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NAPRAWA NA OBIEKCIE POŁĄCZENIA MIĘDZYBIEGUNOWEGO WIRNIKÓW TURBOGENERATORÓW

TURBOGENERATOR FIELD POLE-TO-POLE CONNECTOR IN-SITU REPAIR

Streszczenie: W artykule przedstawiono nowatorską metodę naprawy połączeń międzybiegunowych wirników dużych turbogeneratorów o mocy czynnej od 150 do 490 MW, chłodzonych powietrzem bądz wodorem. Połączenie międzybiegunowe to część uzwojenia wirnika w kształcie litery omega, która łączy ostatnią cewkę bieguna 1 z ostatnią cewką bieguna 2. Jest ono przylutowane do zwoju położonego najbardziej wewnętrznie promieniowo i stycznie, po przeciwnapędowej stronie wirnika. W każdym dwubiegunowym wirniku turbogeneratora zainstalowane są dwa połączenia międzybiegunowe, które są mechanicznie zrównoważone. Ta konfiguracja zapewnia z elektrycznego punktu widzenia 100% redundancję, tj. jedno uszkodzone złącze biegun-biegun nie ogranicza możliwości wytwórczych turbogeneratora.

Abstract: In this article an innovative repair method of the rotor pole-to-pole connectors large turbogenerators with active power from 150 till 490MW, both air and hydrogen cooled, is presented. The pole-to-pole connection is an omega-shaped part of the rotor winding, which connects pole coil 1 with pole coil 2. It is brazed to the most radially inner winding turn of the tangentially outer coil on the Non-Drive End (NDE) of the rotor. There are two pole-to-pole connectors installed in every 2-pole turbogenerator rotor to have a mechanically balanced configuration. This configuration represents from electrical point of view 100% redundancy, i.e one failing pole-to-pole connector is not limiting the operational performance of the turbogenerator.

Słowa kluczowe: *turbogeneratory, wirnik, polaczenie miedzybiegunowe, naprawa na obiekcie*
Keywords: *turbogenerators, rotor, pole-to-pole winding connections, repair with rotor in-situ*

1. Introduction

The requirements for turbogenerator are focused on high reliability, availability and maintainability as well as on high efficiency and high flexibility in order to guarantee low operational & maintenance costs [1]. Furthermore, the market is increasingly demanding more friendly service products with high performance and low cost. Many of the service & repair products should be applicable directly at customer site without need for component shipment to OEM (Original Equipment Manufacturer) premises.

Over the last years, indications have been found on some pole to pole connections of air and hydrogen cooled turbogenerator rotors, both 50Hz and 60Hz. The indications are originating from one of the corners on the T-shaped rotor jumper (Figure 1, Figure 2). Those indications could lead to unit shut down and field windings issues and/ or retaining rings issues together with copper contamination of turbogenerator components. The root cause analysis indicates that low cycle fatigue during start/ stop cycles is the primary root cause mechanism [2].

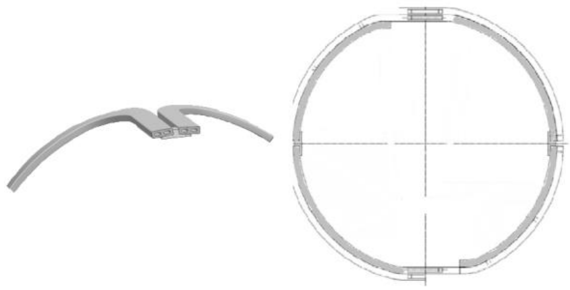

Fig. 1. Original rotor pole-to-pole connection: T jumper (in the middle) and wishbones

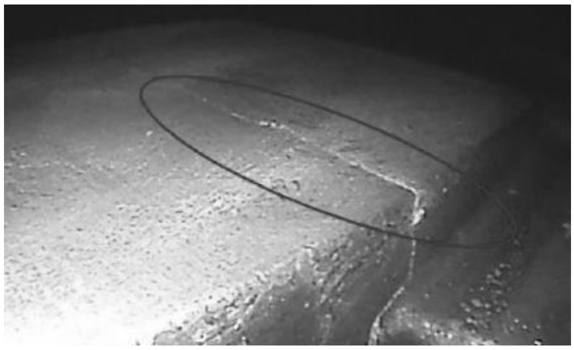

Fig. 2. Exemplary finding in the pole to pole connection during planned inspections

A mechanical opening of both pole-to-pole connections would lead to an open circuit on the rotor winding or a rotor ground fault and subsequent forced outage. In total more than 20 turbogenerators have been found with indications so far; in one case unit experienced a forced outage (production lost).
The first attempt to repair the affected component required a rotor removal together with the retaining ring on the NDE site [2]. This repair could be done on site or in OEM workshops. It considered unbrazing of the original connections and brazing a new one in place of original one (Figure 3). After assembly no balancing is necessary. This is the so-called classic repair approach.

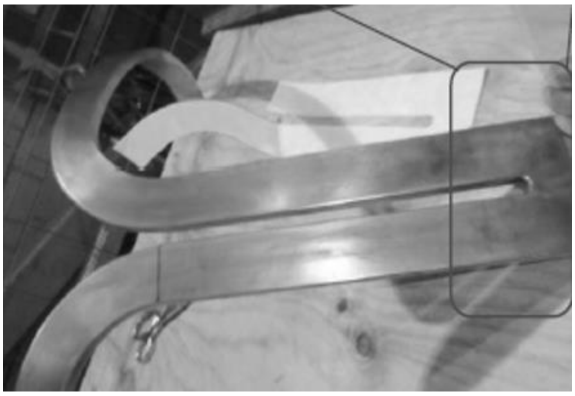

Fig. 3. Upgrade solution (classic repair)

The new repair method proposed in this article allows for a restoring activity with rotor in-situ without retaining ring removal, directly at customer site. Overall repair schedule, including open and close activities, takes less than a week. The classic repair approach requires several weeks total overhaul, including rotor removal and disassembly of rotor components (fan hub, retaining rings, insulations etc.). The proposed repair method with rotor in-situ was fully validated with the help of FEM (Finite Element Method) models and in OEM laboratories on a fully scaled mock-up. The first implementation has been successfully executed on a hydrogen cooled unit back 2021. Till today 4 units have been successfully repaired with this method. The technical assumptions and the proper quality of the upgraded connection have been achieved. All power plants where the repair has been implemented operate with full capacity with positive feedback.

2. New Connection Configuration

After the customer communication about associated risk and OEM recommendations was issued in 2019 [2], a lot of feedback has been received about the possibility to do a rotor connection repair while the rotor remains in the turbogenerator. All feedback was analyzed and studied. Based on this, engineering initiated a dedicated NPI (New Product Introduction) project. The goal of the project was to develop a new rotor connection configuration and associated tooling, and processes, increasing the turbogenerator reliability and availability, especially for unit operation in cycling mode (e.g. few start/ stop operation per day), reducing overall outage costs.
Taking into account the above criteria, engineering has developed a solution which does not require unbrazing the original rotor connection. This approach is quite critical as any heat cycle of the rotor might impact the rotor insulation integrity and copper coils properties. Figure 4 represents the proposed upgraded configuration. It consists of three parts: the main connector (jumper) which is brazed to the two wishbone copper connections. The new pole-to-pole connector as a one piece will be brazed only in two points to the existing rotor winding to bypassing the original pole-to-pole connections. No further braze or supports are required, as during operation the centrifugal force will ensure the right radial support. Moreover, adding additional braze points could reduce the flexibility of the repair solution, which might lead to an unplanned outage.

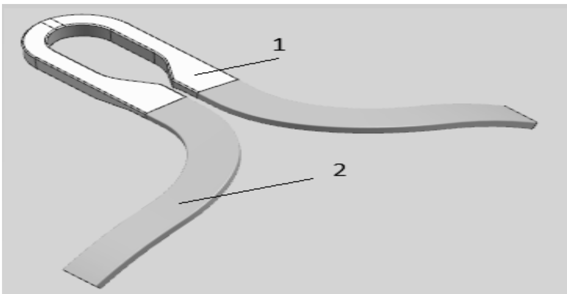

Fig 4. Overview on new rotor connection (3D model) (1) jumper, (2) wishbone arm

3. Validation of Solution

The validation of new connector has been done in three (3) steps.

3.1. FEM (Finite Element Method) Calculations

Since additional component & masses have been added to the rotor, the stresses on the copper turns have been evaluated. The following load cases have been calculated:

- Rated speed
- 110% and 120% rated speed

The results presented no stress increases to existing rotor components.

The next step was to build 2D and 3D FEM models of the new pole-to-pole connector. Different sizes and materials were studied to identify suitable configuration fitting the repair solution purpose. The following load cases were calculated:

- Standstill
- Rated speed
- 110% and 120% rated speed

The stresses in the connection, as well as in the brazing areas were evaluated. Stress distribution in the new connection is presented in Figure 5.

Based on results, engineering could conclude that all requirements (stresses, static loads, cycling mode) even in the most critical areas fulfill engineering qualifications.

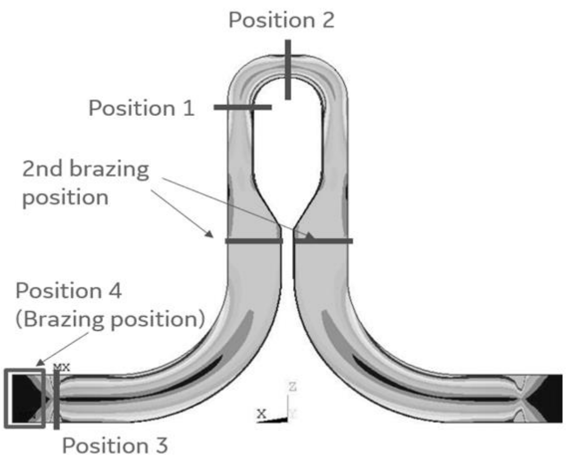

Fig. 5. Stress overview within new connector

3.2 Verification of FEM Model

No physical verification testing on the new connector was required as the original connection with only two braze points was already tested and presented high resistance to the cyclic operation, i.e. after >10^5 thermal cycles no indications were detected.

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3.4. Mockup Development and Testing

To investigate the possibility of the repair with rotor in-situ, the OEM engineered and built a full scaled rotor mockup. It consists of a rotor body, retaining ring, retaining ring end plate, copper coils, fan hub (fan blades are removed prior repair operation, therefore no need to model them), pole-to-pole connection, all necessary insulation, and clearances. Figure 6 shows the 3D model and the mockup itself.

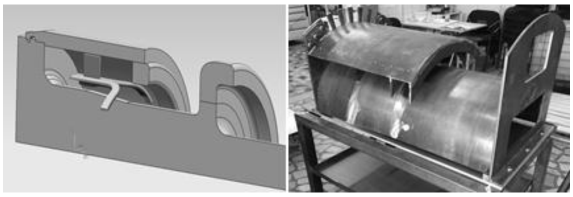

Fig. 6. Model and mockup of the rotor

This mockup allowed our repair experts to test different tools and processes until full success have been achieved. There were two main challenges faced during repair development: limited access under the retaining ring was the first one. The repair work must be done inside a turbogenerator (confined space), operator must reach over the fan hub and the original connection located under retaining ring and with limited visibility perform the new brazing. The second main challenge was not to overheat interturn rotor coils insulation as well as retaining ring insulation. Damage to any of those components would lead to either turn to turn shorts or rotor ground fault. Any of these events would be detrimental for turbogenerator reliability & availability. All brazing operations were done using induction heating devices, using a specialized induction head developed for this repair purpose (Figure 7). After several trials, engineers were able to develop coil splitting tools, new pole-to-pole support tools and a brazing head. Finally, a proper pulsating braze process has proposed and validated. The 1st step of the new in-situ repair process addresses the inspection of existing connections and proper components cleaning. To reduce the risk of damaging the rotor connection or rotor winding during the brazing process, it is recommended to perform test brazing outside turbogenerator on developed qualification platform (Figure 7).

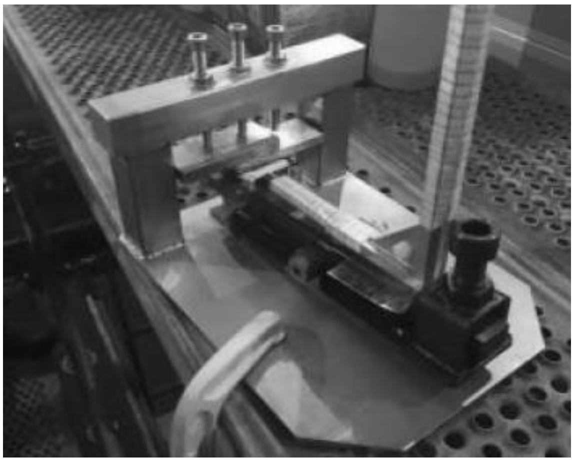

Fig. 7. Brazing inductor on qualification platform

As different brazing machines can be used, the test helps to finally determine the required ratio of power and pulsing time. Once done, all susceptible rotor components are covered with clean fire-resistant welding blankets. The winders take the new pole-to-pole connector inside turbogenerator, position it under retaining ring and accurately mark both ends (footprint mapping). With help of another tool, the rotor coils above the brazing positions are split. Mica sheets, acting as heat barriers, are inserted into those gaps to protect interturn insulations and adjacent. Next, the new pole-to-pole connector is inserted between positioning clamp and rotor winding and finally pressed against the winding.

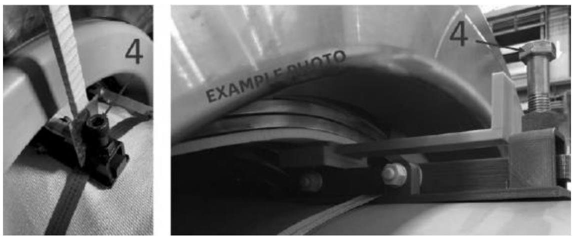

Fig 8. Clamping device (example)

All repair steps must fulfill OEM engineering qualification criteria. The final checks are done with help of the brazing head clamping device (Figure 8).
Once all checks are confirmed, the winders start the brazing process. The smoke extractor is always switched on during the entire operation. Once brazing is executed, winders wait until components cools down, release and remove the clamping device together with inductor. Next, winders move the tooling to perform 2^{nd} braze on the neighboring wishbone. At the end, winders check all braze points, remove the previously inserted components and tools, and clean all the components when necessary. When the 1^{st} connector is fully repaired, the repair team moves to perform 2^{nd} pole-to-pole connector brazing. In total four new brazes are done. Finally, all mechanical and electrical checks are done to prove mechanical and electrical integrity of the new components and that whole rotor is suitable for long term operation.
All the described steps, once well-established, became a part of a standard rotor repair procedure. Based on this, several trials have been performed. All braze components have been removed from the mockup and tested in the laboratory. Visual, Ultra Sonic, Microscopic investigation have been done on all braze joins. All braze areas fulfilled engineering acceptance criteria (Figure 9).
All necessary trainings and qualifications are today done with help of the full scaled mockup and developed process.

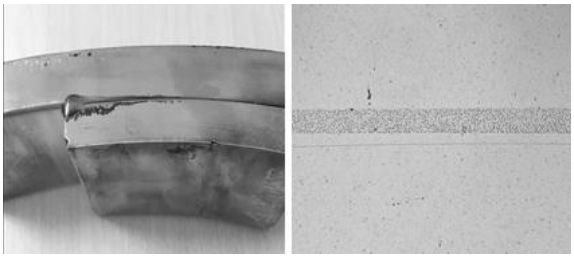

Fig. 9. Visual and Microscopic picture of new braze joints

4. First On-Site Repair Experience

Finally, the OEM was awarded by a customer an order to perform the first on site implementation of the repair method on a large hydrogen cooled turbogenerator. On the unit, an indication had been detected on one of original pole-to-pole connections one-year prior repair.
The most challenging activity on site was to guarantee enough access to the rotor winding. This was achieved by developing a dedicated scaffolding which was installed inside the machine. It provided operators sufficient space, reduced risks, and improve safety during the repair execution. This first implementation was

a complete success, including on-line support and additional consultations of the site crew with repair engineering, which operated from home offices (COVID 19 restriction).

Fig 10. On site implementation (from top): New connector in position, Inductor in place, Final repair effect

The unit was returned to service within less than one week and with full success.

5. Closure notes

This article presents an innovative approach to the rotor repair of large turbogenerators. A systematic engineering approach was used to develop and implement a successful repair method. FEM and life test method verification were executed to choose the new configuration as well as new brazing parameters. This solution provides increased life of the component and significantly reduced the execution time (approx. 4 times) and costs. So far 4 units have been repaired with this approach. More are currently planned. The proper quality of the upgraded connection has been achieved. All powerplants where the repair has been implemented, operate with full capacity with positive feedback.

6. Literature

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