PREDICTION AND PROCEDURES IN MAINTENANCE OF STATOR WINDING

WINDING WEDGE-TIGHTNESS TESTING IN ORDER TO IMPROVE THE RELIABILITY AND EXTENSION OF THE HYDRO GENERATOR LIFE IN HPP„DJERDAP 1“

Dragan Belonić

PE ELECTRIC POWER INDUSTRY OF SERBIA
Branch HPP Djerdap
HPP Djerdap 1

PRESENTATION FOR IRMC 2022

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1) INTRODUCTION

For the needs of quality maintenance of the stator windings, it is necessary to conduct appropriate tests in order to determine the state of insulation and to detect significant degradation processes.

The **goal** is **to detect the degradation process**, the condition before it leads to an unplanned, premature failure. In this way, the **problem can be approached in a timely manner** and the **necessary intervention can be planned to prevent failure**.

1) INTRODUCTION

Introductory notes

In the period from September 2009 to November 2019, HPP „Djerdap 1" was revitalized, in stages, and works on 5 of 6 units were completed. After the completion of the revitalization of each individual unit, regular maintenance of the generator equipment was started, in accordance with the defined operating instructions and data of the generator manufacturer.

2) WINDING WEDGE-TIGHTNESS TESTING

Causes of loose stator windings on new-revitalized generators

2) WINDING WEDGE-TIGHTNESS TESTING

Causes of loose stator windings on new-revitalized generators

- action of electromagnetic forces on stator bars
- thermal stresses (heating and cooling cycles due to a large number of starts and stops)
- residual deformations of the form, shape of the stator bar body insulation
- quality and technology of slot content materials making and type of stator winding wedging in stator core slots

2) WINDING WEDGE-TIGHTNESS TESTING

Causes of deterioration of winding wedge-tightness during the exploitation

2) WINDING WEDGE-TIGHTNESS TESTING

Causes of deterioration of winding wedge-tightness during the exploitation

The materials used for wedging the stator windings (wedges and slot fillers) suffer great mechanical (vibrations caused by electromagnetic forces) and thermal stresses during operation, which lead to changes in their characteristics and dimensions.

Over time, these parts are damaged and worn, and the fastening of the windings in the stator slots becomes loose.

2) WINDING WEDGE-TIGHTNESS TESTING

Causes of deterioration of winding wedge-tightness during the exploitation

Also, poor tightness of the stator core can, over time, lead to damage to the stiffening elements of the stator winding and worsening of the stator wedge-tightness.

2) WINDING WEDGE-TIGHTNESS TESTING

Methods of stator winding wedge-tightness control

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Methods of stator winding wedge-tightness control

The control of the stator winding wedge condition, i.e., determining the existence of loose wedges, **is usually done by „tapping" the slote wedges** with a suitable tool (hammer), listening and / or determining the degree of their movement, **either manually by experienced masters or by modern electronic devices.**

The corresponding result of these tests are given in the table in which the degree of looseness of individual slot wedges of the stator windings is defined.

2) WINDING WEDGE-TIGHTNESS TESTING

Methods of stator winding wedge-tightness control – manual method

The standard, manual test method includes **mechanical tapping on slot wedges** and **acoustic determination** of the quality of the wedge-tightness. The response is different for well-wedged wedges - **low vibration / wedge movement and compact ringing sound** compared to badly wedged - **noticeable vibration / wedge movement and hollow sound.**

2) WINDING WEDGE-TIGHTNESS TESTING

Methods of stator winding wedge-tightness control – with electronic devices

In addition to the manual method, appropriate automatic electronic devices with an accelerometer probe are increasingly being used. These devices perform mechanical excitation of controlled wedges and readings of their vibrational response.

2) WINDING WEDGE-TIGHTNESS TESTING

Methods of stator winding wedge-tightness control– for winding with ripple springs

Winding wedge-tightness control for windings which are wedged with top ripple springs can also be controlled manually by reading the size of the gap to the top ripple springs through the appropriate openings on the slot wedges or appropriate electronic devices that have inductive sensors instead of the accelerometer that can measure wedge displacements with an accuracy of 0.0254 mm (0.001 in).

2) WINDING WEDGE-TIGHTNESS TESTING

Comparison of methods for determining the state of winding wedge-tightness in HPP „Djerdap 1"

	Manual „hammer“ method	Electronic method with SWA Iris Power device	Comment
Accuracy / Precision	Subjective / Questionable	Good / (95-100%)	High accuracy is obtained with an electronic SWA device
Time required to test one generator	40 working hours	20 working hours	2-3 workers are needed for the "manual method", and one person is enough to use an electronic device. The electronic device shortens the required test time.
Data recording	Manually	Computerized	The electronic device gives a graphical and numerical display of the results
Test repeatability	Subjective	Yes	Consistent results as the Electronic device measures each wedge 30 times in a period of 3 seconds
Results analysis	Hard / possibility of error	Easy / error free	Graphic and numerical data from the electronic device is easier to analyze
Quality of decision making	Subjective	Objective	The results from the electronic device enable an objective decision to be made

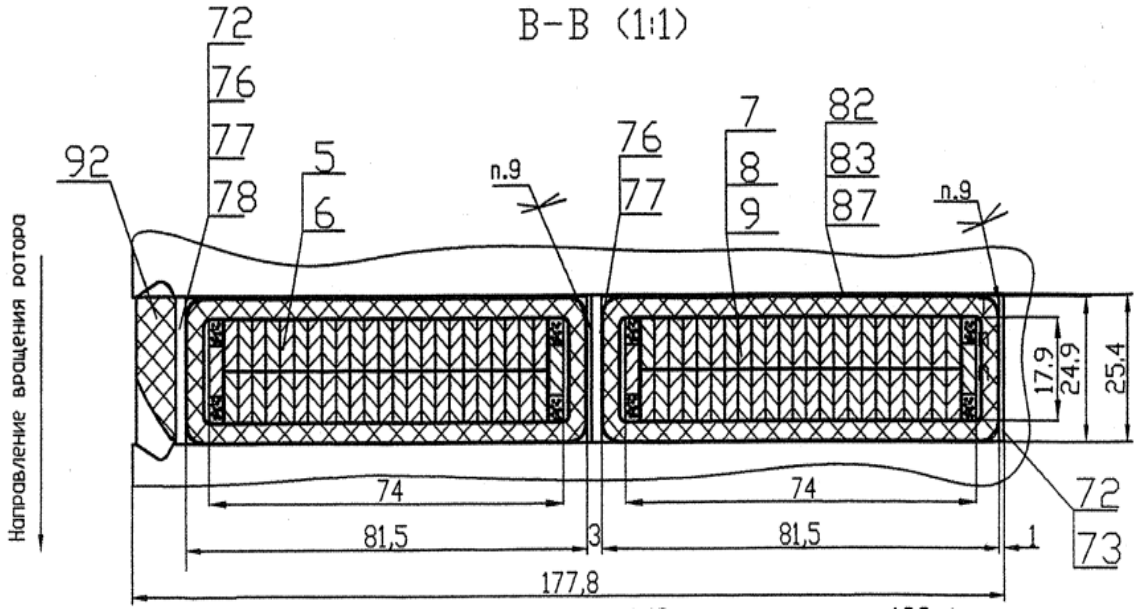
3) CHARACTERISTICS OF REVITALIZED STATOR WINDING

Stator winding design and type of wedging in HPP „Djerdap 1“

3) CHARACTERISTICS OF REVITALIZED STATOR WINDING

Stator winding design and type of wedging

A schematic representation of the applied winding wedging system is given in the following figure:



Slot content:

5, 6 – top bar; 7, 8, 9 – botom bar;
72 – elastic polyurethane strip;
73, 76, 77, 78 – fiberglass strips;
82, 83 – semiconductive side ripple fillers;
87 – semiconductive flat side fillers;
92 – slot wedge

4) CRITERIA FOR STATOR WINDING WEDGE-TIGHTNESS CONTROL

Defining the criteria for replacing the loose slot wedges

4) CRITERIA FOR STATOR WINDING WEDGE-TIGHTNESS CONTROL

Defining the criteria for replacing the loose slot wedges- IN GENERAL

Criteria for classifying whether a slot wedge is loose or not, as well as at what percentage or quantity of slot wedges in one slot there is a need to re-wedge the complete slot, are not determined by appropriate standards.

The recommendations of the generator manufacturer, as well as the world experience in operation and maintenance, direct the generator users to independently adopt and determine the appropriate criteria for the needs of quality maintenance of the stator winding, i.e., its wedge-tightness.

4) CRITERIA FOR STATOR WINDING WEDGE-TIGHTNESS CONTROL

Defining the criteria for replacing the loose slot wedges – EPRI recommendation

Criteria for testing winding wedge-tightness based on EPRI recommendations:

- The existence of a damaged wedge or lack of wedge is unacceptable,
- Loose wedges in the amount of more than 20% in a single slot or badly wedged more than 10% of slots is unacceptable.

4) CRITERIA FOR STATOR WINDING WEDGE-TIGHTNESS CONTROL

Defining the criteria for replacing the loose slot wedges - EXAMPLES

Based on the available information from relevant professional papers, as well as the recommendations of certain manufacturers, the criteria for determining when it is necessary to RE-WEDGE certain SLOTS can be defined.

4) CRITERIA FOR STATOR WINDING WEDGE-TIGHTNESS CONTROL

Defining the criteria for replacing the loose slot wedges

Criteria 1

Re-wedge the slot if:

- less than 75% of the wedges are well wedged,
- three or more adjacent wedges are loose,
- the end wedges are loose.

4) CRITERIA FOR STATOR WINDING WEDGE-TIGHTNESS CONTROL

Defining the criteria for replacing the loose slot wedges

Criteria 2

- if the first 250 mm of the slot wedges at each end of the slot are well wedged and any other 25% of the wedges in the same slot are well wedged then it is not necessary to re-wedge that slot,
- only in the case of extremely badly wedged wedges in the middle of the slot, which is manifested by large vibrations of the same and the appearance of visible damage to the wedge material, the slot must be re-wedged.

4) CRITERIA FOR STATOR WINDING WEDGE-TIGHTNESS CONTROL

Defining the criteria for replacing the loose slot wedges

Criteria 3

- the end wedges must be well wedged,
- the length of the free part of the stator bar in the slot should not exceed 400 mm.

4) CRITERIA FOR STATOR WINDING WEDGE-TIGHTNESS CONTROL

Defining the criteria for replacing the loose slot wedges – HPP „Djerdap 1“

In HPP „Djerdap 1", based on the recommendations of the generator manufacturer, as well as previous experience from expoitation, the following criteria were adopted to assess the state of stator winding wedge-tightness, i.e., criteria for determining when **it is necessary to re-wedge individual slots**:

- it is necessary to re-wedge all the slots where there are 6 or more bad wedges (16 wedges per slot),
- in some cases, it is allowed to have 5 loose wedges in the slot, but if they are arranged in a "chess" arrangement,
- if the last three upper and lower wedges are well wedged - do not re-wedge the slot,
- if the previous condition (3) can be met by re-wedging the upper-end or lower-end wedges, also do not re-wedge the complete slot,
- the upper-end and lower-end wedges, if they are "bad", must be re-wedged,
- in the case of extremely badly wedged wedges in the middle of the slot, which is manifested by the appearance of visible damage to the wedge material, the slot must be re-wedged.

4) CRITERIA FOR STATOR WINDING WEDGE-TIGHTNESS CONTROL

Comparative analysis of presented criterias for replacement of slot wedges

At HPP „Djerdap 1", one slot has 16 slot wedges of individual length 106 mm.

Re-wedging is necessary if:

1. *EPRI – more then 20% of wedges in single slot are loose (**more then 3 loose wedges in single slot**).*
2. *Criteria 1 - Less then 75% slot wedges are good wedged (**more then 4 badly wedged slot wedges**), three or more adjacent wedges are loose, the end wedges are loose.*
3. *Criteria 2 – end up 250 mm poorly wedged (**end up 3 badly wedged slot wedges**) and more then 75% the remaining wedges badly wedged (**more then 8 badly wedged remaining wedges**).*
4. *Criteria 3 – end up wedges are not good wedged and/or there are **4 in a row bedly wedged slot wedges**.*

A comparative analysis of the previous criteria, on the example of generators in HPP "Djerdap 1", shows that some criteria have stricter requirements (EPRI), approximately the same requirements (Criteria 1, Criteria 3) and much lower requirements (Criteria 2).

4) CRITERIA FOR STATOR WINDING WEDGE-TIGHTNESS CONTROL

Defining the criteria for replacing the loose slot wedges

Volume of re-wedging od stator windings on revitalized generators

UNIT (start of exploitation)	A6 (06. 2011.)	A4 (10. 2013.)	A5 (03.2015.)	A1 (10.2017.)	A2 (11.2019.)
(year of overhaul) number of completely re-wedged slots	(2013.) - 97 -	(2018.) - 32 -	(2020.) - 11 -	(2020.) - 101 -	(2021.) - ~ 60 -*
	(2016.) - 10 -	(2020.) - 18 -	(2021.) - 3 -		
	(2018.) - 28 -				
	(2019.) - 72 -				
	(2020.) - 45 -				

** - estimation of the number of re-wedged slots in the overhaul of generator A2 (July 2021.)*

4) CRITERIA FOR STATOR WINDING WEDGE-TIGHTNESS CONTROL

Results and chronology of performed stator winding wedge-tightness controls

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Results and chronology of performed stator winding wedge-tightness controls

The recommended periods for controlling the stator windings wedge-tightness are defined to be performed in each major overhaul or every 5 years (whichever comes first).

4) CRITERIA FOR STATOR WINDING WEDGE-TIGHTNESS CONTROL

Results and chronology of performed stator winding wedge-tightness controls

In the previous exploitation period of the revitalized generators at HPP „Djerdap 1", appropriate controls of the winding wedge-tightness were done more often.

UNIT (start of exploitation)	A6 (06. 2011.)	A4 (10. 2013.)	A5 (03.2015.)	A1 (10.2017.)	A2 (11.2019.)
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	(2020.) - 45 -				

4) CRITERIA FOR STATOR WINDING WEDGE-TIGHTNESS CONTROL

Results and chronology of performed stator winding wedge-tightness controls

By analyzing the obtained results from the appropriate controls and monitoring the trend, the terms and scope of the necessary work on re-wedging of each individual stator windings were determined.

4) CRITERIA FOR STATOR WINDING WEDGE-TIGHTNESS CONTROL

Results and chronology of performed stator winding wedge-tightness controls

The general conclusion is that in the initial period of operation (in the first 2-3 years of operation) there are major changes in the state of winding wedges, when an average of approximately 15-20% of poorly wedged wedges are stated.

The trend of winding wedge-tightness state shows that after 5 years of operation (with regular annual re-wedging of "bad" end wedges) the stator winding has an average of 10% of badly wedged wedges.

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4) CRITERIA FOR STATOR WINDING WEDGE-TIGHTNESS CONTROL

Results and chronology of performed stator winding wedge-tightness controls

The control of the stator winding wedge tightness of individual generators, in the previous exploitation period, was performed equally by the manual method ("hammering„) and with the electronic device SWA Iris Power.

4) CRITERIA FOR STATOR WINDING WEDGE-TIGHTNESS CONTROL

Results and chronology of performed stator winding wedge-tightness controls

The figures below shows examples of the results of the control of the stator winding wedge-tightness of the generator No. 6 by the manual method (Figure No. 1) and the electronic device (Figure No. 2).

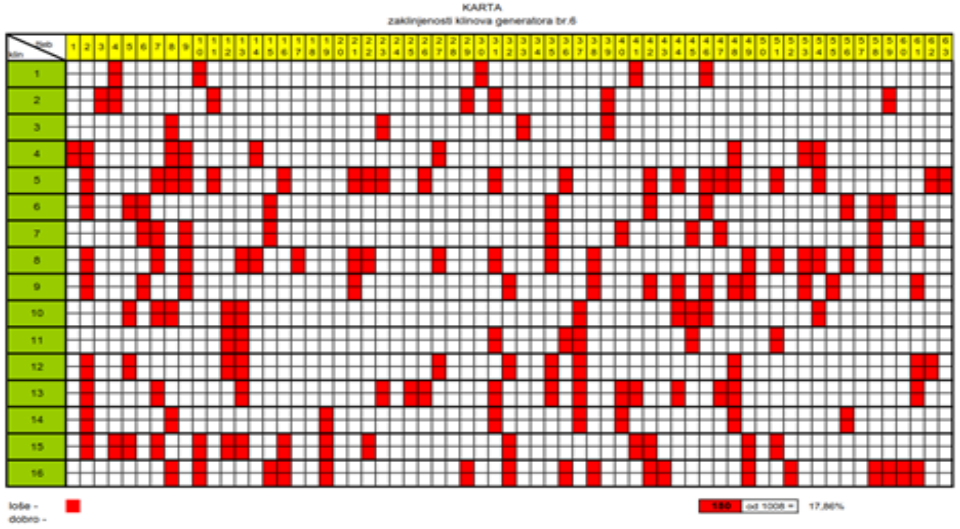


Figure No.1

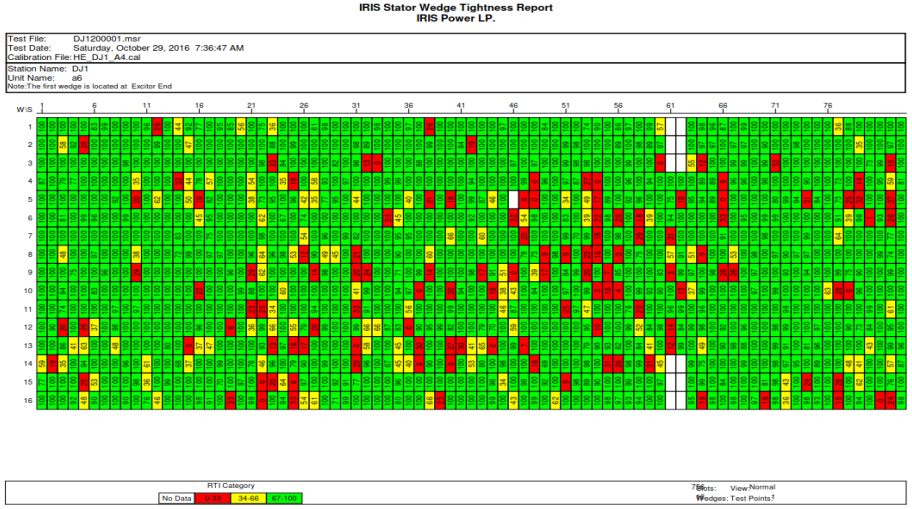


Figure No.2

5) CONCLUSION

Controlling the state of the stator winding wedge-tightness and repairing the observed deviations is an important operation in the maintenance of the generator.

A well-tightened stator winding can last two to three times longer than a poorly wedged winding.

In practice, it is known that the frequency of failures due to the weakening of the wedgening of the stator bars is frequent, and the cost of failure is high.

Almost a third of failures of rotating electrical machines are caused by a fault in the stator insulation.

5) CONCLUSION

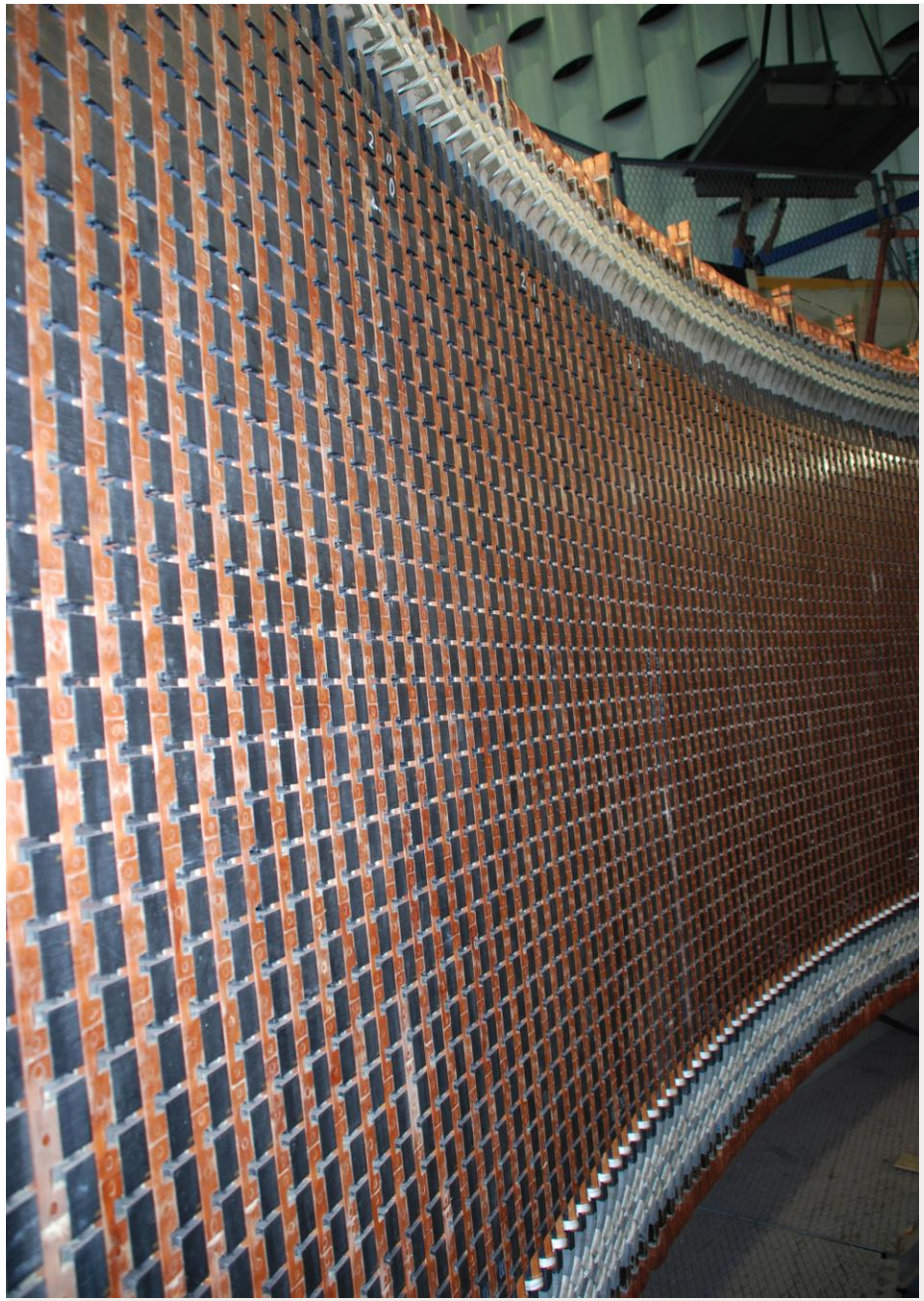
Based on the controls performed so far on the stator windings and wedging works, it can be stated that, after 2 to 3 years from the commissioning of the unit, it is necessary to perform a slightly larger scope of re-wedging.

5) CONCLUSION

The scope and period of wedge-tightness control, as well as the decision on the time and size of the required stator winding re-wedging directly depend on the adopted criteria for assessing the state of wedge-tightness in each individual power plant, and the adopted criteria are usually defined by the generator manufacturer's recommendations, and sometimes by the experienced power plant staff engaged in the maintenance of the generator.

5) CONCLUSION

In HPP „Djerdap 1", the adopted criteria for assessing the state of wedge-tightness were based on the recommendations of the generator manufacturer and the existing long-term practice of the power plant staff.



THANKS FOR YOUR ATTENTION

Presentation for IRMC 2022