Snowy Technical Standards	
SHL-ELE-157	***Guidelines for Writing Technical Specifications for Hydro Generator Rotor Pole Rewind***

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1. Executive Summary

This standard gives guidelines for setting the requirements when writing a technical specification for rewinding rotor poles on existing rotor pole bodies. Considering the failures of hydro generator rotor pole winding becoming more frequent due to age, this guidelines can assist in making new windings and fit onto the existing pole bodies.

The existing pole windings contain asbestos and hence removing them and re-using the copper is generally not economically viable.

If asbestos is not in the old copper winding insulation the copper can be reused after proper cleaning, visual inspections, NDE tests on brazed joints and measurements are done to find the suitability for re-use.

2. Scope

This standard applies to manufacturing of new rotor pole windings (or repair of old) and inserting onto the old pole body to replace failed salient pole rotor pole winding. This should be used only as a guideline in writing the technical specification and necessary changes should be made to satisfy each project requirements.

3. Definitions

Word and/or picture	*Definition*
SHL	Snowy Hydro Limited
QA	Quality Assurance
ITP	Inspection and Test Plan
IRS	Inspection and record sheet
NDE	Non-Destructive evaluation
IR/PI	Insulation resistance/Polarisation index
JIRA	Snowy Hydro's Change Management process

4. General Requirements

4.1. The contractor shall design and supply the required number of rotor pole windings inclusive of any other components necessary to complete the supply and installation of the rotor windings.

5. Quality Assurance

5.1. The Contractor must provide a documented Quality Assurance plan and Inspection Test Plan (ITP) and get SHL agreement before commencing any work including the procurement of material. For more information regarding ITPs refer to the ‘documentation’ section.

5.2. The Contractor shall explain in their Quality Assurance Plan how they will demonstrate and document their quality assurance system in the following areas:

5.2.1. Dimensional accuracy of winding

5.2.2. Straightness of winding in all directions

5.2.3. Quality of materials e.g. insulation and copper

5.2.4. Management of surface defects in the copper that will compromise the turn and/or ground wall insulation

5.2.5. Integrity of the turn and ground wall insulation system (damage, contamination)

5.2.6. Clean conditions/contamination prevention in the workshop and on site

5.2.7. Verification, monitoring and recording of key manufacturing variables e.g.

- Brazing alignment
- Brazing temperature
- Turn insulation curing pressure
- Turn insulation curing temperature (of insulation) and time

5.2.8. Lifting, moving and handling of windings and materials in the workshop and on site

5.2.9. Packaging and shipping

5.3. Where SHL have requested a hold point, work shall not continue until SHL have given approval. Where a methodology, ITP or other document has been approved by SHL, the Contractor shall follow it. Any deviation from the agreed work must be raised with SHL and approved prior to proceeding with the deviation.

5.4. SHL request that they, be able to attend the manufacturing/repair facility and witness the manufacturing/repair and installation work.

6. Technical Requirements

6.1. Standards

6.1.1. All materials and workmanship used during the carrying out of this work shall comply in all respects with the requirements of the appropriate latest standards and codes issued by Standards Australia or other such standards, as SHL may direct or approve from time to time including:

- AS 1359.60- Rotating Electrical machines- Tests
- IEEE Standard 115- Test Procedures for Synchronous machines
- IEEE Standard 118- Test code for resistance measurements

- AS 2062- Non-destructive testing- Penetrant testing of products and components.
- BS EN 12799:200- Brazing. Non-destructive examination of brazed joints
- BS EN14324:2004- Brazing. Guidance on application of Brazed joints.
- BS EN ISO 18279:2003- Brazing. Imperfections in brazed joints.
- ISO 17672: Brazing. Filler Metals
- IEEE Standard C50.10- Rotating Electrical Machinery - Synchronous Machines
- IEEE Standard C50.12:2005- Salient Pole Synchronous Generators
- AS/NZS 3992:2015- Pressure equipment - Welding and brazing qualification
- AWS B2.2/B2.2M:2016- Specification for brazing procedure and performance qualification
- AWS C3.2M/C2.2:2008- Standard method for evaluating the strength of brazed joints.

6.2. Specifications

6.2.1. The new windings shall be the same shape and dimensions of the old windings (dimensions according to original drawings) unless otherwise agreed to by SHL. If the Contractor or SHL propose any changes, the reasons should be established and followed up with a thorough engineering investigation to prove the proposed concept. This information will be used to approve the change via the SHL JIRA process.

The engineering investigation must ensure the changed dimensions will last for the desired design life (generally considered to be 50 years for pole windings). The investigation must account for all electrical, mechanical, thermal and environmental stresses experienced in service, paying particular attention to the pole connections. The winding rating and ability to install the winding on the old pole body must be covered in the investigation.

> **Note:** due to potential dimension changes in the turn insulation, a change in the coil depth may be unavoidable. In this case, this dimension change can be accounted for by dressing the collar thickness, or getting new collars made to a different thickness. However, the engineering investigation above shall confirm that the reduced collar thickness doesn't compromise the maximum compression pressure or insulating properties of the collars.

6.2.2. Based on the history of the particular unit being rewound, it may be justified to consider the re-design of the pole connections. If this is decided, a thorough engineering investigation to prove the proposed concept. This information will be used to approve the change via the SHL JIRA process. The engineering investigation must ensure the changed dimensions will last for the desired design life (generally considered to be 50 years for pole windings). The investigation must account for all electrical, mechanical, thermal and environmental stresses experienced in service, The investigation is expected to be at least 2D FEA modelling to decide fatigue life and desired ratings.

6.2.3. The new windings must be easily interchanged with the old pole windings and must have a similar weight to avoid excessive balancing efforts later.

6.2.4. All windings must be designed to be installed at any location of the rotor with a universal flag connection design.

6.2.5. The entire winding design must maintain adequate dielectric strength and creepage distances to ensure no in-service failures during operation or high voltage testing according to the agreed standard.

6.2.6. The winding must be made entirely of electrical grade copper with no burrs, surface imperfections or deformities that would risk damage to the turn insulation.

6.2.7. The winding must have pole connectors with silvered mating surfaces. Silver plating must be done with pure silver to 100 microns.

6.2.8. The copper winding must be of strip-on-edge type with rectangular section copper strips either brazed or bended edgewise.

6.2.9. All brazing joints must be away from the highly stressed areas such as pole connections. The new location of the brazed connections shall be suggested by the Contractor based on engineering calculations/modelling and approved by SHL prior to starting. An example is given in Appendix A.

6.2.10. The temperature rise of the new windings shall be the same or lower than the original windings at rated generator MVA.

6.2.11. All insulation must be of Class 155(F) or higher in accordance with ANSI Standard C50.10. All materials used must be of self-extinguishing type upon removal of the source of heating.

6.2.12. The turn insulation shall be of resin rich Nomex ® 410 or similar reviewed by SHL.

6.2.13. Rotor pole winding shall be applied with Class 155 or higher red colour air drying electrical oil resistant varnish.

6.2.14. Collar material to be NEMA G11 laminates. They must each be a single piece. The compressive strength must be agreed between SHL and the Contractor, but generally is around 400MPa.

6.3. Manufacture/Repair

6.3.1. If a decision was made to use the old copper winding after stripping the old insulation, the following items shall be completed:

- The winding shall be stamped/stenciled in an obvious location to identify its original location and weight.
- The removed rotor windings should be heated in an oven to burn off the old insulation. The temperature and time required for burning should be agreed with SHL depending on the turn insulation material. It is generally around 350C for about 12 hours.
- After taking out of the oven the insulation should be stripped off using hand tools and copper cleaned by garnet blasting or similar. Care shall be taken to ensure the cleaning process does not erode the copper or reduce its thickness locally as this may lead to non uniformities in coil height along its length, and hence openings between turns. The cleaned copper winding must be checked

for cleanliness, burrs and imperfections, and brazed joints should be tested for cracks.

- Turns are to be separated only with wooden or glass shims/wedges. Extreme care is to be taken not to over stress the copper as the turns are separated.
- It is suggested that the pole connections be replaced if the winding is to be separated as part of a repair. If so, the same copper shall be used, and any brazed joint near the connector shall be moved away from the high stressed area based on FEA study.. An example is given in Appendix A.

6.3.2. Any brazing shall be completed according to the following requirements:

- A methodology document is prepared that details the consumable materials, tools, clamping arrangement, technique, material temperatures and testing to be used for the joint. SHL shall approve this methodology prior to commencing work.
- Trials of the joint shall be completed by the machine/people completing the work. The trial pieces shall be destructively tested using the Tensile and Bend tests according to AS/NZS 3992 to prove the methodology and workmanship.
- All brazed/soldered connections on the new/repaired windings shall have NDE testing completed to check for indications. No indication will be accepted.
- Photos shall be taken and submitted to SHL in the final report showing the braze process being completed.

6.3.3. The turn insulation must consist of at least two layers and insulation components shape must be such that there is full overlap of insulation joints between the layers.

6.3.4. The turn insulation must be evenly trimmed along the outside edges of the completed coil so that approximately 1 mm is left protruding from the coil surface.

6.3.5. The curing/pressing of the turn insulation shall be completed according to the following requirements:

- The turn insulation shall be consolidated together without any gaps
- The curing pressure should be equal to or more than the forces experienced at runaway speed. If this isn’t possible/practical, a typical pressure of 13.8MPa (2000PSI) can be applied. The pressure used during the works shall be agreed between Contactor and SHL prior to work starting.
- The winding compression device to be used for baking the turn insulation shall apply a uniform pressure on winding. Special care must be taken to prevent the end turns from deforming or slipping due to the forces applied during curing.
- The temperature of the coil must be measured directly and continuously to ensure recommended temperature for the epoxy used and must be cured for

the recommended time by the epoxy manufacturer. Curing time starts when the recommended winding temperature is reached.

- The temperature of the coil shall be monitored and recorded throughout the curing process to confirm the temperature is continuous.
- If the winding compression device uses torqued threaded screws to apply the pressure, then these screws should be re-torqued as the oven heats (typically every 100 degrees).
- An image is shown in Appendix A of an example of a winding in a press ready for curing (M1U03 in 2018).

6.3.6. The lifting technique of the windings on site shall be detailed and agreed to by SHL. Of particular interest is how the windings will be removed from the poles if required.

6.3.7. The installation of the ground wall insulation shall be completed according to the following requirements:

- The following method is generally used in the past and adopted by many manufacturers.
- Pole body insulation must be applied using Nomex creepage strips at the corners of the pole body and solid Epoxy Glass Laminates of Class F with +/- 0.25mm accuracy across the length and width of pole body. The collar inner edge must be snuggly fit to the pole body around the entire circumference and a suitable electrical grade sealant agreed by SHL must be used to seal the joint between the pole body and inner collar edge to prevent the ingress of contaminants. In selecting the sealant, care must be taken to avoid materials which emanates abrasive gas in service to prevent brushgear damage.
- After pole winding is positioned on the pole body and side pack until the clearance between the winding bore/insulation and pole body is < 0.25mm.
- Apply High temperature Class F air curing epoxy applied to coil and outer collar and glued on under pressure

6.4. Delivery to site

6.4.1. Contractor must provide suitable packaging for transportation from place of manufacture and long term storage at Laverton or at agreed location.

6.4.2. Windings to be transported such there is no risk of moisture ingress due to weather, condensation or contamination.

6.5. Installation of winding

6.5.1. If a winding is repaired, it shall be re-installed in its original position on the rotor rim.

6.5.2. Dependant on winding design, a slightly different winding depth may result in the need to dress/pack out out the collars to achieve an appropriate height (relative to the pole shoe that contacts the rim). The contractor shall document their proposal for what the relative height should be, and how they intend to achieve this. This shall be approved by SHL prior to pole installation.

> **Note:** this will only apply for those pole designs where the coil sits hard on the inner collar, which in turn sits hard against the rotor rim. Examples include M1, M2, T1, T2, Guthega. T3 design, for example, does not do this.

6.5.3. If, after pole compression, gaps are identified between the winding and collars, the contractor shall document a proposal for how they intend to rectify the issue. If they intend to fill the gaps, they shall specify the materials (including adhesives) to be used, the technique to be used to retain such packers in place during service (including runaway events), how they will install the packers without damaging the winding, the expected lifetime of the repair, and any suggested maintenance requirements. SHL approval is required prior to beginning such works.

> **Note:** an example of coil gap repair methodology on M1U03 is in the 'references' section.

6.6. Testing and commissioning requirements

6.6.1. The rotor pole windings must be subjected to the following inspections and tests as a minimum prior to being fitted to the rotor rim:

- Dimensional checks at various stages of fabrication, and on the final product to be within the agreed manufacturing tolerances.

  > **Note:** a picture of a non compliant winding on the M1U03 rotor repair in 2018 is shown in Appendix A.

- Straightness of the windings to confirm they will have maximum contact area on the collars. Straightness to be accepted by both Contractor and SHL.

  > **Note:** an example of a non compliant winding on the M1U03 rotor repair in 2018 is shown in Appendix A

- Visual inspection for any defects and damages
- Destructive testing of the trial pieces of any brazed/soldered joints to prove the methodology and workmanship
- NDE tests (magnetic particle or dye-penetrant) on all brazed/soldered joints to confirm they are free of any indications.
- DC resistance test. The values across all pole windings at 20C shall be within 2% of the design value.
- Surge test on turn to turn insulation at 100V across each turn. There must be no breakdown.

- AC 50Hz withstand of ground wall insulation at agreed value based on excitation voltage for 1 minute. There must be no breakdown
- AC Voltage drop test on turn to turn. Voltage across each turn shall not deviate by more than 5% .
- Impedance test. No pass/fail criteria.
- Weight of the ‘as found’ pole, after removal from the rotor rim, and before disassembly of the pole.
- Weight of the completed winding. Each winding weight shall be within 2% of design weight.
- IR/PI of winding. Expected results >100M ohm and 1.5 PI

7. Documentation

7.1. The mill certificates shall be provided by the contractor for all metals used, and must show the chemical and physical properties.

7.2. Data sheets shall be provided by the contractor for the following:

- Brazing consumables
- Turn and ground wall insulation materials (including the actual insulation/resin, tapes, creepage insulation, adhesive paste, collar packing material, resins/ epoxys, dowel material etc)
- Varnishes

7.3. Contractor must submit the final report in a draft form before the shipment of the pole windings from the place of manufacture. SHL will review and give their comments within one calendar week of receiving the report. Contractor must not ship the windings before receiving SHL agreement. Contractor shall submit the final report within two calendar weeks from receiving SHL comments.

7.4. The Final report shall have the following information as a minimum.

7.4.1. Brief overview of the methodology of the manufacture/repair and QA process

7.4.2. Coloured photos of a rotor pole winding at different stages of the manufacturing/repair process and testing including;

- Stacking of copper winding
- Brazing of copper winding and flag joint
- Insulating the copper winding showing inter-turn insulation overlap
- Reinforced winding before commencing curing
- Top and bottom insulating collars
- Pole winding before and after applying red varnish
- Pole inside the wooden box ready for shipment

7.4.3. Any documented methodologies required for SHL approval as discussed in the 'Technical Requirements' section.

7.4.4. The completed ITPs/IRSs for each major stage of the manufacture/repair, transport and installation. ITPs/IRSs shall clearly show results and acceptance criteria. Any specific inspections or testing requested by SHL shall be included in the ITPs

7.4.5. All information that was required to verify the agreed Quality Assurance Plan.

7.4.6. Details of any specific remedial works, or issues that were addressed during the supply/install works. This information will be used for future reference.

7.4.7. Details of turn insulation curing including:

- TIme cures for
- Temperature recording of winding
- Pressure applied, and confidence that the pressure was maintained during the whole curing time.

7.5. The following drawings shall be supplied giving the following information as a minimum;

- Copper conductor details such as dimensions, applicable standards
- Turn insulation details such as dimensions, applicable standards
- Pole winding connection details including the fasteners
- Top and bottom insulating collar details such as dimensions, applicable standards
- Complete pole winding details including three dimensional view, front and side elevation views and a plan view.
- Handling and lifting information

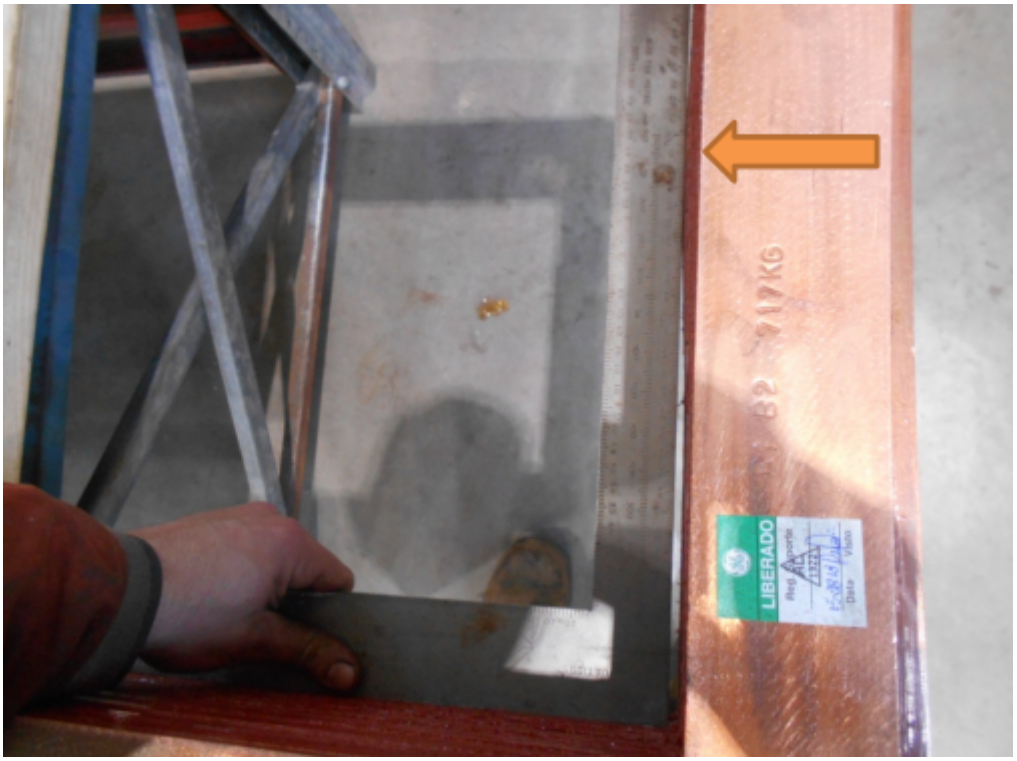
7.5.2. All drawings must be in latest CAD format according to the SHL drawing specification.

8. References

- Snowy O&M manuals (ASEA manuals contain helpful information)
- M1U03 rotor pole connection failure documentation - FO35345. (As of 25/01/2019 repair documentation yet to be put into AOdocs)
- Example Methodology Statement on Winding Gap Filler (M1U03 FO35345)
- Example Methodology Statement on braze repair (M1U03 FO35345)
- Example Methodology Statement on coil re-insulation (M1U03 FO35345)

APPENDIX A

Replaced pole connection showing brazed joints > 400mm from pole connection



Previous dimensional non-conformance on a new winding that prevented the winding fitting onto the pole body

Previous flatness issues on new coils supplied for M1U03 rotor repair in 2018

M1U03 pole 10 clamped and ready for turn insulation curing. Dedicated hydraulic presses are more suitable than this arrangement. Significant engineering was required for this implementation.