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ELECTRICAL EQUIPMENT FOR OFFSHORE RIG HAKURYU No. 2 OF JAPAN PETROLEUM DEVELOPMENT CORPORATION

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I. INTRODUCTION

Fuji Electric recently delivered a set of power supply equipment and excavation electrical equip ment for the Hakuryu No. 2 offshore rig of Japan Petroleum Development Corporation. This equipment employed completely new control systems such as the thyristor Leonard control system which was used for the first time in Japan for the main circuit control of excavation motors. An outline of this equipment is given in this article (*Fig. 1*).

The Hakuryu No. 2 is one of the world's largest semi-submersible type rigs with an excavation depth capacity of 9,000 m and a maximum working ocean floor of 200 m.

II. EXCAVATION EQUIPMENT AND REQUIRED CHARACTERISTICS

1. Construction of Excavation Equipment

The following is a simple explanation of the types of equipment used as excavation machinery (*Fig. 2*). First the bit which is attached to the front end of the drill pipe is lowered to the well bottom. By turning the drill pipe at the ground level, the bit is provided with an appropriate load and rotation and the soil is excavated. The bit is lubricated and cooled by the muddy water which is sprayed out from the bit tip through the drill pipe. Simultaneously, the removal and collection of chips is performed by the muddy water which circulates up the ground level between the outside of the drill pipe and the wall. The drill string for the excavation consists of, from the top, the drill pipe, drill collar and bit which are all connected in that order. All of these have sufficient bore for the circulation of muddy water. The main functions of the drill pipe are circulation of the muddy water, transfer of the turning movement to the bit and chinning below the drill collar. However, a tool joint is connected for the hoisting and lowering work during replacement of the bit. The drill collar is a thick steel pipe used to provide the required load for the bit.

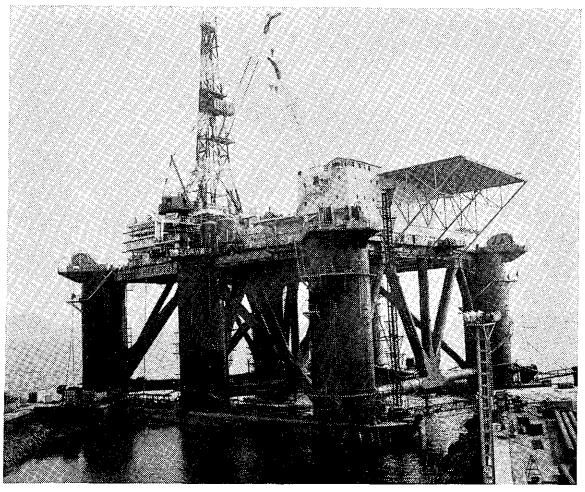

Fig. 1 General view of Hakuryu No. 2

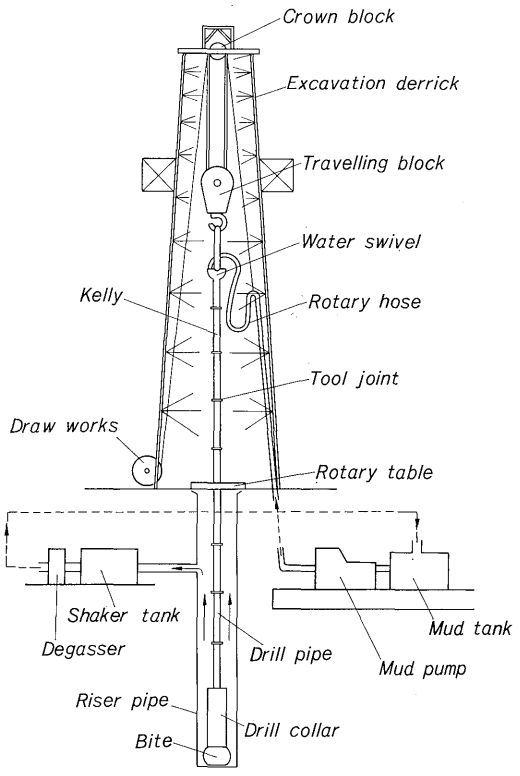

Fig. 2 Basic component of a drilling rig

The upper end of the drill bit is connected to the kelly which is suspended from the travelling block via the water swivel. The circulating muddy water is supplied to the water swivel by the rotary hose. The rotation of the rotary table is transferred to the kelly via the bushing.

2. Required Functions of the Excavation Machinery

The excavation factor of the well is naturally influenced considerably by the quality of the soil. However, the bit loads, rotation speed and chip removal capacity matched with the soil quality also have a great effect. Therefore, efficient, economical excavation can be achieved by balanced operation of the draw works, rotary table and mud pump.

1) Draw works (refer to *Fig. 3, Fig. 4*)

The draw works hoist the gross weight of the drill pipe during normal excavation with a lift of approximately 30 m from the top of the rotary table. During insertion of the casing, the works must hoist the total weight of the casing from the well bottom. In order to avoid impact distortion to the derrick, fittings and other equipment and also to prevent deterioration of the inside of the well, it is necessary to start the hoisting at a low speed and then be able to accelerate rapidly in order to speed-up the work after starting.

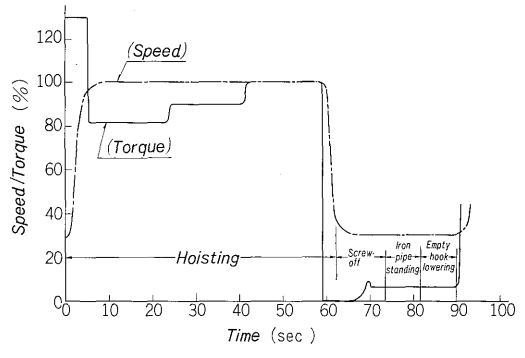

Fig. 3 Conceptional curve of hoisting character

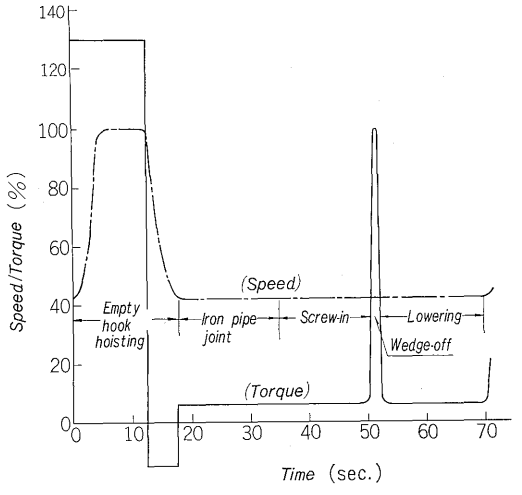

Fig. 4 Conceptional curve of lowering character

Table 1 **Maximum Lifting Rate**

Position	Reduction gear ratio	Load hoisting speed (m/sec)	Max. lifting rate (ton)
1	1 : 0.0669	0.33	374
2	1 : 0.1194	0.58	212
3	1 : 0.2140	0.05	114
4	1 : 0.3748	1.85	68

During normal operation, the hoisting of an empty hook during lowering from just over the rotary table to the top of the drill pipe stand should require a minimum of 10 to 15 seconds. In the case of deep wells with large loads, the hoisting time should also be as short as possible so that the inside of the well shaft does not deteriorate.

In order to make maximum and minimum load operation easy, the draw work have a multi-level transmission for speed conversion. In the Hakuryu No. 2, there is a four foward level transmission. Relations of gear ratios of main motor vs drum are shown in *Table 1.*

The hoisting the lowering work for bit replacement requires about half the time required for excavation work. It is highly desirable that the hoisting and lowering work be very efficient in off-shore drilling where the costs per time are very high. Therefore in this equipment, the efficiency of the hoisting and lowering work has been increased by providing equipment with the speed/torque characteristics as shown in *Fig. 5.*

2) Mud pump

The mud pump is a horizontal type reciprocating piston pump. The pump characteristics are basically constant torque with the ejection pressure regulated by changing the liner and the ejection amount regulated by altering the runner and rotating speed. The mud pump is also used for cementing work but in such cases, delicate work characteristics are required and therefore the drive motor characteristics should be such that the drive motor rotating speed decreasing in proportion to the load torque when the load torque increases.

3) Cementing pump

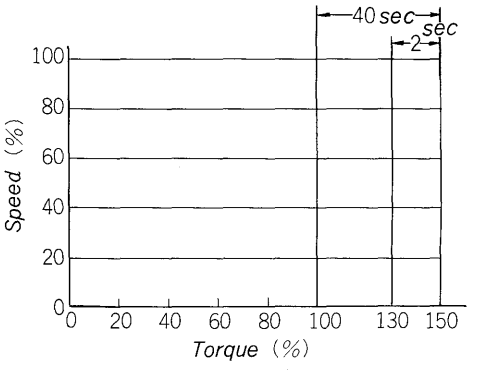

Fig. 5 Speed-torque character for DW motor

Cementing is filling cement between the casing inserted in the well and the well wall. No special characteristics need be considered for the motor.

III. SPECIFICATIONS AND FEATURES OF MAIN EQUIPMENT

1. Main Generator

Type :	Drip-proof, 3-phases self-exciting AC synchronous generator
Number :	Four
Output :	1,350 kVA 720 rpm (power foctor 0.7 lag) continuous
Voltage :	500 V 60 Hz 3 phase
Insulation :	B class
Exciting system :	TR system
Accessories :	Automatic voltage regulator, with cross current compensator, automatic synchronizing and load balancing device
Drive engine :	Fuji Diesel type
Type :	12 VN 2.5 CH 1,700 PS 720 rpm

The load of the power supply generator occupies a large percentage of the capacity of the excavation equipment (thyristor Leonard control). Therefore, it is necessary to consider the heat applied to the damper winding of the generator due to the higher harmonic current caused by the commutation of the thyristor. These special considerations concerning the damper winding were used for design and munufacture.

The equivalent reverse phase current absorption factor of the generator generally has an effective value of around 12%. However, in this equipment, this absorption factor is very high, 25%.

2. Auxiliary Generator

Type :	Drip-proof, three phase, self exciting AC synchronous generator
Number :	One
Output :	250 kVA 1,200 rpm (pf 0.8 lag) continuous
Voltage :	450 V 60 Hz 3 phase
Insulation :	B class
Exciting system :	TR system
Accessories :	Automatic voltage regulator

3. Drive Motor for Excavation Machinery

Type :	Internal-pressure explosion-proof, forced-cooling DC shunt motor
Number :	Nine
Output :	600 kW
Voltage :	DC 0 to 600 V
Ratings :	Continuous
Rotating speed :	0 to 1,100 rpm
Insulatioh :	F class
Accessories :	Tachogenerator for speed detection

Of these nine motors to power the excavation equipment, three are used for the draw works, four for the mud pump and two for the cementing pump. Operation of the draw works employs two or three motors depending on the load conditions. In both cases, the motors are mechanically coupled with a chain. When an inverter circuit is added to the No. 1 draw works and an empty hook is lifted during loworing work, regeneration takes place in the power supply and the load is rapidly stopped. In such cases, draw works No. 2 and 3 are mechanically coupled by the driving shaft and shifting the ignition angle, they are electrically in off-state by thy ristor. There are two mud pumps, No. 1 and No. 2, and each of these are mechanically coupled with two motors.

The motors used for the excavation equipment must operate under rigorous conditions as mentioned above and their accelerating time exerts considerable influence on the operation efficiency. For this reason, mill motors of the type specified in JEM-600 with small GD^2 are used. In each motor, there is a control tachogenerator for speed detection inside the frame on the anti-coupling side. The motors are all of the same size and the same ratings so that they can be interchanged.

1) Draw works motors (*Fig. 6*)

The draw works motors are located near the oil well where there is an atmosphere of explosive gas

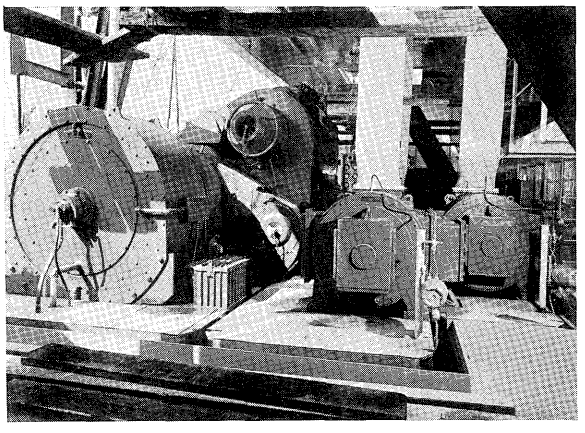

Fig. 6 Outerview of draw works motor on the ship

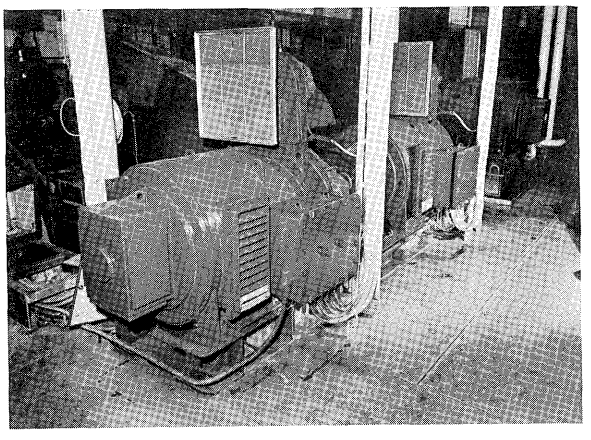

Fig. 7 Outerview of mud pump motor on the ship

under normal conditions of motor use. For this reason, the inner-pressure explosion-proof construction is used and during operation, the motors are normally ventilated with pure air. The inner pressure of the draw works motors is higher than the external air pressure during operation. Therefore, an explosion-proof type differential pressure transmitter is provided in the draw works motors for inner pressure detection. With this device, the pressure inside the motors can be monitored during operation.

There is one blower motor for the three draw works motors and it is connected so that pure cooling air is supplied to all three. The blower motor is a totally enclosed outdoor cage type induction motor which is located outdoors away from the oil well. The blower itself is a turbo-fan.

2) Mud and cementing pump motors (*Fig. 7*)

The mud and cementing pump motors are also of the inner pressure explosion proof construction so that they can be interchanged with the draw works motors. However, the blower motor is of anti-explosion proof construction because of the location.

4. DC Motor Panel

This panel consists of three panels connected in series: the AC panel, thyristor panel and DC main circuit panel.

The AC panel is in series with the AC main switchboard and the power supply bus bar is a sheathed bus bar inserted directly into the panel from the AC main switchboard. The panel is more compact since terminal connection space used by external connection terminals is eliminated.

Each of the three panels in series is coupled by a bus bar box and all panel connections from the AC main switchboard to the output terminal of the DC reactor are made by exposed conductors. The switchboard forms a single unit.

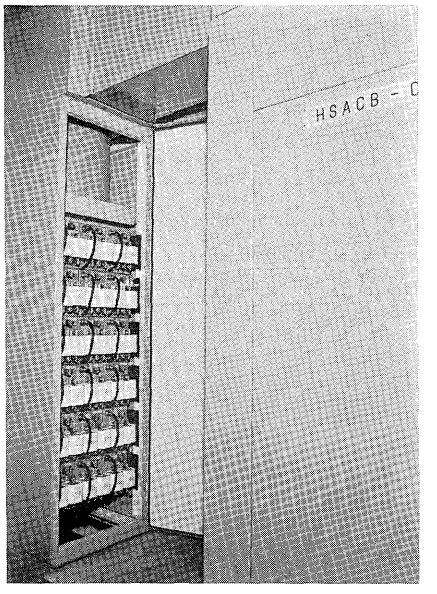

Fig. 8 Innerview of the thyristor panel

1) AC panel

The AC panel consists of one power supply panel, six AC panels and one distribution board. It is connected in series with the AC main switchboard and is of the drip-proof, floor mounting dead frame construction.

The front surface of the panel contains the devices required for supervisory control such as meters, indicators and control switches.

2) Thyristor panel (*Fig. 8*)

The thyristor panel was manufactured with complete consideration given to special shipboard conditions such as salt, humidity and vibrations. The thyristor panel consists of seven thyristor converter panels, five TRANSIDYN panels and one air cooler panel connected in series. Air ducts are provided on the top and bottom of the panel and a totally enclosed air circulation cooling system is employed (refer to *Fig. 9*).

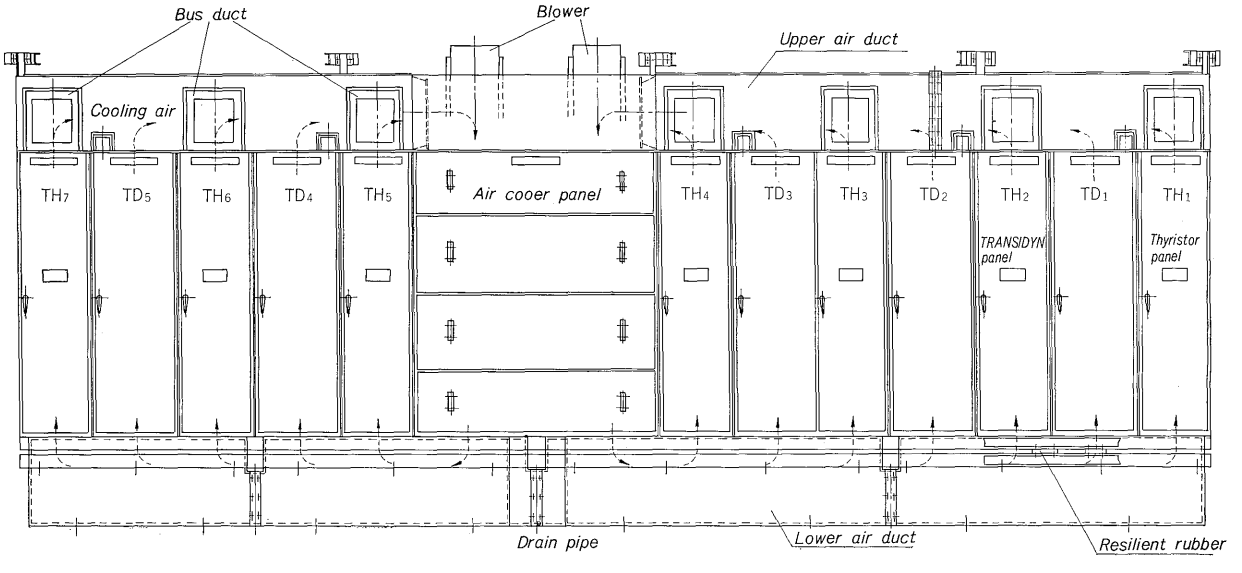

Fig. 9 Outline of thyristor panel

The cooling air is sucked up by the cooling fans in each panel and enters the air cooler panel via the top air duct. It is then returned to each panel via the booster fan, air cooler and bottom air duct. A space heater is provided in the bottom air duct to prevent dew from forming when the machinery is not operating.

This panel is fixed to the floor via resilient rubber which provides sufficient damping is respect to vibrations from the engine. The anti-vibration effects are further enhanced by the use of flexible leads in the conductors and flexible piping for cooling water piping. Special attention was given to the thyristor arrangement. In order to avoid the effects of noise from the exterior, the control wiring was shortened considerably and equipment work was simplified.

(1) Thyristor converter panel

Thyristor converter panel consists of 1S・3P・6A construction with 18 drawer-type thyristor units accomodated in a cubicle (BAKGP 02-25 A, AC 2,500 V, 400 A elements). The printed boards for the thyristor gate pulse transmission circuit are of molded finish in consideration of shipboard conditions.

(2) TRANSIDYN panel (*Fig. 10*)

The TRANSIDYN panel consists of standard tray type units in a cubicle. The printed boards for the TRANSIDYN equipment have a special coating for wet and corrosion proofing. All of the connectors are plated. Special metal braces are used in the tray unit printed board insertion parts as a measure against vibrations so that the printed boards always are maintained in the correct position.

(3) Air cooler panel

The air cooler panel consists of two air coolers, a blower motor and an air duct accomodated in a cubicle. The blower motor is provided to compensate for windage loss inside the air cooler and duct and a turbo-fan is attached at both the left and right shaft ends of the motor. The air coolers have a 50 kW heat exchange capacity. The quantity of cooling water is 300 ℓ/min., the maximum temperature of the pure cooling water is 33°C and the ambient temperature is 50°C.

3) DC main circuit panel

The DC main circuit panel consists of three DC reactor panels, one space heater panel, one blower panel and one high-speed air circuit breaker panel. All of these panels are connected in series and are of the drip-proof floor type. The front surface of the panel contains all of the devices required for supervisory control such as meters, indicators and control switches. A graphic panel is provided for monitoring of the switching conditions of the disconnecting switch and the equipment operating conditions. Instruments are all centralized around this panel.

5. Motor Control Panel and Controllers

The motors for the excavation machinery are provided with a control panel and controller at the machine site so that operation control is possible when main circuit switching and operation preparation conditions are achieved in the DC motor panel in the engine room.

1) Draw works motor control panel (*Fig. 11*)

This control panel is of the outdoor water-proof, inner-pressure explosion-proof type and is located on the draw works air control panel. All of the devices attached to the panel are water-proof and supervisory instruments such as the ammeter, tachometer and indicators are encased in hard glass to facilitate supervision at the site.

The air control panel under this panel contains a reducing valve and air filter for inner-pressure

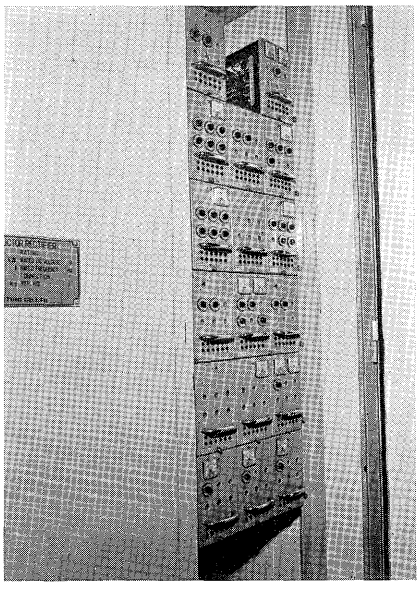

Fig. 10 Innerview of TRANSIDYN panel

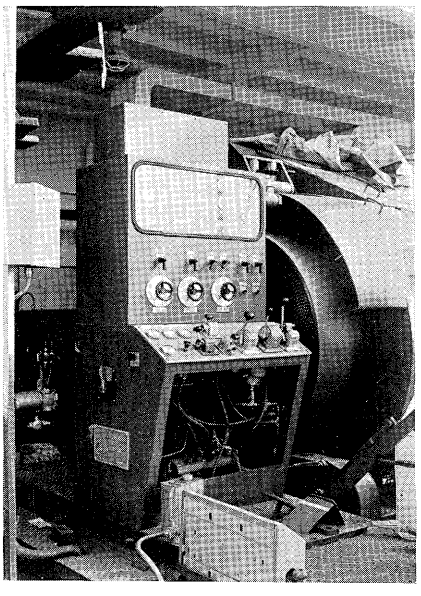

Fig. 11 Outerview of DW operator panel

explosion-proofing of the control panel. Air of 7 kg/cm^2 can be supplied inside the panel by pressure reduction. There is an air exhaust valve located on the upper left side of the panel. This valve exhausts any gas remaining inside the control panel during operation. A TELEPERM type differential pressure transmitter is provided on top of the panel for supervision of the pressure inside the panel during operation. *Fig. 11* shows the condition with the front door of the air control panel removed.

2) Foot type motor controller for the draw works

This foot type motor controller (pedal is seen in lower right side of *Fig. 11*) is located in the drill floor and is used for speed control of the draw works motors during hoisting and lowering work. The spring and through-shaft bush of the controller are made of corrosion resistant materials since the controller comes into contact with alkaline muddy water.

The controller is of water-proof anti-pressure explosion proof construction and it contains a limit switch and variable resistor of the same construction as the variable resistor for the master controller used in the motor control panel. Conrol is achieved by meshing of the fan shaped gear directly connected to the foot pedal with the pinion attached to the variable resistor. When the foot pedal is pressed all the way down, operation is at full speed. It is at idling speed when the foot pedal is stopped by the stopper, and the motor is stopped when the stopper is removed and the pedal returns to its uppermost position.

3) Mud pump motor control panel

This panel is of the desk type and controls the operation of the No. 1 and No. 2 mud pumps. All of the devices used in the panel are of water-proof construction and all of the supervisory instruments such as the ammeter, tachometer and indicators are encased in hard glass to facilitate monitoring.

4) Cementing pump control panel

This panel is located on top of the cementing pump machine-side operating panel. All of the devices used in the panel are of water and dust proof construction and the supervisory instruments such as the ammeter and indicators are encased in hard glass to facilitate monitoring.

IV. CIRCUIT CONSTRUCTION AND CONTROL REQUIREMENTS

1. Power Source Circuit Construction

The main circuit of the power source is shown in *Fig. 12*. The generator output is all fed as load via the step-down transformer except for the excavator power. In other words, the output is fed to the 440 V line via the power transformers (650 kVA × 3) and to the 110 V line via the lighting transformers (40 kVA × 3).

When the transformers are connected in the system, an exciting rush current of 7 to 8 times normal generally flows but when the system capacity is low in respect to the transformer capacity, it can be considered that this rush current will have an adverse effect on other devices in the system.

In this power source equipment, the system connection of the power transformers is such that the power supply generator start when the power transformers are connected to the system. Therefore, one selector switch is located in the synchronuous panel and the arrangement is such that only the air circuit breaker closes the solenoid drive mechanism. This is achieved by making the generator position such that it is operated by this switch. In this case the control power supply for the air circuit breaker is either the

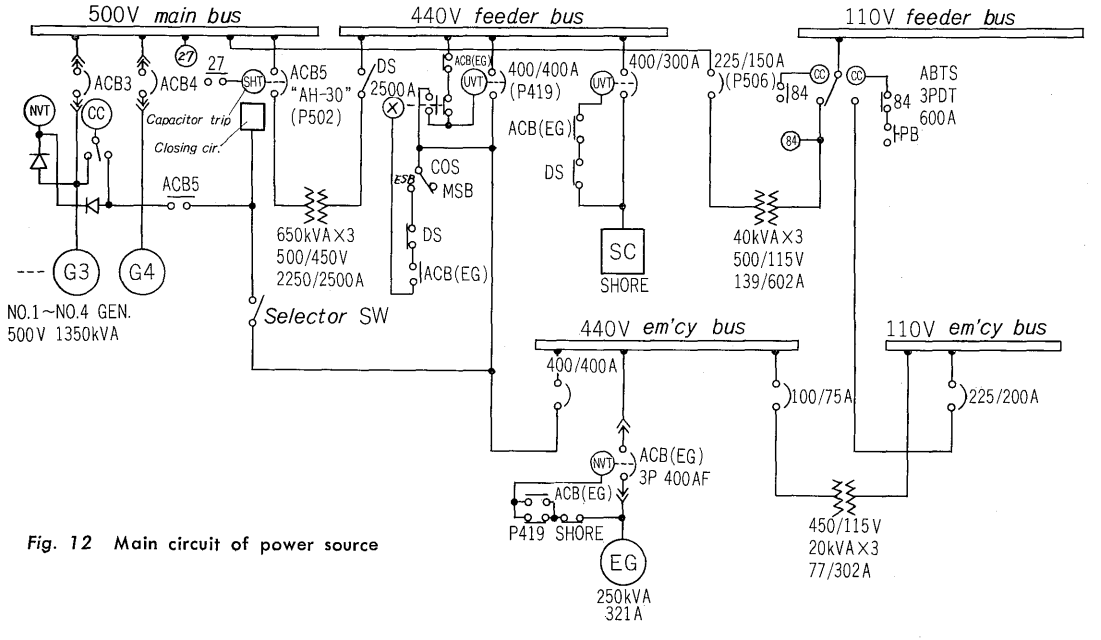

Fig. 12 Main circuit of power source

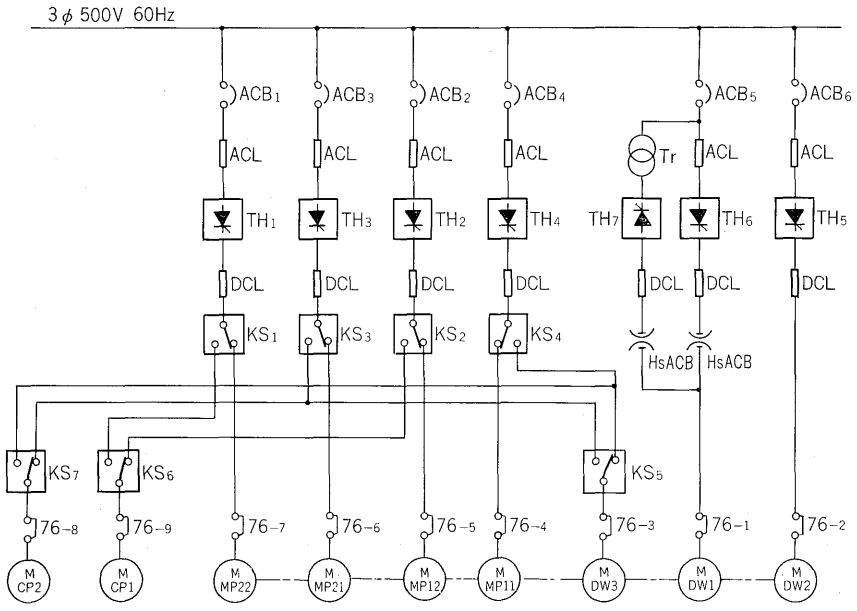

Fig. 13 Main circuit of drilling unit

auxiliary generator or a power supply on land. The control circuit of the air circuit breaker on the primary side of the power transformer is also the same.

2. Main Circuit of Drilling Unit

The main circuit of the drilling unit is shown in *Fig. 13*. This drilling unit consists of 6+1 thyristor converters for nine motors. The Nos. 1 to 4 thyristor converters operate among the seven DC motors (not the draw works motors No. 1 and No. 2) by changeover using the disconnecting switches.

Since all devices are not placed in operation at one time in accordance with the drilling machinery application conditions, the thyristor converters are changed over among the various motors by the disconnecting switches. Therefore, various interlocks are provided for confirming that the switching operations of the changeover disconnecting switches are performed completely for the desired equipment operation. If the interlock conditions are confirmed, the main circuit air breaker is closed.

Confirmation of the switching operation is made on the graphic panel placed on top of the changeover disconnecting switch. The changeover operation can be confirmed by lighting of the indicator lamps on this graphic panel.

3. Control Circuit

1) Disconnecting switch changeover and thyristor converter selection

The selection of the thyristors which are to be used for the operation of certain motors is determined by the changeover operation of the changeover disconnecting switches. However, an analog switch has been provided. It is operated by the input signal of the auxiliary contact of the disconnecting switch at the time of the changeover operation.

There is analog switching between the speed regulator of the motor control circuit and the main current regulator. In this way, the thyristor converters to be operated in accordance with the disconnecting switch changeover operations are selected.

2) Motor speed control

This excavation machinery power equipment employs a speed control system with thyristor Leonard control. An automatic current regulator minor loop is used in the main current system of the motors and automatic speed regulator feedback control with a tachogenerator is used in the speed system. Therefore, the response and stability are excellent and the motor rush current during acceleration and deceleration can be kept down to the required minimum.

Since the automatic speed regulator control with the automatic current regulator minor loop is the Fuji Electric standard system, it will not be explained here. Special points are as follows: by using the automatic current regulator minor loop, the current limit system is in harmony with the load and by using the aforementioned analog switches, there is completely electronic changeover between the thyristors and the motors.

Normally, current limiting is simply intended to protect electric devices such as the motors and thyristors. The torque speed characteristics are determined by considering all things such as prime mover characteristics, excavator characteristics and operational feasibility.

Fig. 14 shows a block diagram of the control system used for the draw works (two and three), the mud pump and the cementing pump. This block diagram shows the basic operation of the thyristor Leonard control system. In the actual circuit, there is also an operation command computer to confirm operat-

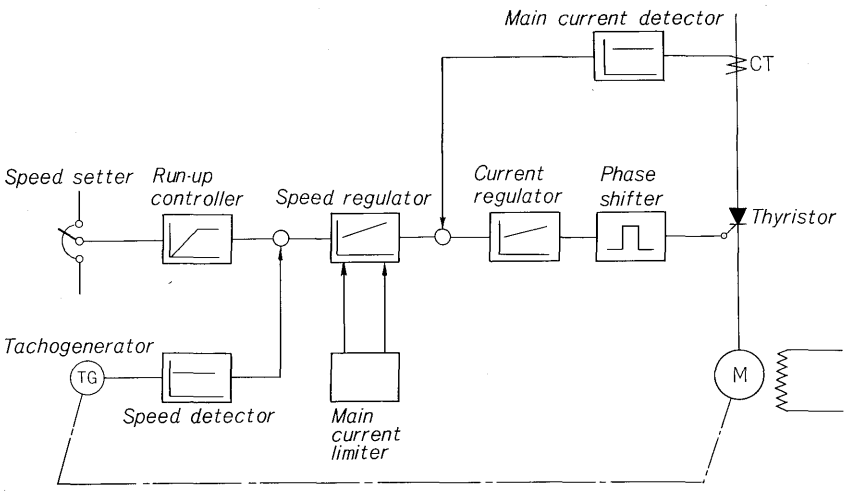

Fig. 14 Block diagram of thyristor Leonerd control system

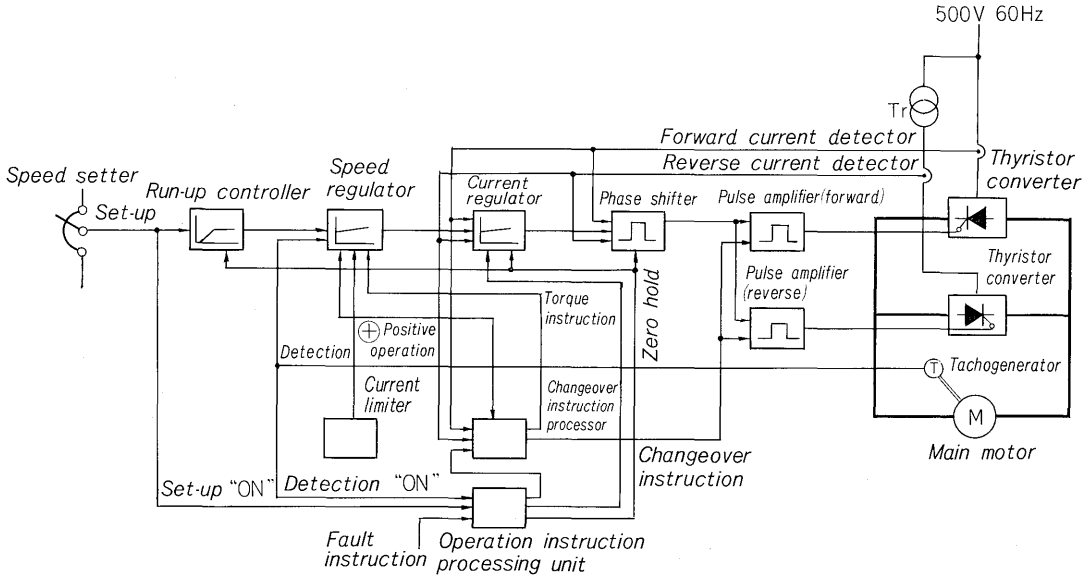

Fig. 15 Block diagram of circulating current for thyristor Leonard control system

ing conditions.

Reversible operation is possible only for the draw works No. 1 motor. In its control circuit, there is no circulating current and a reversible thyristor Leonard control circuit is used. *Fig. 15* shows a block diagram of the control system used for the draw works No. 1 motor.

3) Fault warning and indication

In this equipment, fault indications are given on the main switchboard for the main generator and the drive engines and on the DC meter panel for the DC motors and the control equipment. In addition, faults are also indicated on the motor control desks of the draw works, mud pump and cementing pump.

Fault indication in the motor control panels features as few indicators as possible to facilitate monitoring by the operator and centralization through the use of one common indication for items with the same type of fault. There are 24 points on the main distribution panel and 30 points on the DC meter panel for a total of 54 points. On the draw works control panel there are 12 points and 10 points each on the mud pump and cement pump control panels. Therefore, the motor control panels are very simple and monitoring is easy.

Based on the experience gained with this equipment, Fuji Electric will devote future research to the realization of even better excavation equipment.