UDC 621. 313. 2. 077. 3 : 621. 314. 63. 07

FUJI DSR TYPE THYRISTOR-LEONARD EQUIPMENT

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I. INTRODUCTION

The rapid progress of semiconductor techniques in recent years has resulted in the continuous development of compact, high capacity transistors, diodes, thyristors and integrated circuits. By utilizing such elements, Thyristor-Leonard equipment has become more efficient and compact with higher capabilities and fewer moving parts. As a result, the control ability is better, reliability is improved and handling is easier. With these features, the range of application of the equipment for speed control in all types of industry is rapidly expanding. The Fuji DSR type Thyristor-Leonard equipment (brand name) described in this article is a general purpose series combining in one unit a Fuji DS motor (brand name), a thyristor converter conforming to the motor characteristics and a control device for the converter. The output is suitable for the most commonly used DS motors of from 0.55 kW to 150 kW. The unit block system in which each unit handles one function is employed in the construction of the equipment. In this way, there is rapid response to various types of control and functional requirements. This article will introduce various aspects of the Fuji DSR type Thyristor-Leonard equipment.

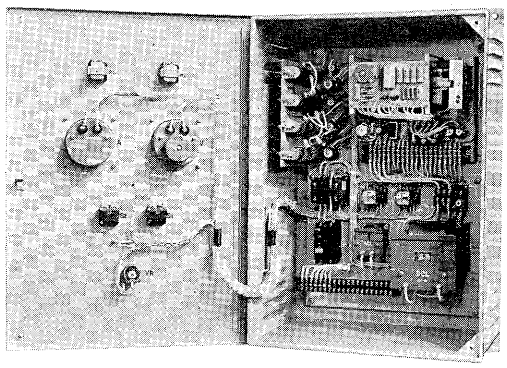


Fig. 1 Outer view of wall mounted type DSRWE–140/3.3

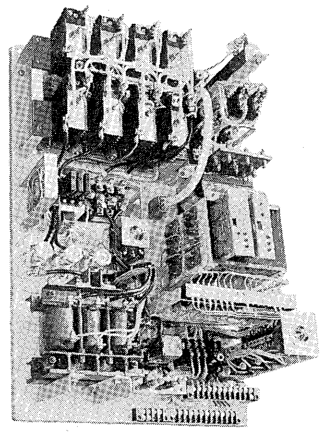


Fig. 2 Outer view of panel type DSRN–220/6.3

II. STANDARD SERIES

The Fuji DSR Thyristor-Leonard equipment is of the general purpose type and can be supplied rapidly to meet customers requirements. The series has been arranged after careful investigations of motor output, equipment construction and speed control systems.

1. Types

The types of this Thyristor-Leonard equipment differ according to construction, speed control, acceleration, rotating direction and the braking and field control systems. These differences are explained below and the circuits are given in section III.

1) Construction

(1) Wall mounted type (DSRWE and DSRW)

Fig. 1 is an outer view of this type of equipment. This equipment is for use with a DS motor of comparatively small capacity and is easy to install independently because of the wall mounting system. A DC reactor, AC molded case circuit breaker and AC magnetic contactor are supplied separately as options. Except for these, all required parts for main and control circuits are housed compactly in a steel plate case.

(2) Panel type (DSRNE and DSRN)

Fig. 2 is an outer view of this type of equipment. The internal parts of this equipment are exactly the same as in the wall mounted type. The only difierence is that the steel plate case is not provided since this type is intended for insertion in a panel.

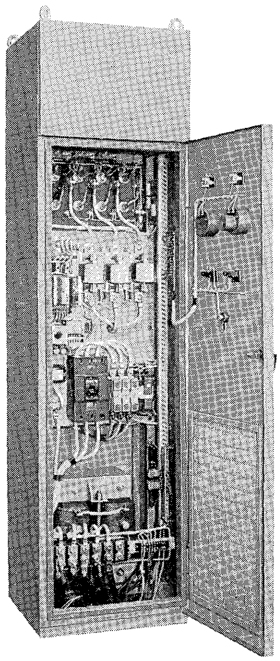


Fig. 3 Outer view of cubicle type DSRC-220/45

Table 1 List of wall mounted type and panel type

DSR Leonard equipment types: Wall mounted type	DSR Leonard equipment types: Panel type	Max. output capacity (kW)	Max. capacity of DS motor (kW)	Cooling system	AC supply
DSRWE-140/3.3	DSRNE-140/3.3	3.3	1.5	Self cooling	Single phase 200 V/220 V 50/60 Hz
DSRWE-140/5.6	DSRNE-140/5.6	5.6	2.2		
DSRW-220/6.3	DSRN-220/6.3	6.3	3.7		Three phase 200 V/220 V 50/60 Hz
DSRW-220/11.3	DSRN-220/11.3	11.3	5.5		
DSRW-220/17.2	DSRN-220/17.2	17.2	7.5		
DSRW-220/45	DSRN-220/45	45	22.0		

Table 2 List of cubicle type

DSR Leonard equipment type	Max. output capacity (kW)	Max. capacity of DS motor (kW)	Cooling system	AC supply
DSRC-220/6.3	6.3	3.7	Self cooling	Three phase 200 V/220 V 50/60 Hz
DSRC-220/11.3	11.3	5.5		
DSRC-220/17.2	17.2	7.5		
DSRC-220/45	45	22		
DSRC-220/78	78	45	Forced air cooling	
DSRC-220/107	107	55		
DSRC-220/128	128	75		
DSRC-440/214	214	125		Three phase 400 V/440 V 50/60 Hz
DSRC-440/256	256	150		

(3) Cubicle type (DSRC)

Fig. 3 is an outer view of this type of equipment. It forms an independent unit for installation in a vertical cubicle to be placed on the floor. All control units and parts required for motor speed control are included.

Tables 1 and *2* give the output, applied motor input, AC supply and other data for these three types.

2) Speed control system

There are two systems for speed control of the DC motor: the system in which counter e.m.f. of the motor is detected and fed back as input of the speed control circuit, and the system in which the speed is detected directly by a tachometer dynamo and fed back as input to the speed control circuit. The former system is known as a direct voltage regulator (DVR), while the latter is called as automatic speed regulator (ASR). This DSR Thyristor-Leonard equipment is divided into these two series. The letter V written after the equipment type designation stands for the DVR system and the letter S stands for the ASR system.

3) Acceleration system

There are two types of acceleration system for the DC motor: the constant acceleration system and the current limiting acceleration system in which the acceleration current is limited to a constant value. The constant acceleration system is indicated by the letter A after the V or S of the speed control system. When there is no letter following the V or S, the current limiting acceleration system is used. In this DSR Thyristor-Leonard equipment, the current limiting system is standard and the constant system is optional.

4) Rotating direction and braking system

The motor has a standard non-reversible drive and semi-standard reversible drive. Reversible drive operation is achieved by changing the polarity of the motor armatures using a magnetic contactor. The standard braking system is a no-brake system with natural attenuation caused by the braking force of the load. A dynamic braking system in which braking resistor is applied to both the positive and negative terminals of the motor only during braking is semi-standard. The accessories required for this dynamic braking system are optional. The type of braking system is indicated as follows after the acceleration system indication:

Non-reversible, no-brake system ....no letter
Non-reversible, dynamic system ....letter B
Reversible, dynamic system ....letter R

5) Field control system

There are many cases where field control is used in conjunction motor speed control. In this Leonard equipment, the constant field exciting system is standard. Up to certain determined speeds, there is counter e.m.f. control at a constant field. For higher speeds, an automatic field control system in which a wide range of speed control is possible by converting to constant counter e.m.f. and field weakening control and also employing counter torque and constant power control; and a manual field control system are semi-standard. The accessories required for these semi-standard systems are optional. The type of system used is indicated as follows after the rotating direction and braking system indications:

Constant field exciting system ....no letter
Automatic field control system............letter U
Manual field control system ....letter P

Summarizing all of the above mentioned indications, the type indication for one unit of DSR Leonard equipment is made up as follows:

$$\text{(equipment type)}-\begin{pmatrix}V\\ \\ S\end{pmatrix}\begin{pmatrix}\square\\ \\ A\end{pmatrix}\begin{pmatrix}\square\\ B\\ R\end{pmatrix}\begin{pmatrix}\square\\ U\\ P\end{pmatrix}$$

where □ means that no letter is used. For example, cubicle-type, DSR Leonard equipment with a 220 V, 22 kW, DS motor, ASR system, constant acceleration system, reversible braking system and constant field exciting system would be indicated as follows:

DSRC–220/45–SAR

The standard equipment is indicated as:

$$\text{(equipment type)}-\begin{pmatrix}V\\ S\end{pmatrix}(\square)(\square)(\square)$$

All other indications refer to semi-standard equipment.

2. Standard Specifications

The common standard specifications of this DSR Thyristor-Leonard equipment are shown in *Table 3*.

3. Manual and Auxiliary Stations

In addition to this DSR Thyristor-Leonard equipment are series of the MCA series of motor controlling adaptors which facilitate all type of control. In this MCA series, there are manual stations for start and stop and forward and reverse drive of the motor, slow starter stations used when the motor is started by the constant acceleration system, and auxiliary stations for cascade control with ratio drive, parallel drive and instrumentation controller for several units of equipment. As can be seen in *Fig. 4*, the stations are accomodated in compact cases and can be installed freely from the main Leonard equipment.

4. External Dimensions

Fig. 5 shows the standard external dimensions of the DSRWE and DSRW types, and *Fig. 6* shows those of the DSRC type. Dimensions of the semi-

Table 3 **Standard specifications of DSR Thyristor-Leonard series**

Item	Specifications
Rated input voltage	Type DSRWE, DSRNE: 1 φ 200/220 V 50/60 Hz Type DSRW, DSRN, DSRC: 3 φ 200/220 V 50/60 Hz or 400/440 V 50/60 Hz
Allowable AC input fluctuation	−15 to +10% of rated voltage −3 Hz to +2 Hz of rated frequency
Rated DC output voltage	DSRWE, DSRNE: DC 140 V DSRW, DSRN: DC 220 V DSRC: DC 220 V or DC 440 V
Rated field voltage	DC 180 V (incl. fixed resistor)
Overload capacity	150% of rated motor current is standard.
Speed control range	ASR system: 1 to $^1/_{20}$ of rated speed DVR system: 1 to $^1/_{20}$ of rated speed (1 to $^1/_{100}$ is possible in ASR system in case of no ambient temp. variation)
Control precision	ASR system: 1% (with 10 to 100% changes in rated speed and torque) DVR system: 3% (with 10 to 100% changes in rated speed and torque)
Allowable ambient temp.	−10°C∼+40°C

standard types are larger than those of the standard types. *Fig. 7* gives the dimensions of manual stations MCA–H4, H4R and H4S, while those of MCA–H5, H5R and H5S are shown in *Fig. 8*.

5. DS Motor

Fuji DS motors are intended for general use and are have a standard range of 0.55 to 75 kW. It has also motor output of 150 kW for general purpose Leonard equipment. The DS motor has three types of protection system: the drip-proof fully-guarded self-ventilated type, the open externally ventilated type and the totally enclosed non-ventilated type. The standard tachometer dynamo for use with the ASR system is of the shaft-mount type. *Fig. 9* is an external view of the 37 kW, 220 V DS motor.

III. CIRCUIT

The circuit is based on the standard type but semi-

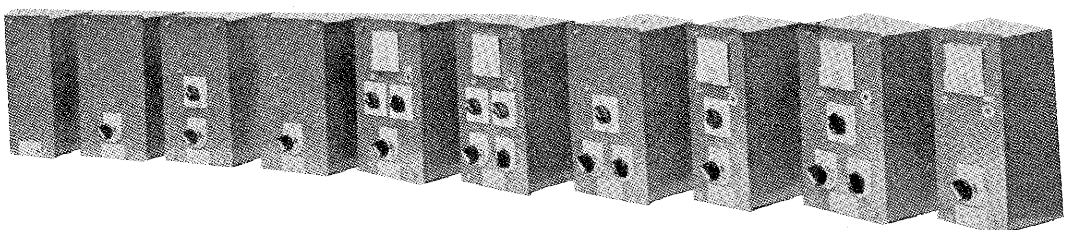
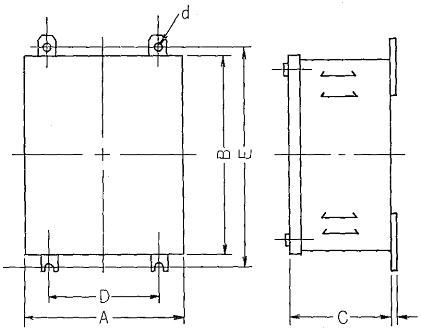
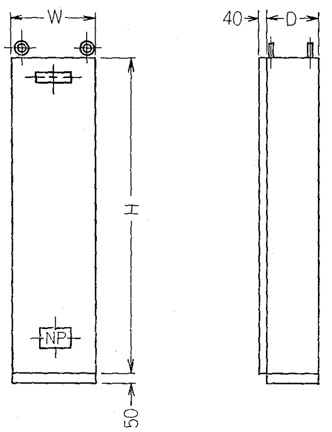


Fig. 4 Outer view of MCA series



Type	A	B	C	D	E	t	d (ϕ)
DSRWE-140/3.3	350	510	302	280	530	6	11
DSRWE-140/5.6	350	510	302	280	530	6	11
DSRW-220/6.3	580	840	302	510	870	6	14
DSRW-220/11.3	580	840	302	510	870	6	14
DSRW-220/17.2	580	840	302	510	870	6	14
DSRW-220/45	720	1,050	352	650	1,080	6	14

Fig. 5 Dimension table of type DSRWE and DSRW (standard series)



Type	W	H	D
DSRC-220/6.3	500	1,500	350
DSRC-220/11.3	600	1,700	350
DSRC-220/17.2	600	1,700	350
DSRC-220/45	800	1,900	600
DSRC-220/78	800	2,100	800
DSRC-220/107	1,000	2,100	900
DSRC-220/128	1,000	2,100	900
DSRC-440/214	1,000	2,100	900
DSRC-440/256	1,000	2,100	1,000

Fig. 6 Dimension table of type DSRC (standard series)

standard types can easily be constructed by adding the necessary options. The main explanation will be devoted to the standard types with supplemental

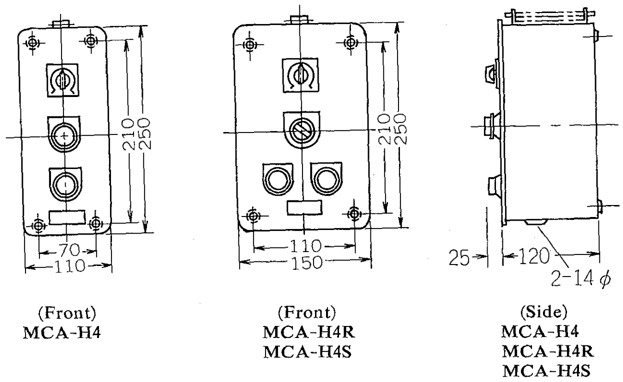


Fig. 7 Dimension of type MCA-H4, H4R, H4S

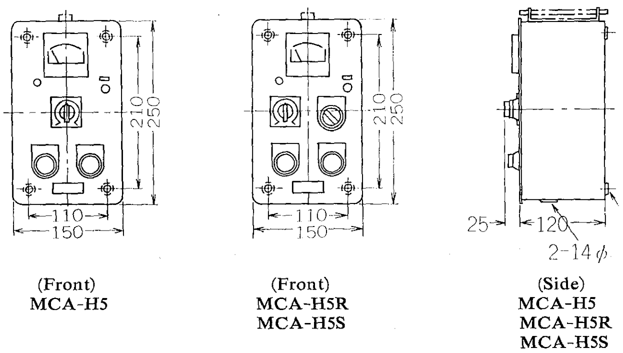


Fig. 8 Dimension of MCA-H5, H5R, H5S

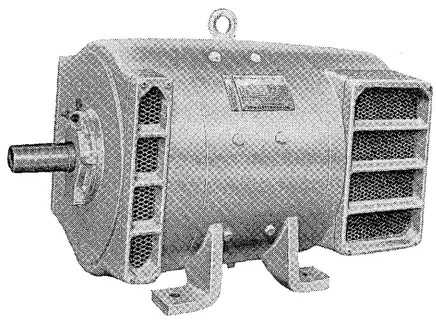


Fig. 9 Fuji DS motor 37 kW 220 V

explanations for the semi-standard types.

1. Block Diagram of Control System

Fig. 10 is a block diagram of the standard DVR control system for the DSRWE or DSRNE types. *Fig. 11* is a block diagram of the standard ASR control system for the DSRC type.

(1) Thyristor converter

The thyristor converter employs a mixed bridge connection system with thyristors and silicon diodes. The DSRC type of forced cooling system provides effective cooling by means of thyristor fins used in conjunction with AC and DC reactors. This system allows for a reduction in the external dimensions and weights of the reactors and the general equipment.

(2) Speed regulator

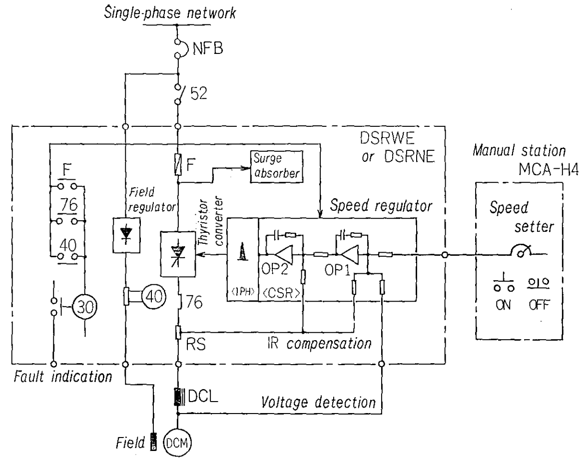


Fig. 10 **Block diagram of type DSRWE or DSRNE with DVR standard control system**

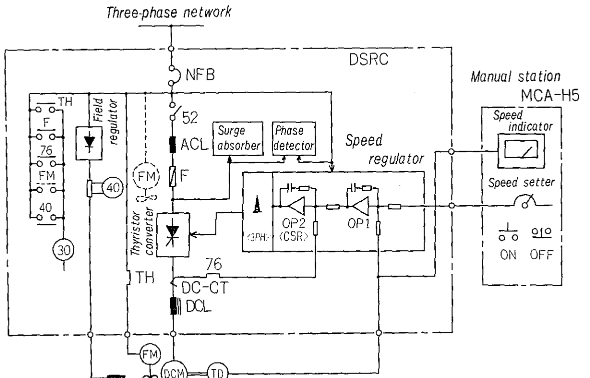


Fig. 11 **Block diagram of type DSRC with ASR standard control system**

The speed regulator consists of a speed current regulator ⟨CSR⟩, two gate shifters ⟨1PH⟩ or ⟨3PH⟩ and a constant voltage supply. The current speed regulator contains an operational amplifier, OP1, for current control and another, OP2, for speed control. It automatically controls the power source and rotational speed of the motor. The operational amplifiers are constructed mainly from linear integrated circuits. The constants have been chosen to allow for high reliability and stability indispensable in industrial applications. The amplifier is of the MICRO PACK MP–A construction.

A speed instruction from the manual station serves as standard input for OP1. Feedback input consists of motor counter e.m.f. in the DVR system and voltage of the tachometer dynamo TD in the ASR system. These inputs form main speed control loop. The output voltage of OP1 becomes the current instruction input of OP2. The current feedback voltage detected by the DCCT or the series resistor drop serves as the feedback input of OP2. These inputs form a minor current control loop. Each amplifier contains PI regulator elements which match the control loop characteristics and optimum regulation for stable speed control is achieved. The output voltage of OP1 serves as the current instruction for the motor and high precision current limiting control is achieved by means of the sharp saturation characteristics of the MICRO PACK MP–A. The OP2 output voltage controls the triggering phase of the thyristor in the thyristor converter by means of the subsequent gate shifter. It also controls motor voltage and current. Details of the speed current regulator and the gate shifters are given in section III–2 and III–3.

(3) Phase detector

When there is a discrepancy in the phase rotation during external wiring in the case of a three-phase power supply, the Leonard equipment will not operate stably. This equipment contains a simple phase detector consisting of a resistor, capacitor and neon lamp. When there is a mistake in the phase connections, the neon lamp flashes and erroneous connections can be prevented.

(4) Field regulator

The simple field regulator which consists of a single thyristor and diode bridge facilitates field current setting. It is more compact and efficient than the previous series resistor type.

(5) Indicator circuit

Indicator relay (30) is operated when the fuse (F) for the thyristors is blown, the DC overcurrent relay (76) operates, field relay (40) is switched off, the overcurrent relay (TH) is switched on in equipment with a motor cooling fan, or the air flow relay (FM) is switched on in equipment with a thyristor cooling fan. When this relay is operated, it interlocks with the starting circuit and stops the Leonard equipment.

(6) Surge absorber

In equipment for use with a power supply of AC 200/220 V, exterior surge voltages from the power supply side are limited to values below the PRV values of the thyristors and silicon diodes by means of a circuit composed of a capacitor, resistor, silistor and lightening arrester. This circuit provides sufficient protection for the semiconductor elements. This surge absorber circuit is mounted compactly on a printed board. In equipment for use with an AC 400/440 V power supply, a bridge type surge absorber consisting of a silicon diode, capacitor and resistor is employed. This not only effectively absorbs surge energy but also suppresses turn-on currents which increase rapidly to the thyristors.

(7) Over-current protection

When the control circuit is operating normally, overcurrent above the current limiting value never flow in the thyristor converter or the motor.

However, when overcurrent continue for a long time even when they are within the current limiting range, DC overcurrent relay (76) operates. When large overcurrent occurs for a short time during some fault, fuse (F) on the AC side is blown and damage to the thyristors and silicon diodes is prevented. In all cases, indicator relay (30) operates and the Leonard equipment is stopped.

2. Speed Current Regulator

The speed current regulator is the most important part of the Thyristor-Leonard equipment since it determines the control capabilities of the equipment as a whole. The control capabilities of the regulator are in turn determined by the capacity of its operational amplifiers. In this regulator, the operational amplifiers consist mainly of liner integrated circuits whose constants are selected to permit the high stability and reliability required in industrial applications. Since the MICRO PACK MP–A type with an outer shield mold are used, the capabilities of the Leonard equipment are increased above the high gain (about 20,000) and high reliability of the linear integrated circuits. For example, if the ambient temperature range is constant, it is possible to keep the speed fluctuation at ±0.1% and achieve a speed control range of 1 to 1/100 in the ASR system. The amplifying characteristics of the MICRO PACK MP–A are as shown in *Fig. 12*. *Fig. 13* shows the circuit of the current-speed regulator. OP1 is the operational amplifier for speed control and OP2 is for current control. The standard DC powers supplied for control are +12 V (P), 0 V (M) and −12 V (N). The rated output of the operational amplifiers is 0 to ±10 V. The PI regulation of both the speed and current control loops is performed by the variable resistors VR1 and VR2 in the case of P regulation and presetting of the C1 and C2 capacitors in the case of I regulation. VR3 is a variable resistor used for setting the current limiting value. Since this equipment employs these compact operational amplifiers with high amplification factors, the accessories can also be compact and have low power requirements. Thus the regulator as a whole is very compact and is mounted on one standard Fuji printed board (100×169 mm) as shown in *Fig. 14*.

3. Gate Shifters

The circuits of the gate shifters differ somewhat depending on whether the AC source is single phase or three phase.

1) Gate shifter for single phase

Fig. 15 shows the circuit of gate shifter for single phase. This gate shifter contains a DC constant voltage circuit which rectifies the secondary side of

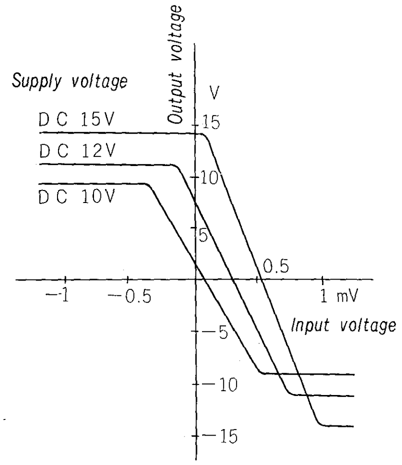


Fig. 12 Amplifing characteristics of type MICRO PACK MP–A

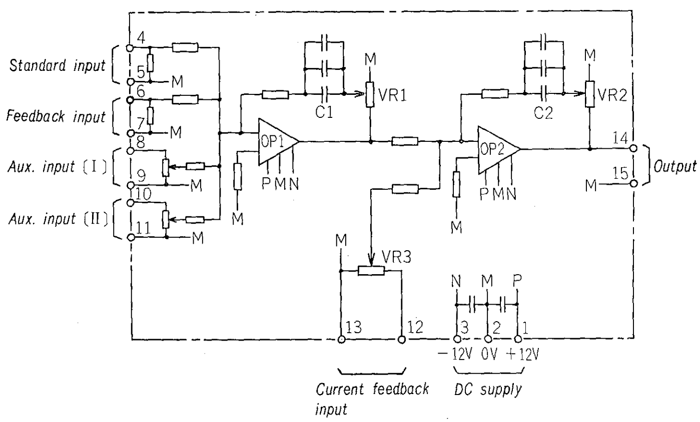


Fig. 13 Circuit of current-speed regulator

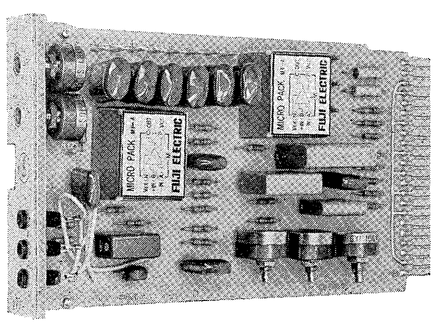


Fig. 14 Printed board of current-speed regulator

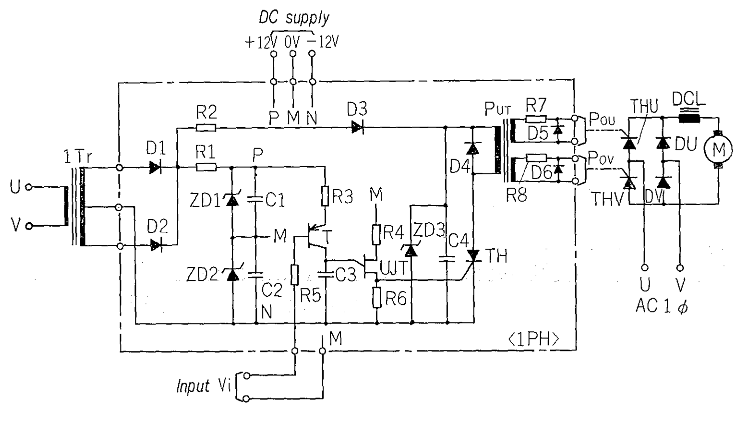


Fig. 15 Circuit of gate shifter for single phase

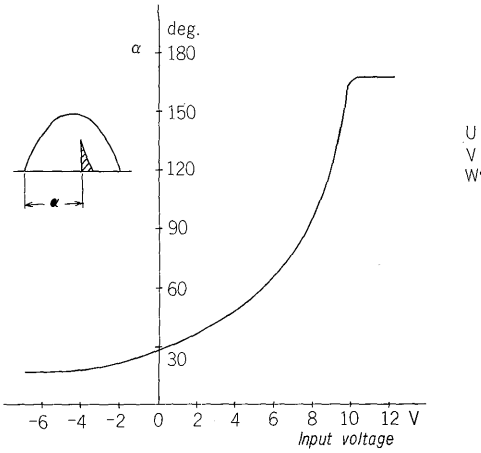


Fig. 16 **Characteristics of gate shifter for single phase**

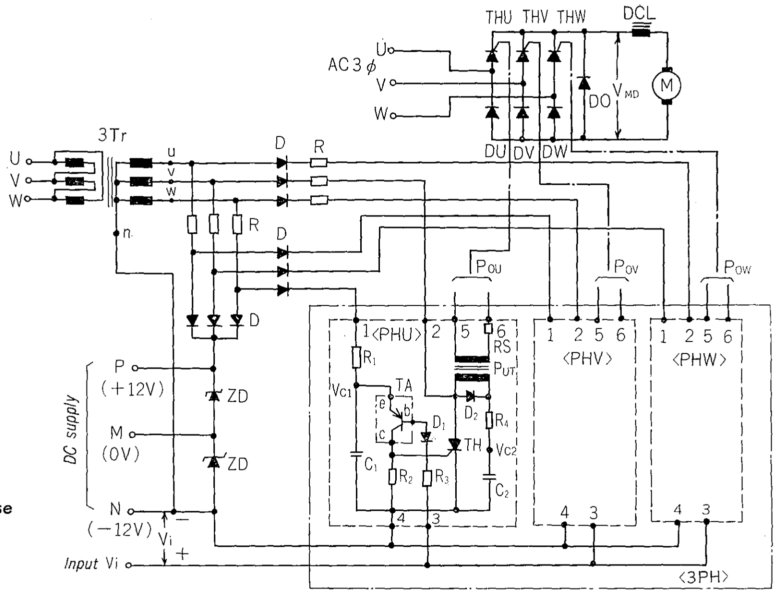


Fig. 17 **Circuit of gate shifter for three phase**

transformer 1TR attached to the center tap, and supplies the control source P (+12 V), M (0 V) and N (−12 V). P, M and N are also supplied to the speed-current regulator. Transistor T controls the discharge current of capacitor C_3 in accordance with the magnitude of the input voltage V_i from the speed-current regulator output. The on time of the uni-junction transistor is altered, the pulse is amplified by the thyristor TH and pulse transformer P_{UT}, and a triggering pulse is supplied to the thyristor converter. Pulse outputs P_{OU} and P_{OV} are the same triggering pulses given out every other half cycle, but the thyristor converter output is the wave form of a single phase mixed bridge since the thyristor converter is turned on only by thyristors with positive forward voltages.

Fig. 16 shows the characteristics of this gate shifter. The ⟨1PH⟩ part enclosed by the broken line in *Fig. 15* is mounted on one standard printed board, 100 × 169 mm.

2) Gate shifter for three phase

Fig. 17 shows the circuit of gate shifter for three-phase. This gate shifter consists of the ⟨3PH⟩ part enclosed by the chain line (······) in the figure. This ⟨3PH⟩ part is divided into the ⟨PHU⟩ ⟨PHV⟩ and ⟨PHW⟩ parts for the U, V and W phase shifting circuits respectively. Control source P (+12 V), M (0 V) and N (−12 V) are supplied by an external DC constant voltage power supply. Operation of the U phase will be described below.

Fig. 18 shows the dynamic mode for the U phase. The waveforms of the control source N between the point V_{C1} on the positive side of the discharge capacitor C1 and ⟨PHU⟩ input 1 is shown in (c). The waveforms of the phase relations between AC power supplies UV, VW and WU are shown in (a) and the voltages between control source N (transformer 3Tr neutral point n) and the points u, v and w on the secondary side of three-phase transformer

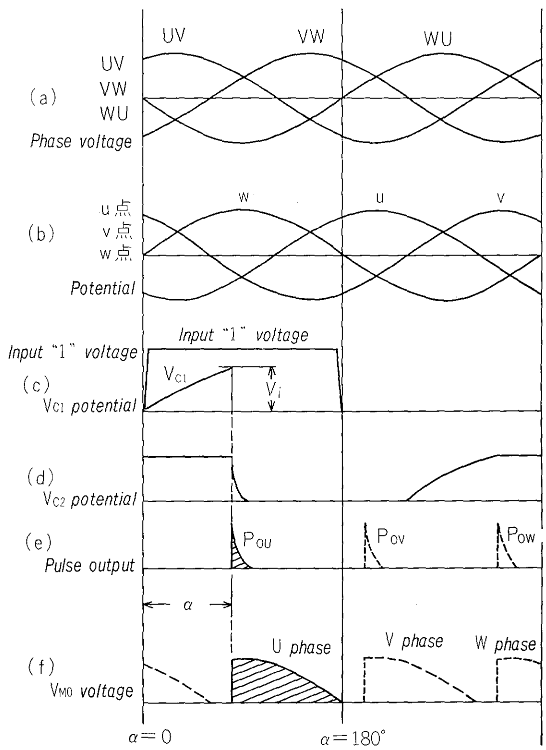


Fig. 18 **Dynamic mode of gate shifter for three phase (U-phase)**

3TR are shown in (b). The T_A part within the ⟨PHU⟩ part is an amplifier circuit consisting of two transistors. There is a positive feedback connection between the two transistors and they are used for operation both as uni-junction transistors and as thyristors. In other words, if the voltage between point e and control source N is equal to or greater than the voltage between point b and control source N, the point e is short circuited and the voltage between points e and c becomes zero. Then the short circuit is removed. Therefore, if the voltage between N and point V_{C1} in (c) and the input voltage V_i from the speed-current regulator are equal, transistor T_A is turned on, the load of capacitor C_1 is supplied to the gate of thyristor TH and thyristor TH is turned on.

At this time, as is shown in (d), capacitor C_2 is discharged by the peak voltage between N and the point v in the previous cycle. This causes the trigger pulse P_{OU} as shown in (e) to occur on the secondary side of pulse transformer P_{UT} due to the turning on of thyristor TH. Then the U-phase thyristor THU of the thyristor converter is turned on and its output is the voltage V_{MO} with the waveform as shown in (f).

Therefore, if the input voltage to input 1 of ⟨PHU⟩ is constant and the discharge time constant determined for R_1C_1 is constant, the voltage rise at point V_{C1} will also be constant. The phase angle α is changed when V_i is equal to the voltage between N and point V_{C1} due to a change in input voltage V_i and it is possible to perform phase control in this way. The feature of this gate shifter is that there is very little phase unbalance in the shift characteristics even when the discharge time constants of R_1C_1 differ slightly among the phases. This feature is especially effective when α is small. There is thus no special need for a resistor to control phase unbalance. *Fig. 19* shows the characteristics and *Fig. 20* shows an outer view of the printed board of this gate shifter. The three parts ⟨PHU⟩ ⟨PHV⟩ and ⟨PHW⟩ for the phases U, V and W are all mounted on one standard printed board (100 × 169 mm).

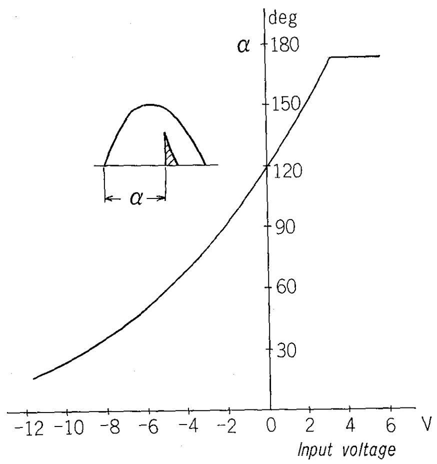


Fig. 19 Characteristics of gate shifter for three phase

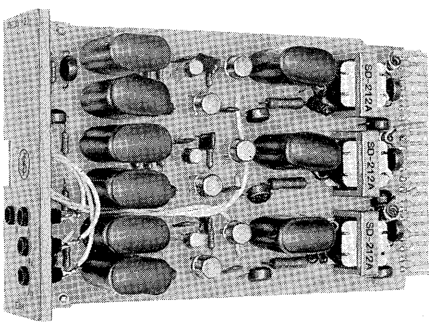


Fig. 20 Printed board of gate shifter for three phase

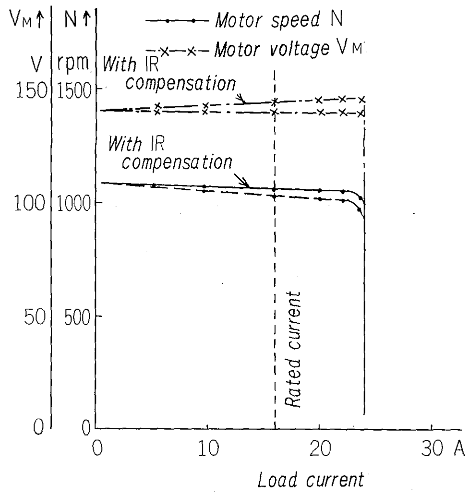


Fig. 21 Load regulation characteristics of type DSRWE-140/3.3 with DVR system (Motor 1.5 kW 140 V 1,050 rpm)

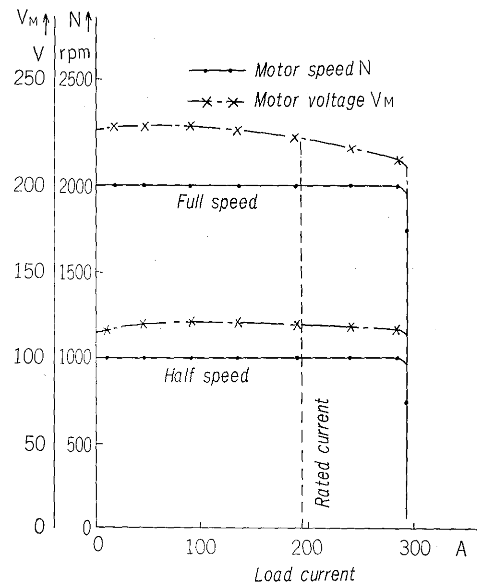


Fig. 22 Load regulation characteristics of type DSRC-220/45 with ASR system (Motor 37 kW 220 V 2000 rpm)

IV. CHARACTERISTICS

1. Static Characteristics

Fig. 21 shows the load regulation characteristics of the DSRWE-140/3.3-V type Leonard equipment with the DVR system and a 140 V 1.5 kW motor. The percentage of motor speed fluctuation even in the case of a full load change is only about 3%. Therefore since IR compensation is used, the motor voltage is increased in accordance with increases in load current. *Fig. 22* shows the load regulation characteristics of the DSRC-220/45-S type Leonard equipment with the ASR system and a 220 V 37 kW motor. In both cases, the current limiting value is 150% of the rated current.

2. Dynamic Characteristics

Fig. 23 and *24* are oscillograms of acceleration characteristics due to current limiting in the DSRWE-

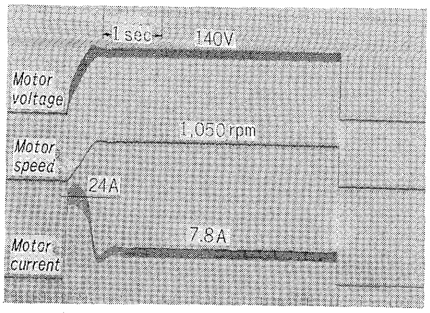


Fig. 23 Oscillogram of acceleration of type DSRWE-140/3.3-V (Motor 1.5 kW DC 140 V 1,050 rpm)

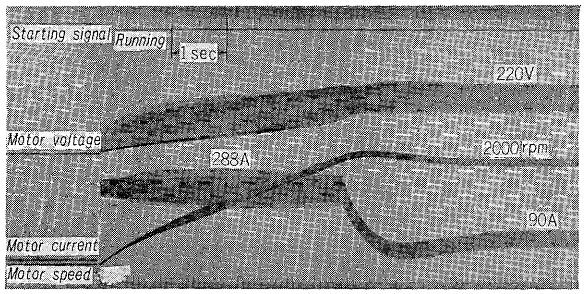


Fig. 24 Oscillogram of acceleration of type DSRC-220/45-S (Motor 37 kW DC 220 V 2,000 rpm)

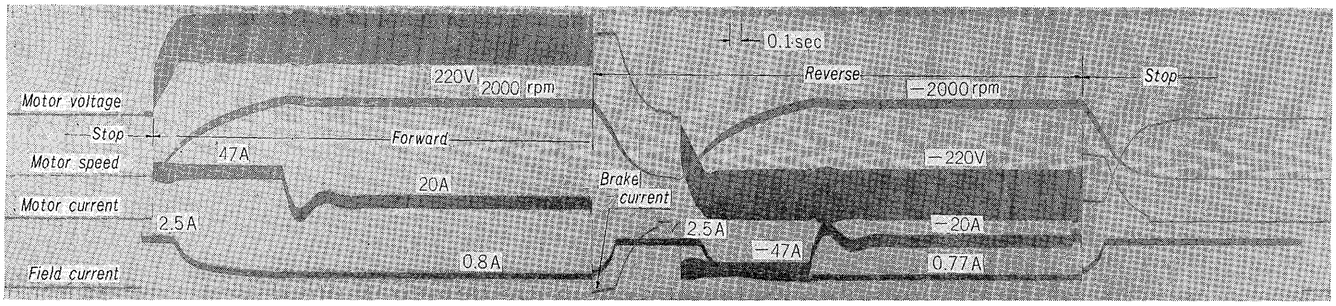


Fig. 25 Oscillogram of acceleration and deceleration of type DSRC-220/11.3-SRU (Motor 5.5 kW DC 220 V 2,000 rpm)

140/3.3-V and DSRC-220/45-S types respectively. *Fig. 25* is an oscillogram showing the acceleration and deceleration of DSRC-220/11.3-SRU type Leonard equipment with the ASR system, a 220 V 5.5 kW motor, a current limiting accerelation system, a reversible dynamic braking system and an automatic field regulation system.

When the motor is operating in the forward direction, and operation is changed to reverse, the forward magnetic contactor is cut out, the dynamic brake is actuated, the field is automatically controlled from weak to strong and the motor is decelerated.

When the motor speed is almost zero, the zero voltage detecting relay operates, the reverse magnetic contactor is actuated and the motor is accelerated to the reverse speed. Simply by turning the operation switch to forward, reverse or stop; automatic forward, reverse or stopping operation is possible.

V. APPLICATIONS

This DSR type Thyristor-Leonard equipment can be employed with motor capacities of from 0.55 kW to 150 kW. Therefore, it is general purpose equipment for use anywhere within that range. There are three standard series: the wall mounted type, panel type and cubicle type. The installation space can thus be freely chosen. By using the equipment in combination with the MCA series, it is easy to satisfy a wide range of control requirements. Since a speed control range of 1 to 1/100 of the rated rotational speed is possible, it is possible to achieve stepless control from very small to very high speeds without gears when this equipment is used in cases where control was formerly achieved by gear changing. This is especially valuable in the control of machine tools where the requirements have been increasing recently. The equipment can also be employed in many other fields including iron and steel, paper, ship winches and spinning.