UDC 621. 313. 322-81-832

NEW SERIES OF TURBO-GENERATOR FOR PRIVATE THERMAL POWER PLANT

By Ryoichi Kuramochi &
Toru Nakata
Design Dep't., Kawasaki Factory

I. INTRODUCTION

Recent years have seen in this country a remarkable progress in utility plants as substantiated in the continual construction of one thermal plant after another with a record high capacity. It must not be overlooked on the other hand, that a like degree of activity is being carried on in the establishment of private thermal power plants for various industries. While private generating plants are generally smaller in capacity, they are usually expected to supply both steam and electric power to a plant and, since the total fuel cost is bound to diminish as a result of an overall program for the utilization of surplus gas, waste liquor and waste heat for the entire factory, the generating cost of these private thermal power plants actually tends to become lower than the cost of maintaining the latest utility thermal plant. When considered in combination with the possibility of securing stabilized and high quality process steam, moreover, the economy of running a private thermal power plant becomes increasingly evident and it is in these circumstances that a good number of industries have come to have private thermal power plants either newly constructed or additionally built.

Inasmuch as the turbo-generator for a private thermal power plant is closely related with the total function of a whole factory, the generator in question has a number of requirements to meet more or less different from those normally associated with a utility thermal plant. What is of particular importance with regard to the former is the factor of reliability, for the turbo-generator is required to run uninterruptedly for a long time. Behind this is a valid reason that the stoppage of the turbo-generator would not only bring about the failure in electric supply but would, at the same time, have a far-reaching effect upon the operation of the entire factory such as the absence of process steam and the problem of surplus gas, for instance. It may be noted that this unfavorable effect will invariably be reflected in the cost of manufactured goods.

Another element which demands our special attention is the ease with which the generator may be maintained without interruption during its extended operation. This requirement, again, is only natual when it is understood that the upkeep of a private thermal power plant is not the end itself in an industry using it but is a means and that, consequently, its operation needs to be undertaken with as little care as possible.

With the private turbo-generator, in addition, the necessity arises to take into consideration various sets of load characteristics peculiar to different industries such as, for example, the effects of greatly fluctuating loads in the iron manufacturing works and the impact of harmonic currents as a consequence of rectifier loads in the chemical industry.

Fuji Electric, on the basis of its coordinated experience in the manufacture of turbo-generators for private thermal power plants, has now succeeded in making a new series of turbo-generators for private thermal power plants and believes that this description of its outline may benefit prospective customers of this new system.

II. OUTLINE OF NEW SERIES TURBO-GENERATOR

The turbo-generator for private thermal power plant in this new series is an air-cooled generator available in two varieties of 50 cycles and 60 cycles. As for the output, twelve standard outputs are provided between 2.5 Mva and 31.25 Mva for 50 cycles, while eleven standard outputs from 3.15 Mva to 31.25 Mva are envisaged for 60 cycles. For an output higher than 12.5 Mva, standard outputs are stipulated in I.E.C. (International Electrotechnical Commission) Recommendation Publication 34–3 1962 regarding turbo-generators on 50 cycles supply and the standard outputs of the present new series are made to correspond with the stipulated values.

The standard rated voltage of the turbo-generator, meanwhile, is 6.6 kv under 12.5 Mva and 11 kv for higher Mva. Where a lower voltage than the standard rated voltage is required, the frame number of the generator will not be altered but the design of the stator winding alone will be modified and standard series adopted. When a rated valtage of 11 kv is required under 12.5 Mva, on the other hand, application of the frame number may sometimes be changed but such requirements may be met without any problem concerning its manufacture.

The standard rated power factor of a generator is of 0.8 lagging as determined by I.E.C. When a value other than 0.8 is required for the generator power factor by reasons of conditions of factory loads, conditions of parallel systems or operative schedules of the generator, however, application of the frame number may be subjected to modification.

The short-circuit ratio of a generator should be over 0.47 and under 0.63 according to the I.E.C. standard and the present standard series takes 0.6.

The following are standard specifications of a new series turbo-generator:

1) Type:	Horizontal shaft cylindrical rotor type and self-ventilating and re-circulating type with air-cooler
2) System of ventilation:	Self-ventilating type
3) Rated items:	
(1) Rating:	Continuous
(2) Output:	2.5 Mva~31.25 Mva
(3) Terminal voltage:	Less than 12.5 Mva, 6.6 kv over 12.5 Mva, 11 kv
(4) Phases:	3
(5) Frequency:	50 or 60 c/s
(6) Rated speed:	3000 rpm or 3600 rpm
(7) Power factor:	0.8 lagging
4) Insulation:	B
5) Limits of temperature rise:	Stator winding 80°C (embedded detector method) Rotor winding 90°C (resistance method)
6) Stator winding connection:	Y-connection (all neutral terminals brought out of the generator)
7) Cooling system:	Totally enclosed type with air-cooler
8) Excitation system:	Static excitor with silicon rectifier
9) Cooling water temperature:	32°C

Fig. 1 shows the outer view of a new series turbo-generator in the above specifications, main characteristics of which are as follows:

(1) Short-circuit ratio:	About 0.6
(2) Voltage regulation:	About 40% when power factor is 0.8 About 30% when power factor is 1.0
(3) Impedance:	Xd appox. 167% Xd′ appox. 16% Xd″ appox. 11%
(4) Deviation factor of the voltage wave:	Less than 5%
(5) Capability curve:	See *Fig. 2*
(6) Allowable unbalance load:	Less than 12.5% of negative sequence current

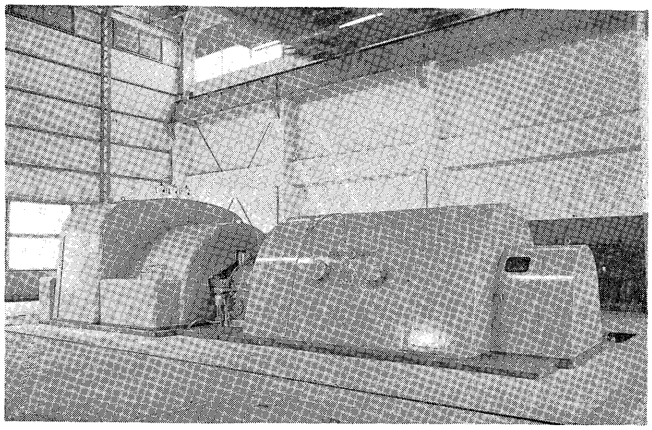


Fig. 1 Outer view of new series turbo-generator

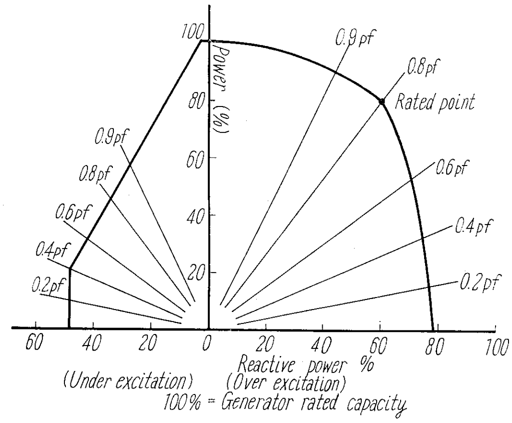
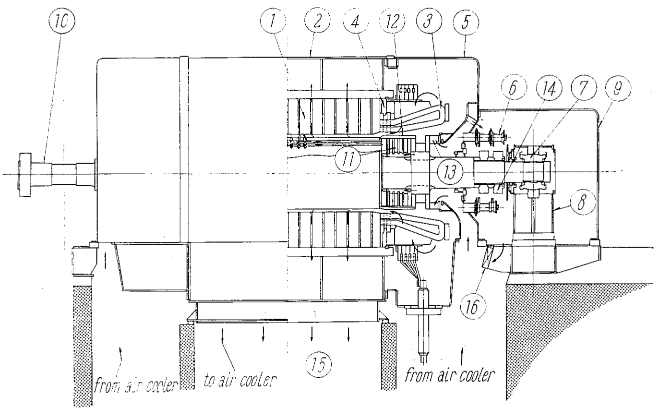


Fig. 2 Capability curve of new series turbo-generator

III. CONSTRUCTION OF NEW SERIES TURBO-GENERATOR

As far as the construction goes, the new series turbo-generator is divided into two types with respect to the manner in which the slip ring is attached to the rotor shaft, namely the normal type and the overhanged slip ring type. Theoretically, a two-pole turbo-generator develops a great deal of mechanical loss because it runs at a high speed, so that better characteristics are obtained with an extremely small rotor diameter. However, there is a problem of critical speed, which is to be higher than ½ of the rated speed by 10 to 15%. From the constructional point of view, the overhanged slip ring type must have the rotor lead go through the shaft so that it takes more manufacturing processes than the normal type. However, the overhanged slip ring type can satisfy the conditions of critical speed up to a longer core length than with the normal type. This being the case, we take the normal type for a short core length for each frame number and the overhanged slip ring type for a longer core length in order to obtain superior characteristics.



(1) Stator iron core
(2) Stator frame
(3) Stator winding
(4) Press ring
(5) Fan shield
(6) Brush retaining stud
(7) Bearing bush
(8) Bearing pedestal
(9) Slip ring cover
(10) Rotor shaft
(11) Rotor winding
(12) Retaining ring
(13) Fan
(14) Slip ring
(15) Exhaust duct
(16) Filter

Fig. 3 Sectional drawing of generator (single flow type)

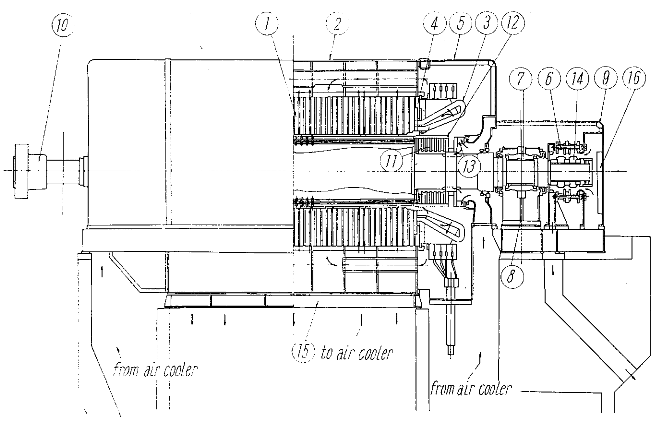


Fig. 4 Sectional drawing of generator (double flow type)

The cooling system of the new series turbo-generator is a totally enclosed type with air-cooler but the cooling system of the stator may be either a single flow type or a double flow type. The cooling-air circut of each type is shown in *Fig. 3* and *Fig. 4,* respectively. The standard generator employs a long core length double flow type.

With any high speed machine, vibration is one of the most important factors to determine the efficiency and performance of that machine. In order to cope with this vibration, the new series turbo-generator effects a sufficient dynamic balance test on various parts. Moreover the rotor is also subjected to a low speed dynamic balance test as well as to a heat balance test under which its temperature is maintained on an equal level with the temperature during its rotation. Since the rotor shaft is a flexible shaft, a high speed dynamic balance test is also conducted.

The construction in brief of the different parts follows :

1. Stator Frame

The stator frame holds an iron core, withstands torque and magnet pull, and forms the ventilation circuit and serves as well to prevent noise. For these purposes, the frame is of welded construction consisting of steel plates incorporating skin stress construction here and there to lighten the weight and to increase rigidity.

Sufficient precautions are taken to see that the natural frequency and its nodes in a states of combined stator frame and stator iron core will not correspond with the frequency and nodes of vibration forces.

2. Stator Iron Core

The startor iron core is of silicon steel plate of class S with little loss. It comprises a layer of half-lapped segments divided into several pieces around and in the axial direction an air duct is provided at each bloc of a few centimeters to increase the cooling effect of the core and the coil. The stator iron core, moreover, has the air gap at both ends becoming gradually larger. This results in decreasing the end leakage flux of the generator which is effective in lessening stray-load loss and eventually in increasing the efficiency of the generator.

The stator iron core is fitted to the stator frame through dovetail keys but a special measure is provided to see that the vibration of the iron core will not directly affect the stator frame.

3. Stator Coil

The insulation of the stator coil is B class insulation comprising mica for the most part. The coil is composed of strands insulated by means of glass fiber which, after winding, is subjected to vacuum-pressure impregnation in asphalt compound. The in-slot portion is baked with mica while the coil end is provided with a varnished glass tape. In addition, the slotted portion is also given corona

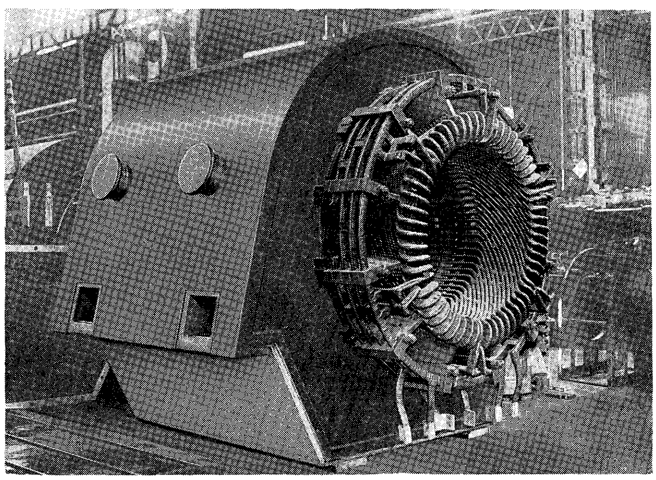


Fig. 5 Stator

protection by low-resistance graphite paste while the straight part at the exit of the slot is given high-resistance graphite paste to prevent end corona so that drastic potential gradient may not take place there.

The stator winding of the new series turbo-generator is of lap-winding and, according to capacity, may be either of multi-turn coil or of one turn having a Roebel type bar. In either case, the coil-end part has a spacer of rigid nature inserted between coils which are then bound up together in a body and the winding is fixed to a support provided on the stator frame so that the deformation or breakage of the winding will not take place due to short-circuit or any other accident. *Fig. 5* indicates a photograph of completed stator winding.

4. Rotor Shaft

The rotor shaft is of single-piece forging of special steel. Since this rotates at an extremely high speed, it should be of high tension material and the shaft material itself must, at the same time, be ferromagnetic material. As for the question of strength, it is necessary to see if there are any irregularities of the grain structure during the manufacturing process. For this reason, strength tests are made of not only test pieces for surface and internal inspection (the latter by means of a core drill) but also pieces for ultrasonic test and sulfur print to see if there may not be uniformity of material and fault.

Another vital problem with the rotor shaft is that of vibration. The generator shaft is what may be termed a flexible shaft with the first critical speed existing at a point lower than the rated speed. With the new series turbo-generator, therefore, the first critical speed is set 10% higher against ½ of the rated speed lest the phenomenon in which the rotor itself whirls at an angular speed of one half the rotation, or oil-whirl, should correspond with the critical speed. An electronic computor is used for the calculation of critical speed and due note is taken of the second critical speed as well.

5. Rotor Coil

Since the voltage of the rotor coil is low, mechanical characteristics of the insulator count more than do its electrical characteristics. The insulator is housed in a slot and thoroughly heated and compressed in advance so that the coil may not be displaced due to strong centrifugal force acting on the coil during its rotation and that the rotor balance may not be disturbed and vibration caused. For the conductor of the new series turbo-generator, hard-drawn copper is employed, while for generators with a higher output is used copper with silver with high creep strength because of the largeness of the rotor diameter and strength of centrifugal force. This helps prevent thermal deformation.

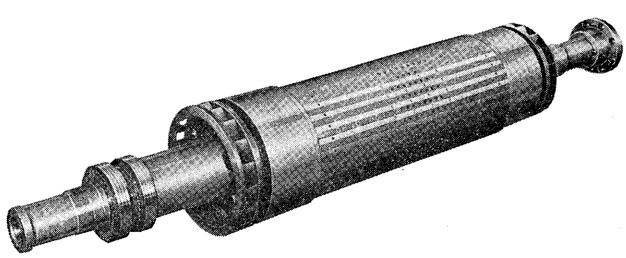


Fig. 6 Rotor

6. Retaining Ring

Centrifugal force at the end of the rotor coil is received by a retaining ring. Consequently, the retaining ring is subjected to an enormous amount of force coupled with its own centrifugal force so that the retaining ring must be amply sturdy and rigid. Although the retaining ring of the new series turbo-generator uses non magnetic material, the non magnetic character and the highness of yield point are characters generally contradictory with each other and the manufacture of an ideal retaining ring was, on this score, very difficult.

Fuji Electric, however, has succeeded in making special steel achieve precipitation hardening by heat treatment as a result of extensive research extending over several years and the record of its actual usage is highly encouraging. Subsequently, retaining rings of required strength have come to be manufactured in Japan thanks to the utilization of work hardening such as cold working using high-manganese steel or working to be conducted under the recrystallization temperature. These rings are used for large sized generators.

The retaining ring form a flux path that short-circuits the interpolar space of the rotor and create a flux pathe for leakage flux as a result of armature reaction of the stator coil, so that, by making the retaining ring non-magnetic, the leakage of rotor flux may be decreased and stray loss by stator leakage flux may be lessened. The efficiency of the new series generator is greatly enhanced by the use of a non magnetic retaining ring, which also serves to prevent loss of stator end due to under-excited operation as well as local heat.

7. Fan

The fan is provided at both ends of the rotor, respectively. These fans provide ventilation necessary for cooling and the wind pressure necessary for the circulation of that wind. The fans used are radial fans because they supply high wind pressure and they do not require much axial space and are considered to be advantageous with respect to critical speed. The fans are constructed in such a manner that the vanes of nickel chrome molybdenum steel are rivetted to the side plate of forced steel.

8. Bearing

The bearing is carefully designed and manufactured as it is used with a high speed generator. The problem of oil whirl arising at half the rated speed—a problem peculiar to a high speed machine—is met by shortening the bearing metal and by making double arc of the sliding surface. The retaining surface of the bearing pedestal and the bearing bush is made supherical and self-aligning so that the shaft may not be subjected to undue stress by reason of error in erection or bending of the shaft. And since the counter-torque at start increases when the rotor weight increases, highly pressurized oil is fed from under the bearing bush in order that the shaft may float before it starts running. Leakage of oil arising at the bearing pedestal and the penetrating section of the shaft constitutes a problem also common to high speed machines. As a countermeasure in this respect, we place much labyrinth packing in the penetrating section and blow in pressurized air into the packings as taken from within the generator or the slip ring cooling fan casing so that oil will not leak outside.

Lubrication of the bearing is of a forced lubrication system and takes lubricant from the same pipe as that of the turbine.

9. Method of Preventing Shaft Current

No shaft current will arise provided perfect symmetry is ensured for a two-pole generator. However, since the shaft current of some degree cannot be helped because of unbalance as a consequence of errors in manufacture and assembly, an insulating plate is inserted under the bearing base on the anti-turbine side to prevent the formation of a short-circuit thereby checking the shaft current. Also, an earthing brush is fitted to the shield on the turbine side of the generator in order to prevent accumulation of electrostatic charge at the turbine.

10. Air Cooler

The air cooler is made up of a so-called U fin tube, namely a cooling tube of BsTF4 (equivalent of Alblack) with coiled copper wire around the outside diamter and grouped en masse by solder. This provides a conspicuously large cooling surface and yields a high cooling capacity with the smallness in size. Inside the water chamber is fitted a highly pure zinc plate against corrosion by sea water.

The cooling tube are mounted in horizontal positions and it is possible to clean them by simply taking off the cover for the water chamber.

The inlet temperature of cooling water is set for 32°C for the air cooler but it is possible to adapt it to 25°C or 20°C easily.

11. Slip Ring and Brush

The slip ring is of forged steel and sufficiently resistant against wearing. The ring, furthermore, employs a construction of shrinkage fit of the shaft so that eccentricity will not result from the stress and temperature rise during its rotation. Helical grooves are cut on the surface of the ring and ventilating holes are provided in the axial directino for cooling.

A large number of brushes of electrographite are arranged in parallel. Current distribution among the brushes tends to be uneven when the peripheral speed of the slip ring is high as with the turbo-generator. This problem, however, is settled by a good selection of brush material and provision of helical grooves on the ring surface. While brushes need to be replaced at an interval of four to six months, they may be replaced, with our generator, during the operation.

IV. EXCITING SYSTEM OF NEW SERIES TURBO-GENERATOR

The exciting system of the new series turbo-generator uses a static excitor with silicon rectifier. This device gives the generator compound characteristics by controlling the exciting current from the current transformer in conformity with the load so that it is possible to maintain a voltage in a case of a sudden change in the load and to increase the transient stability. Since this is entirely static, its maintenance affords considerable advantages over the rotating type excitor.

The standard exciting system is divided into type OH and type CL. For a capacity of a generator over 10 Mva, type OH is used as a principle, whereas for the capacity under 10 Mva the type CL is used. *Fig. 7* shows a connection diagram of type OH and *Fig. 8* type CL.

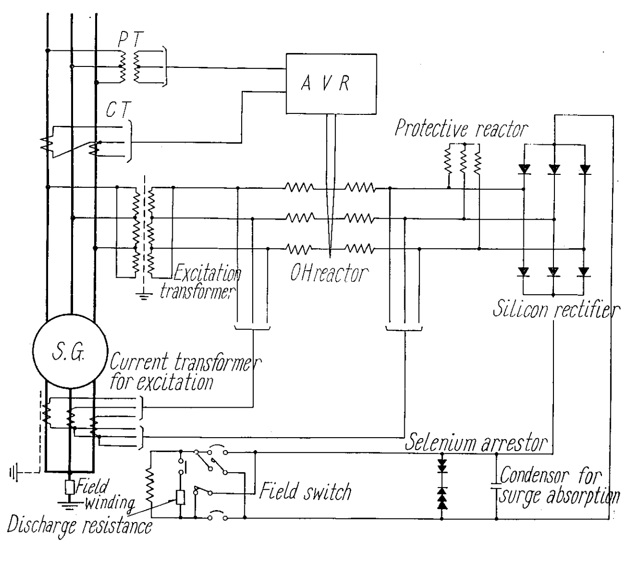


Fig. 7 Connection diagram of OH type exciting system

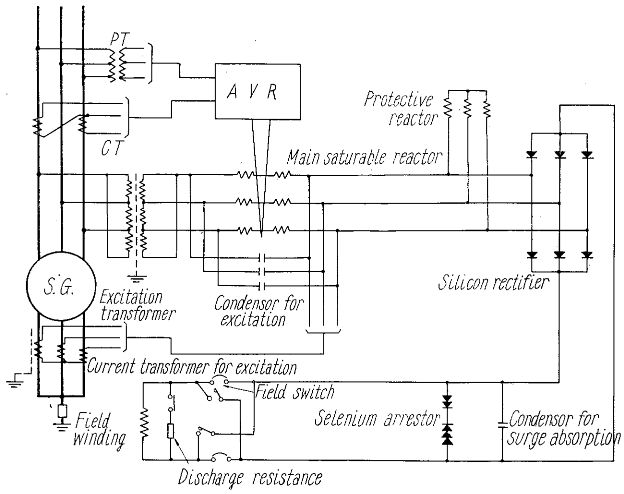


Fig. 8 Connection diagram of CL type exciting system

V. CONCLUSION

So far has been a description of the outline of new series of turbo-generator for private thermal power plant. The objectives sought in turning out the new series have been to enhance the reliability of the generator on the basis of thorough examination of the manufacturing experience in the past, to facilitate maintenance and inspection, and to lower the cost by making it small in size and light in weight. The new series has enabled standardization of different parts, facilitated stocking of rotor shaft material and established a system where the generator can be manufactured and delivered within a short delay from order. It will give us a great pleasure if the new series turbo-generator for private thermal power plant proves to the liking of customers at a time when construction of private thermal power plants is actively carried on.