Investigation of MQXFB S2 insulation thickness NC

TE-MSC: NC Report H16OC0338A (EDMS 2444386)

F. Lackner, E. Fernandez Mora, F. Wolf, & support from 927 team

TE-MSC-SMT 24/06/2021
Content

- Short history
- Visit at CGP with Rosario
- Sample measurements
- Intermediate conclusions on sample preparation
- 10-stack validation at CERN
- Measurements at CGP
- Conclusions
MQXFB Nb₃Sn cable
Observations NC H160C0338A

- Insulation braiding report: EDMS 2443752.
- NC on MQXFB cable H16OC0334A insulation thickness: EDMS 2425323.
- NC on MQXFB cable H16OC0336A insulation thickness: EDMS 2430116.
- NC on MQXFB cable H16OC0337A insulation thickness: EDMS 2436034.
- Meeting on nonconformities on the braiding insulation thickness https://indico.cern.ch/event/978362/
Visit at CGP, routine of sample preparation

1. Braiding operation MQXFB based on agreed parameters for both production lines (Aut. + Man.).

2. Initial braiding carried out on the full cable length ($L_{cable}$) minus 6 m requested sample length ($L_{sample}$).

3. Machine is stopped after the condition $L_{cable} - L_{sample}$ has been achieved.

4. Subsequent the braiding is cut and secured with tape. Tape overlapping 50% of fiber and 50% on cable.

5. Braiding is retaped on 6 m sample in same way with 50% overlapping.

6. Machine restarts for last 6 m. Remark CGP: Torque and tension force not anymore very high.

7. The sample is cut after finalizing the 6 m braiding.

**Stop of braiding (744 m)**

**Restart braiding (6 m)**

Difference in stabilization time between **automatic** and **manual** controlled machine, potential source for error?
Test campaign at CGP (26 m sample)

Investigate if sample preparation is causing irregular braiding results:

Automatic control (A)
- 20 m braiding
- 6 m braiding

Manual control (M)
- 20 m braiding
- 6 m braiding
The samples (A) automatic control

<table>
<thead>
<tr>
<th>Insulation thickness (μm)</th>
<th>S1</th>
<th>S2</th>
<th>S3</th>
<th>AVE</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>(135*)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S2</td>
<td>150</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S3</td>
<td>150</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AVE</td>
<td>150</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Start/end position not verified

<table>
<thead>
<tr>
<th>Insulation thickness (μm)</th>
<th>S1</th>
<th>S3</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>153</td>
<td></td>
</tr>
<tr>
<td>S3</td>
<td>153</td>
<td></td>
</tr>
</tbody>
</table>

AVE 152
The samples (M) manual control

20 m

Start/end position not verified

6 m

<table>
<thead>
<tr>
<th>Insulation thickness (μm)</th>
<th>S1</th>
<th>S2</th>
<th>S3</th>
<th>AVE</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>151</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S2</td>
<td>149</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S3</td>
<td>148</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AVE</td>
<td>149</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

S1: 146*
S2: 148
S3: 149
AVE: 148

*Note: Start/end position not verified
Summary of the ten stack measurements

Observations

- Braiding thickness type A is larger than type M, however higher precision than M claimed by CGP, recent optimizations carried out, now 500 mm to stabilize on type A – exchange with CGP 23.06.21

- Sample length of 6 m seems sufficient to stabilize braiding image and to determine braiding thickness

- The uncertainty of the 10-stack measurement equipment is neglected for analysis

Result overview

<table>
<thead>
<tr>
<th>Automatic control (A)</th>
<th>Manual control (M)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 m braiding</td>
<td>20 m braiding</td>
</tr>
<tr>
<td>6 m braiding</td>
<td>6 m braiding</td>
</tr>
<tr>
<td>(132 µm)</td>
<td>151 µm</td>
</tr>
<tr>
<td>150 µm</td>
<td>149 µm</td>
</tr>
<tr>
<td>150 µm</td>
<td>148 µm</td>
</tr>
<tr>
<td>150 µm</td>
<td>149 µm</td>
</tr>
<tr>
<td>150 µm</td>
<td>148 µm</td>
</tr>
<tr>
<td>150 µm</td>
<td>148 µm</td>
</tr>
</tbody>
</table>
Intermediate conclusion on sample preparation

- Hypothesis about braiding stabilization on machine A has not been confirmed, nevertheless optimizations have been put in place at CGP. Stable braiding after only 500 mm currently achieved.
- Sample length of 6 m seems sufficient to stabilize braiding image and to determine braiding thickness
- Further investigations regarding S2 thickness determination are ongoing (next slides)

Recommendations by SMT to be agreed with LMF & MSC QC (root cause):

- Restart MQXFB braiding operation at CGP on automatic machine
- Stop applied sample preparation at CGP – reduce uncertainties
- Imposing further efforts to harmonize measurement data
The measurements

**CGP**
- 2 laser measurements
  - **Bare cable** verification to determine major faults, usually offline to avoid unnecessary stops
  - **Insulated cable** measurements on thin edge (top & bottom)
  - Computation of insulation thickness based on laser unit & feedback from CERN 10-stack

**CERN**
- 10-stack measurement (5 MPa)
  - Calibration with Al block
  - 10-stack insulated, cycled 3x
  - 10-stack non-insulated, cycled 3x
    - Observed reduction of thickness/cycle
  - Feedback to CGP to adjust parameters

\[ t_{insl.} = \frac{(h_{ins. \ stack} - h_{bare \ stack})}{20} \]
Requirements for thickness measurement

**Tolerance**

- **Thickness** measurement of the braiding
  - 145 µm ± 5 µm
  - Under compression (5 MPa)

**Requirement on the measurement equipment**

- **Resolution** of the measurement system by 1/10 of the tolerance [1]
- **Accuracy** by 1/3 of the tolerance [1]

** Requirement on the distance measurement system:**

- Resolution: 0.5 µm
- Accuracy: 1.7 µm

---

Measurement strategy

The sample

- Cable 10 stack
- Counter acted keystone angle

The method

1. **Thickness** measurement of the **insulated** stack (3 cycles)
   \[ h_{\text{ins. stack}} \]

2. **Removal** of insulation

3. **Thickness** measurement of the **uninsulated** stack (3 cycles)
   \[ h_{\text{bare stack}} \]

4. **Subtraction** of the measured stack heights and **division** by the number of layers
   \[ t_{\text{insl.}} = \left( h_{\text{ins. stack}} - h_{\text{bare stack}} \right) / 20 \]
The measurement system at CERN

Calibration

Sketch of the test station (left) and photography of the test station (right).

Calibration measurement performed with the Al bar.
The 10 – stack measurement at CERN

Measurements

Measurement of the insulated cable stack.

Measurement of the bare cable stack.

Observations

- Large **STDEV** of the **LVDTs**
- **Decrease** after each cycle of measured height
- **Standard deviation** up to ±20µm

**STDEV of the LVDTs of the insulted and bare stack measurement.**
Potential Sources of uncertainties

Observations (dominated by systematic errors)

- Poor Tolerances at contact and measurement surfaces
- High surface roughness of components
- No central alignment of calibration bar and ten stack
- Calibration bar out of aluminum with thickness deviation of ±25µm

Sketch of the test station with definition of contact interfaces.
Interface planes

Base support interface to cylinder

Hydraulic cylinder

Press tool

Stack groove
Measurement at CGP

\[ f_{avg} = \frac{1}{b-a} \left[ \int_a^b f_{top}(x_t)dx - \int_a^b f_{bottom}(x_b)dx \right] \left( f_{calibration}(CERN) \right) \]

Parameters at CGP are adjusted based on feedback from CERN
CGP indicated mismatch during visit
Summary on the test method

Test station

- The uncertainty by the test station is at least in the order of ±20µm, based on STDEV of LVDT
- The calibration and ten-stack measurements are performed off centered, aim for uniaxial cond.
- Thickness deviation of calibration bar is ±25µm – change towards rectified steel reference bar
- Overall alignment (incl. flatness, parallelism) of other components will be controlled

- SMT aims to reduce STDEV

REMARK on the sample

- The stack height decreases with each load cycle
- Average value of three cycles is evaluated - STDEV shall be considered. Impact height change/cycle
- Reflection: Thickness validation at 5 MPa justified? Further QC on coil does not imply any validation at 5 MPa. How and where this provides a “reference” an input on the design parameters?
Recommendation and Discussion

The test station

- **Reduce** the standard deviation of the LVDTs during the measurement of the reference material
  - Improve the **alignment** of the samples during measurements
  - Check and improve the **contact surfaces** of the tolling as needed

The samples

- Implement camera-based yarn count?
  - Quantify **observations** in braiding density by a **yarn count**
  - **Inspect** and **document** the insulation of the **full length** of the cable **before cutting**
  - Make transparently available all measurements and documentation received by CGP

Aim to further reduce uncertainties, while improving the reliability and coherence of the applied method. Targeting a harmonized understanding of all applied parameters at both, CGP and CERN
Thank you for your attention.