QUESTIONNAIRE REPORT ON CONDITION MONITORING TOOLS FOR HYDROGENERATORS

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1 INTRODUCTION

The objective of the questionnaire was to survey the water power generation industry's experience of condition monitoring tools. The answers and main analysis are given in the document hereafter.

The condition monitoring tools of this survey concern the main components of the generator, excluding the normal electrical or mechanical protection.

The answers received come from 16 countries, representing 37 answers (15 manufacturers and 22 users); USA has given a global answer.

This work is a continuation of an earlier paper published in Electra n° 115, Dec 1987 Operation of Air Cooled Hydro Generators.

2 ANALYSIS

The answers received were numerous, but a wide range of the responses was observed, leading to a difficult analysis. Among the different topics, mention may be made particularly of the two following parameters: "criteria" and "cost": these two factors were not clearly defined. The relevant criteria depend essentially on both the monitoring method and on the measuring tool. It would be "utopian" to try to describe the applicable criteria in a few words. With regard to the cost, there is some confusion between the cost of the equipment and the cost of the test itself, taking account of the energy production losses, particularly if the test takes a long time.

In general, the summary of the answers is given in the same order as that suggested in the questionnaire. Most answers concerned the following items:

- stator core monitoring tools
- stator winding monitoring tools
- rotor winding monitoring tools
- bearing monitoring tools

In general, it appears that the use of "on line" condition monitoring tools is growing. There is a wide range of new techniques, for example partial discharge measurement for the stator winding. However, their use is currently limited because interpretation of results is judged by many to be difficult or necessitating expert analysis, or as in the case of optic fibres, often considered as fragile.

Older techniques maintain a large degree of confidence. For example, visual examination is emphasised as a guide to indicate further tests required to confirm the generator condition.

3 CONCLUSION

The following list gives the main techniques used to monitor the different components of a generator. It indicates also the main characteristics of each method.

The development of "on line" techniques can be observed, although the problem of their interpretation is apparent.

It is hoped that this list can be used by manufacturers and particularly users, to help them to establish a test schedule for periodical condition monitoring of their generating plants, in order to increase the service availability.

4 Responses

Country	Abbreviation	Manufacturer	User
Austria	AU	1	1
Belgium	B		1
Brazjl	BR	2	5
Canada	CND	1	
China	RC	1	
Croatia	CR	1	
England	UK	1	1
France	FR	1	1
Hungary	HG	1	
Italy	I	1	
Japan	JP	2	3
Norway	NW		2
Russia	RUS		1
Sweden	SW	1	1
Switzerland	CH	1	2
USA*	USA	1	.1
	TOTAL	15	22

Number of Answers 37

*: Global answer for the country manufacturers and users

5 STATOR CORE

5.1 Insulation degradation

5.1.1.1 Ring flux test

Number of Answers		**Interpretation**		**Necessity**	
Manufacturers	11	Easy	18	Recommended	17
Users	14	Without too much Difficulty	7	Recommended with Restrictions	8
		Expert Analysis		Not Recommended	
		Under Debate			
Total	25	Total	25	Total	

This test is done "off line" and is very well known. It is done at a flux density near to the rated value. It is generally carried out during erection or major overhaul and can be considered more as a quality test than a monitoring tool.

Advantages:

- test made between 75 to 100% of normal core flux density.
- it permits at the same time improvement in the compactness of the stator laminations after stacking.

Disadvantages:

- In practice performed on a new or rewound stators.
- necessitates disassembly of the rotor
- necessitates powerful test equipment which is often not very conveniently available. allows detection of hot spots only on the internal surface of stator core.

Criteria :

- difference of temperature between adjacent areas. The acceptable difference is generally between 5 to 10 degrees.
- This criteria depends on the method of checking (ie by IR camera or thermocouples).
- The use of a camera is more frequently employed in combination with touch test.

Cost : -

- generally the price of the equipment is classified as medium, but such equipment can be used for several machines or power stations.

5.1.1.2 Low flux ring test

Like the EL CID method (Electrical Core Imperfection Detector)

Number of Answers		**Interpretation**		**Necessity**	
Manufacturers	10	Easy	5	Recommended	12
Users	8	Without too much Difficulty	2	Recommended with Restrictions	3
		Expert Analysis	9	Not Recommended	
		Under Debate	1		
Total	18	Total	17	Total	15

This test is made "off line" at low flux density level.

Advantages:

- can be made without removal of the rotor
- more complete detection of faults on the magnetic core low power equipment

Disadvantages:

- problem of interpretation4
- poor results at core splits.

Criteria:

- peak of current above a certain value (100 mA given by UK). The comparison between the actual and the previous measurements is often done.

Cost :

- generally considered cheaper than the ring flux test equipment.

5.1.1.3 Other means to check the insulation of the stator core

Visual check: Recommended by some manufacturers and users (to detect the presence of iron oxide); easy but does not give early indication of problem.

Voltage measurement along the teeth (CR) cheap and simple similar to the low ring flux test.

Vibration of stator frame (BR)

Vibration of stator core (I-AU-USA-CH-HG RUS) allows "on line" information but the interpretation is difficult. This method allows detection of problems with the clamping system preventing damage to the core and winding. It also, determines the quality of attachment between the core and the frame. Comparison between the present values and previous readings is often carried out.

Insulation of stator bolts checked by AU.

Infrared thermal imaging (USA) "on line", comprehensive temperature monitoring of entire stator.

Hammer (USA) by impulse or vibration test, but a large impulse exciting force is required as well as many sensors.

5.2 Tightness of the magnetic core

5.2.1 Calibrated torque spanner

Number of Answers		Interpretation		Necessity	
Manufacturers	12	Easy	19	Recommended	17
Users	14	Without too much Difficulty	2	Recommended with Restrictions	6
		Expert Analysis	1	Not Recommended	
		Under Debate			
Total	26	Total	22	Total	23

This check is made "off line".

advantages :

- low cost, simple

disavantages :

- necessitates space for tools, sometimes partial dismantling
- limited accuracy due to the friction
- time consuming to check all the bolts of the magnetic core (1 or 2 days)

criteria :

- the torque decrease is generally controlled.

cost :

- cheap

comments :

This check is done generally during the erection of the generator and it is recommended for control of the core tightness, approximately every 5 to 10 years. In order eliminate the problem of friction, some countries (FR- AU- CR) recommend a check on the tightness by elongation of the bolts or by using special jacks.

It is important to point out that use of high yield strength rods (with high level of residual elasticity) makes it possible to carry out tests only at long intervals.

5.2.2 Other means

Visual examination mentioned by CDN, NW, USA, FR, BR, CH, and RUS. This method is subjective, and only limited areas can be inspected, but it is effective in deciding what test should be performed.

Knife can be used also (very old method), the criteria being the penetration depth. Such a method identifies local faults, and is easy but necessitates manual work.

Vibrations of bolts (8 manufacturers, 3 users), several possibilities: amplitude of the signal (JP), the speed of the signal (I) and more generally the frequency. This method gives a lot of information on the mechanical system, but necessitates expert analysis and involves a complicated measurement.

Special bolts used for special cases in some countries, (UK-FR-BR-RC). The accuracy of this system is considered as limited and interpretation is difficult. '

Vibration of the stator frame (BR) by the reading of frequency.

Core compressibility (AU-FR) by measurement of accessible parts of the core when the air gap is sufficient

Ultrasonic test (USA), quicker than torque spanner (no problem of friction), but it is necessary to know the material and dimensions of bolts etc...

quadrature axis Hall effect probe (USA) "on line", detects wave form anomaly and is recommended.

6 STATOR WINDING

6.1 Insulation degradation

6.1.1 Partial Discharge

Partial discharge measurement is becoming more and more popular, two methods are generally considered:

- "on line" system which necessitates permanent coupler directly connected to the stator winding and an analyser which can be common to several units.
- "off line" system which necessitates portable equipment.

6.1.1.1 "on line" system

The general method used is to record the starting point or fingerprint at the beginning of the service life of the stator winding and to note changes. These have then to be analysed.

Number of Answers		**Interpretation**		**Necessity**	
Manufacturers	9	Easy		Recommended	8
Users	13	Without too much Difficulty	4	Recommended with Restrictions	13
		Expert Analysis	13	Not Recommended	1
		Under Debate	5		
Total	22	Total	22	Total	22

advantages

- "on line" system which can detect the beginning of insulation degradation.
- allows detection of discharges, even in local areas.
- allows detection of looseness of the bars or coils in the slots.
- easy to do.

disadvantages :

- problem of interpretation (how to evaluate).
- The readings are influenced by many external parameters, so the interpretation requires experts, with reference to very large data base, and much time.
- The system is expensive to install and requires expensive equipment.

AU mentions the "EDT" system, used on line requiring an HV coupler.

6.1.1.2 "off line" system

Method used with an applied voltage.

Number of Answers		Interpretation		Necessity	
Manufacturers	4	Easy	1	Recommended	11
Users	9	Without too much Difficulty	5	Recommended with Restrictions	2
		Expert Analysis	7	Not Recommended	
		Under Debate			
Total	13	Total	13	Total	13

advantages :

- repeatability is better and allows the possibility of judging local high density of voids.
- used particularly in FR and JP.

disadvantages :

- not "on line", so difficult to judge the tightness of bars in the slots during operation.
- The periodicity varies greatly between 1 to 10 years, and checking time is about 1 day.
- The cost of the equipment is considered as medium, but the equipment can be common for several units or power stations.

6.1.2 Other "off line" systems

DC high voltage test ;

Number of Answers		Interpretation		Necessity	
Manufacturers	8	Easy	16	Recommended	16
Users	16	Without too much Difficulty	7	Recommended with Restrictions	8
		Expert Analysis	1	Not Recommended	
		Under Debate			
Total	24	Total	24	Total	24

This test is made "off line", this technique is old and is very well known. Several tests are mentioned: the polarisation index at a relatively low voltage or the test performed at high voltage (generally up to twice the rated value) measuring the leakage current or the DC high voltage strength test (equivalent to the AC dielectric test but with a 1.7 equivalence factor). The figures given above are global because of the difficulty in understanding the differences due to lack of details. The polarisation index mentioned by several countries (CDN, FR, UK, JP) is easy but can not give information on the rate of degradation.

About the DC high voltage test:

advantages :

- easy, the test gives good indication on the general insulation condition.
- particularly allows the endwindings to be checked.

disavantages :

- it is a global test which can not detect partial faults on the stator insulation.
- The stress pattern is modified from the rated condition due to the influence of some conditions by use of DC voltage.
- This test can be destructive.

Criteria:

often used is the value of the leakage current, by comparison with previous readings, problem of interpretation (how to compare the current value with the capacitance of the winding). This method constitutes a global method.

6.1.2.1 Other means

Visual examination although subjective, this method allows rapid detection of evident trouble on the insulation, particularly on the end windings.

Ozone : (4 manufacturers, 3 users) This "on line" check allows principally the detection of superficial discharges which modify the, air by ionisation, (a level of a certain ppm of ozone may give an alarm). The test is easy, but the analysis is considered generally uncertain.

partial discharge locator (USA) "on line" new method, measures the partial discharge magnitude on each coil.

end turn capacitive test (USA) "on line" for water cooled machines to detect water leakages.

AC current test (8 users) global test "off line". The result can be "passed" or "not passed" but also the variation of the current allows detection of the existence of voids in general.

tangent delta (2 manufacturers, 4 users) global test to determine the general condition of the stator winding although its interpretation is sometimes difficult.

Direct axis Hall effect probe (USA) "on line", measures the wave form discontinuity to check the integrity of each coil to detect set of shorted turns or strands.

6.1.3 Temperature RD's

The temperature reading is not a direct method of monitoring the insulation condition, but it indicates to the user the power limit up to which the generator can operate without heating, which is dangerous for the insulation service life.

Number of Answers		**Interpretation**		**Necessity**	
Manufacturers	13	Easy	30	Recommended	31
Users	20	Without too much Difficulty	1	Recommended with Restrictions	
		Expert Analysis		Not Recommended	
		Under Debate			
Total	33	Total	31	Total	31

This "on line" check is judged cheap, and is considered indispensable, even if only a limited number of points can be measured and if the temperature is not exactly that of the copper. It cannot measure "hot spots".

6.1.4 Other means

Fibre optic (5 manufacturers, 4 users) (CDN, UK, AU, BR, USA, CH), "on line", although its interpretation is easy, it is not considered as recommended now, due to its cost and fragility. This method is possible at high voltage locations. The equipment is expensive.

Electrical resistance "off line", global method which cannot detect hot spots. This technique is more of an investigative tool.

Cooling water (AU), reading of the temperature rise in hollow strand to detect restrictions in these conductors.

Pyrometry (UK-NW) for water-cooled units, (USA) quick but the sensor provides only a limited view of the winding. This method .is used occasionally:

6.1.5 Wedge tightness

UK recommends electro magnetic probe "off line", cheap to check the winding security but this generally necessitates the rotor removal:

6.1.6 Partial discharge

Number of Answers		**Interpretation**		**Necessity**	
Manufacturers	10	Easy	4	Recommended	6
Users	8	Without too much Difficulty	9	Recommended with Restrictions	9
		Expert Analysis	1	Not Recommended	
		Under Debate			
Total	18	Total	14	Total	15

The test is made "on line", however the interpretation is difficult and the cost is high.

6.1.7 Wedge tap test

(test of slot wedging)

Number of Answers		**Interpretation**		**Necessity**	
Manufacturers	11	Easy	14	Recommended	19
Users	12	Without too much Difficulty	8	Recommended with Restrictions	2
		Expert Analysis		Not Recommended	
		Under Debate			
Total	22	Total	22	Total	21

An old and low cost method which rapidly gives the condition of bar tightness in the slot. Unfortunately this method is subjective and requires experience. It is not possible to know how tight the bars are in the slots. It is simpler with the removal of the rotor for a complete examination.

6.1.8 Wedge Tightness by Measurement

Number of Answers		**Interpretation**		**Necessity**	
Manufacturers	8	Easy	12	Recommended	17
Users	14	Without too much Difficulty	4	Recommended with Restrictions	2
		Expert Analysis	3	Not Recommended	
		Under Debate			
Total	22	Total	19	Total	19

This is an "off line" method. Alternative, possible methods: displacement of the spring element in the slot, measurement of the force on the slot wedges. Interpretation is sometimes difficult.

6.1.9 Other means

AU mentions **EDT** and frequency analysis of acoustic signal to check the adequacy of wedge tightness (used only for "hard wedging"). Interpretation seems difficult. "Off line" method with rotor implemented.

Ozone (2manufacturers, 3 users) used occasionally. Interpretation can be difficult. Fiber optic (2 users, l manufacturer) used occasionally.

Vibration (5 manufacturers, 3 users). Criteria: amplitude or frequency. Problem of interpretation makes this method recommended with restriction.

Visual (USA) "off fine" important to decide what other tests have to be considered. Recommended by Russia but with expert analysis.

7 ROTOR WINDING

7.1 Interturn failure

7.1.1 AC drop test

Number of Answers		Interpretation		Necessity	
Manufacturers	12	Easy	20	Recommended	25
Users	15	Without too much Difficulty	5	Recommended with Restrictions	1
		Expert Analysis	1	Not Recommended	
		Under Debate			
Total	27	Total	26	Total	26

This "off line" test is very well known, periodicity generally admitted: about 5 years. The criteria are in the range (5% to 20%), with a majority of 10%. This test is judged easy and effective but necessitates some disassembly. An interturn fault (if absolute) can be detected. Cost is considered as low.

7.1.2 Impulse-test,

Number of Answers		Interpretation		Necessity	
Manufacturers	8	Easy	6	Recommended	7
Users	6	Without too much Difficulty	3	Recommended with Restrictions	4
		Expert Analysis	2	Not Recommended	1
		Under Debate	1		
Total	14	Total	12	Total	12

An "off line" test, periodicity is-between 3 to 10 years. The test is carried out at high frequency and results depend on the signal response. The test needs a low energy source but can be performed only on sir 1e or a few coils, and there is a risk of damage between turns due' to the high voltage. The cost is medium and checking time is approximately 1 day.

7.1.3 Other means

Pole to pole flux variation (CND) relatively new, the principle is the variation of flux density to detect shorted turns, fast, "on line" method.
DC distribution test (JP).

7.2 Rotor to ground failure

7.2.1 Megohmmeter

Number of Answers		Interpretation		Necessity	
Manufacturers	12	Easy	29	Recommended	30
Users	20	Without too much Difficulty	3	Recommended with Restrictions	1
		Expert Analysis		Not Recommended	
		Under Debate			
Total	22	Total	32	Total	31

An "off line" method, old, very well known, periodicity recommended between 1 to 5 years, cheap, fast. Although easy, this method gives limited information if there is an insulation failure. Wide range for the criteria: between 1 Mohm or less to 100 Mohm.

7.2.2 Other means

DC high voltage test (CH) recommended.

"on line" ground failure detector for rotor winding.

Capacitive reactance of the rotor (JP-CR) is measured through slip rings. Interpretation is easy or without too much difficulty.

AC high voltage test (AU-I-HG) "on line", risk of damage, recommended with restriction.

FRA (Frequency response analysis) (UK) "off line", high cost, interpretation still under debate

(SW) uses rotor mounted **flux measurement** system using telemetry.

7.3 Rotor winding temperature

RTD's (3 manufacturers, 3 users) "on line" method, gives the temperature during operation but problem of reliability. Interpretation easy. Necessity between recommended and recommended with restriction.

infrared thermometry (CND UK-CH) "off line", used occasionally, necessitates partial removal (covers), recommended with restriction.

Electrical resistance measurement

This method previously done "off line", can be done "on line" by using transducers.

Number of Answers		Interpretation		Necessity	
Manufacturers	12	Easy	19	Recommended	20
Users	12	Without too much Difficulty	2	Recommended with Restrictions	1
		Expert Analysis		Not Recommended	
		Under Debate			
Total	24	Total	21	Total	21

Periodicity between 1 to 5 years for the "off line" method. For the "on line" method the accuracy is considered as limited. This test gives an average value and its cost is considered as low.

Fibre optic (CH) "on line". Interpretation without too much difficulty, recommended with restriction.

7.4 Pole face temperature

Telemetry (6 manufacturers, 1 user) "on line", direct reading, necessitating special equipment, easy interpretation, recommended with restriction.

Fast pyrometer (CH) high cost.

Paper strips (5 manufacturers, I user) easy, used occasionally, necessitates dismantling, easy, recommended with restriction.

7.5 Rotor connections visual examination

Number of Answers		**Interpretation**		**Necessity**	
Manufacturers	13	Easy	17	Recommended	25
Users	14	Without too much Difficulty	7	Recommended with Restrictions	
		Expert Analysis	1	Not Recommended	
		Under Debate			
Total	27	Total	25	Total	25

"off line" method, easy, necessitating partial dismantling and time is subjective. Periodicity between 1 to 5 years.

7.6 Electric resistance measurement

Number of Answers		**Interpretation**		**Necessity**	
Manufacturers	9	Easy	10	Recommended	11
Users	10	Without too much Difficulty	5	Recommended with Restrictions	5
		Expert Analysis	2	Not Recommended	1
		Under Debate	1		
Total	19	Total	18	Total	17

"off line" method, The voltage variation or the resistance value constitute the main-criterion. Easy, but problem for the reading of very low resistance, partial dismantling and special equipment needed. Time required important.

7.7 Other means

AC voltage pole to pole (BR) comparing the values, this test necessitates partial dismantling.

connection temperature, (AU) good indication but powerful DC source required and problem of staff security. Russia recommends the measurement of the electrical connection resistance.

X rays (BR) to detect cracks, but problem of staff security. (More a quality tool than a monitoring tool)

8 AIR GAP

'Some manufacturers recommend the air gap monitoring system only for large diameter generator (ie generally for a stator diameter above 7m and having a small air gap).

Number of Answers		**Interpretation**		**Necessity**	
Manufacturers	12	Easy	4	Recommended	9
Users	8	Without too much Difficulty	10	Recommended with Restrictions	6
		Expert Analysis	3	Not Recommended	2
		Under Debate			
Total	20	Total	17	Total	17

The test can be done "off line" or "on line". The criteria is the variation of airgap, tolerance of 10% is often given. The cost is comprised between low and medium. Interpretation is without too much difficulty.

Capacitance probe (3 manufacturers, 5 users) "on line" system. Interpretation is classified between easy and without too much difficulty. This method is expensive but has the advantage of good accuracy.

Other means

Fiber optic (CND- JP) Reliability problem, necessitates expert analysis (RUS).

Static ultrasonic sensors (BR) "on line

Inductive sensor (USA SW) core flux measured by a coil. Low cost but does not give the absolute value of the. airgap.
Rotor and stator mounted inductive sensors measuring to each stator tooth, to each pole face distance respectively.

8.1 BEARING

8.1.1 Temperature

in the pads

Number of Answers		**Interpretation**		**Necessity**	
Manufacturers	13	Easy	32	Recommended	33
Users	20	Without too much Difficulty	1	Recommended with Restrictions	
		Expert Analysis		Not Recommended	
		Under Debate			
Total	33	Total	33	Total	33

"on line", easy, the protection of the machine is limited, because the detection of fault is. Made belatedly, but still limits damage.
However for the majority such equipment is necessary, even if each pad is not fitted with a resistance temperature detector in the oil

Number of Answers		**Interpretation**		**Necessity**	
Manufacturers	13	Easy	32	Recommended	33
Users	20	Without too much Difficulty	1	Recommended with Restrictions	
		Expert Analysis		Not Recommended	
		Under Debate			
Total	33	Total	33	Total	33

“on line” easy

8.1.2 Chemical analysis

Number of Answers		**Interpretation**		**Necessity**	
Manufacturers	9	Easy	13	Recommended	25
Users	19	Without too much Difficulty	6	Recommended with Restrictions	
		Expert Analysis	6	Not Recommended	
		Under Debate	1		1
Total	28	Total	26	Total	26

"off line", necessitates outside test laboratory. JP (one user) measures the viscosity degree, ROBT, degree of oxidation, IS degree to be monitored. More generally some users and manufacturers determine the presence of metallic particles and/or water. SW uses gravimetric test to indicate malfunction of bearing or .oil.

8.1.3 Vertical deflection and load measurement

Number of Answers		Interpretation		Necessity	
Manufacturers	11	Easy	4	Recommended	6
Users	8	Without too much Difficulty	6	Recommended with Restrictions	11
		Expert Analysis	6	Not Recommended	
		Under Debate			
Total	19	Total	16	Total	17

"on line", easy to monitor but interpretation is difficult. Due to this feature this condition monitoring tool is mainly recommended with restriction and used in very specific cases. The sensor can be installed on the thrust-bearing bracket to record the displacement.

8.1.4 load measurement

force sensor (USA) gives the actual force but hard to fit.

calorimetry (CR) accurate but complex.

oil film pressure (JP) complex

8.2 Insulation

Two ways to measure the insulation "on line" system of'1off line" with periodic checks.

8.2.1 "on line" system

Number of Answers		Interpretation		Necessity	
Manufacturers	12	Easy	16	Recommended	15
Users	12	Without too much Difficulty	4	Recommended with Restrictions	6
		Expert Analysis	1	Not Recommended	
		Under Debate			
Total	24	Total	21	Total	21

The main- principle is the measurement of the shaft current, but the shaft voltage can also be monitored. The test is easy and continuous although outside interference on the reading can occur. The shaft current device is generally considered as expensive and a warning can arrive too late to save the bearing. The checking can be done by monitoring the insulation resistance (double layer insulation type).

8.2.2 "off' line" system

Number of Answers		Interpretation		Necessity	
Manufacturers	11	Easy	20	Recommended	24
Users	14	Without too much Difficulty	4	Recommended with Restrictions	1
		Expert Analysis		Not Recommended	
		Under Debate			
Total	25	Total	24	Total	25

cheap, easy but unfortunately non-continuous. The method is that of reading the insulation resistance.

8.3 Oil infection

(26 answers), this device "on line", cheap is particularly used with the control system (not exactly a monitoring tool).

8.4 water-oil system

oil level recommended (13 manufacturers, 15 users)

water flow recommended (12 manufacturers, 15 users)

oil flow recommended (11 manufacturers, 14 users)

oil membrane pressure recommended by 1P (adopted for the latest pumped storage power station).

9 VIBRATIONS AND COOLING

9.1 Bearing

radial vibrations

(14 manufacturers, 13 users), the amplitude, velocity or acceleration are often indicated as variables which are monitored. Frequency analysis is also indicated as a possible method, but interpretation is difficult and there is a problem of response at low frequencies.
The cost is considered as medium. The interpretation ranges between easy to necessitating expert **analysis**.
Necessity: 19 recommended, 6 recommended with restriction.

bearing and shaft vibration
(8 manufacturers, 11 users). The cost is medium. The majority finds the interpretation requires an expert.
Necessity: 7 recommended and 8 with restriction.

shaft runout (considered more a quality test than a monitoring test)

proximity probe
(8 manufacturers, 13 users), the system is used "on line" or "off line", the values measured are the same as for the vibrations, some difficulties of interpretation can appear, especially for frequency analysis. This test is often used for diagnostic checks during commissioning or major outage. Necessity: 15 recommended, 4 with restriction.

Stator radial vibration to detect any vibration being the signature is a fault (e.g.: on the rotor such as a short circuited turns etc.)

Split phase circulation current A protection method, but can be used for detecting air gap eccentricity etc.

9.2 Cooling

cold air temperature
(14 manufacturers, 17 users), low cost, easy to interpret, recommended Some countries (BR-B) also recommend monitoring hot air temperature.

water temperature
(14 manufacturers, 16 users), low cost, easy to interpret, recommended

water flow
(13 manufacturers, 12 users), low or medium cost, easy to interpret, recommended in general.

9.3 Fans

air temperature (6 manufacturers, 8 users), low cost, easy to interpret, recommended.

motor current (5 manufacturers, 2 users), low cost, easy to interpret, recommended.

9.4 Others

For bulb unit AU recommends monitoring the bulb vibrations

9.5 OTHER

9.5.1 Braking

(15 manufacturers, 12 users). In general air pressure and shoe position are monitored. Change of braking time is also mentioned for monitoring the leakage through in the wicket gate and the brake efficiency.

9.5.1.1 Slip rings

(11 manufacturers, 18 users), features which can be monitored are

- the slip rings and brushes by visual examination
- the brush wear
- the vibration on the collector rings
- the temperature (slip rings and collector compartment)

9.5.1.2 $C0_2$ fire protection

(8 manufacturers, 10 users), in view of the disparity in the answers, no main guideline can be extracted. Moreover the fire protection is considered sometimes as unnecessary due to the extinguishing components which constitute the main materials of modem insulation systems.

Others

IEEE Standard 492 Guide for Operation and Maintenance of Hydro-Generators can be consulted.

9.6 LIST OF COMMONLY USED MONOTORING TOOLS

9.6.1 STATOR CORE

- Ring flux test
- Low flux ring test
- Calibrated torque spanner
- Visual examination

9.6.2 STATOR WINDING

- Off line discharge analyser
- DC high voltage test
- TgS and its variation
- RTD measurements
- Wedge tightness tap test
- Compressibility of the ripple spring
- Force measurement on the spring
- Visual examination
- Partial discharge analysis

9.6.3 ROTOR WINDING

- AC drop test
- Impulse test
- AC high voltage test
- Megohmmeter reading
- Electrical resistance measurement
- Visual examination of the connections
- Electrical resistance measurement of the connections
- Capacitance of the rotor

9.6.4 AIR GAP

- Distance probe
- Capacitance probe

9.6.5 BEARING

- Temperature of oil, pads
- Chemical analysis
- Vertical deflection
- Insulation measurement (shaft current or voltage reading)

9.6.6 VIBRATIONS

- Radial vibrations of bearings Shaft vibrations

9.7 LIST OF ADVANCED MONOTORING TOOLS

9.7.1 STATOR CORE

- Infrared thermal imaging
- Quadrature axis
- Hall effect probe

9.7.2 STATOR WINDING

- On line partial discharge analyser
- Direct axis
- Hall effect probe

9.7.3 ROTOR WINDING

- Telemetry

9.7.4 AIRGAP

- Induction air gap

9.8 LIST OF MONITORING TOOLS UNDER DEVELOPMENT

9.8.1 STATOR CORE

- Vibration of stator core
- Vibration of bolts
- Core compressibility

- Ultrasonic test

9.8.2 STATOR WINDING

- Ozone measurement
- Pyrometry
- Vibrations

9.8.3 ROTOR WINDING

- Field measurement
- Capacitance of the rotor
- Frequency response analysis
- Fibre optic

9.8.4 AIRGAP

- Fibre optic
- Ultrasonic sensor

9.8.5 BEARING

- Force sensor
- Oil film pressure
- Calorimetry

9.8.6 VIBRATION

- Stator vibration

9.8.7 COOLING AIR ANALYSIS (particles,...)