U.S.NRC

United States Nuclear Regulatory Commission

Protecting People and the Environment

Chapter 9

THE GENERATOR, EXCITER, AND VOLTAGE REGULATOR

HRTD
Human Resources
Training & Development

Learning Objectives

As a result of this chapter, you will be able to:

1. Describe functions of the generator, exciter, and voltage regulator.
2. Identify major components of the generator, exciter, and voltage regulator.
3. Explain the purpose of the Generator Differential Fault Protection system.

Learning Objectives (continued)

4. Describe key considerations for connecting generator and engine, to protect bearings and engine crankshaft.

5. Describe how diesel engine operation relates to the power demand on the generator.

Converting diesel engine rotating shaft output (mechanical HP) to electric power (KW output) is accomplished by connecting the generator rotor to the engine output shaft, at the end of the crankshaft.

The electric generator makes this conversion by means of a process called "magnetic inductance." A magnetic flux field is created through which configured electrical loop windings are rotated to produce an output voltage. This voltage is collected by means of slip rings and brushes to power electrical loads. This process is illustrated in Figures 9-1 through 9-4.

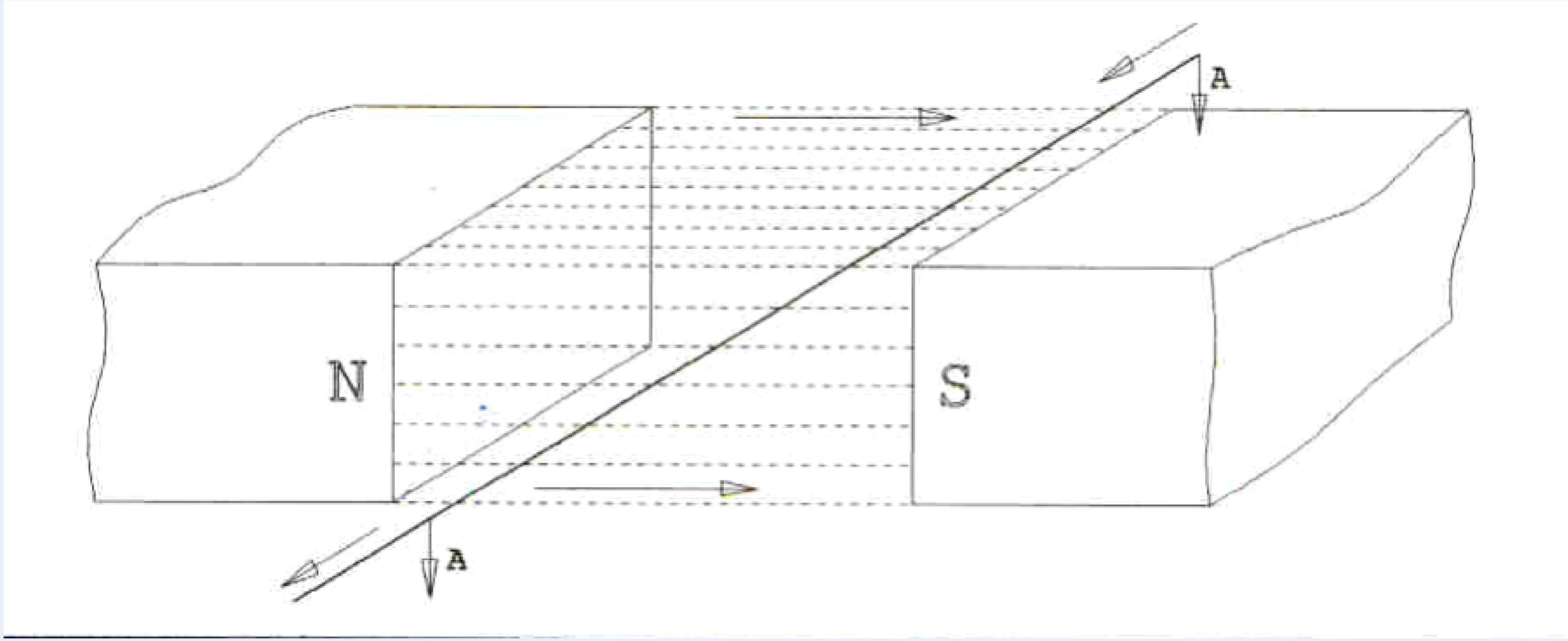


Figure 9-1   A Conductor in a Magnetic Field

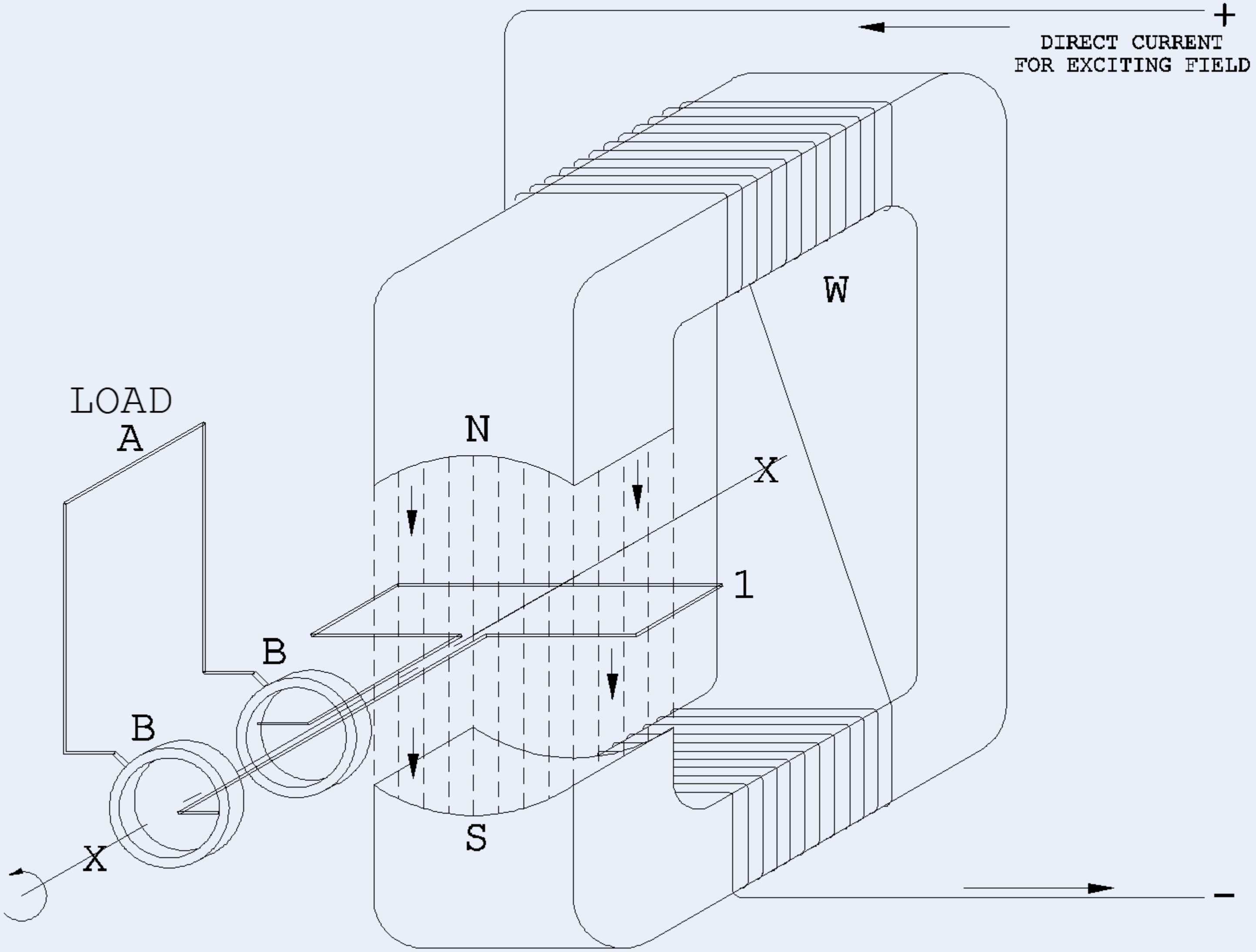


Figure 9-2   A Simple Generator (Alternating Current)

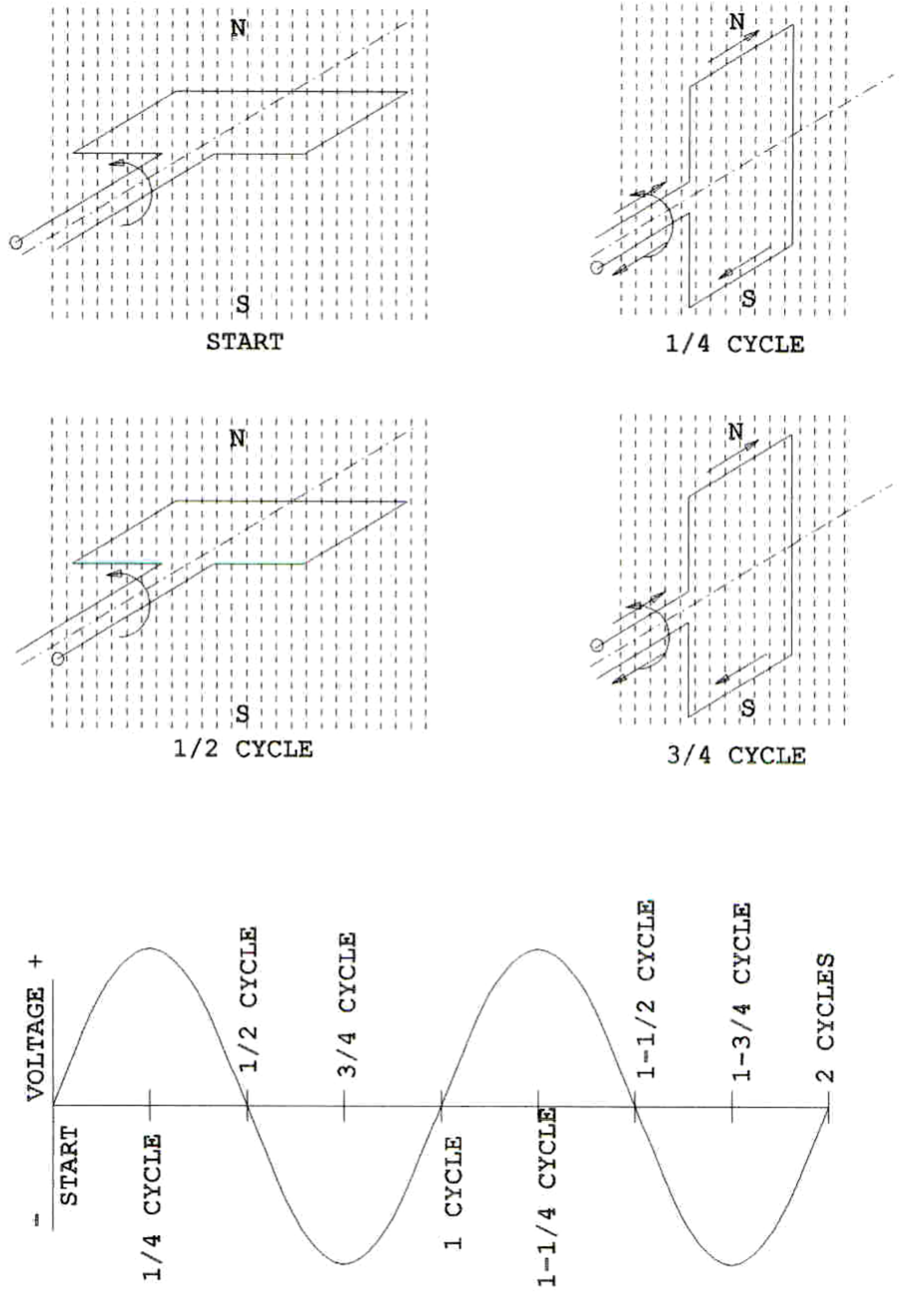
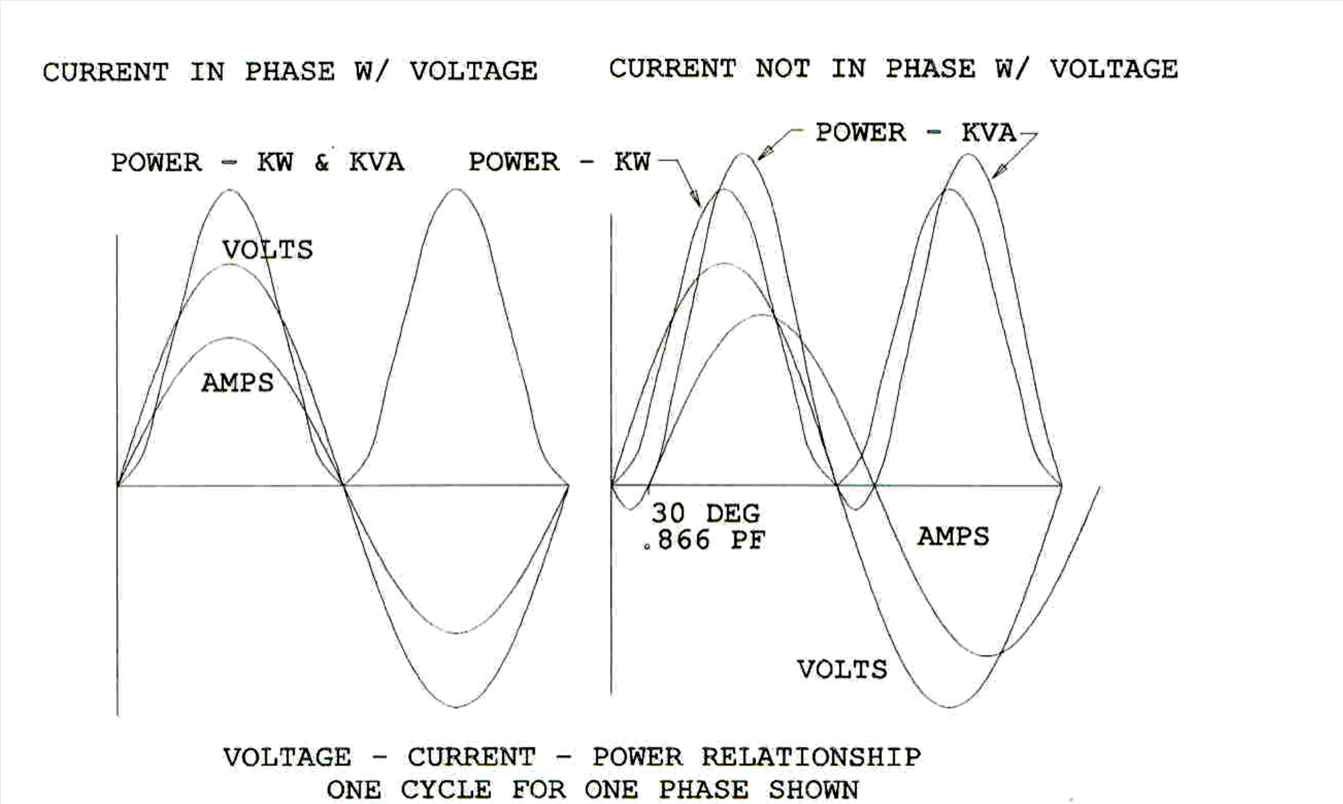


Figure 9-3

Single Phase Sine Wave



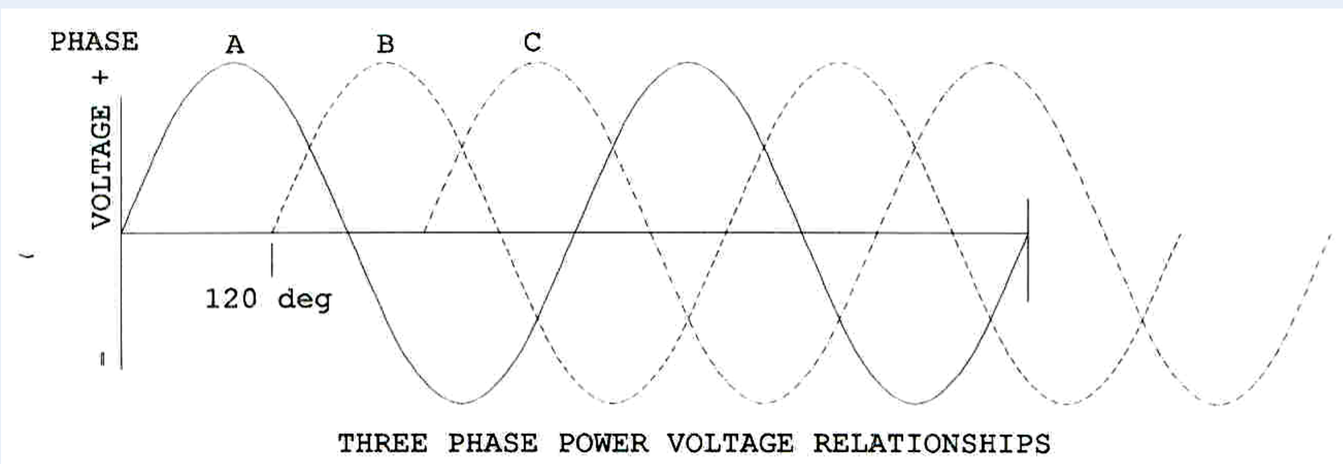


Figure 9-3

Single Phase Sine Wave

Rotating the generator output windings through a stationary magnetic field requires transmitting the larger output current through slip rings and brushes, rather than the smaller field current.

This is not practical for high output machines.

In EDG generators:

- The field is rotated by being attached to the rotor of the generator.
- The output windings are stationary, installed within the generator stator (the stationary part of the generator).

Figure 9-5 is a cutaway of a generator with parts identified. The air gap is shown, and must have:

- Concentricity
- Proper Clearance

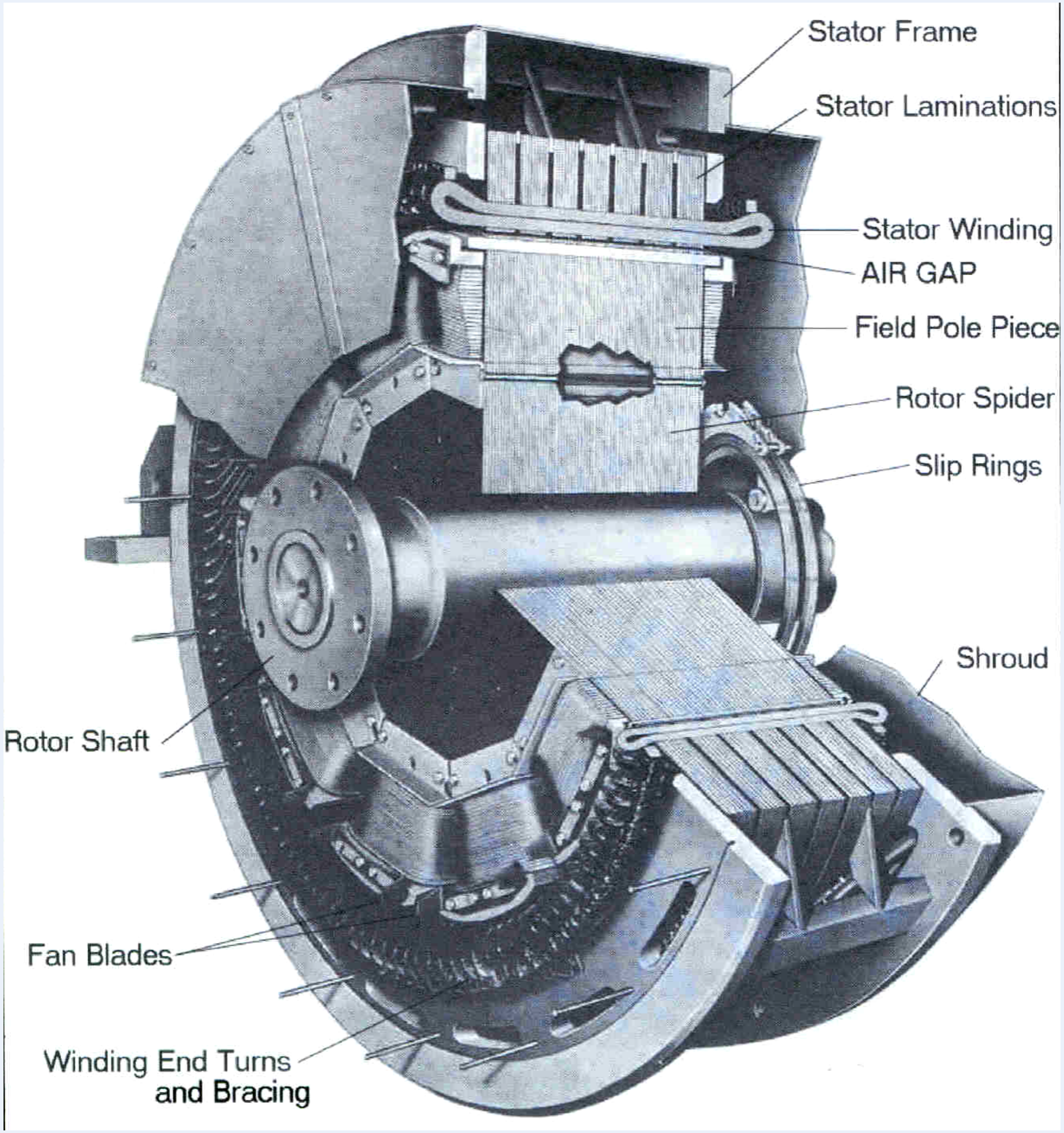


Figure 9-5

Cut-away of Generator – Identification of Parts

Figure 9-6 shows a generator under test.

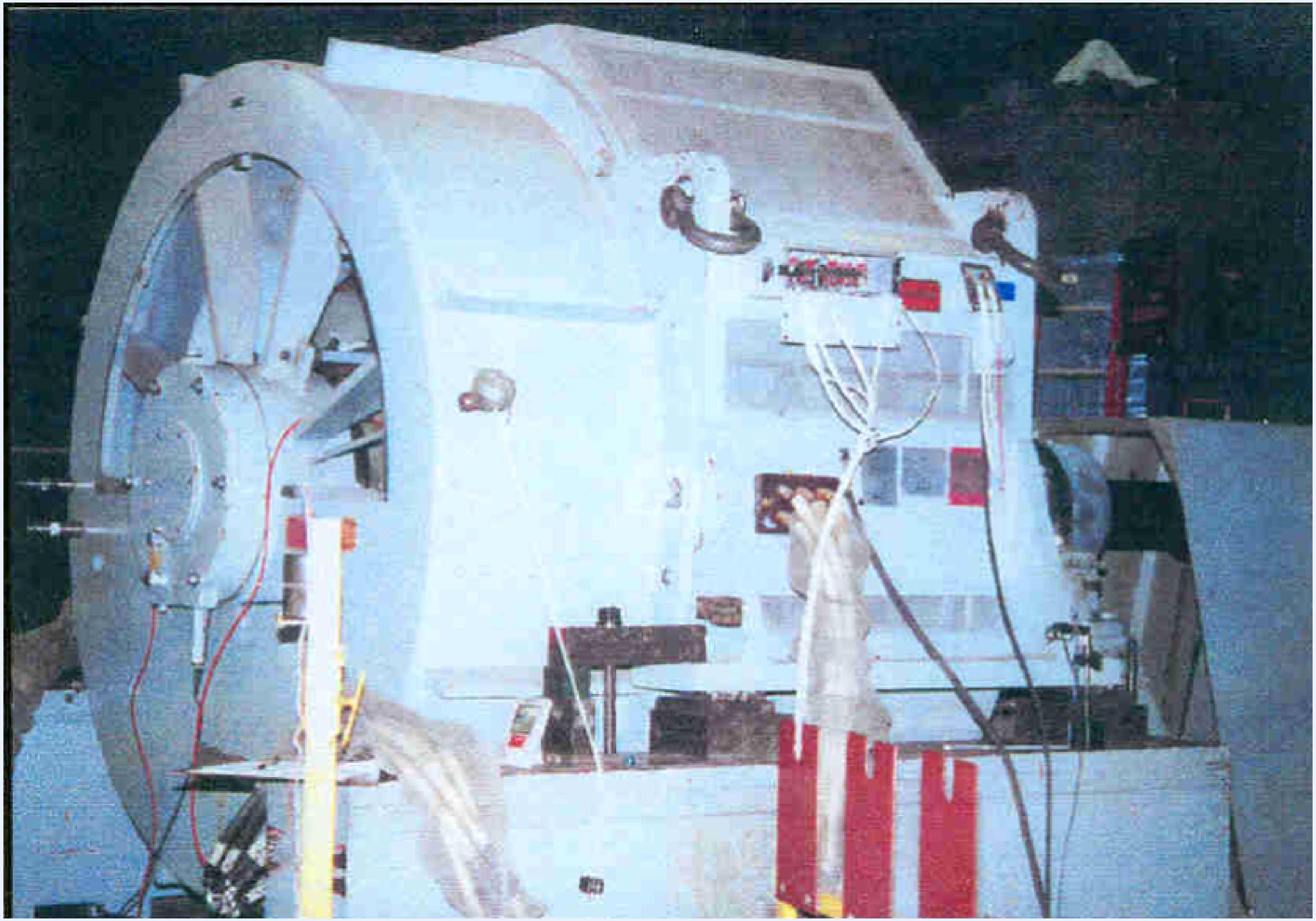


Figure 9-6 A Simple Generator (Alternating Current)

Figures 9-7 through 9-22 illustrate components and assemblies of the generator

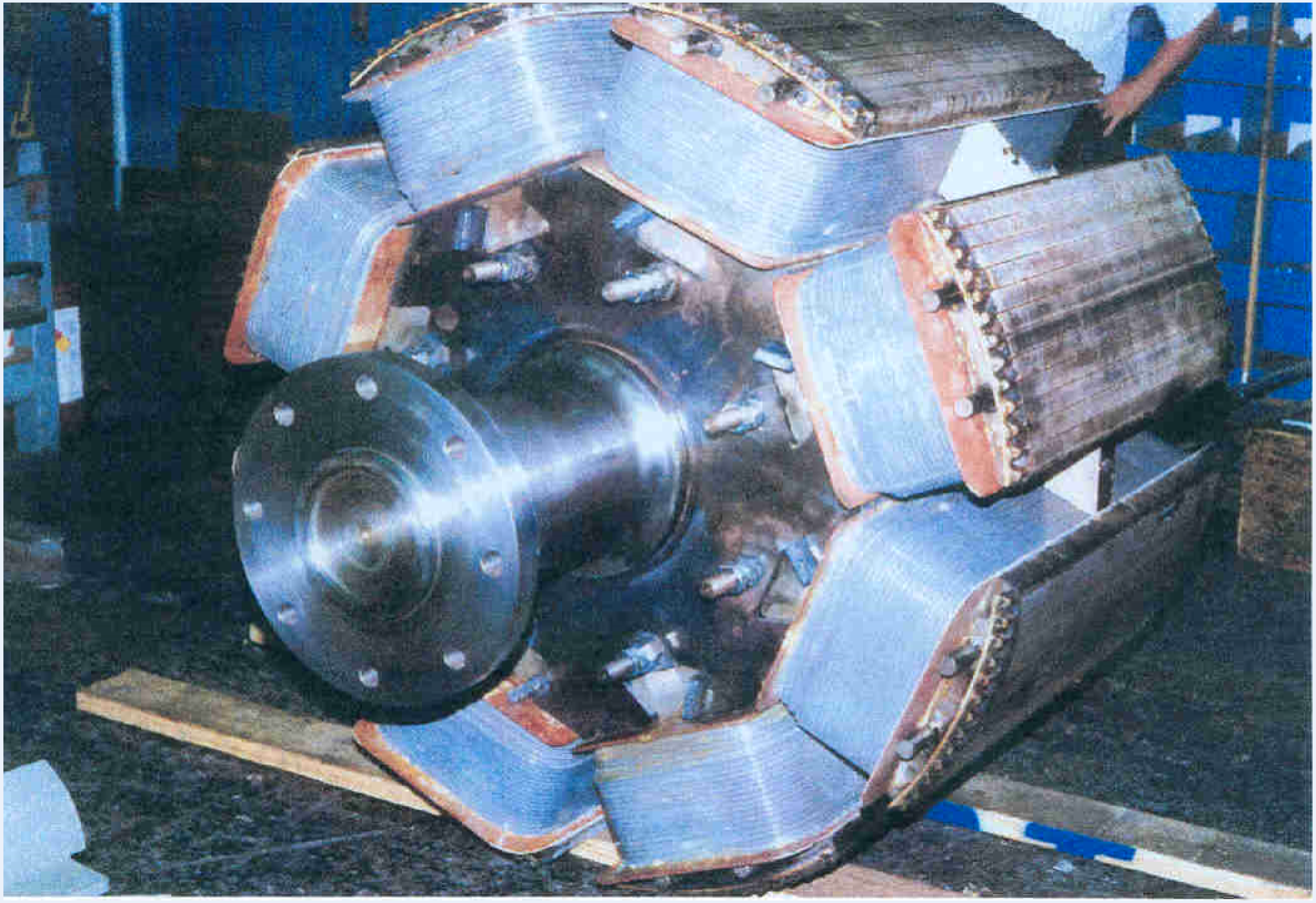


Figure 9-7 Complete Rotor Assembly -- coupling end of shaft view

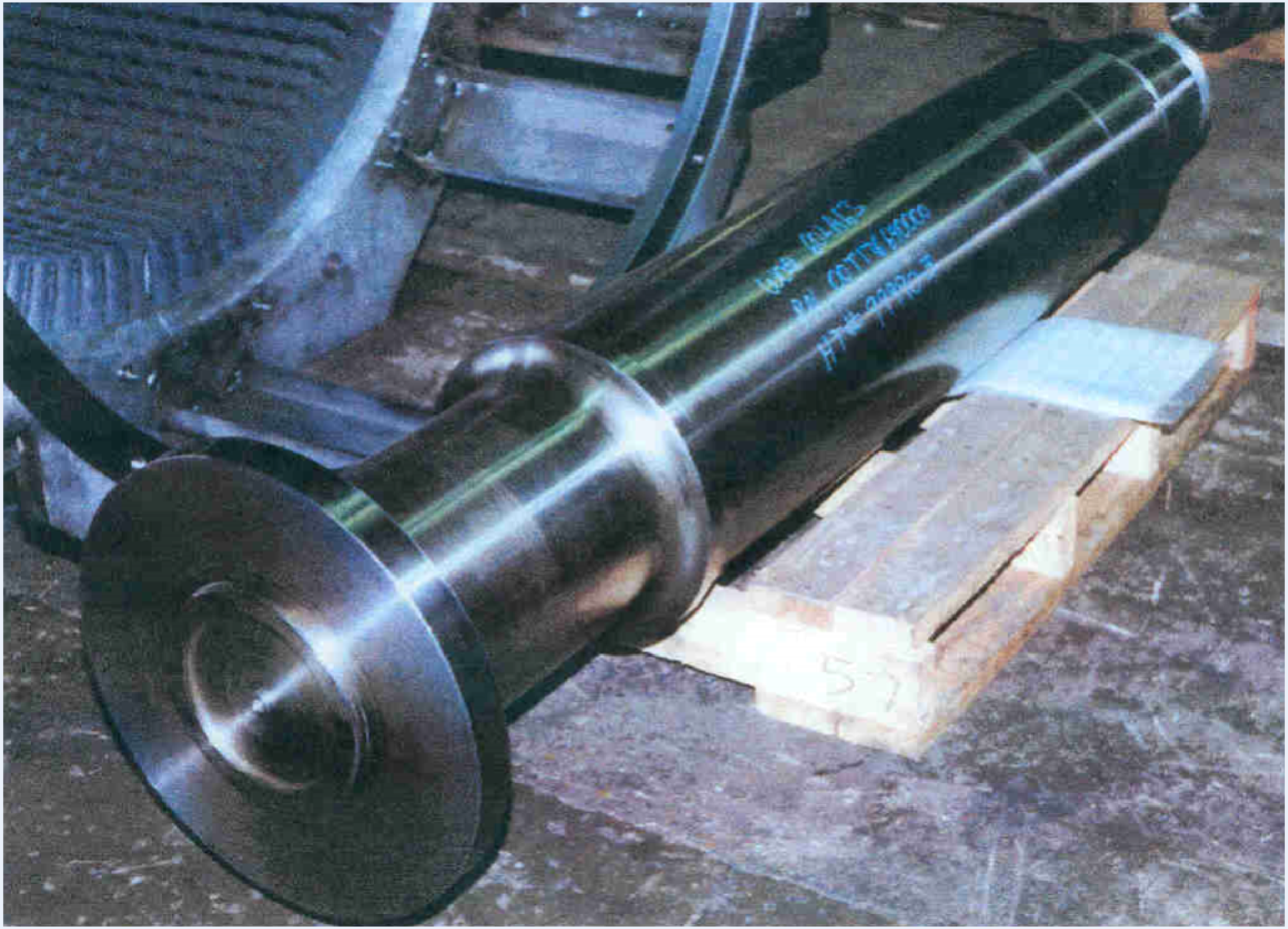


Figure 9-8   Generator Shaft -- coupling end view

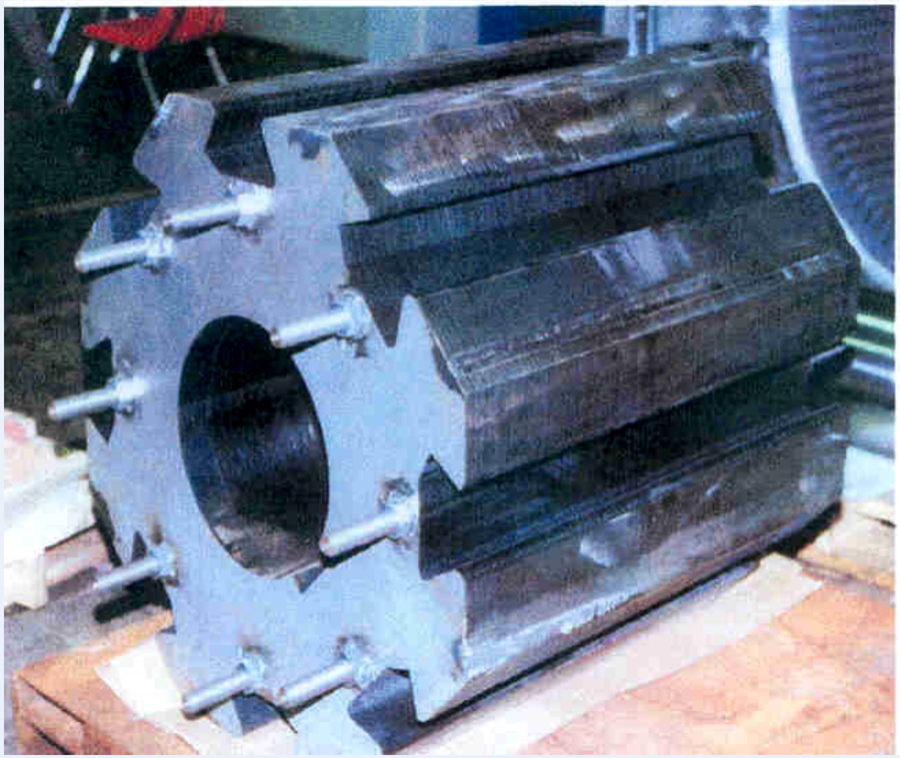


Figure 9-9 Rotor Spider (Hub)

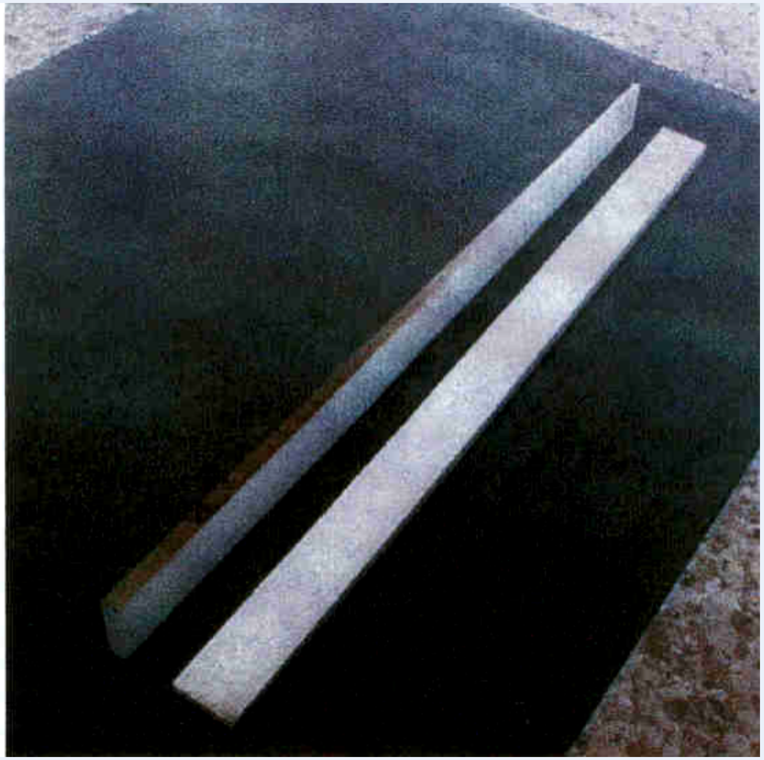


Figure 9-10 Field Pole Wedges

Figure 9-11 Field Pole Blocking

Figure 9-12 Field Pole with Amortisseur Bars (windings)

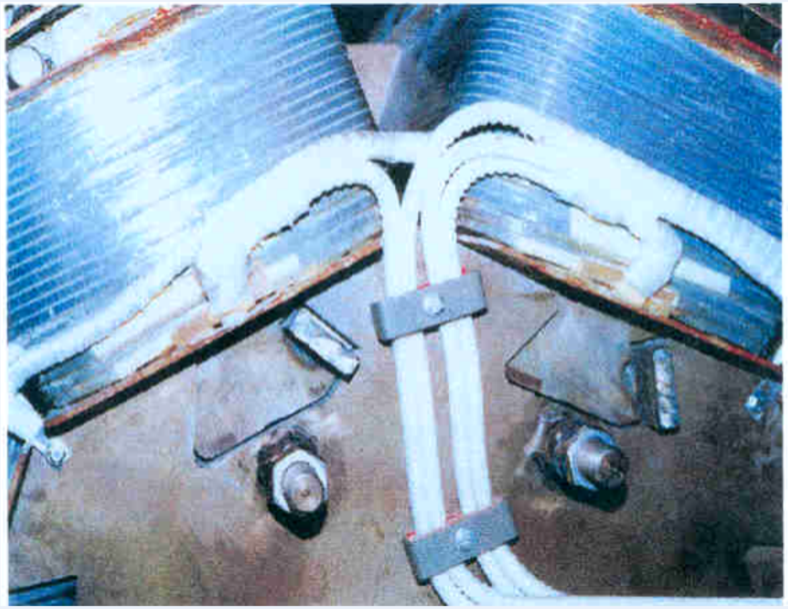


Figure 9-13

Field Wiring to Slip Ring Wiring

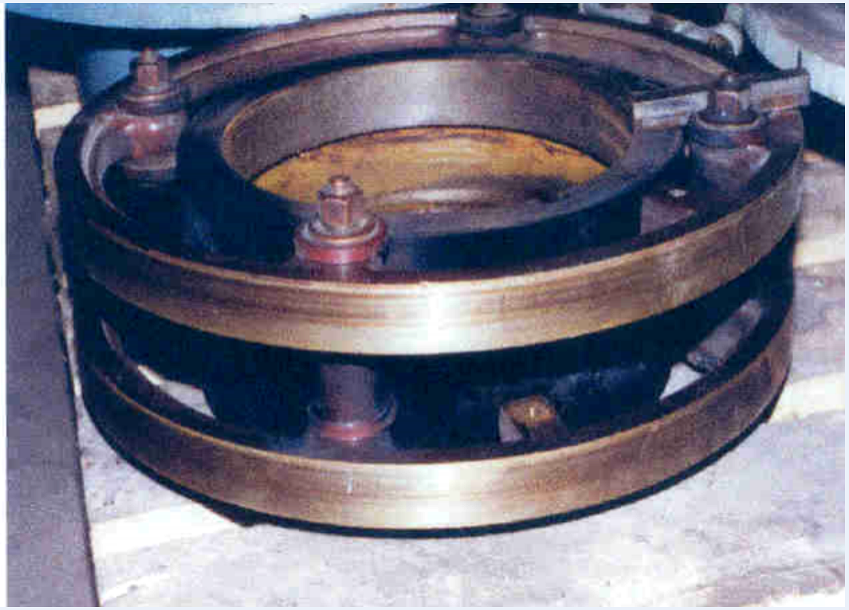


Figure 9-14

Slip Ring Assembly

Figure 9-15

Winding Coil Form

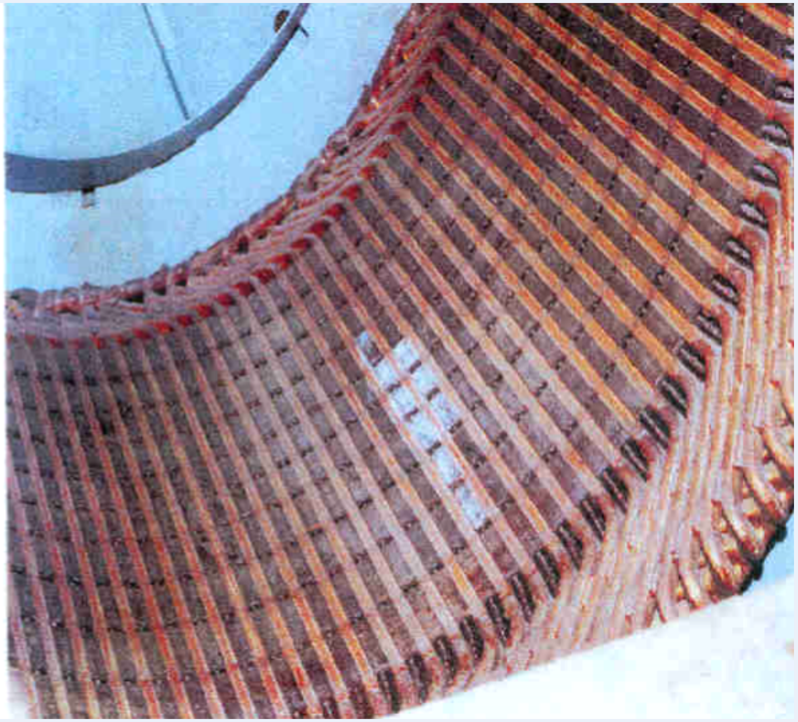


Figure 9-16

Windings Installed in Stator Slots

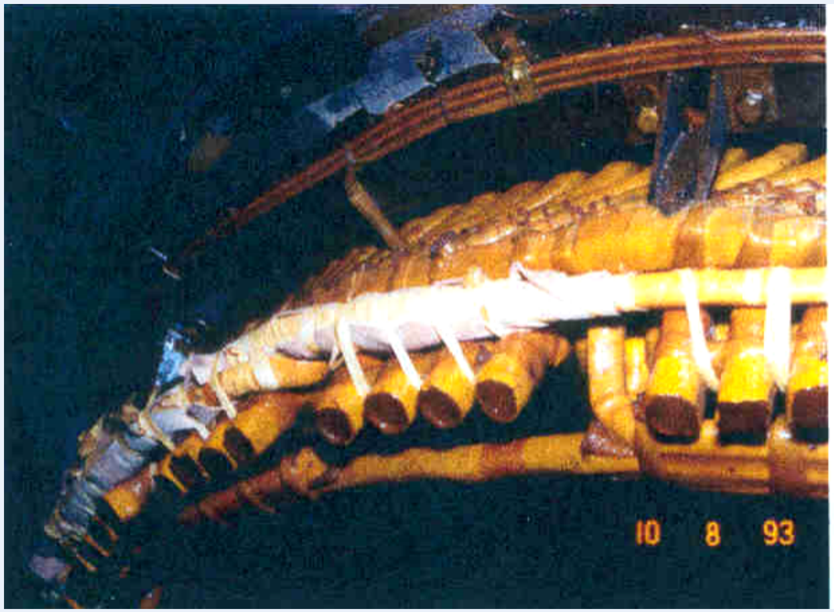


Figure 9-17

Coil Tying and Bracing

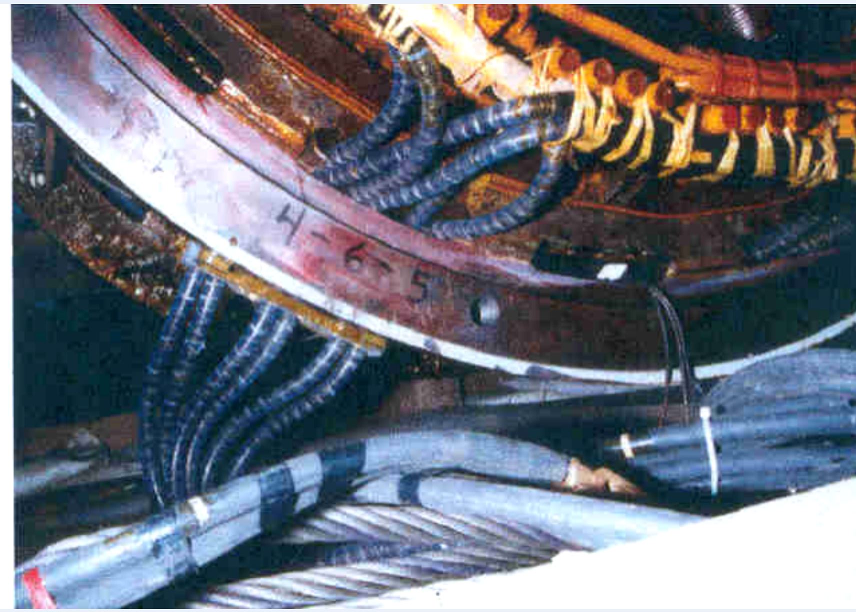


Figure 9-18

Lead Cable Termination

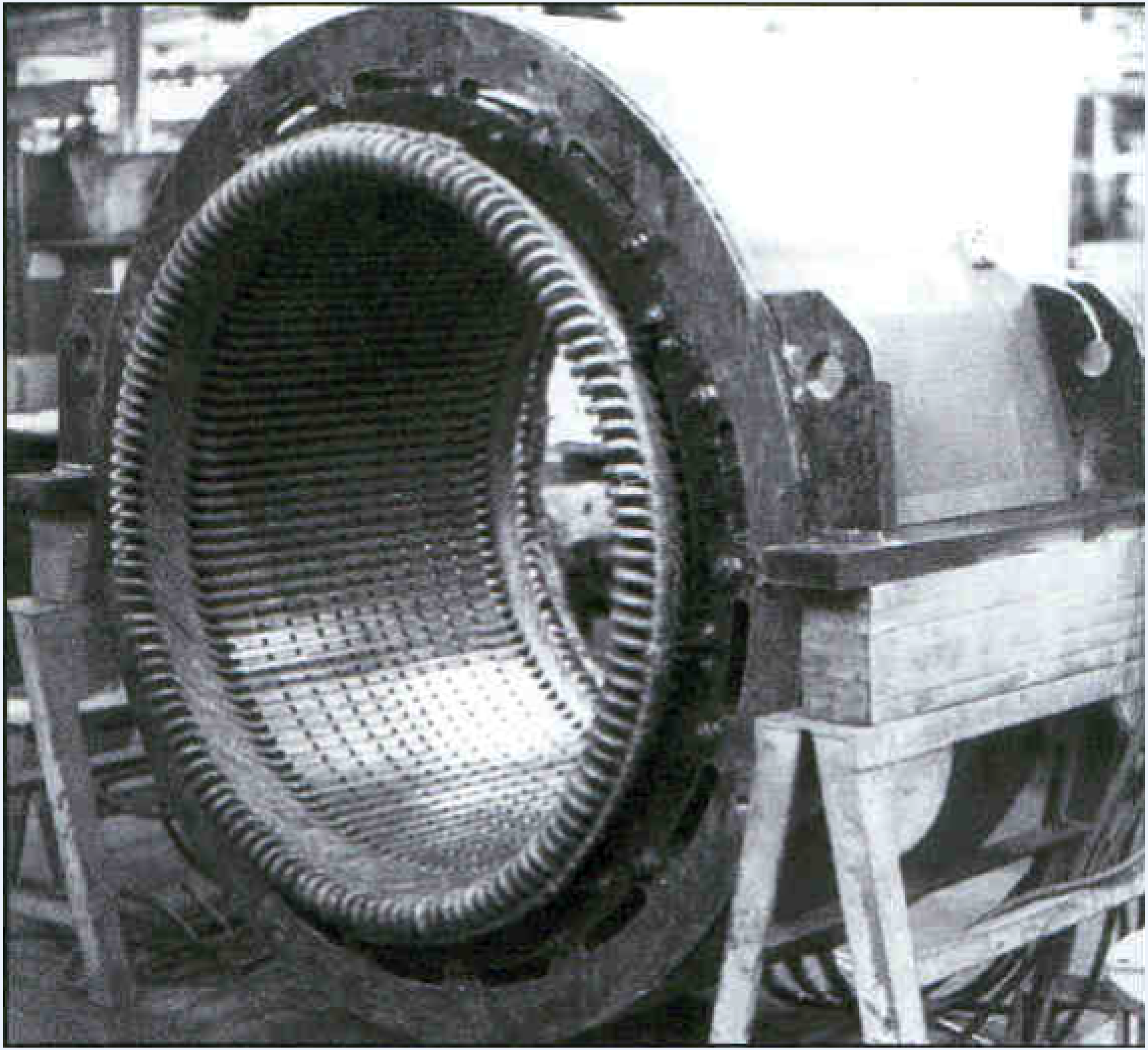


Figure 9-19

Complete Stator Assembly

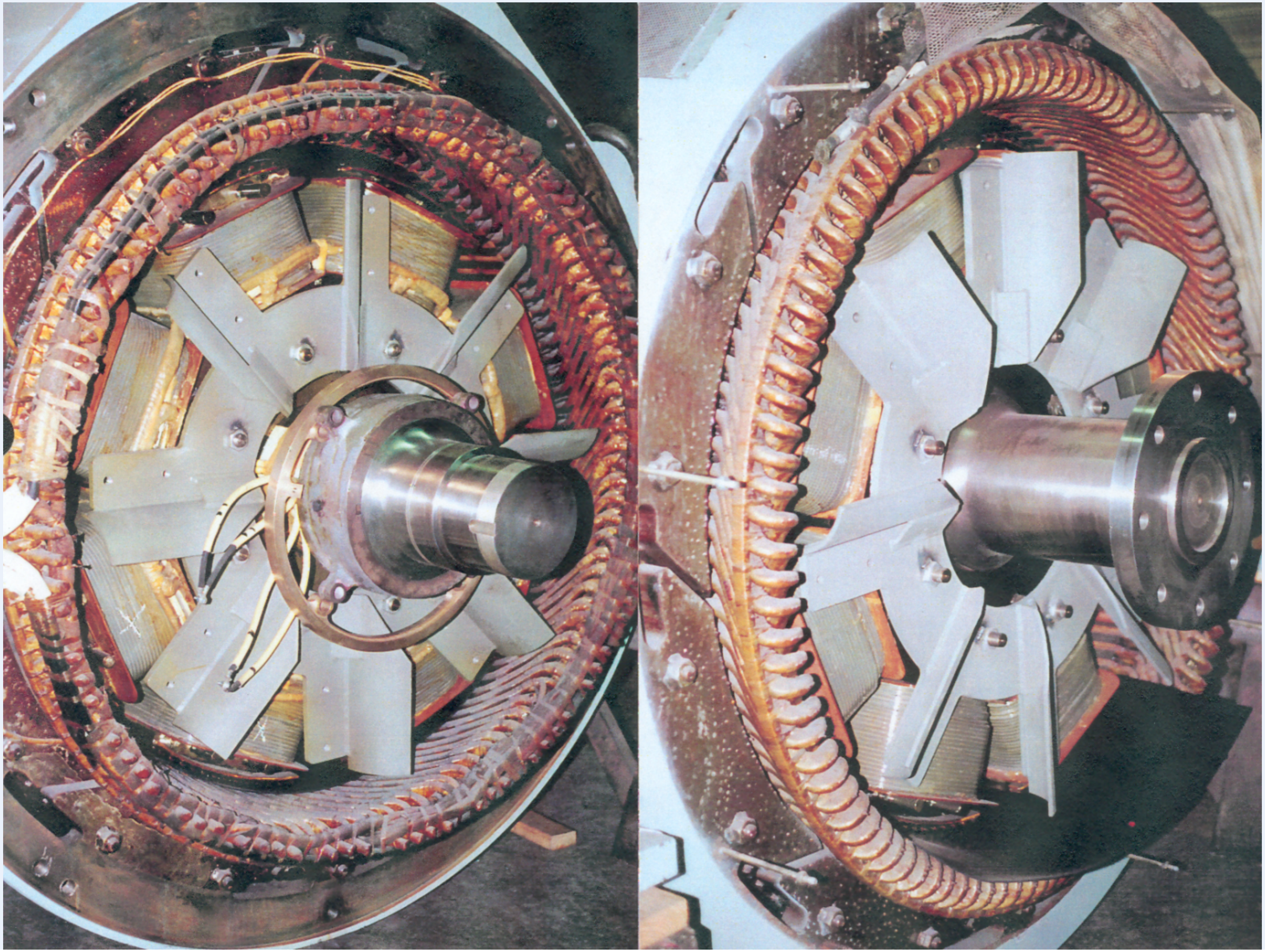


Figure 9-20 Rotor Installed within Stator – Note fan assembly & slip ring assembly

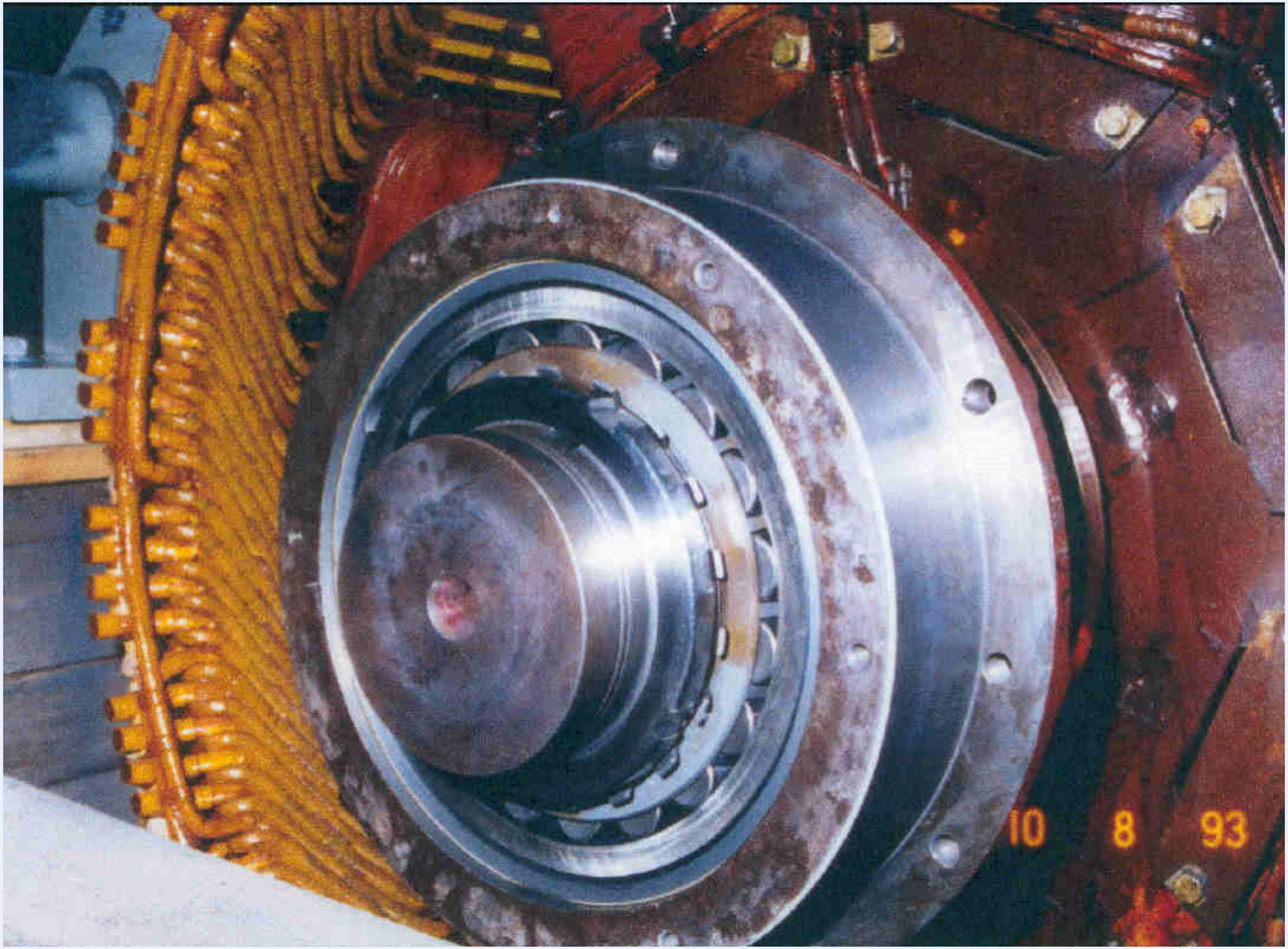


Figure 9-21 Bearing and Housing Assembled to Rotor Shaft

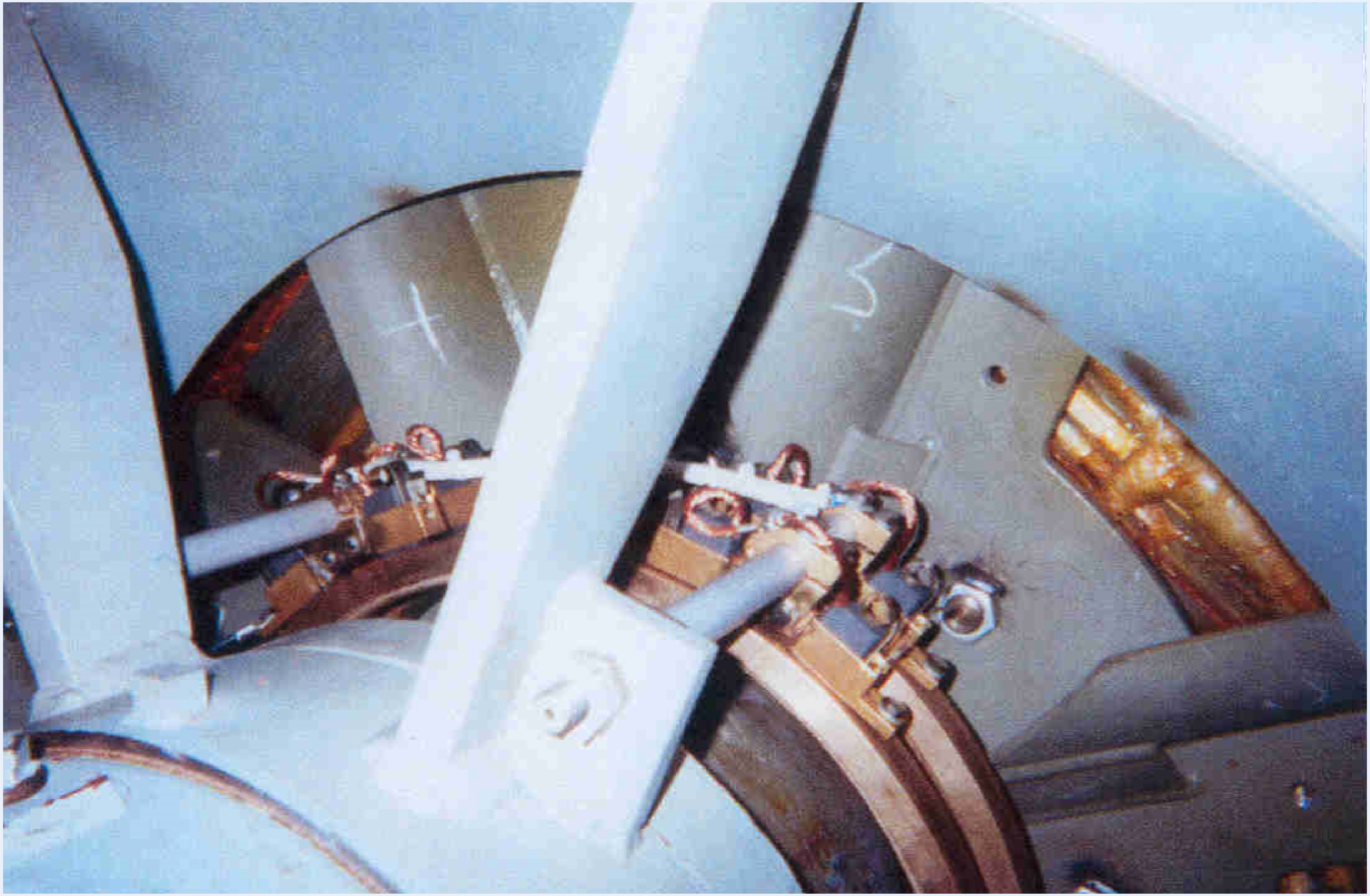


Figure 9-22 Brush Rigging and Slip Rings

The Exciter and Voltage Regulator

Exciters provide voltage and current to the field of the generator sufficient for the generator to pick up, accelerate, and maintain accident loads (mostly large pumps driven by motors).

The voltage regulator controls the exciter to maintain proper generator output voltage at the demand load.

Figure 9-23, Block Diagram, illustrates a typical generator static exciter and voltage regulator system equipped with current (series) boost.

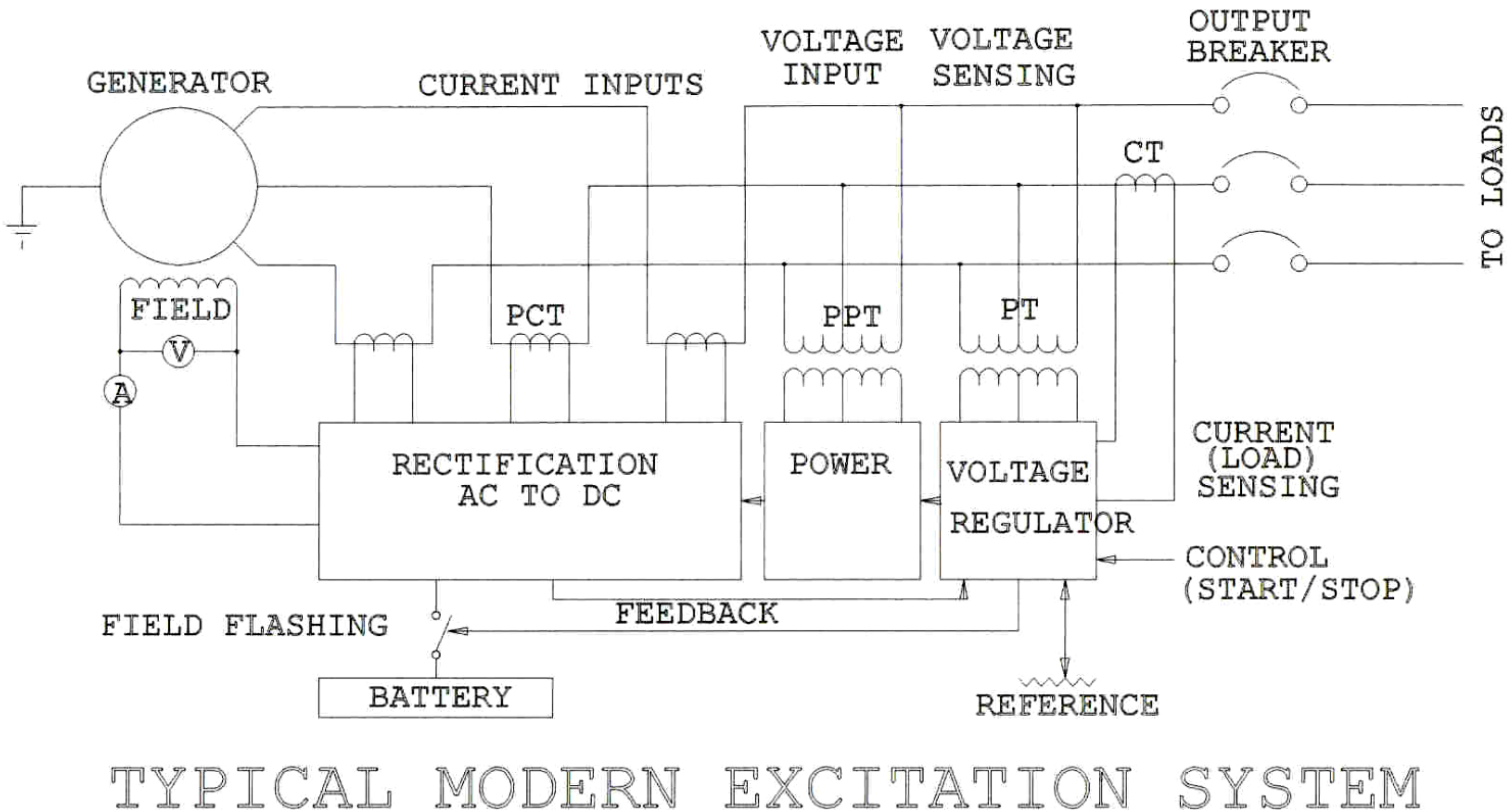


Figure 9-23 Exciter System Block Diagram (SEVR / SB Types)

In Brushless Exciter Generators:

- Main generator output voltage may be converted to d-c voltage or current to excite the stationary field of a small a-c exciter generator mounted directly on the main generator shaft.
- This power may also be provided by a ‘permanent magnetic alternator’ (PMA) or from a battery.

Brushless Exciter Generators (continued)

- The field of this exciter generator is controlled by a voltage regulator.
- The rotating armature of the exciter generator provides an a-c output voltage which is rectified by shaft-mounted diodes.
- The d-c current produced is fed directly into the main generator field without going through slip rings.

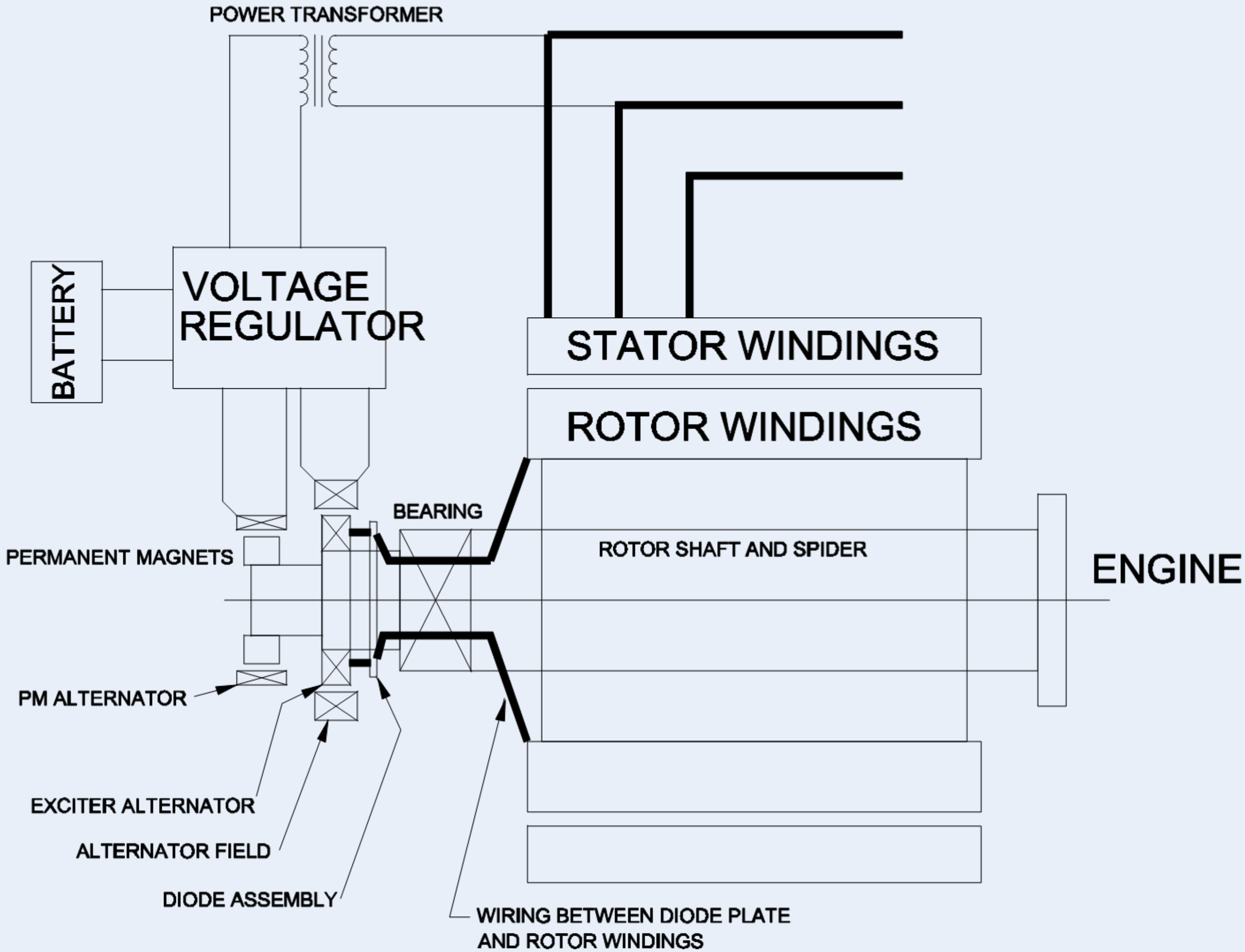


Figure 9-24 Brushless Exciter System Diagram

Digital Voltage Regulation

The only excitation system component that lends itself to digital control would be the voltage regulator. There would be very little advantage in using digital voltage regulation, rather than existing analog designs, as the voltage dip from starting large motor loads is too highly influenced by generator magnetic characteristics.

Making the voltage regulator 'more responsive' or 'faster' would have little effect on the voltage dip and recovery time, as present (analog) voltage regulators are capable of having the excitation at maximum well before the full extent of the voltage dip is felt.

Generator Frequency

Frequency = $N * P / 120$

Where:

F = frequency in hertz (Hz)

P = number of poles (always an even number)

N = generator speed in RPM

Example: A generator operated at 900 RPM with 8 poles will generate 60 hertz output.

For 60 Hz Generator: $N = 7200/P$, or $P = 7200/N$

Generator Frequency Control…

Is accomplished by the engine governor:

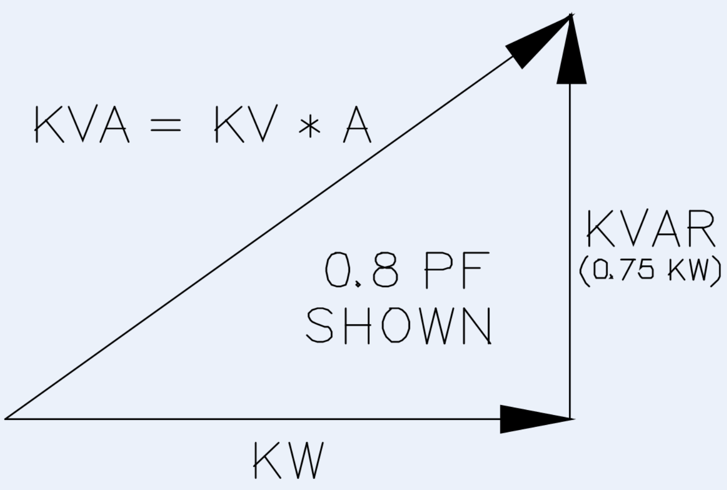
1. Sensing speed changes from the desired speed set point, and then
2. Adjusting engine fuel rate to raise or lower engine speed to the set point.

Generator Output Voltage Control…

Is accomplished by the voltage regulator:

1. Sensing changes in output from the voltage set point, and then
2. Supplying more or less excitation current into the generator field to raise or lower generator output voltage to match the set point.

EDG generator ratings are (must be) expressed in KVA (apparent power) because the inductive motor loading requires higher generator output current than a purely resistive load. This current is out of phase with the voltage as illustrated in Figure 9-4 and below.



Apparent power for the 3-phase EDG output can be calculated at any load by the equation:

$$KVA = 1.73 * E * I / 1,000$$

Where: KVA = kilovolt amperes

1.73 = square root of 3

E = line to line voltage (from Panel Meter)

I = line current (from Panel Meter)

(1.73 * E * I yields only Volt-Amperes)

Real Power -- Expressed in Kilowatts

$$\mathbf{KW = 1.73 * E * I * \cos \Theta / 1{,}000}$$

- KW generator output + generator losses represent the real work of the engine output shaft.
- KW is normally measured using a kilowatt meter rather from voltage and current measurement, as the Power Factor (**cos Ɵ**) is normally not known.

KVAR = square root of (KVA^2 - KW^2)

- It does no work (creates additional heating)
- KVAR is 90° out of phase with "real" power (KW) and is sometimes referred to as "imaginary" power.
- It does not load the engine output shaft (except for generator losses caused by higher current).
- KVAR is present when there is capacitance and/or inductance on the system…
- When KVAR = 0, then KW = KVA (PF is 1, or "unity") ▷

Power Factor (PF):

- **Power Factor** = KW / KVA (in decimal form, often expressed as a percentage, so that 0.8 PF is 80% PF).
- EDG units qualified at 0.8 lagging PF (inductive load). Station loads less demanding, typically near 0.87 PF.
- Because of previous qualification, not necessary to do routine surveillance tests at 0.8 PF.
- Power Factor meters are less accurate than calculating PF using KW, KVAR, and their trig relationship.
- Benchmark: When KVAR = 0.75 ∗ KW, the PF is 0.8

Generator Control Influences…

The following controls influence the generator output:

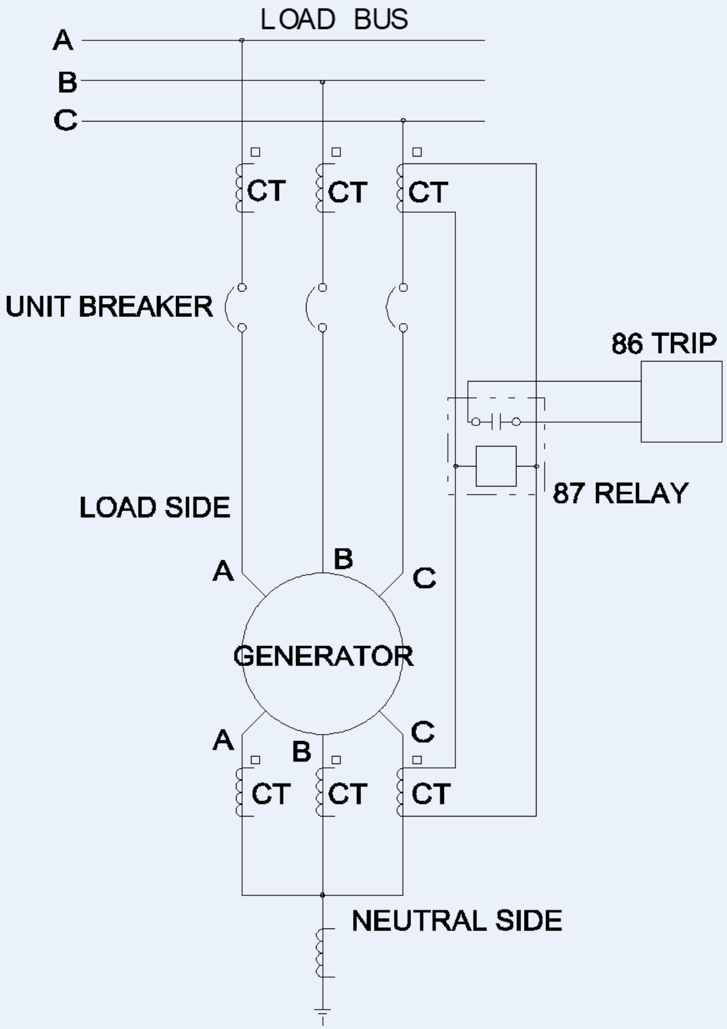
THE GOVERNOR CONTROLS OR RESPONDS TO KW LOADING ON THE GENERATOR.

THE VOLTAGE REGULATOR AND EXCITER SYSTEM CONTROLS OR RESPONDS TO KVA and, thereby, KVAR.

➡ Fundamental relationships to use during runs ⬅

Generator Differential Protection

GOAL: To protect the generator from destruction faults within the bounds from the output circuit breaker, the load side, and ground on the neutral side by shutting down both the generator and engine. This shutdown circuit is required, does not have coincident logic, and is not bypassed during an emergency demand.



GENERATOR DIFFERENTIAL CURRENT CIRCUIT

Figure 9-25

Generator protection against each phase current on each side of the generator. A difference causes a trip of the generator and engine.

Generator Parameter Monitoring

The generator control panel usually includes the following meters for monitoring generator performance:

Phase Voltages and Phase Currents, Field Volts and Amps, KW and KVAR meters, Synchroscope and associated lights.

Relays and trips are provided to monitor the following:

Generator differential fault, Phase over-current, Over and Under Output Voltage, Over-Under Frequency, Generator neutral ground, neutral over-current, Loss of Excitation, Field Ground and Reverse Power, to name most.

Electrical Stress

- High sustained currents
- High motor starting load currents
- Paralleling out-of-phase
- High operating temperatures

Mechanical Stress

- Dynamic loading
- Fault current loading
- Centrifugal rotational loading
- High operating temperatures
- Paralleling out of phase
- Armature not concentric within the stator
- Vibration (out of balance or bearing problems)

Generator Alignment to Engine

To reduce mechanical stresses in the engine, particularly the crankshaft, the generator shaft must be aligned properly to the engine shaft.

One of your Hands-on exercises was checking the "crank deflection" (aka "crank alignment"). As a brief review, this topic is illustrated in Figure 9-26.

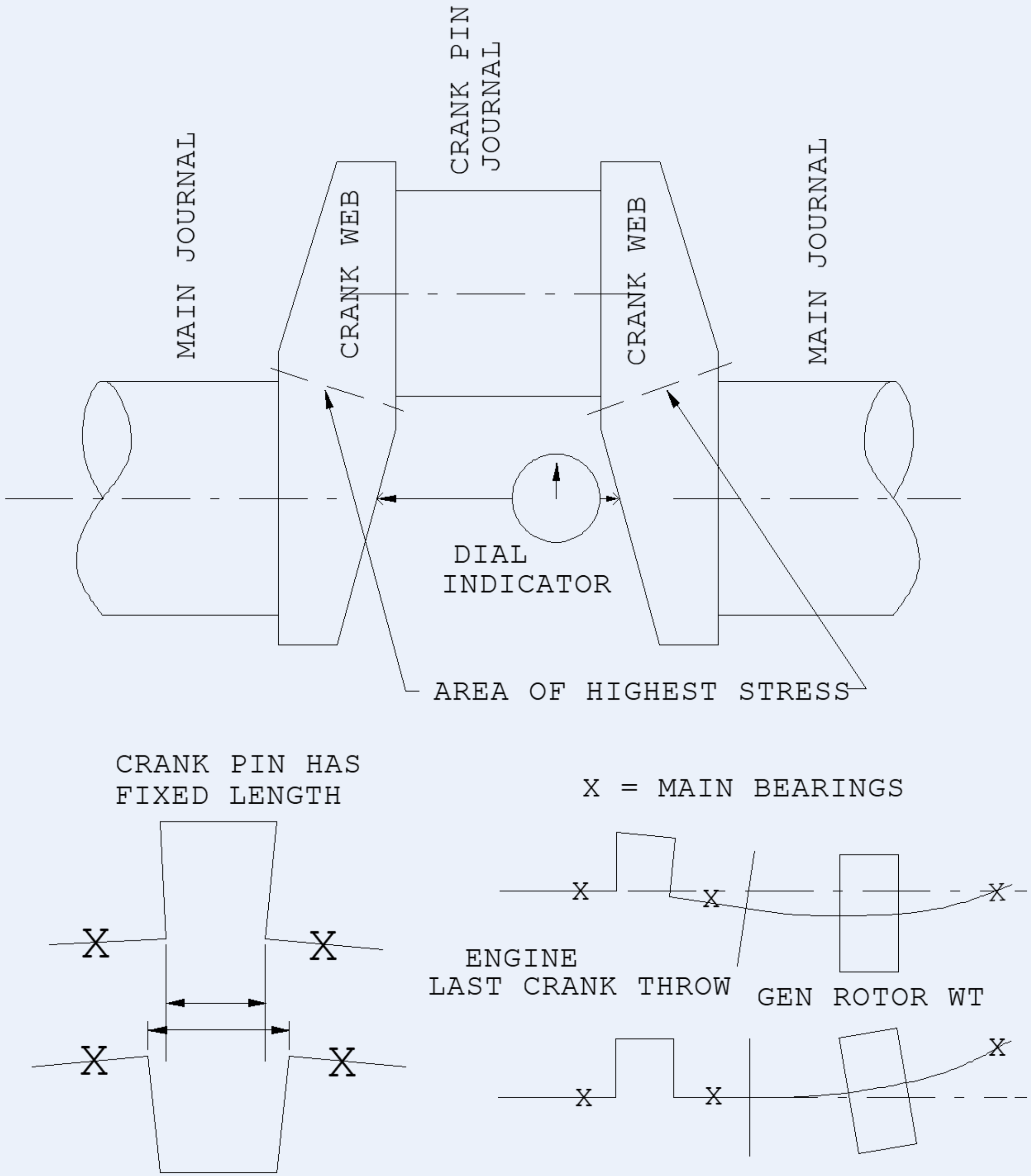


Figure 9-26

Generator must be aligned to limit bending stresses in engine crankshaft, especially in the last crank throw.

Generator shaft and rotor are typically raised.

EDG Generator Tests

- Factory qualification tests
- On-site qualification pre-op tests
- Routine licensee surveillance tests
- Troubleshooting in accordance with manufacturer and licensee procedures

EDG testing will be covered in Chapter 11.

A walkaround session will follow shortly, using the generator in the display area…

END OF CHAPTER 9