore, a wide range of applications and exhibit numerous features and capabilities.