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BRUSHLESS SYNCHRONOUS MOTORS

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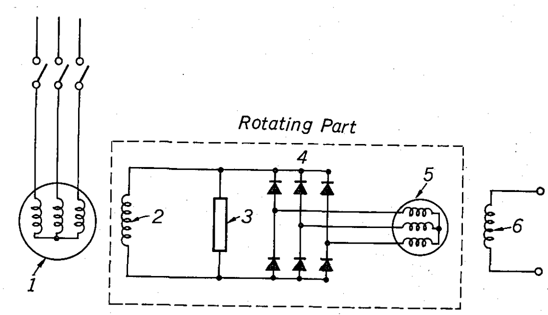
I. INTRODUCTION

Recent improvements in semiconductor elements have made it possible to produce highly reliable brushless excitation apparatus. As a result, numerous ac generators have been produced and are widely used throughout Japan. We have manufactured several types of brushless Diesel-engine generators including a 3250 kva machine and a brushless turbine-driven generator with a 22,500 kva, 3000 rpm capacity which is the largest brushless generator ever produced in this country. These generators which have already been delivered to the customers have demonstrated highly reliable and efficient performance. We have recently produced the following types of brushless synchronous motors: two 5100 kw, 22-pole, 327 rpm motors; three 3200 kw, 26-pole, 231 rpm motors; and one 1700 kw, 22-pole, 327 rpm motor. These motors have been developed through experience gained from the manufacture of the aforementioned ac generators using techniques applied to these generators. Using examples of these brushless motors, we will briefly cover the advantages, characteristics, etc. of brushless synchronous motors as well as answers to questions on these motors for your reference and information.

II. BASIC CONNECTION AND ADVANTAGEOUS FEATURES OF BRUSHLESS SYNCHRONOUS MOTORS

The basic connection diagram of our brushless synchronous motors is shown in *Fig. 1*. The brushless synchronous motor consists primarily of the main motor, rotary rectifier, and ac exciter as shown in the diagram. The brushless synchronous motor is designed to generate output current at the ac exciter armature winding installed on the same axis with the motor rotor by exciting the ac exciter stator winding, and to supply the current to the motor field winding through the silicon rectifiers on the rotor. A discharge resistor is also installed on the same rotor and is connected between the motor field winding terminals to restrict the voltage induced in the field winding when starting or when the motor is disconnected to protect the silicon rectifiers



1. Motor stator winding
2. Motor field winding
3. Discharge resistor
4. Silicon rectifier
5. Ac exciter armature winding
6. Ac exciter field winding

Fig. 1 Basic connection diagram of brushless synchronous motors

against overvoltage, thereby improving synchronous motor starting characteristics.

As outlined above, the construction of these brushless synchronous motors is greatly simplified and they are designed to provide the minimum number of rotary parts so as to provide reliable and stable performance. Therefore, these brushless motors have high operational reliability.

Principal advantageous features of these brushless synchronous motors are as follows:

1) Maintenance is greatly simplified, since there are no brushes or slip rings.

Maintenance of slip rings and related components, such as cleaning the current collector, repairs of corroded or damaged slip rings, etc., is no longer necessary. Moreover, damage of the windings from deposited brush particles has been completely eliminated and the service life of the insulation as well as the motor itself has been extended. As a result, operational reliability has been improved and maintenance costs have been appreciably reduced.

2) Suitable for use under adverse environmental conditions.

Maintaining slip rings and brushes used under adverse environmental conditions, such as those found in chemical plants where they are subjected to oil, steam, and corrosive gasses, is an extremely difficult task, especially where pressurized or pressure-resistant explosion-proof construction is required for current collector used in environments exposed to explosive gases. The brushless synchronous motors eliminated these have problems and provide improved safety.

3) Since the ac exciter in brushless synchronous motors serves as a sort of rotary amplifier, the brushless motor requires an excessively low capacity for excitation in supplying exciting current from an external source.
   Therefore, the brushless motor does not require as high a capacity for its control device, simplifying control.
4) Brushless synchronous motors have high stability during system disturbance.

Since the brushless motor has directly coupled excitation system, the motor can obtain excitation energy from the shaft of the main motor, even when system voltage drops, so that the motor can maintain required excitation for stable operation.

III. CHARACTERISTICS OF BRUSHLESS SYNCHRONOUS MOTORS

Brushless synchronous motors are started in the same manner as synchronous motors with slip rings. The brushless motor is accelerated as an induction motor until its acceleration approximates synchronous speed. Subsequently, the field winding of the ac exciter is excited and direct current is supplied from the ac exciter to the motor field winding. Then the motor is pulled into step and begins synchronized operation. In synchronous motors with slip rings, the silicon rectifiers are cut off from the field circuit during starting. Therefore, the current induced in the field circuit when starting, always flows through the discharge resistor. In brushless synchronous motors, the silicon rectifiers are always connected in parallel with the discharge resistor, as shown in *Fig. 1.* Hence, the starting characteristics of brushless motors differ slightly from those of motors with slip rings. That is, the current induced in the field circuit during starting, flows through the discharge resistor in a negative half-cycle since it is blocked by the silicon rectifiers. In a positive half-cycle, it is directly short-circuited by the silicon rectifier. Thus, the torque characteristics of the brushless motor have the mean value of normal torque when current induced in the field circuit flows in a full cycle through the discharge resistor, and torque when short-circuited without the discharge resistor. There is almost no difference in torque within the range where slip is high, but torque near synchronous speed tends to be reduced in comparison with the normal torque.

As mentioned above, the current induced in the field circuit is switched alternately from the circuit with the discharge resistor to the circuit without

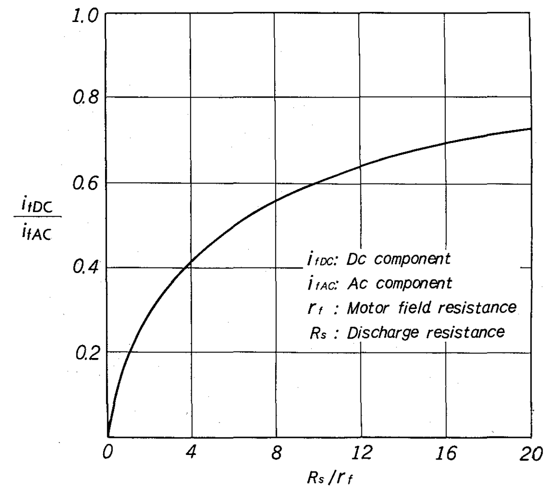


Fig. 2 Relationship between discharge resistor and dc component current induced in the field winding during starting

the discharge resistor by the switching effect of the silicon rectifiers when current value is zero, thereby creating a dc component in the current induced in the field circuit during starting. The extent of this dc component included in the ac component, largely depends upon the ratio of the field winding resistance r_f to the discharge resistance R_s. As shown in *Fig. 2,* the dc component reduces as R_s/r_f is reduced. When dc current flows in the field circuit, braking torque T_B is generated, causing a reduction in effective torque when starting. The value of T_B can be calculated from the following formula:

$$T_B = -\frac{r_a[r_a^2+(1-S)^2X_q^2](1-S)}{[r_a^2+(1-S)^2X_d \cdot X_q]^2}E^2 \text{ (p.u.)}$$

E: Voltage induced in the motor armature winding by dc component (p.u.)

r_a: Armature winding resistance of the motor (p.u.)

X_d: Direct-axis synchronous reactance of the motor (p.u.)

X_q: Quadrature-axis synchronous reactance of the motor (p.u.)

S: Slip (p.u.)

In conventional synchronous motors, the value of r_a is small, and braking torque T_B' as indicated in *Fig. 3,* is maximum value at a point close to slip 1. When slip is reduced, the torque reduces rapidly and becomes almost zero at a point near synchro-

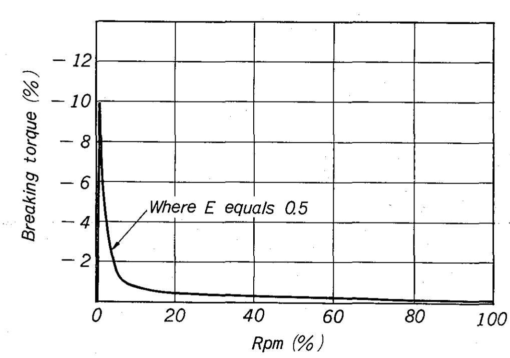


Fig. 3 Braking torque resulting from field current dc component

nous speed.

In the synchronous motor shown in *Fig. 1,* starting torque creates a concave at a point close to slip 1. As previously stated, the amount of the dc component included in the ac component can be held to a sufficiently small value by properly selecting the discharge resistance, and the value of braking torque resulting from the dc current is reduced at a ratio of nearly the square of the dc component value. Hence, braking torque is small. This is advantageous in brushless synchronous motors used for purposes such as reciprocating compressors, where low starting torque is required.

The starting characteristics of a brushless synchronous motors can be determined by setting up differential equations for the circuit with and the circuit without the discharge resistor, and by switching both circuits alternately from the former to the latter for negative and positive field current. Prior to manufacture of these brushless motors, we made a thorough study and investigation of starting torque and pull-in characteristics utilizing a FACOM 222 digital computer.

New types of starting circuits have already been suggested wherein a rotor circuit using thyristors and Zener diodes is employed to cut off the silicon rectifier during starting, and to cut off the discharge resistor during operation, by arresting voltage induced in the field circuit during asynchronous operation. We have also developed new starting circuits. The adoption of any system must be decided in consideration of load counter-torque characteristics when starting. For equipment such as reciprocating compressor which require less counter-torque, it is better to employ a simple discharge resistor method. Therefore, we have adopted the simple construction shown in *Fig. 1* for the brushless synchronous motors which we now manufacture, in an effort to provide high reliability.

There has been a recent trend toward the use of large manufacturing plants such as those found in the chemical industry. Along with this trend, there has been a tendency to use complex, automatic equipment in which synchronous motors have become increasingly important for use in the heart of the plant. Emphasis has been placed on such a problem as disconnection of synchronous motors during system disturbances due to instantaneous drop in power source voltage. Disconnection due to instantaneous voltage drop is influenced by motor GD^2, reactances, time constants, and the fluctuation of field voltage during disturbances. As shown in the example in *Fig. 4,* on condition that motor GD^2, the reactances and the time constants are the same, stability limiting characteristics can be improved by maintaining the exciting voltage at a constant value during the disturbance or by applying impact-excitation. Some disadvantages of synchronous motors with static rectifiers are the size and cost of the equipment required for impact-excitation. In supplying excitation from a separate MG (motor-generator), the power source for the MG is also affected during the disturbance. Therefore, to provide required excitation, flywheel effect must be increased to offset the reduction in MG driving force. Conversely, the excitation system employed in brushless motors is a directly coupled excitation system in which excitation energy is obtained directly from the main motor rotor even during disturbances. In addition, only a low exciting capacity is required for the ac exciter, so it is very easy to maintain motor excitation at a required value.

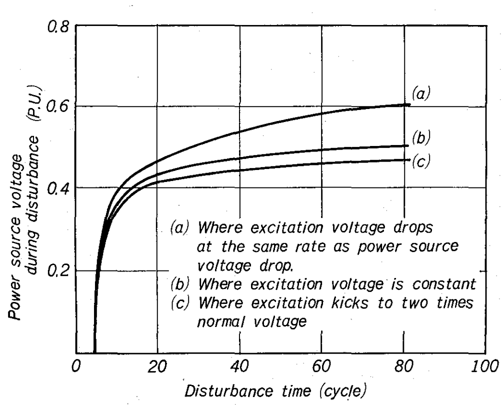


Fig. 4 **Criteria of stability at system disturbance**

Table 1 shows the principal specifications of recently produced Fuji brushless synchronous motors.

Table 1 **Brushless Synchronous Motor Specifications**

Type	Increased Safty Explosion-proof Brushless Synchronous Motor		
Output (kw)	5100	3200	1700
Voltage (v)	3300	3150	3300
Frequency (cps)	60	50	60
Speed (rpm)	327	231	327
Number of Poles	22	26	22
Power Factor	0.9 (leading)	0.9 (leading)	0.9 (leading)
Insulation Class	B	B	B
Ac Exciter Specifications	65 kva 155 v 0.9 pf 12 P. 327 rpm	70 kva 155 v 0.9 pf 12 P. 231 rpm	40 kva 85 v 0.9 pf 12 P. 327 rpm
Rotary Rectifier Specifications	220 v 54 kw 3-phase full-wave connection	220 v 56 kw 3-phase full-wave connection	110 v 29 kw 3-phase full-wave connection
Starting System	Full-voltage starting	Split winding starting	Full-voltage starting
Purpose	Reciprocating compressor	Reciprocating compressor	Reciprocating compressor
Number of Motors	2	3	1

IV. CONSTRUCTION OF BRUSHLESS SYNCHRONOUS MOTORS AND THEIR COMPONENTS

As mentioned in the foregoing, the brushless synchronous motor consists of a motor body, rotary rectifier, discharge resistor, and ac exciter. These

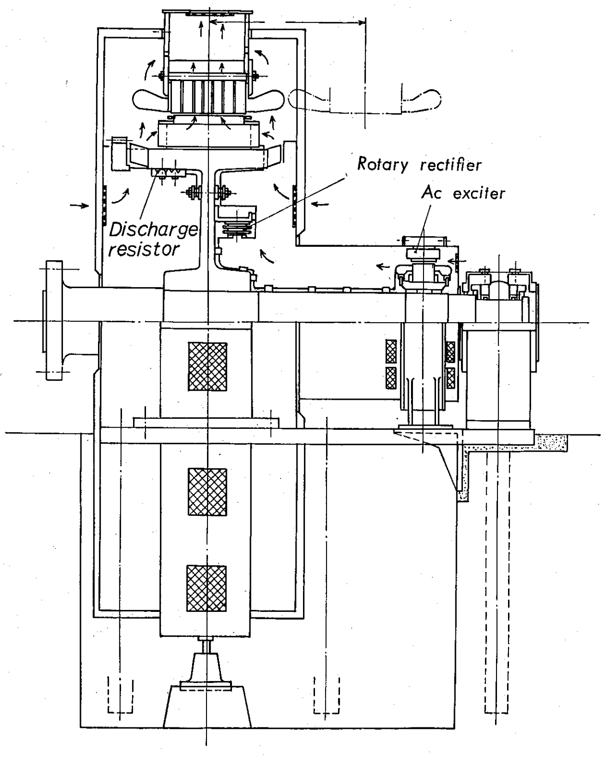


Fig. 5 Sectional view of increased safety explosion-proof type brushless synchronous motor (5100kw, 22-poles, 327 rpm)

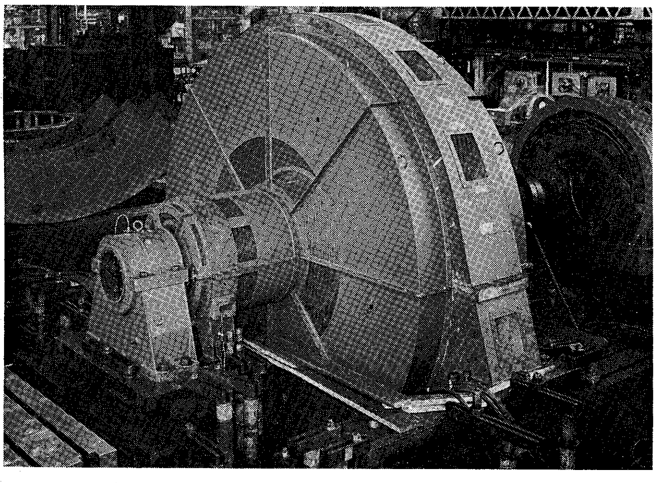


Fig. 6 Brushless synchronous motor (5100 kw, 22-poles 327 rpm)

components are effectively arranged for efficient utilization of space within the motor and the space provided for stator shifting device. The motor has almost the same mechanical dimensions as the usual motor, and is constructed so as to facilitate inspection and maintenance. In the design of the brushless motors, due consideration has been given to ventilation, etc., so that each component can fully display its individual characteristics. Special attention has been given to the rotary rectifier, discharge resistor, and the armature winding of the ac exciter installed on the rotary portion, with respect to centrifugal force applied during steady or overspeed operation, pulsating torque, and acceleration at the time of starting, impulse torque during a sudden short-circuit in the stator side of the motor, etc. Therefore, these brushless motors will withstand forces applied under abnormal conditions as well as those encountered under steady operation.

Of the various brushless synchronous motors recently produced by Fuji Electric, the single-side bearing system has been applied to 5100 kw, 22-pole and 1700 kw, 22-pole motors. The 3200 kw, 26-pole motors do not have their own shafts, but are overhung on the end of the compressor shafts. In the overhung motor, careful consideration has been given to the design of the motor as well as to selection of materials so as to minimize the weight and the length of the rotor and move the center of the load as close as possible to the compressor. *Fig. 5* shows a sectional view of the 5100 kw, 22-pole motor, and *Fig. 6* shows a picture of the same motor temporarily assembled for shop tests.

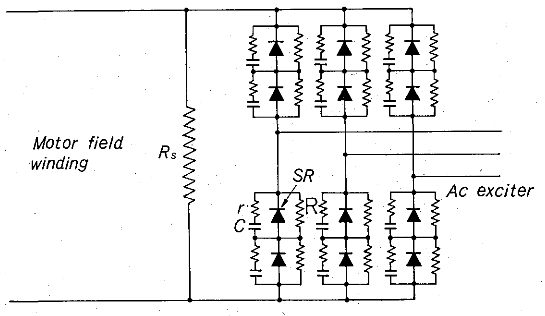
The following is an outline description of the components of these brushless synchronous motors.

1. Ac Exciter

The ac exciter is a rotary armature type synchronous generator. Since the ac exciter load is the motor field winding connected through silicon rectifiers, some problems arise as to the design of the ac exciter. Such problems relate to the selection of the capacity, phase, frequency, power-factor, operating characteristics, etc., which are more or less different from those of conventional synchronous generators. Details on these problems have been covered in a previously published article[1] and are, therefore, omitted from this presentation. Rated output and voltage, number of phases, and power factor for the ac exciter must be decided as based upon the exciting voltage corresponding to the maximum exciting current of the motor, and connection system of the silicon rectifiers. The frequency is optional. The higher the frequency, the lower the field system time constant, thereby the higher motor response. In low-speed machines, such as synchronous motors for reciprocating compressors, frequency must necessarily be limited from the standpoints of construction and economy. However, synchronous motors do not require such a high degree of response as required from generators. Therefore, synchronous motors can display satisfactorily their performance with frequencies slightly lower than commercial frequencies. If a special purpose synchronous motor has a fluctuating load, so called "quick-response excitation" is occasionally required. Even in such a case, the synchronus motor can be sufficiently set to meet fluctuating loads by using a high response control device for ac exciter.

2. Rotary Rectifier

The rotary rectifier consists of silicon rectifiers with



SR : Silicon rectifier element
c-r : Protective circuit for transient voltage
R : Resistor
R_s : Discharge resistor

Fig. 7 **Rotary rectifier connection**

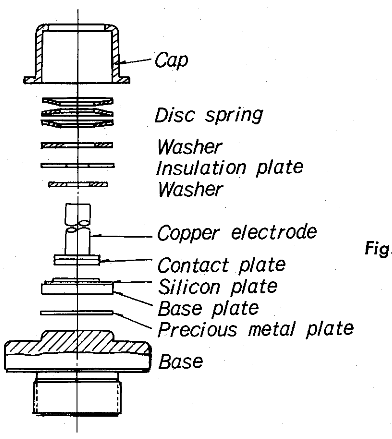


Fig. 8 **Pressure contact type silicon element**

Table 2 **Pressure Contact Type Silicon Element Specifications**

Item	Unit	Condition	Si 250.3	Si 250.3 R
Rated Forward Current	Amp (mean)	Forced-air cooling	280	240
Peak Inverse Voltage	Volt (peak)	Commercial frequency half-wave continuous	1200	1200
Max. Ac Input Voltage	Volt (rms)	—	430	430
Continuous Allowable Temperature for Junction	°C	—	160	160

cooling bodies, the silicon element protective condensers, resistors, and a retaining ring to retain these components against centrifugal force. *Fig. 7* shows the connection diagram of the rotary rectifier used in these brushless synchronous motors.

Either a three-phase full-wave or three-phase half-wave circuit is normally employed in the rotary rectifier. The former can withstand higher voltage than the latter, and requires the use of a smaller ac exciter. Accordingly our recent brushless motors employed a three-phase full-wave circuit. The silicon rectifiers of the rotary rectifier are the heart of the brushless excitation system. We use pressure contact type silicon elements for the rotary rectifier. Si 250.3 directs current from the base to the lead wire and Si 250.3 R permits current to flow in the opposite direction.

This type of elements have previously been employed in our 22,500 kva, 3000 rpm turbine-driven brushless synchronous generator which is operating effectively[(2)]. These silicon elements have proven to be completely effective and reliable without any noticeable adverse effect, even under the powerful centrifugl force encountered in the turbine-driven generator. So called " soft soldering " silicon elements are normally employed in static rectifiers. This type of silicon element is mechanically weak at the soldered connection. Therefore, a question arises as to whether the soldered element is suitable for use in rotary components. Pressure contact type silicon elements have been developed to eliminate this mechanical defect caused by soldering. Pressure contact type silicon elements employ the pressure contact method for the coupling between the base and base plate and between the element and lead wire which utilize the intensity against force in the direction which is vertical to a silicon pellet applied to a thin base plate. The soldered part has been eliminated in this silicon element. *Fig. 8* shows a skeleton diagram of the pressure contact type silicon element, and *Table 2* shows the characteristics of the silicon element. As mentioned in previous publications[(2),(3)], this type of silicon element has excellent electrical and mechanical characteristics, and satisfies the requirements for installation as a rotary component (as a silicon element) in brushless synchronous machine. In addition, selection of elements having sufficient stability was proceeded by highly severe tests of each silicon element to assure conformity with certain test standards. The rated current of the rotary rectifier must be determined with due consideration to maximum exciting current under normal operation (including current diverted to the discharge resistor), maximum exciting current corresponding to impact-excitation (if necessary), current induced in the field circuit during starting or when the motor is disconnected, and current induced in the field circuit during a sudden short-circuit of the stator winding, and through selection of the type of element, the number of parallel elements, and the element cooling effect so that the temperature of the silicon element junction is within the allowable temperature range under all conditions. The rated voltage of the rotary rectifier must be determined with due consideration of maximum exciting voltage under normal operation, ceiling voltage of the ac exciter during impact-excitation (if necessary), and voltage induced in the field circuit during starting or when the motor is disconnected, and through selection of the type of element and the number of series elements so that inverse voltage added to the silicon element is less than the allowable inverse voltage of the element under all conditions. In the connection of the rotary rectifier used in these brushless synchronous motors, two silicon elements are connected in series for each arm. No parallel connections are used in the rectifier. The pressure contact type silicon elements Si 250.3 and Si 250.3 R are of three-phase bridge connection, having rated current with continuous service greater than 720 amp which provides for more than three times rated exciting current. Thus, parallel connection of the rotary rectifier was not considered. A rectifier circuit having the required output can be composed using parallel connections for elements having a lower current rating. In such cases, when one of the parallel branch fails to function, the overall reduction of output can be minimized. This method, therefore, appears to provide a high degree of reliability. However, to apply this method, fuses must be inserted in the circuit. From the standpoint of reliability, it must be admitted that the addition of another component (i.e., fuses) is a disadvantageous feature in providing improved reliability. Increasing the number of components makes the construction of the rotary rectifier more complex and less economical. Therefore, parallel connections should be avoided as long as the silicon rectifier elements leave a margin. On the other hand, one series element has a rated voltage which is more than two times the rated excitation voltage of the motor or the voltage induced in the field circuit during starting. Thus, while only one series element is sufficient, the rotary rectifier is provided with two series elements for each arm to provide for contingencies. Most failures in pressure contact type silicon rectifier elements are due to loss of rectifying power, which results in failure to open the circuit. Hence, if one of the two series elements fails, the rectifier circuit continues to operate properly, increasing its reliability significantly.

Two silicon rectifier elements connected in series and bolted to one cooling body are formed into a single unit and each unit is bolted to the insulated inner circumference of the retaining ring. There are two types of silicon rectifier elements which permit the flow of current in the opposite direction. They provide a simple, standardized circuit connection. The silicon rectifier cooling body also serves in part as an electrical conductor between elements. The cooling body used in the rectifier in these brushless synchronous motors is cast aluminum which is very light and has excellent electrical and thermal conductivity. Fins are provided for improved cooling effects. Moreover, the contact surfaces between the silicon elements and the cooling bodies are coated with an electrically corrosion-proof paint, and the surface of the cooling body is coated with a special paint to prevent damage from corrosive gasses.

In addition to the silicon element described above, the rotary rectifier has protective circuits in which a capacitive resistance series circuit and resistance circuit are connected in parallel for each element. The former circuit suppresses excessive vibrating voltage due to carrier storage effect of the silicon elements during commutation periods resulting from connection of the rectifier circuit to the high inductance ac exciter armature winding. The latter balances the voltage applied to each element through the connection of comparatively high resistance in parallel to each element when more than two elements are connected in series. Each element has inverse characteristics slightly different from the others. The characteristics differ more or less depending upon temperature. Therefore, when elements are connected in series, voltage shared by an element having better inverse characteristics is greater than that of the element having lower characteristics. The element having better inverse characteristics may eventually be adversely affected. The protective circuit serves to prevent such an occurrence.

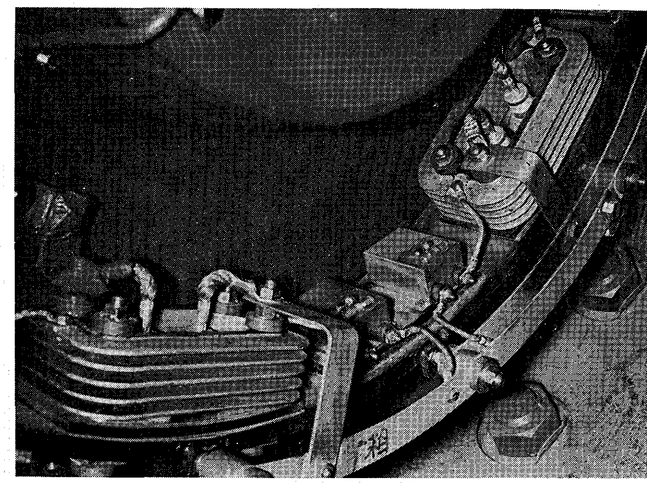


Fig. 9 Rotary rectifier

Condenser C, and resistor r and R in this protective circuit are molded by epoxy-resin into a single unit, and the condenser itself is impregnated by epoxy resin. Therefore, it is mechanically strong and its characteristics are not affected by powerful centrifugal force.

Fig. 9 is a picture showing a partial view of a rotary rectifier mounted on the rotor of a Fuji brushless synchronous motor.

3. Discharge Resistor

The discharge resistor serves to improve motor starting characteristics and to protect the silicon rectifier from voltage induced in the field winding when starting or when the motor is disconnected. Consequently, in designing the discharge resistor, it is not only necessary to select a suitable resistance value, but also to determine the current capacity so as not to exceed the discharge resistor's allowable temperature limit under all conditions, considering maximum current flowing into the discharge resistor when starting and during synchronized operation. The allowable temperature rise can normally be selected within the allowable temperature rise limit of the resistor itself to the extent that it will not have an adverse effect on surrounding insulators. For increased safety explosion-proof construction, the allowable limit must be determined as based on standards for resistors to be used in increased safety explosion-proof construction. The discharge resistor used in these brushless synchronous motors is a kind of "sheathed resistor" in which a resistor is installed in the center of a special steel tube and powdered inorganic insulation material is filled in around the resistor. Since the discharge resistor is formed under pressure and is completely airtight, the resistor itself is not corroded by surrounding gas and will not deteriorate. The resistor has high withstand voltage and insulation resistance. Moreover, since the tube is made of a special steel, its air-tightness is not affected by corrosion. In manufacturing these resistors, internal construction was examined by X-ray photographs. Prior to adoption of this type of resistor, we conducted various tests such as fatigue tests (tension and bending), temperature rise test, the heat-cycle test for deterioration, withstand voltage test, measurement of insulation resistance, etc., to assure that the resistor would hold up during usage. In practical applications to the motors, we attempted to reduce resistor temperature rise and mounted the resistor on the motor rotor after due consideration of space for fitting, ventilation, effect on surrounding insulators, etc..

V. BRUSHLESS SYNCHRONOUS MOTOR CONTROL AND PROTECTIVE SYSTEMS

The ac exciter used in brushless synchronous motors provide for starting as an induction motor without excitation. When the speed of the motor approximates synchronous speed, the ac exciter is excited and the brushless motor is pulled into step and begins synchronous operation.

During the operation of the brushless motor, the power factor is adjusted by adjustment of the ac exciter field current. In conventional motors, the power factor is adjusted manually whereas the power factor can be automatically adjusted according to the application of the brushless motor.

Fig. 10 shows the principal control circuit of 5100 kw, 22-pole and 1700 kw, 22-pole brushless motors. The control circuit for these motors employs a full-voltage starting system. When starting the brushless motor, the main circuit breaker No. 52 is first actuated and after acceleration up to approximately synchronous speed, the ac exciter field switch No. 41 is actuated through the time limit relay to start synchronous operation. During the operation of the brushless motor, the power factor is adjusted manually by adjustment of the ac exciter field circuit variable resistor by a driving motor.

The main circuit of the brushless motor has over-current, low-voltage, and ground-protective relays to protect the brushless motor against overload, low voltage, disconnection, starting failure, grounding, etc. The ac exciter also has a low-excitation protective relay to detect the loss of excitation. Ac exciter excitation power is supplied through the rectifier circuit from the station service power source.

In addition, a storage battery (having a floating charge) is connected in parallel with the ac exciter field circuit. If the power supply for excitation drops due to fluctuations in the system voltage, exciting current is supplied from this battery to the field circuit to maintain the excitation voltage at a constant value, thereby protecting the brushless motor from disconnection. The control circuit for the 3200 kw, 26-pole brushless motor is identical to that of the foregoing two types, except that it has one additional starting circuit breaker since it employs a split winding starting system. Furthermore, the brushless motor employs an automatic power factor adjustment system and has a stepping-out detection circuit.

The brushless synchronous motor has extremely low excitation capacity ac exciter which must be controlled from the outside. Therefore, its control circuit is simple and compact.

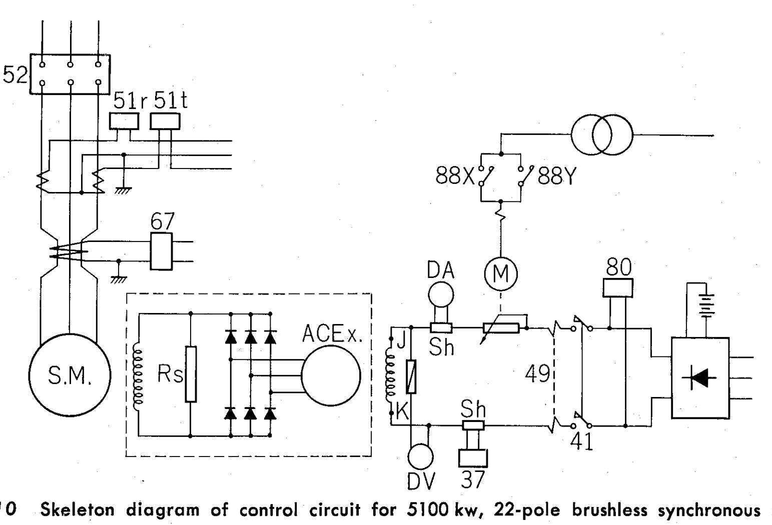


Fig. 10 **Skeleton diagram of control circuit for 5100 kw, 22-pole brushless synchronous motor**

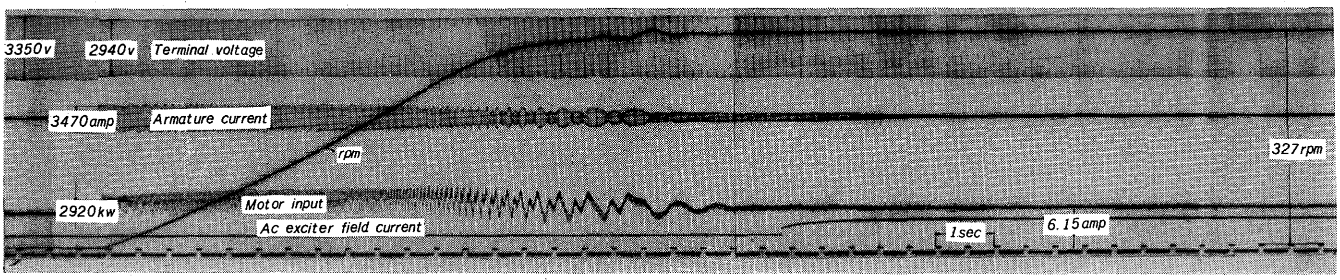


Fig. 11 Oscillogram of starting test (full voltage) for 5100 kw, 22-pole motor

VI. FACTORY TESTS

In tests on these brushless synchronous motors recently manufactured by Fuji Electric, detailed unit and combination tests were conducted by installing three temporary slip rings. (The 3200 kw brushless synchronous motors are overhung types and do not have their own shafts. Therefore, we employed a temporary shaft for testing these motors.) In the unit tests, we divided the brushless motor into two parts; the motor body and the ac exciter with rotary rectifier and discharge resistor. In testing the motor body, we conducted various tests such as measurement of no-load saturation characteristics, three-phase short-circuit characteristics, V-curve, losses, GD^2, and temperature rise tests in the same manner as for conventional motors, by supplying exciting current through the temporary slip rings. In testing the ac exciter portion, the following tests were conducted using the temporary slip rings as output terminals and supplying excitation from the field winding of the ac exciter: measurement of no-load saturation characteristics and three-phase short-circuit characteristics, temperature rise tests, etc. The following combination tests were performed: measurement of no-load saturation characteristics and three-phase short-circuit characteristics, rock-test, no-load starting test, high-voltage test, measurement of insulation resistance, etc. These brushless motors were driven by a direct-coupled dc motor.

Fig. 11 shows a sample oscillogram depicting full voltage starting test results of the 5100 kw, 22-pole motor with load on the spot.

VII. CONCLUSION

The foregoing is a brief explanation of brushless synchronous motors including an outline description of recently manufactured Fuji brushless motors. Brushless synchronous motors have become a practical reality. In addition to their original features such as high degree of efficiency, large gap length and solidity, flexibility in selection of the power factor, constant speed (rpm) regardless of the fluctuation of load, etc., these brushless synchronous motors have gained wide acclaim due to other improved features such as freedom from trouble with respect to failure associated with brushes and slip rings, simplified application, and improved reliability. We believe that there will be a greatly increased demand for this type of motor in the future. We sincerely hope that this pamphlet will assist you in selection of the best motor to fully satisfy your requirements.

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