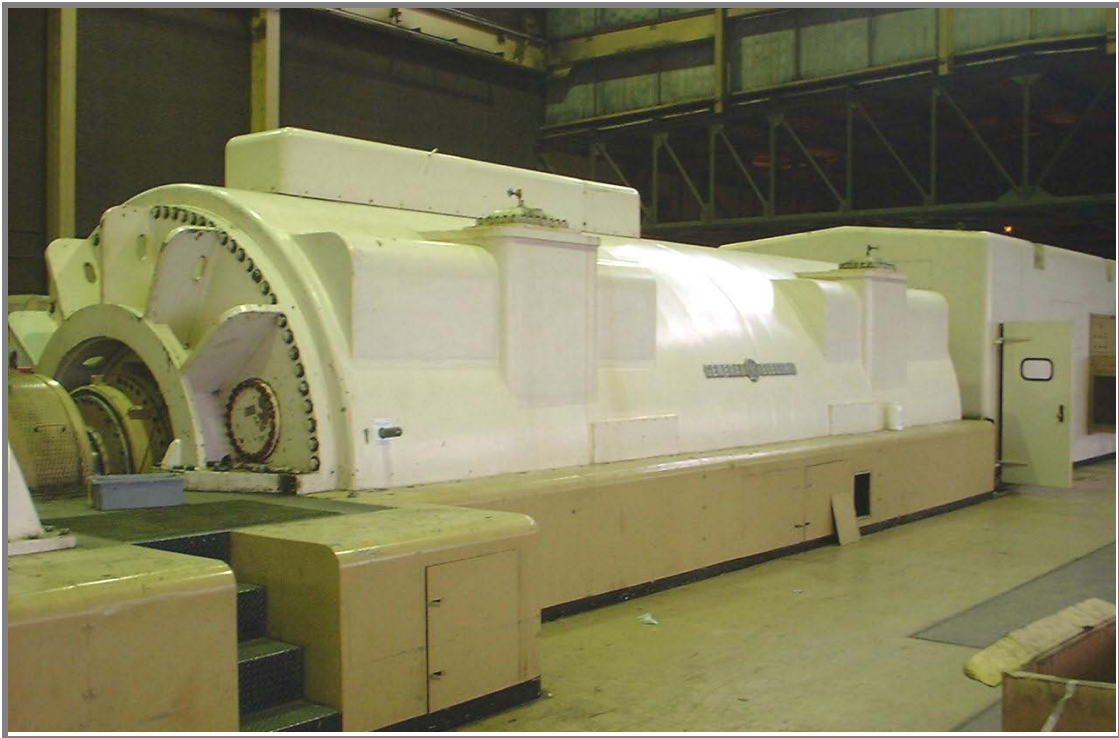


# BASIC AC ELECTRICAL GENERATORS



FREE DOWNLOAD

(This page left blank intentionally)

# BASIC AC ELECTRICAL GENERATORS

## TABLE OF CONTENTS

<b>Introduction .....</b>	<b>1</b>
<b>Generator Types.....</b>	<b>4</b>
<b>Rotating Armature Generator .....</b>	<b>4</b>
<b>Rotating Field Generator.....</b>	<b>5</b>
<b>Polyphase Generators .....</b>	<b>7</b>
<b>Air Cooled Generators .....</b>	<b>10</b>
<b>Temperature Rise.....</b>	<b>10</b>
<b>Reliability.....</b>	<b>11</b>
<b>Construction.....</b>	<b>11</b>
<b>Generator Design and Construction.....</b>	<b>11</b>
<b>Generator Stator and Windings .....</b>	<b>11</b>
<b>Stator Design Hydrogen/Water Cooled Stators .....</b>	<b>17</b>
<b>GENERATOR ROTORS.....</b>	<b>19</b>
<b>Salient Pole Rotors .....</b>	<b>19</b>
<b>Cylindrical Generator Rotor .....</b>	<b>20</b>
<b>Rotor Design Air Cooled Generators.....</b>	<b>25</b>
<b>Rotor Design Hydrogen/Water Cooled Generators .....</b>	<b>27</b>
<b>Rotor Mechanical Design.....</b>	<b>29</b>
<b>Hydrogen Cooled Generator Stator .....</b>	<b>31</b>
<b>Generator Isolated Phase Bus.....</b>	<b>33</b>
<b>Standard Generator Seal Oil System.....</b>	<b>35</b>
<b>Standard Generator Stator Cooling Water System.....</b>	<b>43</b>

# BASIC AC ELECTRICAL GENERATORS

<b>Excitation Systems .....</b>	<b>49</b>
<b>Progress Check.....</b>	<b>52</b>
<b>Answers.....</b>	<b>56</b>
<b>Final Examination .....</b>	<b>58</b>

# BASIC AC ELECTRICAL GENERATORS

(This page left blank intentionally)

# BASIC AC ELECTRICAL GENERATORS

## PREFACE

This training module has been developed to provide you with information pertaining to devices known as Basic AC Electric Generators. The information in this training module is designed to increase your knowledge and improve your abilities as they relate to the module. Within the training module you will find information pertaining to various designs of electrical generators, code requirements, associated accessories, as well as related mathematical principles and their solutions. Additionally, the training module includes associated review questions and answers so that you can gauge your comprehension of the subject material. Subject matter within the module helps prepares the student to take related state, city, and American Society of Power Engineers Licensing exams.

*Information contained in this lesson has been obtained by O&M Consulting Services Inc from sources believed to be reliable. Neither however O&M Consulting Services Inc nor its authors guarantee the accuracy or completeness of any information published herein, and neither O&M Consulting Services Inc and its authors shall be responsible for errors, omissions, or damages arising out of use of this information. This work is published with the understanding that O&M Consulting Services Inc and its authors are supplying information but are not attempting to render engineering or other professional services. If such services are required, the assistance of an appropriate professional should be sought. O&M Consulting Services Inc has supplied American Society of Power Engineers Inc with this Training Module at no charge for free distribution. This document may not be resold; it is for informational purposes only.*

# BASIC AC ELECTRICAL GENERATORS

(This page left blank intentionally)

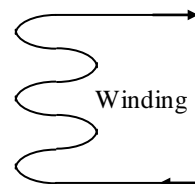
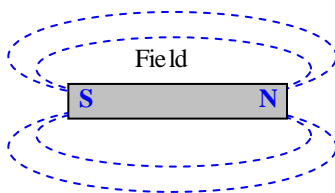
# BASIC AC ELECTRICAL GENERATORS

## Introduction

Faraday's Law; when you see that rotation of the coil continually changes the magnetic flux through the coil and therefore generates a voltage. Generators, motors, transformers, and solenoids each use the principle of electromagnetism. This is the ability to create electrical current in a conductor by moving a magnetic field past the conductor. The reverse is also true: a magnetic field is produced in a conductor by passing electrical current through the conductor. In general, the requirements for electromagnetism are a magnetic field, a conductor, and relative movement between them.

A permanent magnet has a magnetic field around it. The field is lines of magnetism (flux) that bend around the metal magnet. The strongest part of the magnetic field is the region where the lines are closest together. On a permanent magnet, there are two such regions, one at each end of the magnet. These are called the north and south poles of the magnet. (The earth is a magnet, with the strongest part of the magnetic field at the North and South Poles Magnetic of the earth.)

A simple generator has two basic parts – field and winding. The field is the magnetic field and the winding is the conductor formed into a coil.



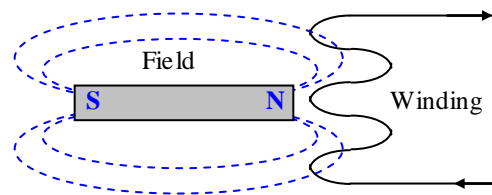
The field is connected to a shaft that may be turned. These are two elements necessary for electromagnetism. When the turning field is placed near the winding, all of the elements are present for electromagnetism. (In fact, the field could be fixed and the windings turned to produce the same effect in a generator. However, this



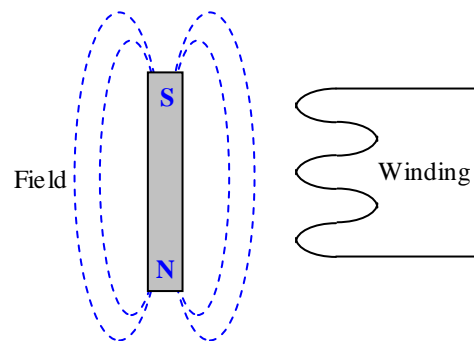
## BASIC AC ELECTRICAL GENERATORS

arrangement is normally used for small generators, where the current produced in the winding is small.)

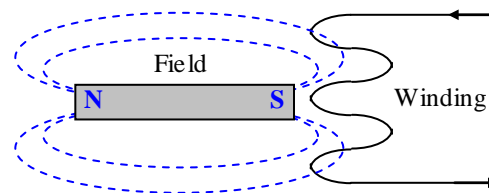
As the field turns past the fixed winding, the amount of current produced in the winding depends upon the strength of the magnetic field moving past the winding. As the North Pole of the field moves past the winding, a large current flows through the winding.



As the field continues to turn and the North Pole starts to move away from the winding, the current decreases as the strength of the field “cutting” the winding decreases. When neither pole is nearest the winding, the current through the winding is zero.



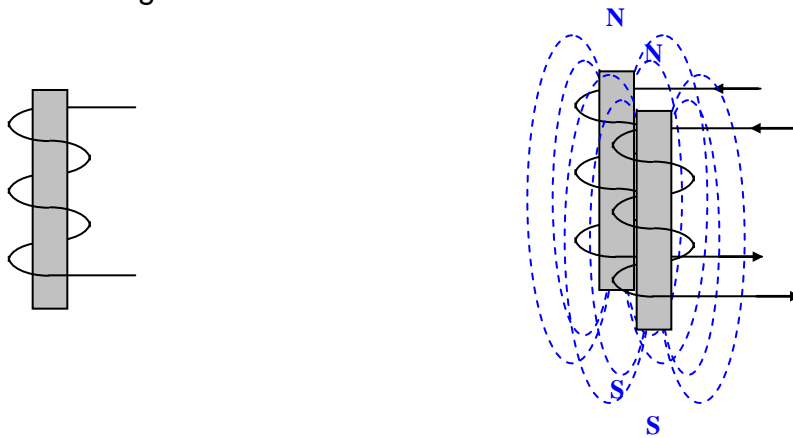
As the field continues to turn, the South Pole moves toward the winding as the North Pole moves away. Current starts to flow in the winding, but in the opposite direction, because of the opposite pole moving closer to the winding. When the South Pole is opposite the winding, the current is again strong, but in the opposite direction.



## BASIC AC ELECTRICAL GENERATORS

As the South Pole moves away, the current in the winding decreases, returning to zero again when neither pole is close to the winding.

While this simple generator produces AC (alternating current), the current produced is not very large since the strength of the magnetic field is not very large. The principle of electromagnetism may be used to produce a magnetic field of much greater strength. If a conductor is wound around a piece of metal, such as iron or steel, and current is passed through that conductor, a magnetic field is produced around this assembly. It is called an electromagnet.



The strength of the magnetic field produced is determined by the amount of current passing through the conductor. When a stronger magnetic field passes a winding, more current is produced in the winding. In a generator, the amount of current produced in the winding can thus be controlled by controlling the amount of current passing through the conductor causing the magnetic field.

The three-phase generator is basically three separate generators in one casing. It has three completely separate windings in which current is produced, but a single rotating magnetic field. Within the generator, there is no electrical connection between the windings. The rotating magnetic field is the rotor and the windings in which current is produced are in the fixed stator.

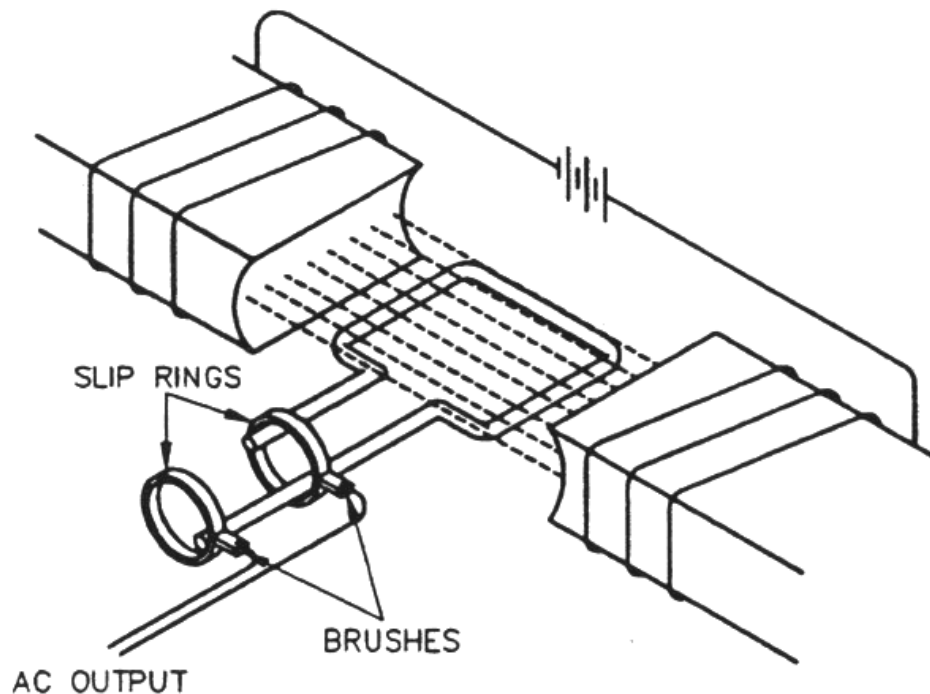
# BASIC AC ELECTRICAL GENERATORS

## Generator Types

Various types of alternating current generators are utilized today; however, they all perform the same basic function. The types discussed in the following paragraphs are typical of the more predominant ones in use.

### Rotating Armature Generator

In the rotating armature AC generator as illustrated in **Figure 1**, the stator provides a stationary electromagnetic field. The rotor, acting as the armature, rotates in the field, cutting the lines of force and producing the desired output voltage. The output voltage is taken from the rotor by the slip rings and brushes. One slip ring is attached to each end of the rotating loop. The brushes make sliding electrical contact with the slip rings. The generator's AC output voltage can be transferred from the slip rings through the brushes to an external circuit.



**Figure 1. Rotating Armature Generator**

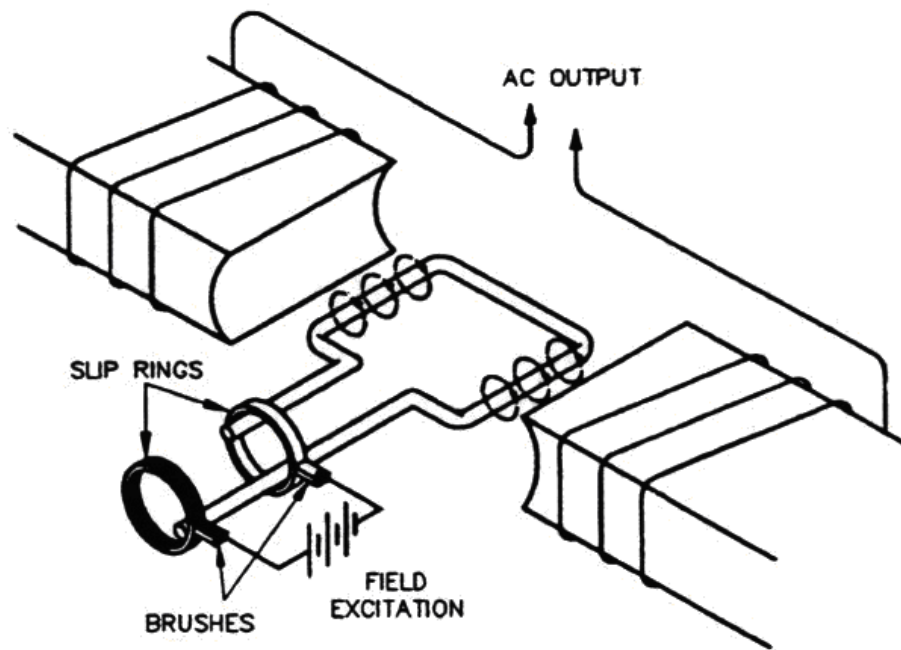
## BASIC AC ELECTRICAL GENERATORS

Rotating armature AC generators are typically used in applications involving small amounts of power. With larger amounts of power, a great deal more current flow occurs through the slip rings and brushes. It is difficult and expensive to build slip rings and brushes to carry large amounts of current. Therefore, most large AC generators are rotating field generators.

### **Rotating Field Generator**

The rotating field AC generator as illustrated in **Figure 2** is by far the most widely used generator. In this type of generator, direct current from a separate source is passed through windings on the rotor by means of slip rings and brushes. This maintains a rotating electromagnetic field of fixed polarity (similar to a rotating bar magnet). The rotating magnetic field of the rotor extends outward and cuts through the armature windings embedded in the surrounding stator. As the rotor turns, alternating voltages are induced in the windings because magnetic fields of first one polarity and then the other cut through them. Because the output power is taken from stationary windings, the output may be connected through fixed terminals. The advantage in this type of construction is that larger amounts of currents can be handled because there are no sliding contacts and the whole output circuit is continuously insulated.

## BASIC AC ELECTRICAL GENERATORS



**Figure 2. Rotating Field Generator**

Slip rings and brushes are adequate for the DC field supply because the current level in the field is much smaller than in the armature circuit.

# BASIC AC ELECTRICAL GENERATORS

## Polyphase Generators

Most electric power is generated and distributed as three-phase rather than single-phase power for the following reasons:

- The cost of transmission is less than for the same voltage and power in a single-phase system.
- A three-phase generator has a 180% greater capacity than a single phase generator of the same physical size.
- Single-phase voltage and power is easily available from a three-phase system by merely tapping any two of the power leads.

A three-phase AC generator is designed to produce three-phase AC power by building more coils in the stator around the rotor. The three coils are equally spaced  $120^\circ$  apart around the inside of the stator. The armature coils are wired so that the generator has three separate output voltages that differ in phase by  $120^\circ$ .

**Figure 3** illustrates a simplified three-phase, two pole AC generator. Each of the three coils generates an AC voltage sine wave as illustrated in **Figure 4a and 4b**. The voltage wave (phase) B begins one third of the way into the A wave cycle, and the C wave begins two thirds of the way into the A wave cycle. This relationship is caused by the position of the coils in the stator. When the voltage in phase A has reached its peak positive value and is returning to zero, the voltage in phase B has reached its peak negative value and is beginning to return to zero. The voltage in phase C has passed zero and a negative voltage is being induced. During a three-phase voltage cycle, the overall voltage induced is never zero.

# BASIC AC ELECTRICAL GENERATORS

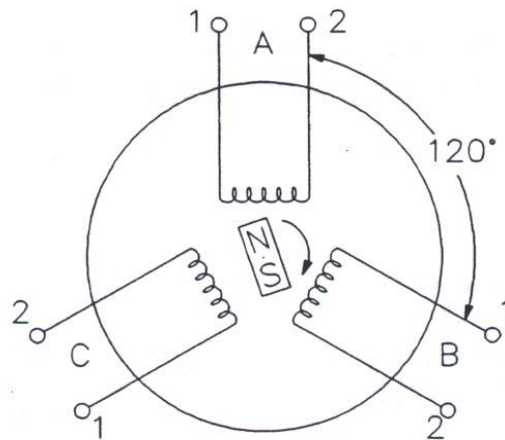


Figure 3. Simplified Three-Phase AC Generator

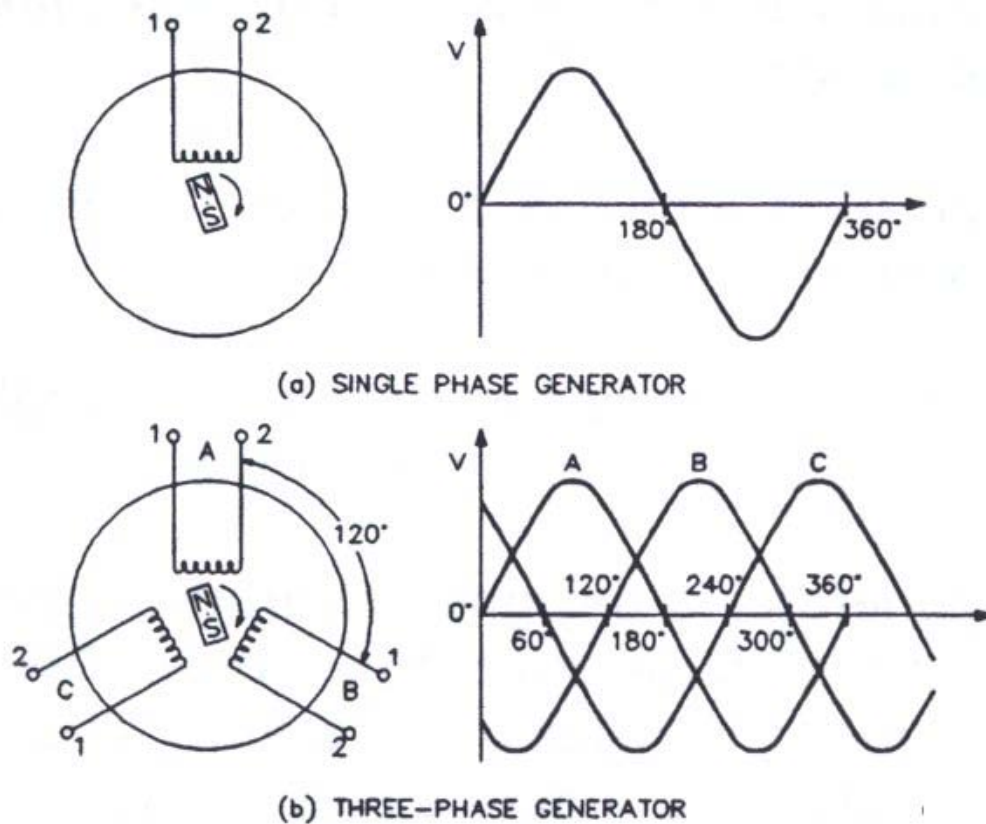


Figure 4. Voltage Output of a Three-Phase Generator

## BASIC AC ELECTRICAL GENERATORS

### Generators Used In Power Generation

Generators used in power generation applications can be placed in three major design classifications based on the cooling medium used: air, hydrogen or liquid cooled. How well the armature winding of a generator is cooled has a significant influence on the overall size of a synchronous generator. The cooling of the armature winding is dependent on a number of factors: cooling medium (air, hydrogen, water); insulation thickness; and overall electrical losses ( $I^2R$  + load loss). As **Figure 5** illustrates, relative heat removal capability improves from air to hydrogen, with increased hydrogen pressure, and even more significant with the use of water cooling.

FLUID	RELATIVE SPECIFIC HEAT	RELATIVE DENSITY	RELATIVE PRACTICAL VOLUME FLOW	APPROXIMATE RELATIVE HEAT REMOVAL ABILITY
AIR	1.0	1.0	1.0	1.0
HYDROGEN 30 PSIG (2.07 BAR)	14.36	0.21	1.0	3.0
HYDROGEN 45 PSIG (3.10 BAR)	14.36	0.26	1.0	4.0
WATER	4.16	1000.0	0.012	50.0

**Figure 5. Generator Heat Removal Capabilities of Various Fluids**

Conventional hydrogen cooling can be utilized on generators rated below 300 MVA, while direct water cooling of armature windings is applied to units above 250 MVA. This division results from design optimization. While it is possible to apply water cooling on machines rated below 250 MVA, the cost/performance benefit suffers. Water cooling adds manufacturing complexity, as well as, requires the need for auxiliary water cooling



## BASIC AC ELECTRICAL GENERATORS

and de-ionizing skid, plus associated piping, control and protection features. At higher ratings, the cost of this complexity is offset by the advantage of producing a generator of significantly smaller size than a comparable conventionally cooled generator. An overview of each of the basic design classifications is provided in the following section.

### **Air Cooled Generators**

Air cooled generators are produced in two basic configurations: open ventilated (OV) and totally enclosed water to air cooled (TEWAC). In the OV design, outside air is drawn directly from outside the unit through filters, passes through the generator and is discharged outside the generator. In the TEWAC design, air is circulated within the generator, passing through frame mounted air to water heat exchangers.

The recent emphasis in the marketplace on steam and gas turbine generators in the 20 to 100 MVA size has forced manufacturers to restructure their air cooled machines. A consequence of the historical development of the turbine generator market was that two lines of generator applications evolved, one for steam turbine applications and the other for gas turbine applications, with little standardization between the designs. As a result of design restructuring, several design and operational issues, which were judged to be critical to the reliability and standardization of generators were identified. Among these issues were performance parameters, availability of features, cycle time and cost effectiveness.

The basic design of a generator is influenced primarily by material and electromagnetic properties, as well as winding temperature rise, industry standards, generator ratings, reliability, etc. A short discussion of the critical factors follows:

### **Temperature Rise**

In the early 1970's, gas turbine manufacturers introduced insulation systems capable of operating at Class F temperatures (155°C, 311°F) for the life of the generator. This

## BASIC AC ELECTRICAL GENERATORS

enabled a significant up rating of generator designs (about 10%) with a minimal increase in cost. To capitalize on this technical capability, manufacturers designed generators with class F insulation and Class F temperature rises. Many such generators are in service and operating successfully.

### **Reliability**

To improve generator reliability, manufacturers pay particular attention to known problem areas based on in service generator experience. The new designs strive for a high level of reliability and availability based on the problems that have caused down time on older designs. In addition, the reliability of the product is improved through design simplification and standardization, discussed below.

### **Construction**

#### **Generator Design and Construction**

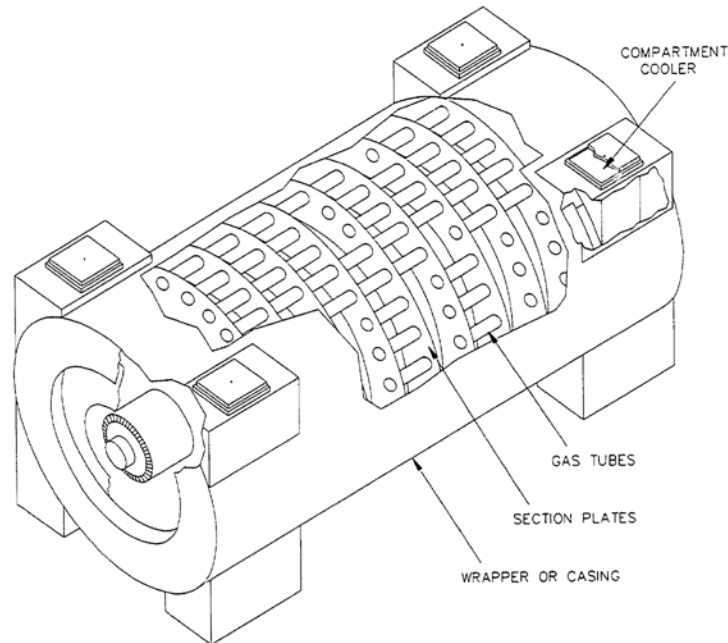
As we go through the generator design and construction the differences between hydrogen cooled and air cooled will be pointed out. There are two main components in the generator, the rotor and the stator. The generator must also have a source of DC current to magnetize the rotor, called the exciter. The generator may have several components and subsystems, depending on its particular features. The following is a discussion on the main components of a generator.

#### **Generator Stator and Windings**

The generator stator, also called the armature, supports the iron core and windings, the rotor, and the compartment coolers reference **Figure 6 and 7**. The stator consists of a steel plate casing called the "wrapper" that covers a frame that in turn holds the iron core. An iron core is used in order to produce a stronger magnetic field for the generation of voltage. There are tubes within the wrapper to help distribute cooling gas. Older units use air at atmospheric pressure for cooling. Newer generators use

## BASIC AC ELECTRICAL GENERATORS

hydrogen under pressure (from 15 to 75 psig) for cooling. Hydrogen is more effective than air in dissipating heat, and the higher the hydrogen pressure, the more effective the hydrogen is in removing heat.



**Figure 6. Generator Stator**

**Figure 6** illustrates a typical stator. The core is made up of thousands of laminated steel sheet metal punchings, each of which is insulated from the others. Note that the core is referred to as "iron" even though it is made up of these steel punchings. The insulation is necessary to avoid creating large currents in the core that would cause it to heat up to an unacceptably high temperature. The punchings are "stacked" with spaces between groups of punchings to allow for cooling ventilation.

# BASIC AC ELECTRICAL GENERATORS

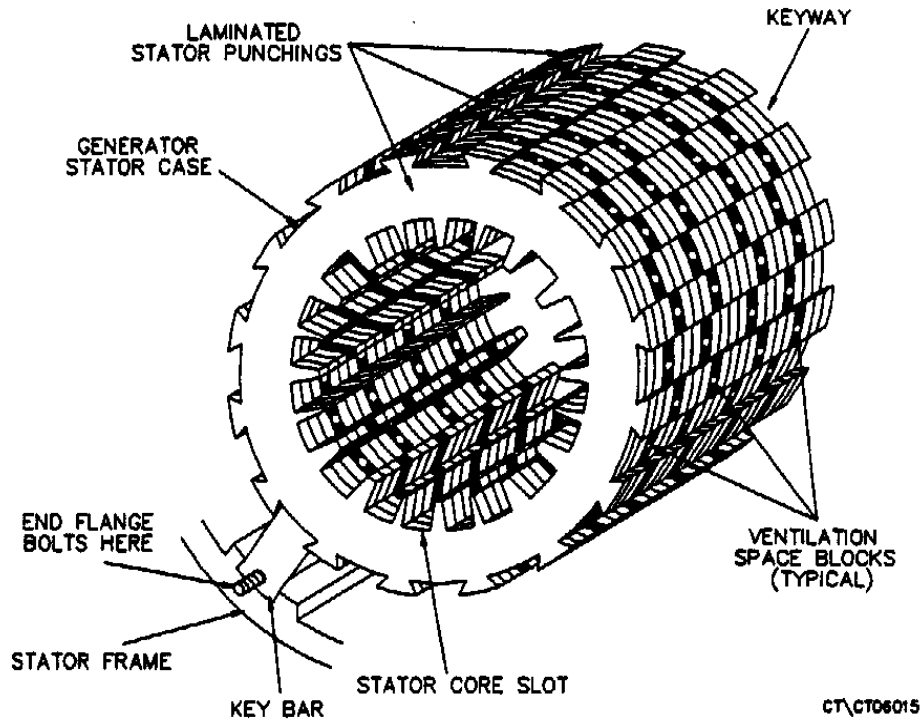


Figure 7. Typical Stator Core

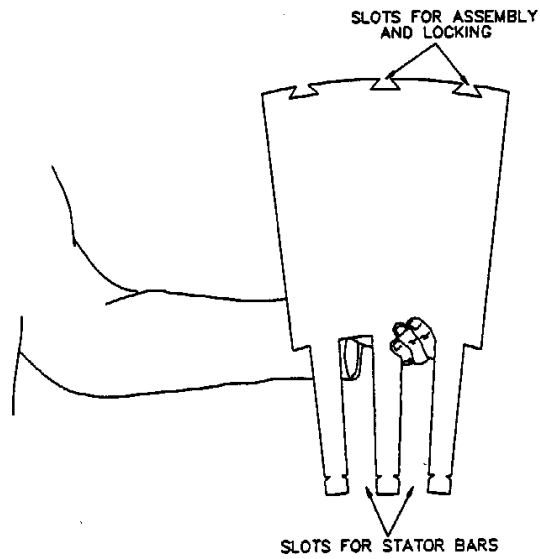
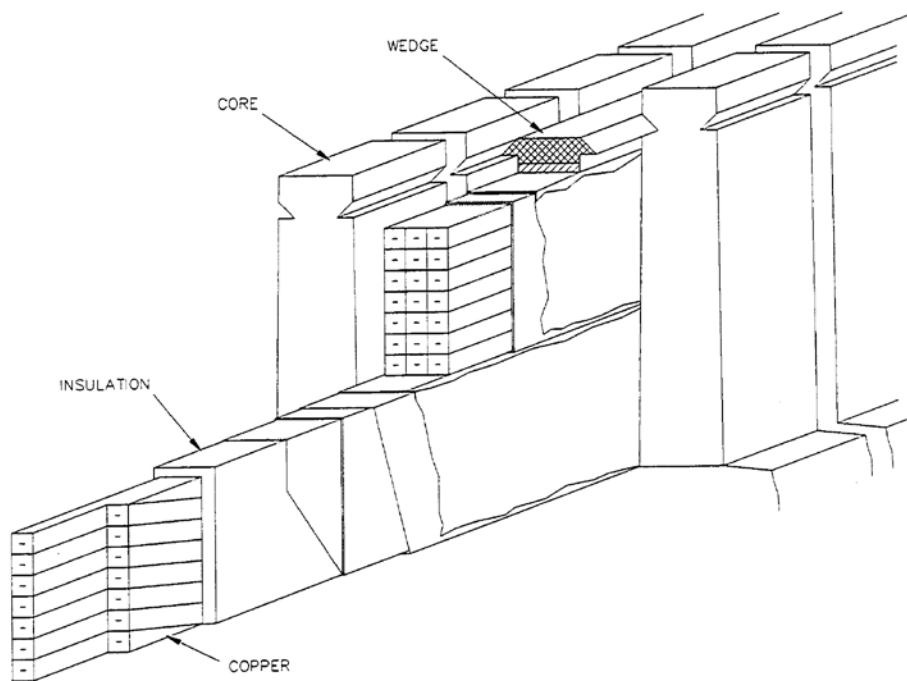


Figure 8. Typical Stator Punching

## BASIC AC ELECTRICAL GENERATORS

The windings or conductors for the stator take the form of long copper bars that are wrapped with insulation. The bars fit into the longitudinal slots on the inside diameter of the core and are held in place by wedges that slide into the top of the slot. **Figure 9** illustrates the assembly of the bars in a slot. Note that there are generally two bars, one on the top and the other beneath, in each slot.



**Figure 9. Generator Stator Construction Detail**

Some generators have liquid cooled stator windings; the liquid may be oil, or more often, water. In these units the copper bars have many passages along their length for liquid to flow.

The stator windings are tied together at the ends of the stator and are brought out through the casing through a bolted on assembly called the lower frame extension (or as it is sometimes called, the bath tub) at the bottom to terminals. There are generally six terminals, one for each end of each of the three phases in the windings.

## BASIC AC ELECTRICAL GENERATORS

The stator frame is divided onto an inner and an outer section, both of which mount on a single base fabrication. The inner frame is a very simple structure designed to support the stator core and winding while providing some guidance to the air flow in the machine. The stator core, made from grain oriented silicon steel for low loss and high permeability, is mounted rigidly in the inner frame. Isolation of the core vibration from the remainder of the structure is accomplished through the use of flexible pads between the feet on the inner frame and the base structure.

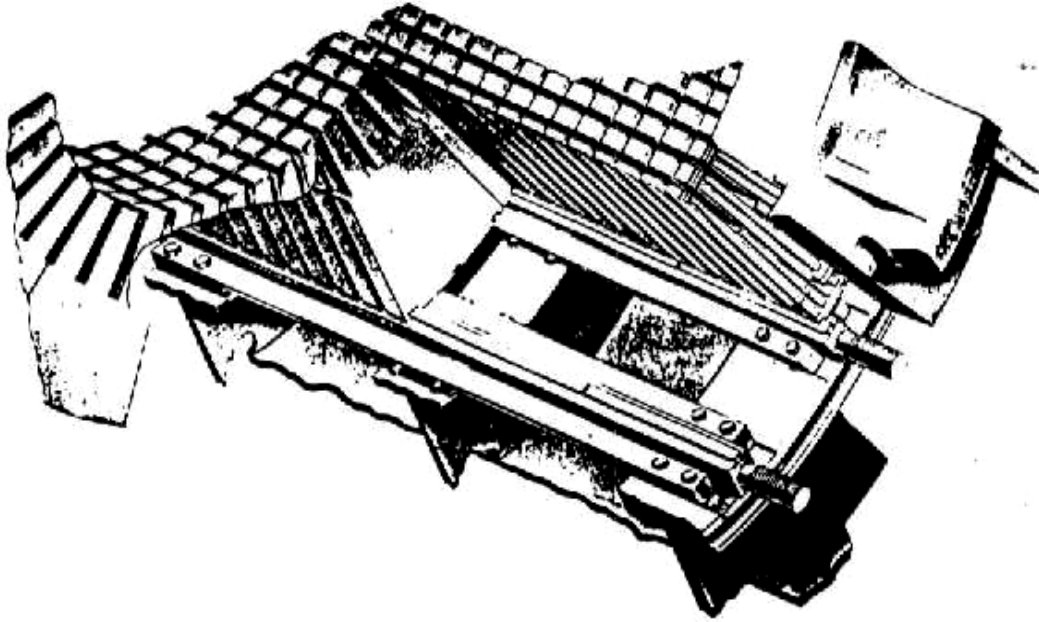
The outer frame is a simple fabricated enclosure, which supports both the air inlets and silencers (if the unit is open ventilated or the roof and cooler enclosure (if the unit is totally enclosed, water-to-air-cooled). The outer frame further acts as an air guide to complete the ventilation paths it also acts as a soundproof enclosure to keep noise levels low. Since the rotor is pedestal mounted, the end shields are very simple structures.

The entire generator is mounted on a single fabricated base, which supports the pedestals, the inner and outer frames, and the brush rigging or the exciter. The base contains piping for oil supplies, conduit for wiring and a number of components associated with the main leads, such as lightning arresters and surge capacitors. The structural vibration of the base is confirmed by tests to verify the vibration frequency is well away from any frequency of concern.

The stator winding is a conventional lap wound design. The insulating materials have been in use since the early 1970's, thus maintaining the proven reliability record. The materials are all designed and tested to provide reliable performance at Class F temperatures for the life of the machine. The bars are secured in the slots with fillers and top ripple springs to restrain the bars radially, and with side ripple springs to increase friction between the bar and the slot wall. The side ripple springs are also conducting to ensure proper grounding of the bar surface. The end winding support

## BASIC AC ELECTRICAL GENERATORS

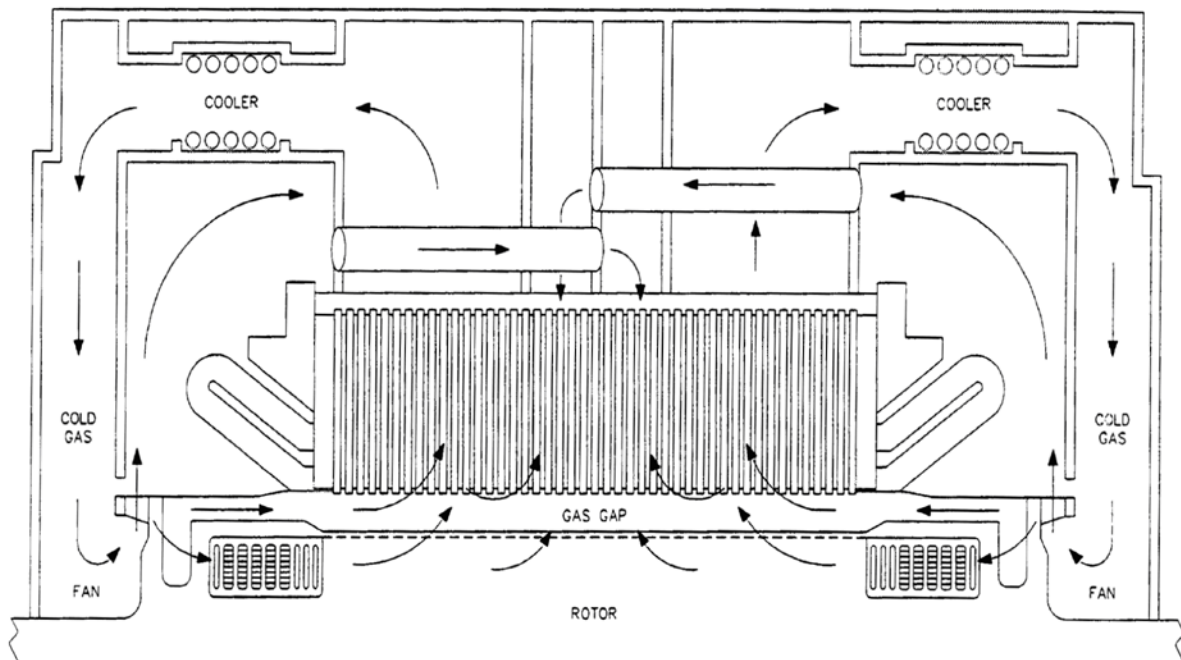
system is the proven approach used on conventionally cooled stators of all sizes built by GE. This system utilizes resin impregnated glass roving ties.



**Figure 10. Spring Mounting**

Hydrogen-cooled generator construction except for the frame is very similar to that of air cooled generators. Most designs use direct radial flow cooling similar to that shown in **Figure 11**. The stator frame, on the other hand, because of the need to contain 30 psig to 75 psig hydrogen, uses thick plate cylindrical construction. End shields are more rugged and contain a hydrogen seal system to minimize leakage. Conventional hydrogen cooling, while available for generators rated below 100 MVA, is most often applied to gas and steam turbine driven units above 100 MVA.

## BASIC AC ELECTRICAL GENERATORS



**Figure 11. Hydrogen Cooled Generator Cooling Flow**

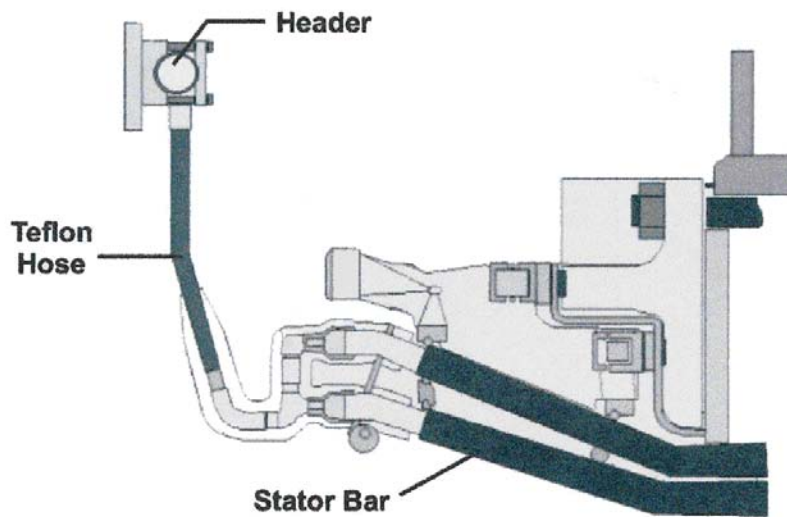
### **Stator Design Hydrogen/Water Cooled Stators**

Even more compact generator designs are achievable through the use of direct water cooling of the generator armature winding. These designs employ hollow copper strands through which deionized water flows. The cooling water is supplied by a closed loop auxiliary-base-mounted skid. The cool water enters the winding through a distribution header on the connection end of the generator Reference **Figure 12**. The warm water is discharged in a similar manner on the turbine end of the generator.

The armature voltage and current of a hydrogen/water-cooled generator is significantly higher than those of air or hydrogen cooled units. As a result, the insulation voltage stress and forces on the armature windings can be several orders of magnitude larger than those experienced on lower rated units. These present unique design requirements that must be addressed if high reliability and long life of the equipment is to be maintained.



## BASIC AC ELECTRICAL GENERATORS



**Figure 12. Stator End Winding Configuration**

The stator insulation material used in modern GE water-cooled generators consists of an epoxy mica based system called Micapal™. Micapal™ I was introduced in 1954, partially as a solution to tape migration and girth cracking problems associated with asphalt insulation based systems.

In the mid 1970's, an improved epoxy mica system was introduced (Micapal™II). This all mica paper insulation has improved mechanical toughness and voltage endurance. While these properties were developed to meet the requirements of very large ratings, the application of Micapal™II on small and mid size units permits further optimization opportunities. Micapal™II has excellent thermal cycling capability, and is particularly suited for the daily start/stop duty required of many gas turbine generators today.

# BASIC AC ELECTRICAL GENERATORS

## GENERATOR ROTORS

### Salient Pole Rotors

One of the two types of rotors typically installed within large generators is the salient pole rotor (Figure 13 A). Salient pole rotors have large diameters and large mass making them ideal for slower spinning rotors, such as on hydroelectric generators. The greater inertia (inertia is a function of the weight, speed of rotation, and diameter) associated with this type of rotor, helps maintain a constant frequency in the power system.

Each field pole of a salient pole rotor has a pole running lengthwise along the cylinder shaped rotor (see Figure 13 A). The pole functions in a similar manner to the core of a transformer. Each pole is wrapped with windings its entire length to form the pole. The windings are made of an insulated copper conductor. A field winding is formed by connecting the windings of each field pole in series with each adjacent field pole. It is termed the field winding since it provides the magnetic field for the generator. Note that in large, modern generators, the rotor will always contain the field winding.



**Figure 13 A. Salient Pole**

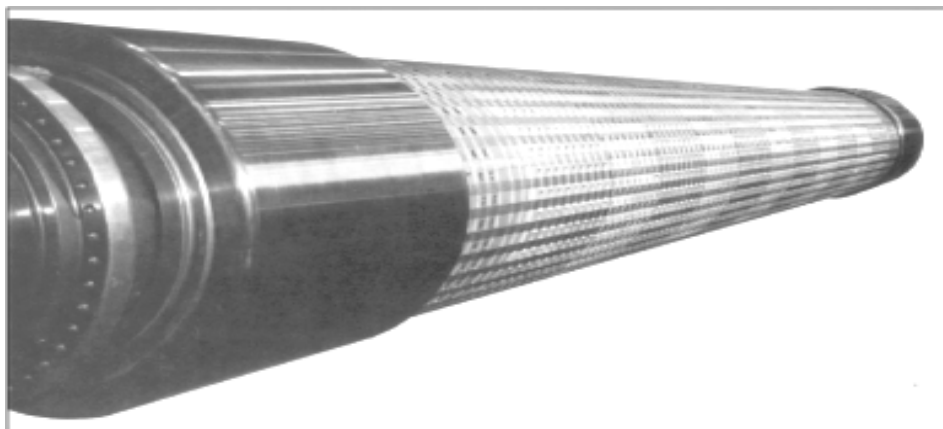
## BASIC AC ELECTRICAL GENERATORS

### Cylindrical Generator Rotor

Cylindrical rotors (**Figure 13**) are used on higher speed generators, such as steam turbine driven generators, due to their faster rotational speed. Higher speed generators would literally tear apart a large salient pole rotor due to the centrifugal force associated with the large diameter and weight. Note that a great amount of inertia is still present with cylindrical rotors due to their high speed of rotation.

A cylindrical rotor is a solid steel shaft with slots that run lengthwise along the outside of its cylindrical shape. Laminated copper bars are inserted within the slots and these conductors are kept stationary with metal wedges. These copper bars form the field winding of the rotor.

The rotor acts as a large electromagnet. When it turns inside the stator, it induces a voltage and current in the stator windings. The rotor takes the form of a long cylinder with slots machined along its length reference **Figure 13 B**. Copper windings fit into these slots and are held in place by wedges that slide into the top of the slots. The slots are insulated from the windings, and each turn of the winding is insulated from the next turn. The windings are held at the ends of the rotor by retaining rings. The wedges and windings often have holes or slots in them to allow cooling gas to flow.



**Figure 13 B. Generator Rotor**

## BASIC AC ELECTRICAL GENERATORS

The rotor is usually connected directly to a prime mover such as a steam turbine in a steam unit or a hydraulic turbine in a hydroelectric unit. Thus, the speed at which the rotor turns and the power output of the generator is determined by the speed at which the turbine spins and the energy input to the turbine. Two pole (3600 rpm) generators are typically used in coal-fired steam units, due to the high pressures and temperatures associated with the steam. That is there is one winding in the field and it acts as one, large electromagnet with two poles as illustrated in **Figure 14 and 15**. Nuclear power plants typically use four-pole rotors. Four-pole rotors are used because a nuclear unit's steam temperature and pressure are lower and the lower the energy content of the steam, the larger the turbine has to be. It would not be safe to rotate large steam turbines at 3600 rpm.

Gas turbines typically use two pole rotors although the turbine itself may spin at a higher speed and use some method of gear reduction to connect to the machine rotor. Most modern day gas turbines or combustion turbines turn at 3600 RPMs.

Hydroelectric generators rotate at much slower speeds due to the energy in the water used to turn the hydraulic turbine. Most hydroelectric units rotate below 300 rpm resulting in a high number of poles. For example, a hydroelectric generator with a rotating speed of 100 RPM will have 72 poles. The number of poles and the rotating speed used for a hydroelectric unit varies greatly depending on the characteristics (difference in incoming versus outgoing water elevation, etc.) of the particular water resource where a unit is located.

## BASIC AC ELECTRICAL GENERATORS

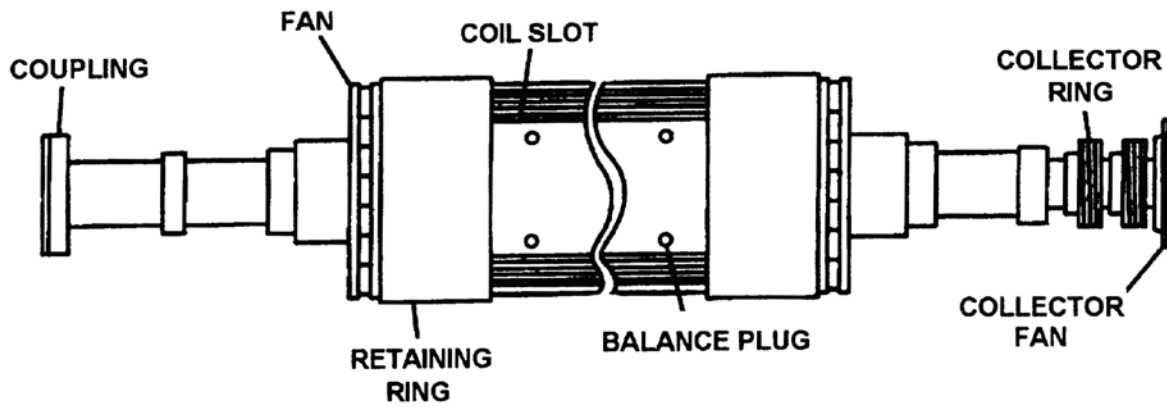


Figure 14. Generator Rotor



Figure 15. Two Poles Imbedded in the Rotor

There are fans mounted on the ends of the rotor to circulate cooling gas inside the generator stator. The fans may be axial or centrifugal as illustrated in **Figure 16**.

## BASIC AC ELECTRICAL GENERATORS



**Figure 16. Fan Mounted On the End of Rotor**

An operator will have to adjust the frequency of the generator in your plant to 60 hertz when you're putting them on line. To do this correctly, you to know each generators proper operating speed. The following formula relates to the frequency of a generator to its operating speed and to the number of poles that it has:

$$F = \frac{\text{rpm} \times \text{number of poles}}{120}$$

**For example**, if you wanted to set a two-pole generator at 60 hertz, you put numbers you know into the formula, like this;

$$F = \frac{3600 \times 2}{120} = \frac{7200}{120} = 60 \text{ hertz}$$

**For example**, if you wanted to set a four-pole generator at 60 hertz, you put numbers you know into the formula, like this

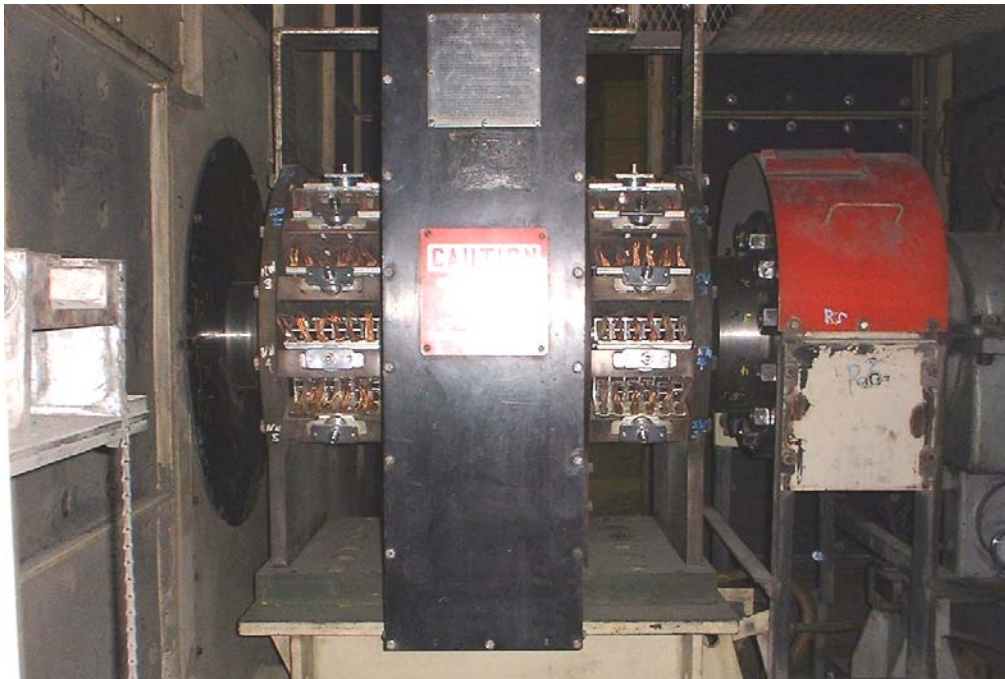
$$F = \frac{1800 \times 4}{120} = \frac{7200}{120} = 60 \text{ hertz}$$

## BASIC AC ELECTRICAL GENERATORS

**For example**, if you wanted to set a twelve-pole generator at 60 hertz, you put numbers you know into the formula, like this

$$F = \frac{600 \times 12}{120} = \frac{7200}{120} = 60 \text{ hertz}$$

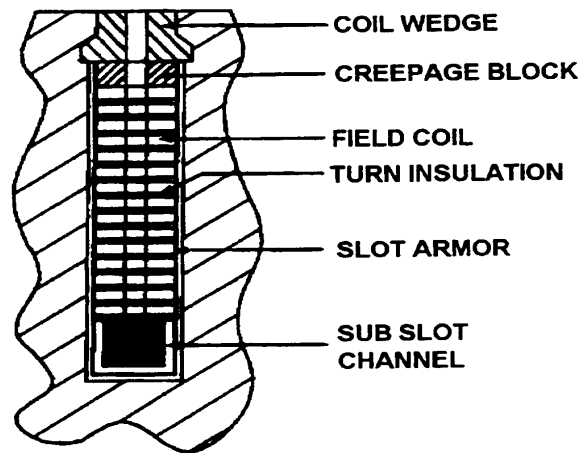
Collector rings are provided at the generator end of the rotor. The field windings are connected to these collector rings as illustrated in **Figure 17**. DC current passes through brushes that ride against these rings, and that current magnetizes the field.



**Figure 17. Collector Brushes**

**Figure 18** illustrates a cross section through one slot with its windings, illustrating the flow of cooling gas as well as the insulation.

## BASIC AC ELECTRICAL GENERATORS



**Figure 18. Cross Section of Rotor Winding Slot**

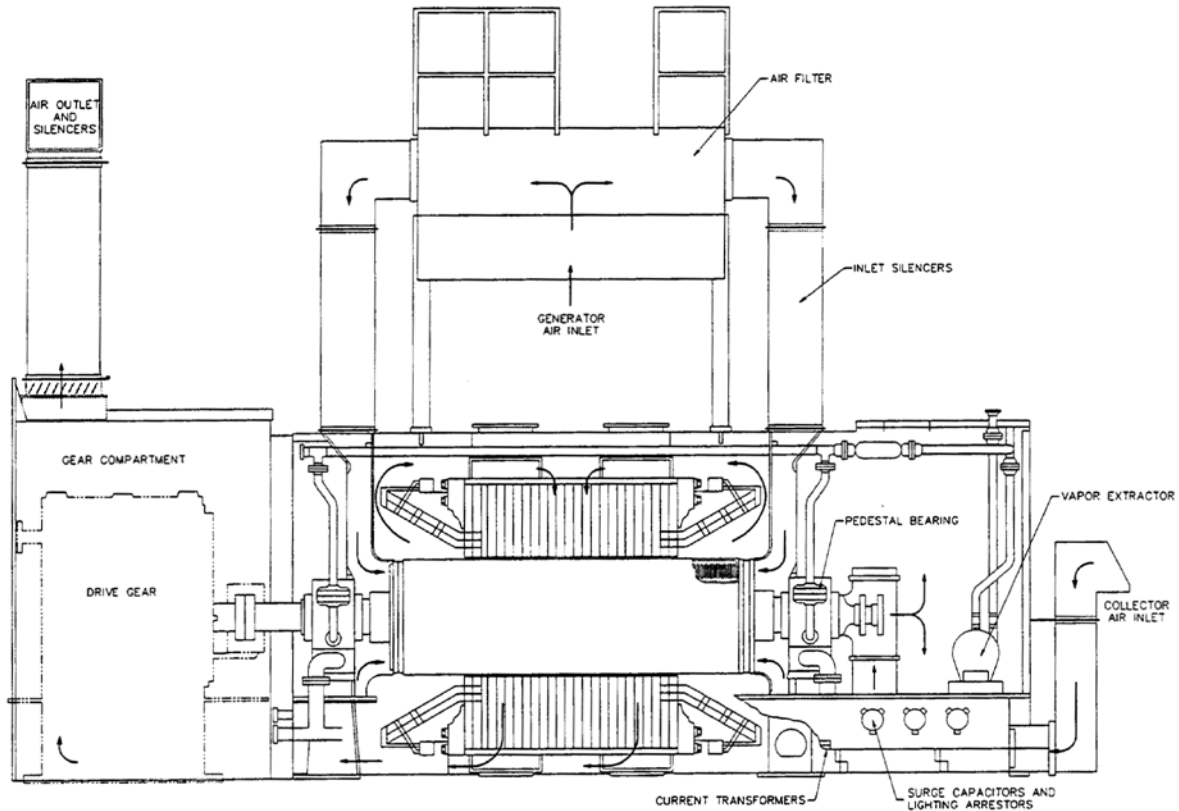
### **Rotor Design Air Cooled Generators**

The rotor is a simple single piece forging, pedestal mounted, with tilting pad bearings for smooth operation. On smaller units, the rotor is sufficiently short that the second critical speed is above running speed, thus simplifying balance as referenced in **Figure 19**.

The retaining rings are nonmagnetic and have good stress corrosion resistance. The retaining rings are shrunk onto the rotor body, thus eliminating any risk of top turn breakage. The retaining rings are secured to the rotor body with a snap ring, a design that minimizes the stresses in the tip of the retaining ring.



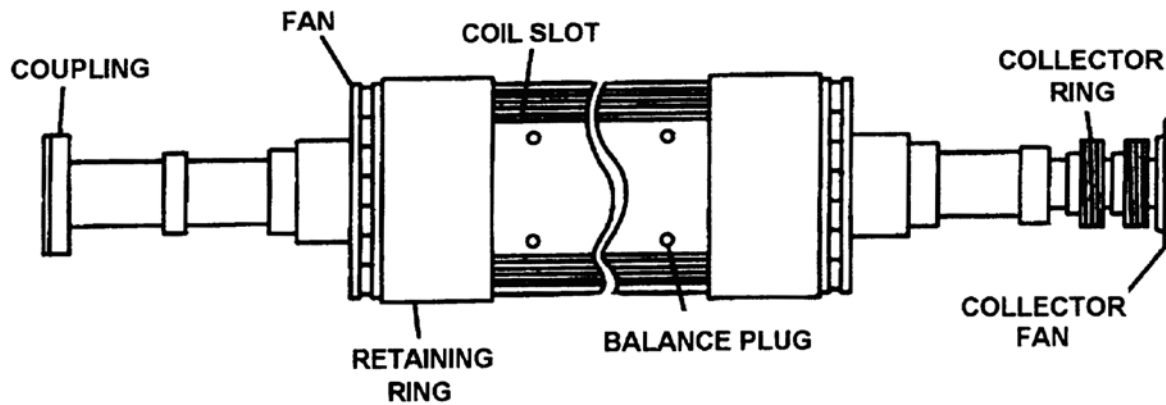
## BASIC AC ELECTRICAL GENERATORS



**Figure 19. Generator Ventilation Pattern**

Radial flow fans are mounted on the centering ring at each end of the rotor as illustrated in **Figure 20**. The fans provide cooling air for the stator winding and core. The rotor winding, which is a directly cooled radial flow design, is self pumping and does not rely on the fan for air flow. The overall ventilation pattern is shown in **Figure 19**.

## BASIC AC ELECTRICAL GENERATORS



**Figure 20. Fan Mounded on End of Generator Shaft**

The rotor winding fits in a rectangular slot and is retained by a full length wedge on the shorter machines. Where cross slots are required on longer rotors, several wedges are used in each slot. The rotor slot insulation, turn insulation and other materials in contact with the winding are full Class F materials.

### **Rotor Design Hydrogen/Water Cooled Generators**

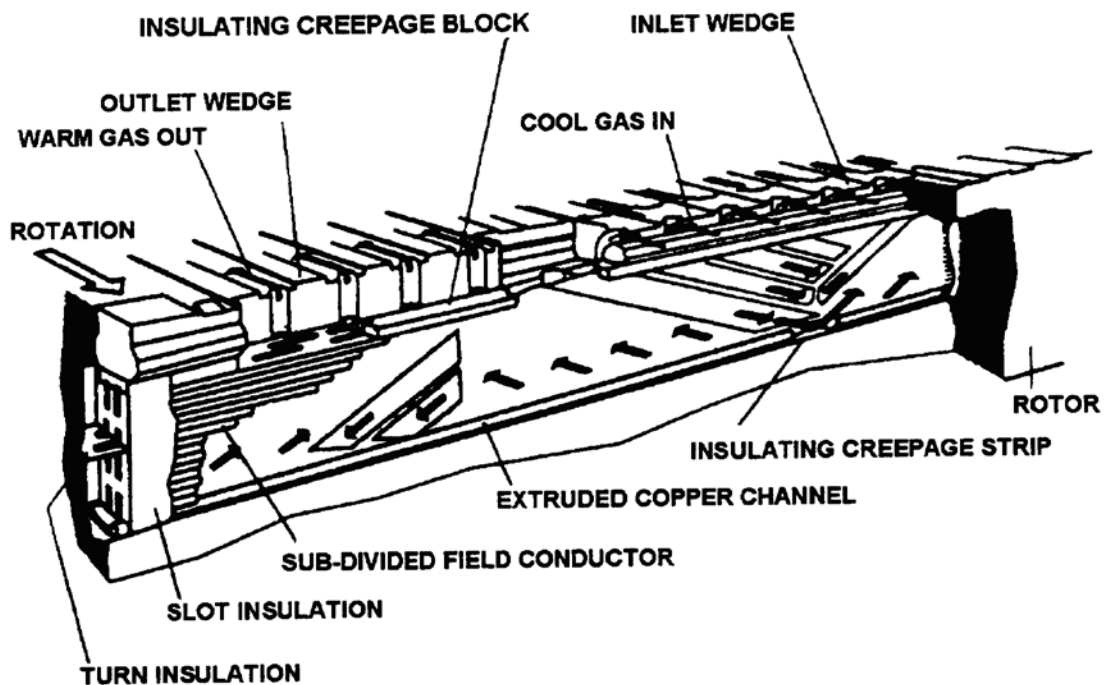
The generator rotor contains the field windings that produce the magnetic flux, which, in turn, produces the stator current and voltage. Proper cooling of the field winding is another challenge that the generator designer must overcome.

All hydrogen/water cooled generators use direct conductor cooling of the rotor winding for heat removal. Smaller two-pole and all four pole generators use the radial flow design. At the end of the rotor body, hydrogen enters the windings through full length subslots and is discharged along the length of the rotor body through radial slots, machined or punched, in the copper conductors. The hydrogen passes from the conductors through the creepage blocks and wedges to the "air gap," where the hydrogen is directed through the stator core to the hydrogen coolers.

## BASIC AC ELECTRICAL GENERATORS

As generator ratings, and consequently rotor body length increase even further, the gap pickup diagonal flow cooling method is employed (**Figure 21**). In this scheme, cold hydrogen is scooped up in the gas gap and driven diagonally through the rotor copper to directly remove the heat. At the bottom of the slot, the gas is turned and passes diagonally outward to the gas gap in a discharge stator core section. The stator core ventilation is coordinated with the rotor cooling gas flow, thus creating an in and out flow of hydrogen through the stator core, through the rotor, and returning to the hydrogen cooler through the core. This cooling method results in a design which maintains the same average copper temperature, independent of rotor length.

There are significant challenges in producing an optimal generator rotor mechanical design. The following describes some of those challenges and features that have been incorporated to meet those challenges.



**Figure 21. Rotor Diagonal Flow Cooling Method**

## BASIC AC ELECTRICAL GENERATORS

### Rotor Mechanical Design

The generator retaining rings, which support the rotor winding end turns against centrifugal force, are the most highly stressed components of the generator. On most designs, the retaining rings are shrunk on to the end of the generator body, as illustrated in **Figure 22**. Locking of the retaining ring to the generator body is required to ensure the ring is not pushed off its fit surface due to the axial force generated by thermal expansion of the field winding.

Important design requirements of retaining rings are that the rings be tolerant to high stress levels, possess adequate low cycle fatigue capability and have acceptable separating speeds. Therefore, a design is required where careful attention is paid to minimize stress concentrations. Large shrink fit interferences are required to prevent separation under overspeed conditions, which result in relatively high stress levels at standstill. In most cases, the ring material must be nonmagnetic to minimize the end leakage flux and reduce heating of the core end structure.

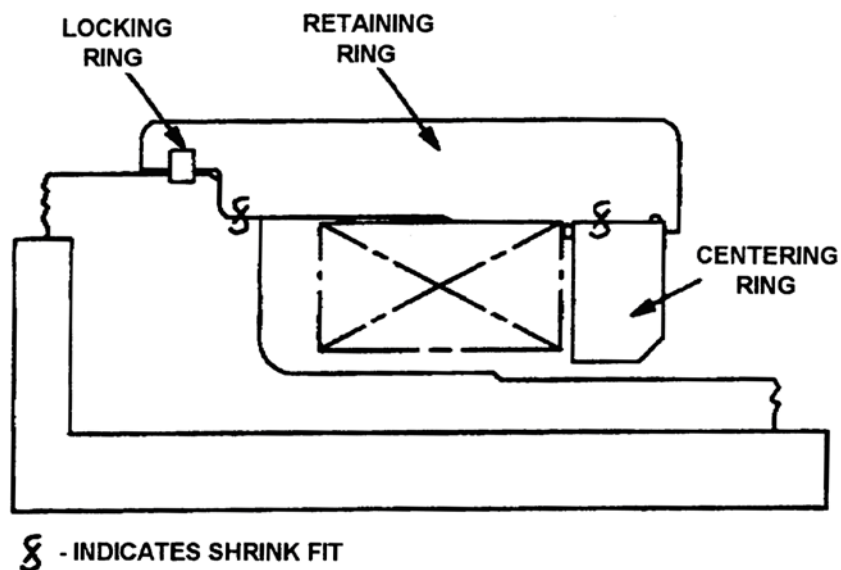


Figure 22. Retaining Rings Assembly

## BASIC AC ELECTRICAL GENERATORS

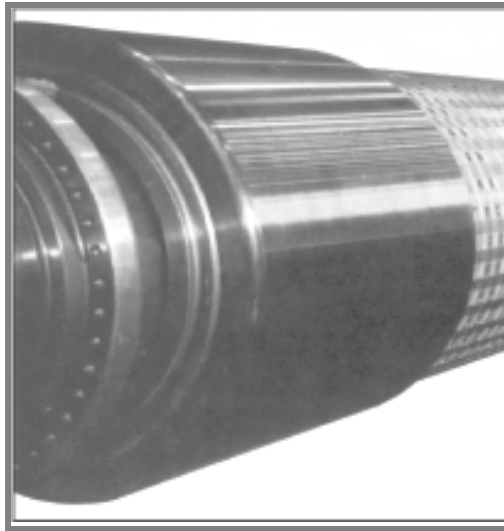
For many years, nonmagnetic retaining rings were made from an 18Mn-5Cr steel alloy. However, in the mid1970's the susceptibility of 18-5 retaining rings to stress corrosion cracking became known. As a result of cooperative programs with retaining ring suppliers, a different alloy, 18Cr-18Mn (originally proposed by GE), was selected as a better retaining ring material. This material has the required properties, including high resistance to stress corrosion cracking in the types of environments to which rings may be exposed during the service life of the generator.

One of the most critical rotor manufacturing requirements, after all the parts are accurately machined and carefully assembled, is the final balance operation. This ensures that the rotor vibration is within acceptable limits and that the rotor remains straight within very close tolerances at all running speeds up to and including the maximum specified overspeed.

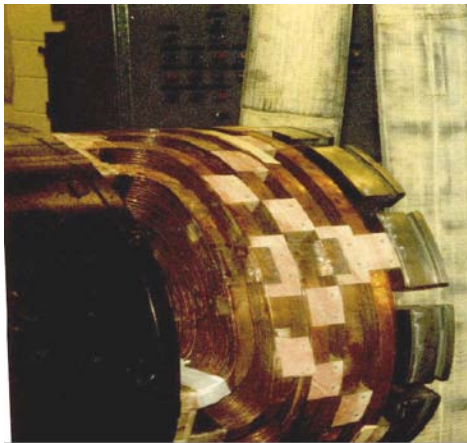
The design work initially includes the accurate calculation of all shaft stiffness. Balancing and overspeed testing are performed at critical speeds at the manufacturers' factory balance facility. A high speed multiplane balancing procedure is used.

The design of modern generators, whether they are air, hydrogen or hydrogen / water cooled, requires a blend of time proven, as well as innovative, design concepts. This successful integration of time proven concepts with modern technology produces generators that can be expected to provide efficient, trouble free service through years of baseload or cycling operation.

## BASIC AC ELECTRICAL GENERATORS



**Figure 23. Rotor With Retaining Ring**



**Figure 24. Rotor Without Retaining Rings**

### **Hydrogen Cooled Generator Stator**

The four (4) hydrogen gas coolers for a generator are located in a vertical position in the associated generator frame, two (2) at each end of the associated frame and on both sides of the axial centerline. The hydrogen coolers are built and installed in the frame so that any one (1) of the coolers may be taken out of service for cleaning while the unit

## BASIC AC ELECTRICAL GENERATORS

generator is still carrying load. This is accomplished by removing the water piping and cooler headers from the ends, without breaking the gasketed seal that maintains hydrogen pressure within the associated generator.

The generator end shields are heavily reinforced fabrications, designed to support the weight of the rotor and to contain the hydrogen gas at maximum pressure without excessive distortion.

The generator rotor bearings, the hydrogen shaft seals, and oil passages supplying oil to these parts, are contained and/or supported by the outer end shields. The end shields are split on the horizontal centerline, facilitating their removal. The joints between the shield halves and the joints between the shields and the stator frame are fitted and provided with grooves for the insertion of a sealing compound, to seal the hydrogen gas in the generator casing.

A shaft seal attached to each outer end shield, adjacent to the bearing inboard, prevents the escape of hydrogen gas from the generator along the rotor shaft penetration points. This arrangement permits inspection of the generator bearings, without removing gas from the machine. The bearing ring and the shaft seal housing at the collector end of the machine are insulated from the generator frame to prevent the flow of shaft currents.

The inner end shields are located between the ends of the armature windings and the outer end shields, to separate the gas discharged from the fans from the gas entering the fans. The fan inlet vanes and nozzle rings are attached to the inner end shields. This together with nozzle ring segments attached to the outer end shields provide optimum gas entrance and discharge conditions for the fans.

## BASIC AC ELECTRICAL GENERATORS

The main power leads are brought out through the lower frame extension from the connection by means of porcelain insulated high voltage bushings. The bottom plate of the lower frame extension is made of non-magnetic material. This is done to eliminate current flow induced in the plate by load current in the bushings.

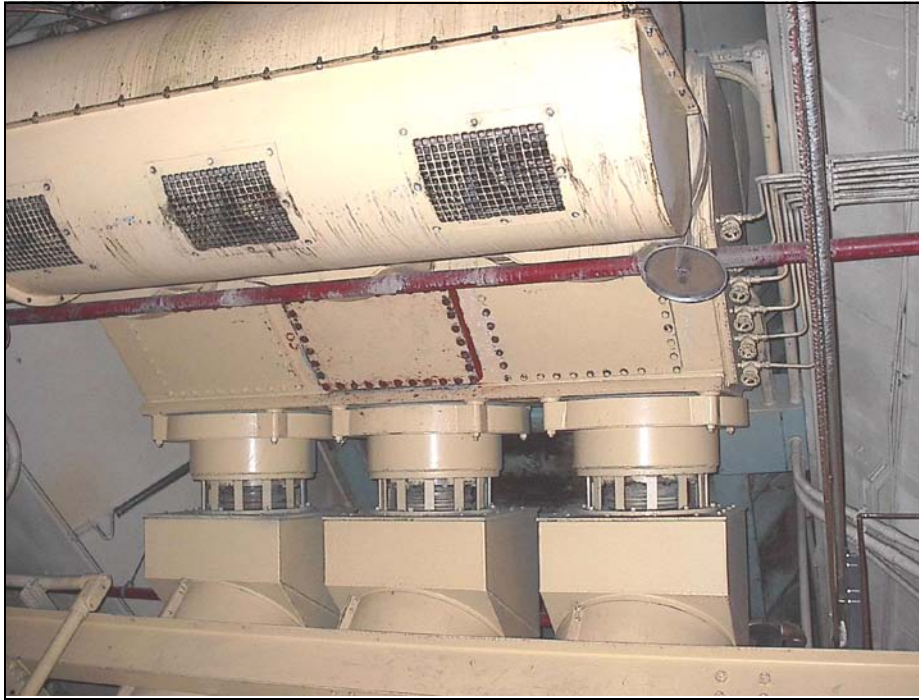
The main leads go from each unit generator stator to its associated Isolated Phase Bus. Each lead is connected to the phase winding in its unit Generator. The leads pass through porcelain-insulated bushings to prevent electrical contact with the housing. The bushings are mounted in the main lead box. A duct for each lead carries hydrogen along the lead for cooling. The hydrogen flows through the center of each bushing before being directed out of each bushing and into the lead box. The three (3) main leads each unit generator's three (3) phases go on to the associated unit's Isolated Phase Bus. The three (3) neutral leads join together to form a single neutral lead going to the unit generator's Neutral Ground Transformer.

### **Generator Isolated Phase Bus**

The purpose of the each unit's Isolated Phase Bus is to connect its unit Generator to the associated main transformer and auxiliary transformer. The metal enclosed Isolated Phase Bus extends from the unit generator terminals to its main power transformer. Removable links are provided at each unit generator, each main transformer, each unit auxiliary transformer, and to the auxiliary transformer. The metal enclosed bus taps to the auxiliary transformer, scrubber auxiliary transformer and surge protection cubicle are self-cooled. The bus, bus joints and bus taps are made of high conductivity aluminum. The bus joints and tap joints are welded.



## BASIC AC ELECTRICAL GENERATORS



**Figure 25. Main Leads to Isolated Phase Bus**

Each Isolated Phase Bus is cooled by a heat exchanger. Air is circulated through the bus by fans and cooled by heat exchangers. An air filter is provided on the return side for make-up air. The cooling water to the heat exchangers is provided from the bearing cooling water system. Low water flow, high air temperature and loss of fan differential pressure, one for each fan actuates alarm switches.

The unit's isolated phase bus is usually protected by unit differential relays 87LU and by generator ground relay 64G along with the other generator protection relays.

On some Generators a liquid detector is a small chamber that contains a float. A liquid detector will alarm if more than 1½ pints of liquid collect in the body of the detector. A magnetic sleeve is connected to the float. When there is a low level in the chamber, the float is down. But if level increases, the float and magnetic sleeve move up. As the sleeve moves up, it moves into the magnetic field of a small magnet connected to a

## BASIC AC ELECTRICAL GENERATORS

mercury switch. Normally, the magnet is held away from the tube that guides the sleeve via spring. But when the sleeve is high enough, the magnet moves toward the sleeve, stretching the spring. When the magnet moves, it pivots the mercury switch. The change in position of the mercury switch causes an alarm to sound to indicate a high level in the liquid detector.

### Hydrogen and Gassing

Hydrogen pressure in the generator must be maintained above atmospheric pressure at all times to keep seal oil from being drawn into the generator. Hydrogen purity range indicator is 50 to 100 percent. The hydrogen purity in the generator should always be maintained above the explosive limit of 75 percent.

The low hydrogen purity alarm actuates when the purity decreases to 90 percent purity. Normal operating purity is greater than 98 percent.

Machine gas pressure high/low alarms are provided. When a low-pressure alarm actuates, hydrogen should be added to the machine. The high-pressure alarm actuates upon overfilling of the machine.

The flow meter for the gas analyzer has a range of zero (0) to 30 cubic feet per hour (CFPH). Normal operating range for the gas analyzer is between one (1) and 1½ cubic feet per hour.

### **Standard Generator Seal Oil System**

Since the unit's rotor shaft ends of the hydrogen cooled generators for each unit must be brought out of the gas tight enclosure, means must be provided to prevent the escape of hydrogen gas from along the shaft. The purpose of the Generator Seal Oil System is to provide the means to prevent the escape of hydrogen from the generator enclosed. **Figure 26** is an illustration of the Seal Oil Skid.

## BASIC AC ELECTRICAL GENERATORS



**Figure 26. Seal Oil Skid**

The Generator Seal Oil System consists of shaft hydrogen seals at both the turbine and the exciter end of the generator, a vacuum tank, a main seal oil pump, a seal oil vacuum pump, and an emergency seal oil pump. Shaft Hydrogen Seals: A seal housing is attached to the generator that contains two annular segmental sealing rings. Vacuum treated oil from the seal oil supply skid is fed between the rings by the seal oil feed groove in the housing. The oil flows between the rings and the shaft in both directions. The oil film in the constricted area between the generator shaft and the sealing rings forms a seal that prevents the hydrogen from leaking past the end shields along the shaft.

Vacuum Tank: During normal operation, oil from the lube oil system enters the vacuum tank through spray nozzles. The inlet spray nozzles are directed upward and separate

## BASIC AC ELECTRICAL GENERATORS

some of the gases from the oil as it enters the tank. Most of the gas remaining in the oil is separated by recirculation through a second set of spray nozzles directed downward.

**Main Seal Oil Pump:** The Main Seal Oil Pump pumps Oil from the vacuum tank to the shaft seals. Excess oil over the seal requirements is returned to the vacuum tank by the recirculating spray nozzles.

**Seal Oil Vacuum Pump:** The Seal Oil Vacuum Pump maintains an absolute pressure of about 0.5 inches of mercury in the vacuum tank.

**Emergency Seal Oil Pump:** The Emergency Seal Oil Pump is driven by a D. C. motor to ensure maximum availability. The emergency pump is started by operation of pressure switch 63-P7 located in the Main Seal Oil Pump line. This pressure switch is adjusted to CLOSE on falling Main Seal Oil Pump pressure. The vacuum tank becomes inoperative when the emergency pump is in operation.

A seal housing is attached to the generator end shield at each end of the generator. This housing contains two (2) annular segmental sealing rings that have an internal diameter a few mils larger than the diameter of the generator shaft. The segments of each ring are held together radially by garter springs. These springs also separate the two (2) rings axially. The rings are free to move radially with the shaft but are prevented from rotating by a stop in the seal housing. Vacuum-treated oil from the seal oil supply skid is fed between the rings by the seal oil feed groove in the housing. The oil flows between the rings and the shaft in both directions. The oil film in the constricted area between the generator shaft and the sealing rings forms a seal that prevents the hydrogen from leaking past the end shields along the shaft. After flowing past the sealing rings, the oil is drained from the housing. The oil that flows toward the generator passes into the seal oil drain, while the oil that passes toward the bearing mixes with the oil discharged from the generator bearing.

## BASIC AC ELECTRICAL GENERATORS

Two drainpipes, one at each end of the generator, receive the oil discharged from the hydrogen side of the shaft seals. The drains connect to an enlarged horizontal length of pipe below the generator designated as the hydrogen detrainning tank. The tank provides a large surface that serves to remove larger hydrogen bubbles from the oil. A transverse partition divides the tank into two compartments that are connected through a loop seal. This arrangement prevents circulation of oil vapor through the seal drain piping resulting from a difference in the fan pressure between the two ends of the generator. A liquid-level device connected to the tank provides visual indication and actuates the alarm system if the oil level in the tank rises above the centerline. The outflow from the hydrogen detrainning tank passes through a float trap that prevents passage of hydrogen. During normal operation the outflow from the detrainning tank returns to the lube oil system. At standstill, it re-circulates through the seal oil system.

Since seal oil is lube oil, the flow of seal oil along the shaft inside the seal also provides lubrication.

Seal oil passes through the shell of the hydrogen side seal oil cooler, while bearing cooling water passes through the tubes. The cooler has inlet and outlet isolation valves and a bypass valve. An in-line filter removes debris from the oil.

During normal operation, oil from the lube oil system enters the vacuum tank through spray nozzles and a float valve that regulates the flow as required by the total seal oil flow. The inlet spray nozzles are directed upward and separate some of the gases from the oil as it enters the tank. Most of the gas remaining in the oil is separated by recirculation through a second set of spray nozzles directed downward. This recirculation that is effected by operation of the recirculation pump and the direction of the spray retards excessive foaming. A float-operated switch actuates the alarm system if the oil level in the tank varies three. If the normal lube oil supply is not available, the

## BASIC AC ELECTRICAL GENERATORS

seal oil is re-circulated and returns to the vacuum tank through the seal drain. One inch in this vacuum tank equals 12 gallons of oil.

The main seal oil pump provides oil to the shaft seals from the vacuum tank at about 66 gallons per minute and a normal operating pressure of 90 psig. The excess oil, greater than the seal requirements, is returned to the vacuum tank through a relief valve and the recirculating spray nozzles. The pump shaft is provided with a mechanical seal to prevent loss of oil from the pump along the shaft. An absolute pressure of approximately 0.5 inches mercury is maintained in the vacuum tank by the operation of the rotary vacuum pump.

Oil for sealing and lubricating the vacuum pump is obtained from a separator tank mounted above the pump. The interior of this tank is baffled to aid in the separation of moisture and oil from the gases discharged from the pump. A gravity drain arrangement is provided that permits moisture to drain continuously from the separator tank. Means of draining the tank manually is also provided. Oil is supplied to the pump from the separator tank through a solenoid-operated valve that is energized from the power supply of the motor driving the pump. This valve OPENS when the motor is started and CLOSES when the power supply to the motor is removed.

The regulating valve maintains a constant differential pressure between the seal oil pressure and the hydrogen pressure in the generator casing [eight (8) psig]. It operates by means of a diaphragm with seal oil connected to the lower side and machine gas pressure connected to the upper side. Each side of the diaphragm is provided with a nut plug to evacuate air and ascertain that each side is filled with oil. Significant changes in the machine gas pressure may require readjustment to maintain the prescribed pressure differential. A differential pressure switch is connected to the seal oil supply and to the machine gas pressure. It is adjusted to actuate the alarm system at five (5) psig.

## BASIC AC ELECTRICAL GENERATORS

The oil for the shaft seals is vacuum treated so that a minimum amount of air and moisture will be released to the generator casing. Maintenance of an absolute pressure of 1-inch of mercury or less in the vacuum tank will result in the maintenance of a hydrogen purity of 97 percent or higher in the generator, and will assure that a negligible amount of moisture will enter the generator from the oil. Therefore, with the vacuum system operative, the hydrogen purity in the generator is automatically maintained at a satisfactory value. This is without the necessity of adding hydrogen other than that required for supplying any loss by leakage and the loss by absorption in the sealing oil.

The oil that passes to the generator side of the seals continuously absorbs hydrogen. The amount of hydrogen that is absorbed is proportional to the gas-side, seal oil flow, and to the degree of solubility of hydrogen in oil. The larger bubbles of hydrogen in the oil are liberated in the seal drain enlargement. The smaller bubbles of hydrogen that go into solution in the oil are not released until the oil reaches the vacuum tank. There the gas is released and passes to the atmosphere through the separator tank of the vacuum pump.

The shaft sealing system includes an emergency seal oil pump that automatically supplies oil to the seals in case of failure of the main pump, or as a result of other failure of the main seal oil supply.

In addition to the emergency seal oil pump, a secondary system is provided through which the seals are supplied with oil from the bearing header. When the system is operating under emergency conditions, the vacuum tank becomes inoperative, with the result that the hydrogen purity within the generator casing will tend to drop. Special measures must be taken to maintain the hydrogen purity at a satisfactory level.

## BASIC AC ELECTRICAL GENERATORS

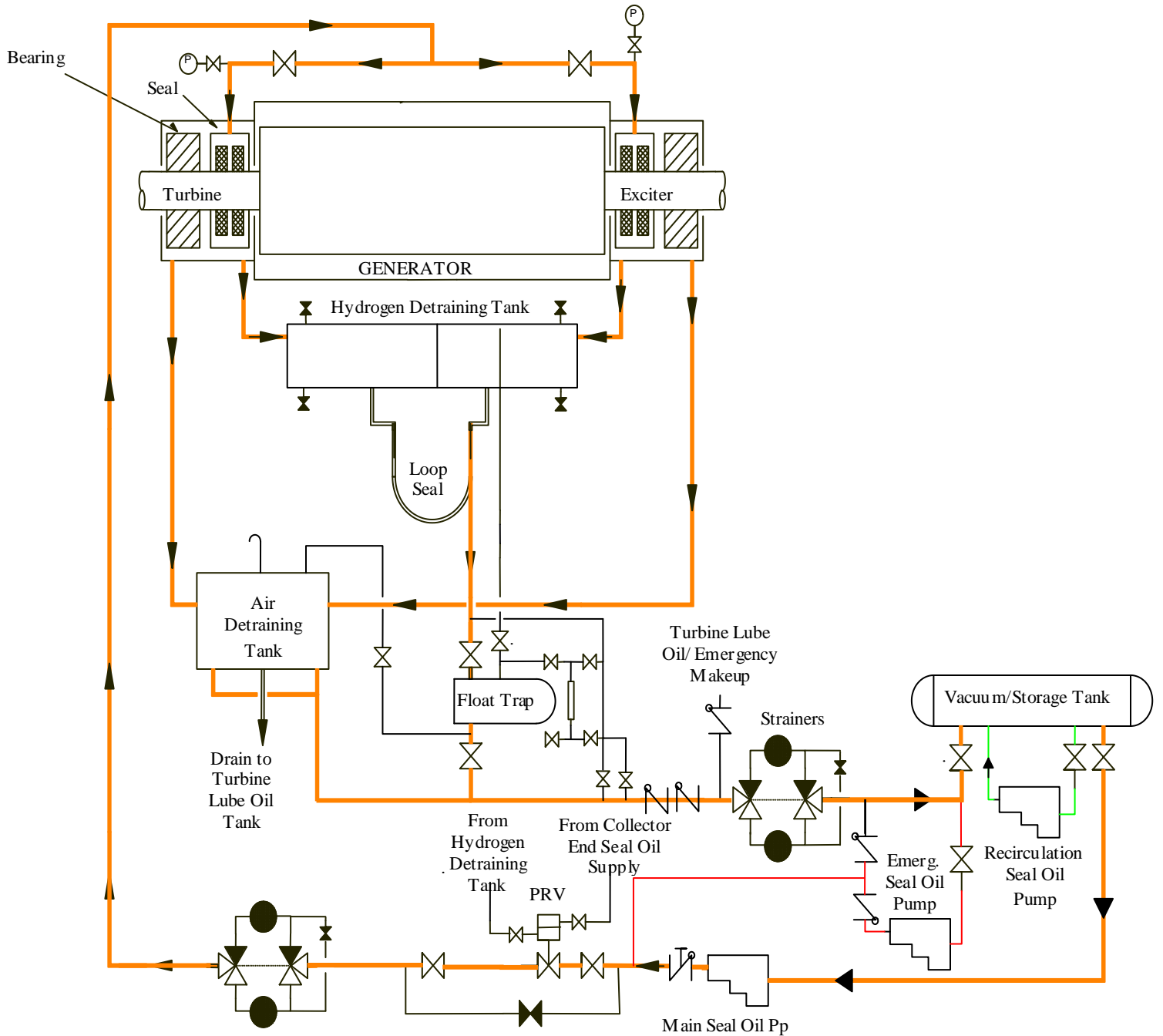
The emergency seal oil pump is of the rotary type and is driven by a DC motor to ensure maximum availability. The emergency pump is started by operation of a pressure switch. The switch is adjusted to CLOSE on decreasing pressure. With the emergency pump in operation, oil enters the pump suction valve that is also connected to the bearing drain. The vacuum tank becomes inoperative with the emergency pump in operation, and the float valve CLOSES so that no oil enters the tank. The oil pump to the shaft seals from the emergency oil pump passes through the regulating valve. The regulating valve operates to control the seal oil pressure of the sealing system. The emergency seal oil pump will automatically start when the seal oil header pressure decreases to 80 psig.

In order to ensure oil supply to the seals with both the main and emergency seal oil pumps inoperative, a secondary emergency seal supply system is provided that is effective at hydrogen pressures above eight (8) psig. The system consists of the check valve that is connected between the bearing and seal oil headers.

Reference **Drawing 1** Generator Seal Oil System Simplified Diagram for review of the Standard Seal Oil System



# BASIC AC ELECTRICAL GENERATORS



**Drawing 1. Generator Seal Oil System Simplified Diagram**

## BASIC AC ELECTRICAL GENERATORS

### **Standard Generator Stator Cooling Water System**

Each Unit's skid mounted Stator Cooling Water System is designed to operate as an independent sub-loop in its associated unit turbine-generator control system. Provision is made for automatic regulation of flow and temperature of clean, low conductivity water to the stator windings. A typical Generator Stator Cooling Water System is illustrated on **Drawing 2**.

Included in each Unit's main cooling loop are the stator cooling water storage tank, two (2) stator cooling water pumps (in parallel), two (2) stator water coolers (in series), and a filter. There is also a branch bypassing the generator supply to a Deionizer for continuous purification of a small percentage of the water. An additional branch is provided for cooling static rectifiers in the Excitation System.

Either of the two (2) AC motor-driven, centrifugal type stator cooling water pumps will produce the required flow of water. Pressure-actuated switches cause automatic startup of the standby pump in the event pressure decreases.

Stator cooling water flows through two (2) series arranged shell and tube exchangers/coolers. Bearing cooling water flows through the tube side with stator cooling water on the shell side. Baffles direct the stator cooling water back and forth across the outside of the tubes as it flows from the inlet at one (1) end to the outlet at the other end.

Bearing cooling water flows through the tubes in a two-pass arrangement. This side of the two (2) cooler sections may be connected either in parallel or series with a sufficient number of valves to isolate either cooler section from the system for cleaning tubes or other maintenance. Some reduction in generator output is necessary to keep inlet stator water temperature at the recommended value while a cooler section is out of service.

## BASIC AC ELECTRICAL GENERATORS

A bypass around the cooler and a proportioning valve to control flow through the bypass are used to automatically maintain inlet stator water at a constant temperature. Water temperature is measured downstream from the proportioning valve and the signal is fed to the valve operator.

All water to the generator is continuously filtered through replaceable wound cartridges of cotton and rayon. Any particle larger than three (3) microns is removed from the water via the filter. Pressure drop through the filter is determined locally via examination of the local inlet and outlet pressure gauges.

Make-up water is introduced into the system through a second, similar filter of smaller size. Particles not initially flushed to drain during initial line flush prior to fill will lodge in the filter rather than enter the Deionizer.

A differential pressure-regulating valve is provided to maintain inlet water pressure less than hydrogen pressure. It does so by controlling inlet stator water pressure. A maximum stop limit prevents the water pressure from exceeding the value required at rated load, regardless of hydrogen pressure. A minimum stop limits water pressure to 22 psig even though hydrogen pressure may continue to decrease. The lower limit of 22 psig applies to the generator and ensures complete purging of bubbles or gas pockets from within the stator windings.

A basket type strainer with a fine mesh screen is located in the inlet stator water line near the generator. After initial flushing of the systems, it is unlikely that significant quantities of foreign material will deposit on the screen. A second strainer with a fine mesh screen is installed in the Deionizer outlet line to retain any resin beads that may pass through the Deionizer retaining screen.

## BASIC AC ELECTRICAL GENERATORS

Inlet and outlet connections to the generator are at the top to keep the internal pan of the circuit full of water, even when the pumps are not in operation. Removable pipe sections make it possible to flush the entire external system without including the generator. Drain connections from the bottom of the generator are used to remove water from the stator winding. Some water is removed by gravity flow and the remainder is forced out with pressurized air. A small bypass between inlet and outlet pipes prevents siphoning action, when the pump is stopped.

Atmospheric pressure is maintained at the outlet by using a larger pipe than for the inlet line, plus a vent line from the generator outlet to the storage tank. The system is, therefore, self-venting at the top of the generator.

The storage tank meets several requirements: the required height of water above the pump suction, space for variation in water volume and removal and venting of gases from the water. A sight glass is provided for visual inspection of water level.

Less than two (2) or three (3) cubic feet per day of hydrogen will permeate through the insulating connections in the generator into the water and will be released within the tank. The released gas is vented to the atmosphere through the vent line. An "S." loop at the low point of the vent provides automatic draining of moisture that may condense in the vent pipe.

A calibrated orifice in the inlet line to the generator provides a means of indicating stator winding flow and initiating an alarm if flow decreases. Because the Deionizer has a maximum recommended flow, there is a flow meter in its inlet line. Below this value, water will pass through the resin bed evenly and without channeling. A flow regulator is located in that branch of the system to provide water cool static rectifiers in the Excitation System. Flow can then be easily adjusted to the recommended value.

## BASIC AC ELECTRICAL GENERATORS

Stator water is maintained at a low electrical conductivity (insulator) by continuous removal of dissolved mineral salts via a mixed bed Deionizer. If stator water conductivity can no longer be held at the recommended level with Deionizer flow at the maximum allowable limit, the Deionizer resin should be replaced. This can be accomplished without reducing load on the generator. Deionizer outlet water quality should be checked before establishing flow into the system. Since Deionizer resin deteriorates at high temperatures, the maximum temperature should not be exceeded.

A minimum of two (2) conductivity cells is installed in the system. These are located in the main flow through the generator, one (1) in the inlet line and one (1) in the outlet line. Both include temperature compensators so that only water purity affects the measurements. Cells can be removed for inspection.

Resistance temperature detectors, thermocouples, thermostats or temperature bulbs, as required for proper operation of the system, are installed in wells in the lines to and from the generator. They are connected to inlet and outlet water temperature indicators with alarm contacts, inlet temperature regulating valve, and automatic turbine runback circuit.

This local panel allows for monitoring of system conditions, the assignment of pumps, operating status and alarm conditions.

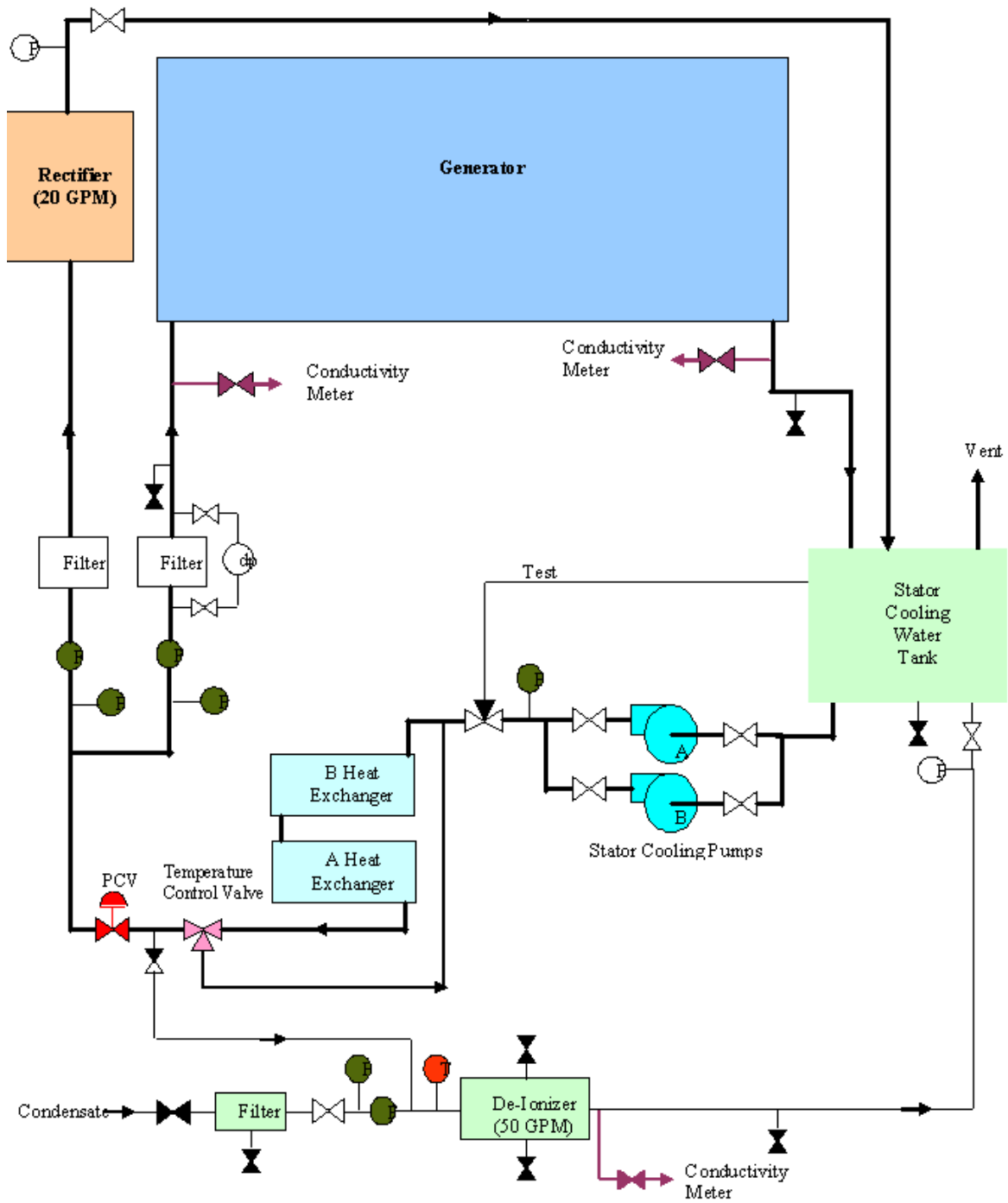
Stator cooling water pumps are rated at 3500 revolutions per minute (rpm) and 300 gallons per minutes (gpm). Normal operating pump discharge pressure range on the stator cooling water pump is 125 to 130 psig. The standby cooling water pump will AUTOMATICALLY start when the pressure decreases to 110 psig. Rated cooling water pump inlet pressure is 22.6 psig. Low cooling water pump inlet pressure alarm actuates at 16 psig.

## BASIC AC ELECTRICAL GENERATORS

The normal operating level in the stator cooling water storage tank is in the center of the sight glass. The stator cooling water storage tank alarm actuates if level increases or decreases four above or below normal operating level.

Normal operating stator cooling water flow range is 186 gallons per minutes (gpm). An alarm actuates if the stator cooling water flow decreases to 133 gallons per minute (gpm).

# BASIC AC ELECTRICAL GENERATORS



**Drawing 2. Stator Cooling System Diagram**

# BASIC AC ELECTRICAL GENERATORS

## **Excitation Systems**

The exciter provides the DC electric power necessary to magnetize the generator rotor.

There are many types of exciters. Sometimes the exciter is separate from the generator, taking the form of a DC generator driven by an AC motor or a small steam turbine. Such a unit is said to be separately excited. More modern units are often self-excited. Self-excited means that the source of power for excitation comes from the unit being excited. The exciters used for self excited units are generally either static systems or shaft driven systems. In a static system the power for excitation is taken directly from the generator terminals. In a shaft driven system excitation power is generated by a small AC or DC generator driven from the unit main shaft. This Section provides a brief description of the types of excitation systems that are used as well as the specific systems used for the example units.

**Separate Exciters** - As described above, some units have separate exciters. They are DC generators that are driven by some prime mover, usually large AC motors. The exciters are usually mounted on the turbine deck elevation near the generators. Often in a plant with more than one unit with separate exciters there is a spare exciter.

**Static Excitation System** - Static exciters take power from the main generator through transformers. The power from the transformers is AC, so it is rectified or converted to DC by rectifiers. The DC power is then fed to the generator field through brushes to the collector rings. The excitation controls regulate the amount of DC power fed to the rotor, which in turn controls the voltage at the generator terminals. There are both manual and automatic controls, which are called voltage regulators.

**Shaft Driven DC Generator Type Exciters** - Some units generate their excitation power by driving a DC generator from the main shaft. The DC generator is often driven through a reduction gear to produce the correct speed. As with the static exciters, the



## BASIC AC ELECTRICAL GENERATORS

current from the DC generator is generally controlled through either an automatic or manual voltage regulator.

Shaft Driven Alternator Type Exciters - Both of the example units have shaft driven alternator excitation systems. The shaft driven alternator is similar to the static excitation system. The principal difference is that the AC power comes from an AC generator, or alternator, which is driven from the shaft of the turbine-generator. The exciter alternator is self-excited in that the DC current to magnetize its rotor comes from the rectifier assembly. There are usually automatic and manual voltage regulators as with the static system.

GE Alterrex Exciter - General Electric has manufactured two different excitation systems of this type. The more common type is called the Alterrex system. The example GE unit has an Alterrex system. A less common variation of this system is called the Althyrex system. The Althyrex system has higher performance than the Alterrex system and is commonly used by utilities where electrical system stability is a concern. The Althyrex system uses a special rectifier called a thyristor, but apart from that and differences in the electronics, the systems are very similar in configuration.

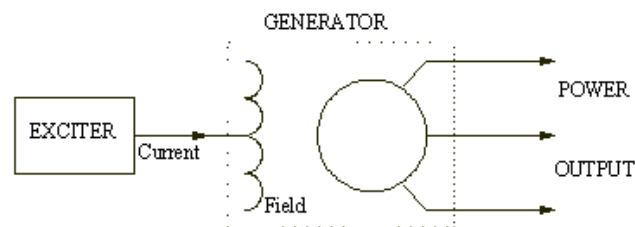
The Alterrex system encloses the shaft driven alternator and rectifiers in a housing (often called the doghouse) mounted at the end of the generator.

Westinghouse Brushless Exciter - The Westinghouse shaft driven alternator excitation system uses what they call the Direct Connected Brushless Exciter. The most important feature of this system that distinguishes it from the GE system is implicit from its name; there are no collector rings and brushes as in a conventional excitation system.

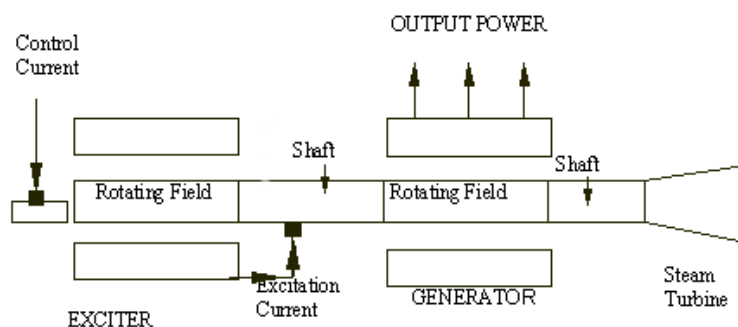
## BASIC AC ELECTRICAL GENERATORS

The example Westinghouse unit uses a Westinghouse called the brushless exciter. The exciter consists of a shaft driven alternator, however it has two significant differences from the GE Alterrex alternator. First, the armature is in the rotor while the field is in the stator. This is the opposite of what is found in almost any other alternator. Secondly, the rectifiers for this system are mounted on the rotor. The advantage of this design is that the leads from the armature can be connected directly to the rectifier and the DC output from the rectifiers can be connected directly to the generator field windings, thus making collectors unnecessary.

EXCITATION: Creation of the magnetic field that allows current to be induced in conductors that have relative motion with the magnetic field.



ALTERNATOR-EXCITER: Exciter that uses brushes to feed current to the rotating main generator field.



**Drawing 3. Simplified Generator and Excitation System**

## BASIC AC ELECTRICAL GENERATORS

### Progress Check

#### Fill in the blank(s)

1. Faraday's law when you see that rotation of the coil continually changes the magnetic flux through the coil and therefore \_\_\_\_\_ .
2. Generators, motors, transformers, and solenoids each use the principle of \_\_\_\_\_ .
3. The strongest part of the magnetic field is the region where the lines are \_\_\_\_\_ .
4. If a conductor is wound around a piece of metal, such as iron or steel, and current is passed through that conductor, a magnetic field is produced around this assembly. It is called an \_\_\_\_\_ .
5. In the rotating armature AC generator, the \_\_\_\_\_ provides a stationary electromagnetic field.
6. In a rotating field generator, direct current from a separate source is passed through \_\_\_\_\_ on the rotor by means of slip rings and brushes.
7. A three-phase AC generator is designed to produce three-phase AC power by building more coils in the stator around the rotor. The three coils are equally spaced \_\_\_\_\_ apart around the inside of the stator.
8. In the early 1970's, gas turbine manufacturers introduced insulation systems capable of operating at Class F temperatures (155°C, 311°F) for the life of the

## BASIC AC ELECTRICAL GENERATORS

generator. This enabled a significant uprating of generator designs (about \_\_\_\_\_) with a minimal increase in cost.

9. As we go through the generator design and construction the differences between hydrogen cooled and air cooled will be pointed out. There are two main components in the generator, the \_\_\_\_\_ and the \_\_\_\_\_.
10. The stator consists of a steel plate casing called the " \_\_\_\_\_ " that covers a frame that in turn holds the iron core.
11. There are \_\_\_\_\_ mounted on the ends of the rotor to circulate cooling gas inside the generator stator.
12. \_\_\_\_\_ are provided at the generator end of the rotor.
13. All hydrogen/water-cooled generators use direct conductor cooling of the rotor winding for heat removal. Smaller two-pole and all four pole generators use the radial flow design. At the end of the rotor body, hydrogen enters the windings through full length \_\_\_\_\_ and is discharged along the length of the rotor body through radial slots, machined or punched, in the copper conductors. The hydrogen passes from the conductors through the \_\_\_\_\_ blocks and wedges to the " \_\_\_\_\_," where the hydrogen is directed through the stator core to the hydrogen coolers.

## BASIC AC ELECTRICAL GENERATORS

14. The bearing ring and the shaft seal housing at the collector end of the machine are insulated from the generator frame to prevent the flow of shaft currents.
15. The purpose of the unit's Isolated Phase Bus is to \_\_\_\_\_ its unit Generator to the associated main transformer and auxiliary transformer.
16. The purpose of the Generator Seal Oil System is to provide the means \_\_\_\_\_  
\_\_\_\_\_ of hydrogen from the generator enclosed.
17. The oil for the shaft seals is vacuum treated so that a minimum amount of air and moisture will be released to the generator casing. Maintenance of an absolute pressure of \_\_\_\_\_ or less in the vacuum tank will result in the maintenance of a hydrogen purity of \_\_\_\_\_ percent or higher in the generator, and will assure that a negligible amount of moisture will enter the generator from the oil.
18. Each Unit's skid mounted Stator Cooling Water System is designed to operate as an independent \_\_\_\_\_ in its associated unit turbine-generator control system.
19. The exciters used for self excited units are generally either \_\_\_\_\_ or shaft driven systems.
20. The Alterrex system encloses the shaft driven alternator and \_\_\_\_\_ in a housing (often called the doghouse) mounted at the end of the generator.

## BASIC AC ELECTRICAL GENERATORS

(This page left blank intentionally)

## BASIC AC ELECTRICAL GENERATORS

### Answers

1. generate a voltage
2. electromagnetism
3. closest together
4. electromagnet
5. stator
6. windings
7.  $120^\circ$
8. 10%
9. rotor, stator
10. wrapper
11. fans
12. Collector rings
13. subslots, creepage, air gap
14. insulated
15. connect
16. to prevent the escape
17. 1-inch of mercury, 97
18. sub-loop
19. static systems
20. rectifiers

## BASIC AC ELECTRICAL GENERATORS

(This page left blank intentionally)



## BASIC AC ELECTRICAL GENERATORS

### Examination

1. In the early 1970's, gas turbine manufacturers introduced insulation systems capable of operating at Class F temperatures (\_\_\_\_\_) for the life of the generator.
  - A. 100°C , 212°F
  - B. 120°C , 248°F
  - C. 155°C , 311°F
  - D. 189°C , 372.2°F
2. Newer generators use hydrogen under pressure (from \_\_\_\_\_) for cooling.
  - A. 15 to 75 psig
  - B. 25 to 80 psi
  - C. 10 to 100 psi
  - D. 10 to 120 psi
3. The bars fit into the longitudinal slots on the inside diameter of the core and are held in place by \_\_\_\_\_ that slide into the top of the slot
  - A. springs
  - B. wedges
  - C. end bells
  - D. the core
4. What type water is used in water cooling of the generator armature winding?
  - A. Distilled Water
  - B. Condensate
  - C. Deionized water
  - D. Treated Water

## BASIC AC ELECTRICAL GENERATORS

5. A generator operating with 12 poles and 60 cycles would operate at a speed of \_\_\_\_\_.
- A. 600
  - B. 1200
  - C. 2400
  - D. 3600
6. How are generator rotor retaining rings attached to the rotor?
- A. Bolted
  - B. Shrunk
  - C. Screwed
  - D. Wedged with end stock
7. Why are the end shields split on the horizontal centerline?
- A. Too large to be made in one piece
  - B. To facilitate their removal
  - C. To allow for better support
  - D. If the rotor was to move it would affect one of the end plates.
8. A liquid detector will alarm if more than \_\_\_\_\_ of liquid collect in the body of the detector
- A. ½ pint
  - B. 1 pint
  - C. 1½ pints
  - D. 2 pints

## BASIC AC ELECTRICAL GENERATORS

9. What are the various types of alternating current generators utilized in today's market?
- A. Rotating Armature and Rotating Field
  - B. Self Exciting and Brush
  - C. Air and Water
  - D. Rotation Field and Direction Field
10. What is the function of an Excitation System?
- A. The exciter provides the DC electric power necessary to magnetize the generator rotor.
  - B. Acts as a rectifier.
  - C. Collects the flux and resends it.
  - D. The exciter provides the AC electrical power necessary to excite the field.