Rotor Testing

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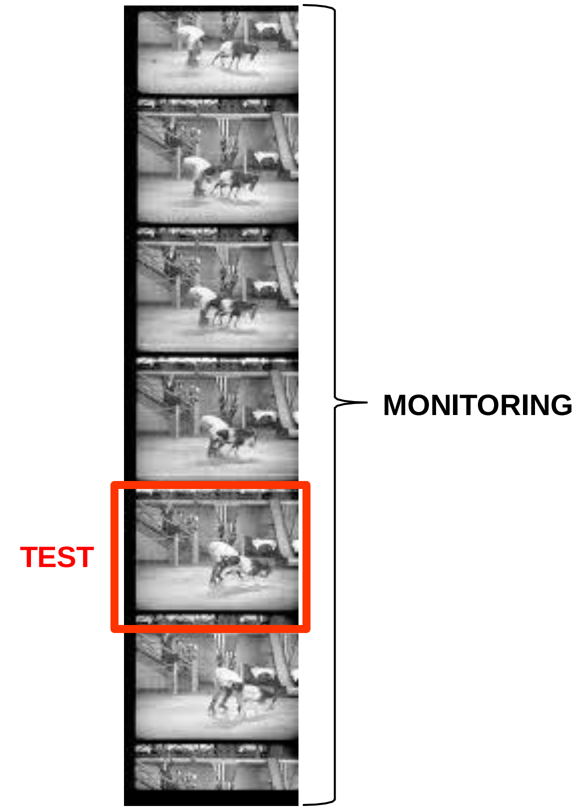
References

- IEEE 115 (Guide): Test Procedures for Synchronous Machines
- IEEE 112: Standard Test Procedures for Motors and Generators
- IEC 60034-3: Specific Requirements for Cylindrical Rotor Synchronous Machines
- IEEE C50.10: General Requirements for Synchronous Generators
- IEEE C50.13: Standard for Cylindrical Rotor 50 Hz and 60 Hz Synchronous Generators Rated 10 MVA and Above
- IEEE 67: Guide for the Operation and Maintenance of Turbine Generators
- IEEE 62.2: Guide for Diagnostic Field Testing of Electrical Power Apparatus – Electrical Machinery
- EPRI TR-107137: Main Generator Monitoring and Diagnostics
- *Handbook of Large Turbo-Generator Operation and Maintenance*, by Klempner and Kerszenbaum

Definitions:

- TEST
  - A critical evaluation, observation, or evaluation.
  - Taking measurements/measures to check the quality, performance, or reliability of (something), especially before putting it into widespread use or practice.

- MONITORING
  - Observe and check the progress or quality of (something) <u>over a period of time</u>; keep under systematic review.



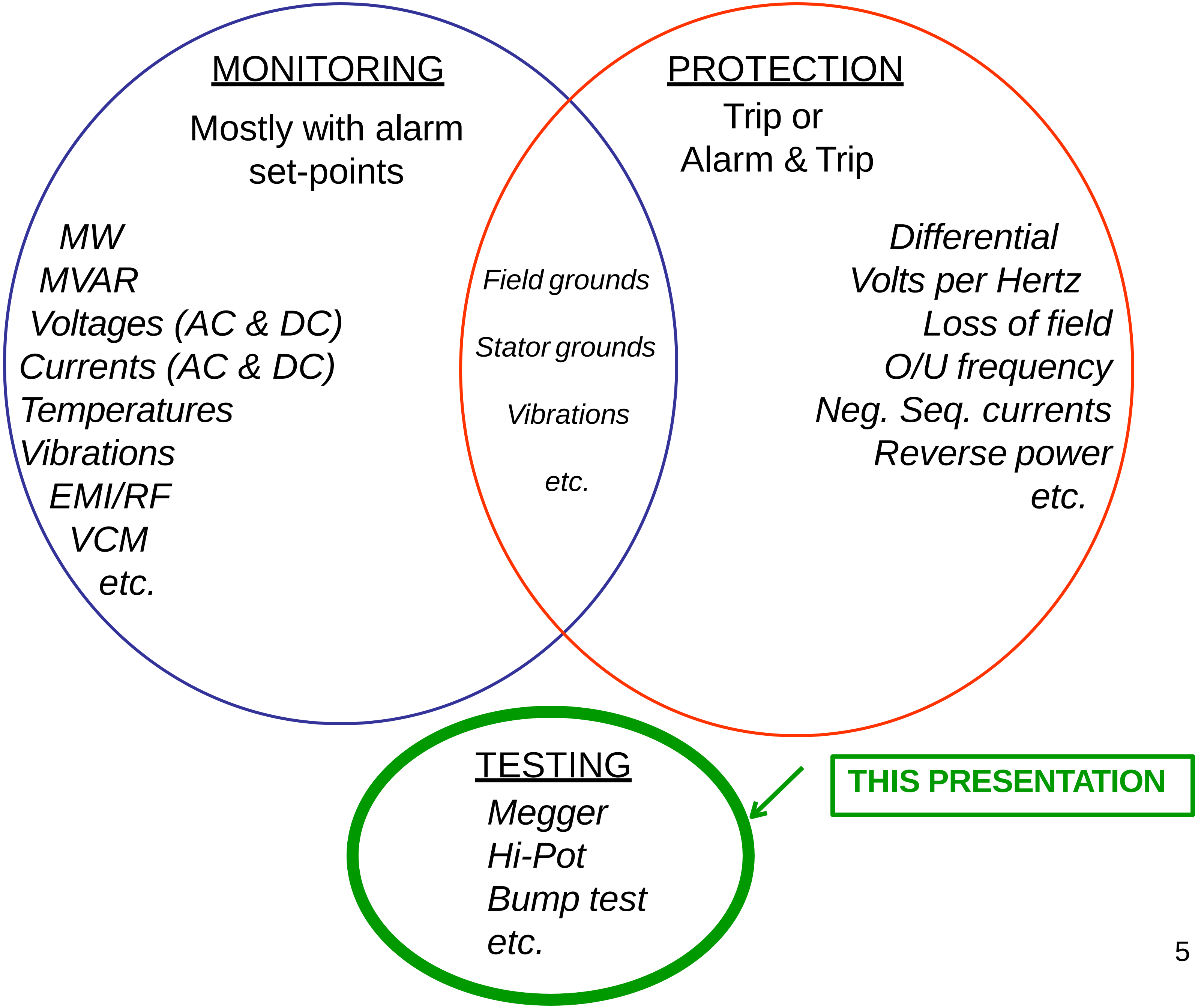
Keeping track of the health of the rotor

- Monitoring
  - Online (real-time or not real-time) measurement of certain variables.
  - Operator → most basic approach
  - Dynamic → some level of computing algorithm
  - Expert System → complex algorithms
  - Typically with alarm set-points
  - Some level of prioritization (importance of monitored parameter)

- Testing
  - Offline or Online
  - Typically PASS or NO-PASS

- Protection
  - Online and offline (e.g.: inadvertent energization)
  - Too fast for operator reaction

Whole Generator



Testing

THIS PRESENTATION

STATOR

Series Resistance
Insulation Res. (Megger)
Polarization Index (PI)
Hipot (AC/DC)
THD
TIF
EMI
Dissipation Factor & Tip-Up
Core vibration
Wedge survey
Acoustics
Corona Probe
SSFR
Insulation Power Factor
EL-CID
SCW flow-rate
etc.

ROTOR

Series Resistance
Insulation Res. (megger)
Polarization Index (PI)
High Potential Test (hipot)
Rotor vibrations
Bearing insulation resistance
Over-speed
RSO
C-core
O.C. characteristics
Shorted turns (RFM)
Impedance vs. rpm
Pole balance
Dye penetrant
Ultrasonic
Eddy current
etc.

Testing Conditions

TEST	ONLINE	ENERGIZED OPEN CIRCUIT	ANY SPEED	NOMINAL SPEED	DE-ENERGIZED	TURNING GEAR	IDLE
SERIES WINDING RESISTANCE					X		X
WALL INSULATION RESISTANCE (“MEGGER”)					X		X
POLARIZATION INDEX (PI)					X		X
HIGH POTENTIAL TEST (“HIPOT”)					X		X
CONTROLLED DC OVER-VOLTAGE					X		X
REPETITIVE SURGE OSCILLOGRAPH (RSO) (shorted-turns)			X	X	X	X	X
OPEN CIRCUIT CHARACTERISTICS (shorted-turns)		X	X	X			
IMPEDANCE VS. SPEED (shorted-turns)			X		X		
ROTOR FLUX MONITOR (shorted-turns)	X			X			
POLE DROP (shorted turns)					X		X
C-CORE (shorted-turns) (requires rotor outside bore)							X
SHORTED-TURN LOCATION (requires removing retaining-rings)					X		X

TEST	ONLINE	ENERGIZED OPEN CIRCUIT	ANY SPEED	NOMINAL SPEED	DE-ENERGIZED	TURNING GEAR	IDLE
BEARING INSULATION RESISTANCE (may require partial disassembly of the unit)					X		X
BEARING INSULATION RESISTANCE (two layers of "sandwich" insulation)	X	X	X	X	X	X	X
OVER-SPEED			X				
LOCATING WINDING GROUNDS					X		X
ROTOR VIBRATIONS	X	X	X	X	X		
DYE PENETRANT					X		X
ULTRASONIC					X		X
EDDY CURRENT					X		X
BORE LEAK (hydrogen-cooled units)					X		X
DIODE INTEGRITY (brushless machines)					X		X
FUSE INTEGRITY (brushless machines)					X		X
SLIPRING RUNOUT	X	X	X	X	X	X	X
BRUSH VIBRATION	X	X		X			

Testing Rotor Parameters

Some Examples:

1) WINDING SERIES RESISTANCE

- The field-winding series-resistance is measured to determine the ohms resistance of the total copper winding in the rotor.
- Measurement accuracy requires significance to a minimum of 4 decimal places.
- Purpose of the test is to detect shorted turns - bad connections - wrong connections - open circuits.
- Test very sensitive to differentials of temperature between sections of the winding – rotor should be at room temperature when the test is performed.
- Results should be compared with original factory data, if available.
- Applicable standards: IEEE 112, IEEE 62.2, IEEE 115, IEEE 118, IEEE C50.13

2) INSULATION RESISTANCE

- Purpose of the IR test is to measure the ohmic resistance between the total rotor winding insulation and ground (i.e. the rotor forging).
- Test generally regarded as initial test to look for gross problems with the insulation system, and to ensure further high voltage electrical testing may (relatively) safely continue.
- Normally, the measurements of IR will be in the mega-ohm range for good insulation, after the winding is subjected to a DC test voltage usually done anywhere from 500 to 1000 V, for one minute. The minimum acceptable reading by IEEE Standard 43 is (V_{line} in kV + 1) MΩ.
- Essential that the rotor winding be completely dried before any testing, so that any poor readings will be due to a "real" problem and not residual moisture.
- Water inner-cooled windings may be meggered with water in them. Results may not be very useful.
- Readings are also sensitive to factors like: humidity, surface contamination, temperature.
- All of the above also applies to the rotor bore copper and collector rings.
- Key reference: IEEE 43

Rotor Grounds

- A generator can, in theory, run for years with a single ground fault in the rotor. However…..
- If a second fault develops on the main DC circuit, in or outside the rotor, serious damage to the rotor may result.
- Typical consequences from two grounds at the same time:
  - Increased rotor vibrations
  - Erratic VAR output
  - Erratic output voltage
  - **Major** damage to the forging, brush-rigging, bearings, H2-seals.
- Most stations monitor and alarm on rotor grounds. Some also trip.

Ground-fault propensity in water-cooled rotors

- Few hundred water-cooled rotors ever produced.
- Two water systems for the generator (SCW & RCW)
- Key concern is the high pressure of the water at the plumbing connecting to the coils in slot area.
- Low megger readings and ground faults not uncommon with these rotors.
- Conductor temperature can be measured indirectly by measuring outlet cooling water.

Searching for grounds

- Grounds in the field winding are normally detected with a megger test or even with an ohmmeter. Those methods DO NOT locate the ground fault.

- The following techniques help to:

1. Estimate the electrical distance to the ground from the collector rings,

2. Estimate the axial location of the ground along the forging,

3. Knowing the electrical distance and axial location of the fault helps in determining in which coil and slot the ground is most probably located.

3) POLARIZATION INDEX (PI)

- Insulation resistance is time dependent as well as being a function of dryness for rotor insulation.
- The amount of change in the IR measured during the first few minutes depends on: the insulation condition, amount of contamination and moisture present.
- When the insulation system is clean and dry, the IR value tends to increase as the dielectric material in the insulation absorbs the charge.
- When the insulation is dirty, wet or a gross insulation problem is present, the charge does not hold and the IR value will not increase, due to constant leakage current at the problem area.
- Ratio between the resistance reading at 10 minutes and the reading at 1 minute produces a number or “Polarization Index”; it is used to determine how clean and dry the winding is.
- The recommended minimum PI values are as follows:

  Class B insulation: 2.0   Class F insulation: 2.0

- Same Megger used for the IR readings should be used to determine the PI.
- PI readings should be done at the same voltage as the IR test and can be used as a go/no-go test before subjecting the rotor to subsequent high voltage tests, either AC or DC.

IEEE Std. 43, Ch. 12 has a long paragraph on the significance (or lack thereof) of Polarization Index measurements on rotors.

4) DC & AC HIGH POTENTIAL (HI-POT)

- Hi-Pot test used to ascertain if winding is capable of sustaining the required rated voltage levels (without a breakdown of the insulation)
- Test consists of applying high voltage to the rotor winding for one minute.
- Best industry practice is to use AC to perform hipot testing of fields.

- For ratings up to and including 500 VDC → V_{test} = 10 x rated excitation voltage, but not less than 1,500 VAC.
- For ratings greater than 500 VDC → V_{test} = 4,000 VAC + 2 x rated excitation voltage.

5) SHORTED-TURNS IN FIELD WINDINGS

- Shorted turns in the field windings may:
  - Reduce the machine's capability to deliver vars
  - Cause rotor vibrations
  - Develop into a ground fault
  - Increase rotor winding temperature

- There is an online technique for finding shorted-turns by monitoring the rotor flux (RFM: Rotor Flux Monitor).

- There are offline (unit not synchronized) techniques for testing for the existence of shorted-turns
  - With the rotor at speed (e.g.: Impedance vs. speed; RSO vs. speed)
  - With the rotor standing-still (e.g.: RSO; pole-drop, "C"-core, etc.)

Rotor Flux Monitor (RFM)

- The most effective means to search for shorted turns in the field winding is the rotor flux monitor (RFM) - discussed in the "monitoring" section, with the machine spinning and energized.

If the RFM does not exist, or if the machine is standing-still, a number of alternative methods exist:

- Repetitive Surge Oscillograph (RSO)
- Open Circuit Test
- Winding Impedance Test
- C-Core Test
- DC Voltage Drop Measurements
- Pole-Drop (Voltage Drop) Test

6) Rotor speed - testing for shaft cracks

- When synchronized, speed is determined by the Grid (unless running “solo”).
- Speed generally measured by a probe mounted next to the rotor, looking at a toothed wheel, or key phasor.
- Speed monitoring during ramping up or down is particularly useful when looking at the vibration profile during start up or shutdown, as the machine goes through its critical speeds. Changes in critical speeds can test for a cracked shaft, for example.

7) BRUSHGEAR INFRARED PERIODIC MONITORING

- Recommended by INPO to the nuclear industry.
- Infrared periodic monitoring of the brushgear may uncover poor brushing issues before they seriously degrade the sliprings or cause short-circuits.
- Typically, IR will uncover loose pigtail connections, fried springs and stack brushes.
- Typical periodicity is every 3 months.

8) Hydrogen Seals and Bearing Insulation

- Megger checks of the hydrogen seal (for H_2 cooled machines) and bearing insulation to ground are done to ensure the rotor shaft is not grounded through the hydrogen seals and/or bearings.

- This is usually done at 500 V DC.

- Megger tests of bearing insulation should yield <u>results > 100 kΩ. Preferable to be in the MΩ region</u>.

Bearing Insulation

- In large TGs peak-to-peak shaft voltages of up to 150V.
- Damage is mechanical action resulting from electric pitting.
- Electrical currents will also change chemistry of oil.
- Control of bearing currents is by grounding the shaft (via *grounding brushes*) and by insulating one or both bearings.
  - Normally NDE side of machine always with insulated bearing.
  - Machines with couplings in both end normally have both bearings insulated
- Couplings can also be insulated.
- Bearing insulation material:
  - Fiberglass or similar, laminated and impregnated with resins, polyesters or epoxies.

Rotor Mechanical Testing

There are generally two types of NDE testing:

Surface - (Visual, Magnetic Particle, Liquid Penetrant and Eddy Current)
Volumetric - (Radiographic and Ultrasonic)

And, generally six different test methods:

Visual (VI)
Radiographic (RT)
Magnetic Particle (MPI)
Liquid Penetrant (LPI)
Ultrasonic (UT)
Eddy Current (ECT)

Some specific tests:

Rotor bore pressure test
Fretting-fatigue cracks in slot dovetails and wedges
Pitting of retaining-rings, zone-rings, fan-hubs and other shrunk-on members
Top-tooth cracking
Bearing-oil wipers-hydrogen seal running surfaces
Etceteras

9) NON-DESTRUCTIVE EXAMINATION (NDE)

- Dye Penetrant
- Eddy Current
- Ultrasonic
- Radiography

10) Bore pressure tests

- Hydrogen must be kept from leaking out thru the bore of the forging.
- Leak of hydrogen is not only an operational problem, but also a safety hazard. Explosions have occurred from H_2 leaks into the brushgear housing.
- Some rotors have only one vertical connector sealed (outer). Most rotor seal the outer and inner vertical stud.
- Older units have a borehole that extends the entire length of the shaft, thus must seal at both ends. In modern units the borehole does not go thru the entire length; thus only one side must be sealed.

11) THERMAL SENSITIVITY TEST

- The purpose of this test is to uncover the source of rotor (and stator) vibrations, before they reach a level that requires removing the unit from operation.
- Identifying the source of vibrations with the unit in operation is considerable easier than with the unit standing still.
- Thermal Sensitivity Testing provides information that can help ascertain if the vibrations are caused by the electrical loading of the rotor winding or are strictly mechanical in origin.
- These types of tests are carried out by all OEMs for troubleshooting purposes; they can also be done by Station personnel.
- This testing will also help to determine if the origin of the vibrations is in the generator or the turbines.
- They can also provide information that allows further filtering of probable causes, narrowing the search.