# Fabrication procedure for poloidal coils of COMPASS-Upgrade tokamak

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# Specification of poloidal field coils of COMPASS-Upgrade tokamak

## This document describe manufacture procedure of coils

**Be aware that coil design is not yet finished and that could be some modification in the design.**

| Rev | datum | Popis změny |
|---|---|---|
| 0.1 | 13.8.2019 | 1.version for potencial manufacturer (czech) |
| 1.0 | 7.10.2019 | Document translated and updated to english |
| | | |

# 1 Introduction and scope of the work

The COMPASS [1] tokamak has been in operation in the Institute of Plasma Physics since 2006 and now it is under upgrade – COMPASS-U [2] with the first plasma planned for 2022. The COMPASS-U tokamak will be larger in size: major radius of 0.89 m compared to 0.56 for COMPASS, minor radius of 0.28 m versus 0.18 m. The plasma current will be up to 2 MA compared to 0.4 MA for COMPASS and the magnetic field on the plasma magnetic axis of 5 T compared to less than 2 T for the previous machine.

This document contains the production process for new PF coils of COMPASS-U tokamak (C-U). There is ongoing development on PF coils which could be ready in second half of the year 2020. Manufacture of the coil is planned betwwen years 2020 - 2021. Tokamak assembly is planned for year 2022. The first plasma is expected at the end of 2022.

PF coils magnets system will be made from hollow conductors of the high conductivity oxygen free copper alloy. To decrease coil´s resistivity they will be cooled to temperature close to LN2 (80 K) to be able to bear high currents (50 kA, 2-3 s). Poloidal field coils are divided to central solenoid coils (8 coils with same diameter and same number of turns) and equilibrium field coils (two times four coils with different diameter and number of turns). CS coils have to be wound on TF core (TF core will be delivered by IPP).

Coil´s manufacture will be divided to three phases:

Phase 1 - Manufacture of the prototype coil

Phase 2 - Manufacture of EF colis

Phase 3 - Manufacture of CS coil (wound on TF core)

# 2 APPLICABLE DOCUMENTS

## 2.1 Standards and Codes

Materials and manufacturing/test methods used in fabrication of the equipment covered by this specification shall comply with the latest revision, in effect at date of issuance of this document, of the following currently approved applicable regulations, safety codes, specifications and standards, including applicable technical definitions as acknowledged and accepted in industry.

These Standards and Codes set forth the minimum requirements. The subcontractor is encouraged to recommend superior or more economical designs, processes, or materials.

# 3 APPLICABLE DRAWINGS

## 3.1 IPP Drawings

Coil design drawings provided by IPP will be listed in Annex. All dimensions refer to room temperature (20° C) conditions. Dimensional characteristics including tolerances and insulation builds are given on the drawings. For the G-10 fillers some geometry is only defined in the model using STP files, available upon request.

## 3.2 Subcontractor Drawings

Subcontractor shall prepare manufacturing and tooling drawings as required to complete fabrication. The manufacturing and tooling drawings shall be submitted to IPP for review and approval prior to use.

# 4 RESPONSIBILITIES

## 4.1 IPP

IPP will identify a point of contact, called the Technical Representative (TR) for this procurement. The name of the TR will be identified in the subcontract.

## 4.2 Subcontractor

The Subcontractor will provide the name and contact information for the project manager and technical point of contact for this procurement. The name of the Subcontractor point of contact shall be identified in the subcontract.

# 5 MATERIALS

**note: there is not decided if purchase of the material will be responsibility of  Subcontractor or IPP.**

## 5.1 IPP Supplied Materials

All supplied material shall be inspected upon receipt and any discrepancies, deviations, or other defects shall be noted and communicated to IPP and supplier as soon as possible. Excess materials shall be returned to IPP at the conclusion of the contract unless otherwise agreed by IPP in writing.

### 5.1.1 Conductor

The conductor material will be C10700 oxygen-free silver bearing copper. Nominal dimensions and characteristics are given in Table 1.

Table 1 – Copper Conductor Characteristics

| Coil a quantity | material of the conductor | height [mm] | width [mm] | hole dia. [mm] | radius [mm] | numb. of turns | medium radius [m] | length of conductor [m] |
|---|---|---|---|---|---|---|---|---|
| 8 x CS | C10700 | 22 ± 0,025 | 25 ± 0,025 | 9 | 1 | 30 | 0.417 | 90 |
| 2 x PF1 | C10700 | 16 ± 0,025 | 14 ± 0,025 | 7 | 1 | 56 | 0.576 | 150 |
| 2 x PF2 | C10700 | 16 ± 0,025 | 14 ± 0,025 | 7 | 1 | 32 | 0.661 | 100 |
| 2x PF3 | C10700 | 15 ± 0,025 | 15 ± 0,025 | 7 | 1 | 36 | 0.746 | 208 |
| 2x PF4 | C10700 | 20 ± 0,025 | 17 ± 0,025 | 9 | 1 | 40 | 1.2 | 380 |

*Note: Dimensions in Table 1 are provided for information only. Refer to the drawings listed in Appendix I for complete dimensions including tolerances.

The conductor for each coil will be supplied on spools in continuous length sufficient to wind the coil per the lengths given in Table 1, plus contingency for manufacturing. The conductor will be supplied by IPP/supplier after pre-processing by grit blasting and priming
The primer will be as follows.

Product name: CTD-450
Thickness: 0,76 µm - 2,54 µm
Manufacturer: Composite Technology Development Inc. 1505 Coal Creek Drive Lafayette, Colorado 80026 , (303) 664-0394

Note: During winding with primed conductors, the method used to maintain conductor tension cannot use a friction method that would damage the coating.

### 5.1.2 Mandrel

Subcontractor is responsible for developing removable winding mandrel for production of “bare” coils.

### 5.1.3 Insulation

Turn insulation will consist of glass and kapton supplied in tapes. As-built dimensions (after allowance for compression during winding) are given on the drawings. Materials are as follows:

Glass tape: S2 glass fiber tape

Kapton: DuPont Kapton HN with Momentive 610 (cured silicon),

Note: An acceptable alternate is for the bidder to apply the co-wound tape as separate layers (Glass & Kapton HN without adhesive) using, multiple spool taping machines.

#### 5.1.3.1 Turn insulation

two-half lapped layers of wound glass fiber tape shall be applied with the glass facing the conductor.

Note: We define the tolerance on a half lap layer as half of width of used tape, that is there is a minimum of a half lap layer with the possibility of exceeding the overlap with an second half. Around bends this tolerance applies to the outer diameter where the inner diameter is allowed to exceed the additional 0.3 mm overlap as required by the radius. Excessive overlap should be avoided to ensure that the radial build of each layer (and the coil overall) is maintained.

#### 5.1.3.2 Layer to Layer insulation

Two-half lapped layers of wound glass fiber and kapton tape shall be applied with the glass facing the conductor.

#### 5.1.3.3 Ground insulation

Six half-lapped layers of glass shall be applied using  wider glass tape. The number of layers of ground wrap and or the thickness of the ground wrap can be adjusted with IPP approval if that is necessary to meet the required dimensional buildup as specified in the drawing.

### 5.1.4 Shims and Spacers

IPP will supply G-10 winding shims and spaces as indicated on the IPP drawings. Trimming of these parts as necessary to wind the coil is the responsibility of the subcontractor. Lead blocks and fillers provided by IPP are to be inspected prior to assembly for burrs or sharp edges and de-burred if necessary. The parts shall be cleaned with an appropriate solvent prior to use.

## 5.2 Subcontractor-Supplied Materials

Subcontractor will supply the equipment and materials listed in the following sections. A detailed listing of all materials to be used in the deliverable scope of supply under this specification shall be submitted to IPP for review and approval prior to the start of materials procurement. Tooling that is developed specifically for fabricating the deliverable items of the subcontract shall be the property of IPP and returned to IPP at the conclusion of the contract unless otherwise agreed by IPP in writing.

### 5.2.1 Tooling

All tooling (including the VPI mold) shall be supplied by the subcontractor. The design of tooling used for fabricating the deliverable items of the subcontract shall be reviewed and approved by IPP prior to use.

### 5.2.2 Coil terminal blocks

Machined blocks for coil terminals shall be fabricated from copper bar or plate per IPP supplied drawings. Certified Material Test Reports (section 10.15.1) shall be provided for the materials used..

### 5.2.3 Braze materials

Braze material suitable will be supplied by subcontractor. Brazing will be done at room temperatures but brazing material have to be suitable for cryogenic temperatures.

### 5.2.4 Coil lead and transition fillers

Any required fillers not supplied by IPP shall be supplied by the subcontractor. The insulating lead blocks and coil fillers shall be constructed of G-10. Material Certifications (section 10.15.1) are required. All machining of G-10 must be done without the use of cutting fluids (dry machining). The fillers and lead blocks shall be free of burrs and sharp edges. All G-10 surfaces unless machined shall be sanded to remove any high gloss surface, to promote bonding of the epoxy to the lead blocks. The parts shall be cleaned with an appropriate solvent prior to use.

### 5.2.5 Void materials

All regions within the winding volume not occupied by conductor or ground insulation shall be filled with certified (section 10.15.1) S-2 glass or G-10 fillers to minimize resin rich areas. When using S-2 glass to fill voids, the glass shall be densely applied to avoid resin rich areas. Void areas where there is no glass or G-10 filler shall not exceed 0.08 mm”.

### 5.2.6 Insulating Resin

Insulating resin shall be supplied by subcontractor. The preferred resin is as follows.
Product name: CTD-425
Manufacturer: Composite Technology Development Inc. 1505 Coal Creek Drive
Lafayette, Colorado 80026 , (303) 664-0394
Description: Two-part system with Epoxy (EP) and Cyanate Ester (CE) catalyst in part A and Cyanate Ester (CE) in part B
Subcontractor may propose an alternate VPI resin with properties equivalent to or superior to the following product.

### 5.2.7 Degreasing/cleaning solvents

All conductors, insulation blocks, and VPI mold parts shall be degreased/cleaned using a solvent that is able to dissolve grease, tar, wax, adhesives, oils and other soils, and is residue-free. Solvent selected by subcontractor shall be approved by IPP prior to use. Recommend solvents are acetone and alcohol, however only alcohol is permitted for use on the primed copper.

### 5.2.8 VPI Mold

The subcontractor shall supply the VPI mold. The design of the mold and sealing shall be submitted to IPP for review and approval (refer to section 5.2.1).

### 5.2.9 Mold release

The subcontractor shall propose a mold release agent or use on the surfaces of mold parts that are to be removed after VPI. Mold release material shall be proposed by subcontractor and approved by IPP prior to use.

### 5.2.10 Other materials

All other materials not listed in section 5.1 or above as required to fabricate, test, and ship the deliverable items shall be supplied by the subcontractor. All insulating materials, including general-purpose kapton adhesive tape for joining and tailoring insulation, shall be of the same composition as the IPP-supplied materials listed in 5.1.3 and 5.1.4. Additional insulating materials provided by the subcontractor shall be reviewed by IPP prior to purchase to verify compliance with this specification.

# 6 QUALITY ASSURANCE (QA) AND MANUFACTURING/INSPECTION/TEST (MIT) PLANS

## 6.1 QA plan

The subcontractor shall submit a Quality Assurance (QA) plan describing the specific quality assurance and quality control procedures and practices, including special process training and qualifications, which will be in force to meet the requirements of this specification. The QA plan and any revisions require review and approval by IPP prior to the start of design or manufacturing of the equipment under this specification.

## 6.2 MIT plan

The Subcontractor shall submit a Manufacturing, Inspection and Test (MIT) plan for IPP approval prior to the start of manufacture. The MIT must delineate the sequence of all processes and operations affecting quality, including in-process and final acceptance inspections and tests. The plan shall identify parts; show their integrated flow into end items; identify critical manufacturing operations; and show inspections and the characteristics/dimensions to be inspected. The Plan may include flow chart(s), Process Sheets, Shop Travelers, and inspection sheets, etc. Equipment to be used for all fabrication, inspections and tests shall be specified.

A traveler, whether integral to the MIT Plan or a separate document, shall be used for data entry and operation sign-offs. Relevant data for inspections and tests includes equipment ID

and calibration status, acceptance values, actual values obtained, and pass/fail determination. IPP will designate selected steps as mandatory "witness" points. Subcontractor shall notify IPP a minimum of five (5) working days in advance of these witness points. Revisions or changes to the approved MIT or traveler shall be reviewed and approved by IPP prior to use.

# 7 FABRICATION

## 7.1 Cleanliness/housekeeping

Cleanliness and housekeeping is an essential element to the success of the manufacturing of the PF coils. The following steps shall be taken during the fabrication of the PF Coils to enforce this practice.

### 7.1.1 Clean environment

The final preparation of all insulating materials, the final preparation of the mold, the application of insulation, and the winding of the coil must be performed in a clean, humidity controlled environment that eliminates the risk of debris and dust particles such as metal chips, dirt, etc., from contaminating the coil insulation prior to VPI. If other activities that pose a risk of contamination are conducted in the same room, the work environment shall be enclosed, shall include an intermediate entry area with double doors in which workers can put on protective wear (section 7.1.3), and shall employ a positive pressure fan with a HEPA filter.

### 7.1.2 Step-Off pads

Step-off pads shall be used at the entrances to the work areas to minimize transport of foreign particles and dirt into the work area.

### 7.1.3 Gloves and lab coats

Latex, vinyl, rubber or cotton lint-free gloves, hair covers, and lab coats shall be worn in the work areas during the handling of insulated conductor, insulation, G-10 fillers or other components used in the construction of the PF coils. Lab coats and hair covers worn outside of the clean area, regardless of length of time, shall not be brought back into the clean area.

### 7.1.4 Markers and Pencils

The use of lead pencils is prohibited in the fabrication stations due to electrical tracking concerns. Used brand of markers have to be approved by IPP.

### 7.1.5 Chips and filings

Filing, grinding, or any other operation that generates any kind of electrically conductive chips shall not be allowed in the clean area (section 7.1.1). Clamping and tooling design

must preclude conductive debris from being generated. For example any fixtures or clamps that could possibly abrade and form conductive chips are not allowed. If such an operation is not planned but is needed (e.g. removal of burrs on conductor) the protective measures to prevent contamination of insulation shall be reviewed and approved by IPP in advance of the work.

### 7.1.6 Material Protection

Material controls shall be addressed in the QA Plan ( section 6.1) or MIT Plan (section 6.2). Copper conductor and all insulating materials shall be stored and processed in controlled areas free from metallic dust or other contaminants. All materials shall be protected from contamination from skin oil, etc. (see section 7.1.3). The winding line shall be covered during off-shifts.

## 7.2 Copper receipt, inspection and handling

### 7.2.1 Identification

The IPP-assigned identification number shall be carried through on all documentation and references for traceability during processing.

### 7.2.2 Receipt inspection

Upon arrival of each shipment of conductors the subcontractor shall inspect the shipment for any visible damage to the packaging and/or the conductor. Any discrepancies shall be immediately noted, photographed, documented on a Non-Conformance Report (NCR), and repaired in accordance with the IPP-approved NCR disposition. Repairs should be photographed. This receipt inspection step shall be delineated on the MIT plan.

### 7.2.3 Conductor handling

The conductor shall be fed into the winding line from the original shipping spools, or transferred from the shipment spools to payout spools in such a way that it is not unwinding and rewinding. When the conductor is transferred and when it is fed into the winding line it shall be inspected and any surface defects shall be repaired. Immediately prior to application of the turn insulation, the conductor shall be wiped down with alcohol to remove excess oil, lubricant and grease. Sufficient time shall be allowed for the alcohol to fully evaporate before turn insulation is applied.

## 7.3 Key winding steps

Key steps of the winding sequence are described in this section. Subcontractor shall include all winding steps in the MIT and sub-tier procedures or travelers referenced by the MIT.

### 7.3.1 Winding tooling and initial steps

Ensure that the winding tooling is cleaned, deburred and prepared for the commencement of winding.

Precautions such as clamping and pinning of spacers in place must also be taken to ensure the spacers don't shift during winding. Planning and measurement is required to ensure the proper shim thickness is used on the lead start side of the mandrel to ensure the full complement of turns fits in the prescribed coil space.

### 7.3.2 Turn insulation

The turn insulation shall be applied to the conductor using an automated taping machine so that precise control of dimensions is achieved. Joints at the end of one roll of insulation and the start of another shall be carefully tailored to retain the number of overlapping layers of glass and Kapton and to avoid excess build. See section 5.1.3.1 for turn insulation details

### 7.3.3 Dimensional control

Apply sufficient tension on the conductor feed and a force normal to the conductor to achieve the nominal compression of the insulation while retaining dimensional tolerances on the gap between turns, the radial build, and the axial build of the winding pack, with minimal wandering of the conductor from its nominal spiral position. To avoid over-compression of the insulation, tension beyond the nominal required to seat the conductor and maintain dimensional control is to be avoided. The dimensional build shall be monitored during winding. Any indication that the build of the turns cannot be held to the tolerance on the drawings shall be recorded as a non-conformance and communicated to IPP before continuing with the winding process.

### 7.3.4 Start and finish leads

The insulation shall be tailored to ensure that the number of overlapping layers of glass and Kapton on the turns is retained on the leads.

## 7.4 Handling of coil prior to VPI

Care shall be taken to avoid damage to the insulation in subsequent handling. Damaged or contaminated insulation shall be photographed, documented in a non-conformance report, and replaced with new insulation in accordance with a repair procedure that is reviewed and by IPP before use.

## 7.5 Pre-VPI electrical tests

Before completing the mold (refer to section 5.2.8) the dry coil shall be tested as indicated in the following sections. Ambient temperature and humidity shall be recorded. Test results shall be reviewed and approved by IPP before proceeding with VPI.

### 7.5.1 DC resistance

DC resistance shall be measured and corrected for temperature as follows:

$R_{20}=254.5\times R_{C234.5}+T_C$

Where:
Rc = measured resistance of the conductor (milliohms)
Tc = temperature of coil when resistance measurement is made (Cº)

Measured resistance shall match nominal value (specified later for each coil). The nominal value is based on the average of the conductor min/max cross-sectional areas (as calculated from the allowable tolerances on the conductor) and a nominal length of coil. Adjustment to the nominal resistance to correct for the as-built length of the wound coil is permissible.

### 7.5.2 AC impedance

AC impedance and phase angle shall be measured over the range 0.1 to 100 kHz. Impedance test device and test procedure shall be proposed by the subcontractor and approved by IPP.

### 7.5.3 Insulation resistance

The insulation resistance shall be measured using 500V DC Megger between the coil and a ground plane. A voltage of 500V DC shall be applied for 60 seconds. Insulation resistance shall be recorded at the start and end of the 60 second test period and shall be equal to or greater than 1000 MegOhms)
Test procedure shall be proposed by the subcontractor and approved by IPP.

## 7.6 VPI preparations

### 7.6.1 Mold cleaning

The subcontractor shall thoroughly clean and degrease all surfaces of the mold prior to coil winding activities using the pre-approved solvent (refer to section 5.2.7).

### 7.6.2 Mold leak test

Prior to VPI, the subcontractor shall demonstrate that the VPI mold is capable of achieving the base pressure, leak and out-gassing rates, as specified in the MIT/Traveler, from room temperature up to the planned out-gassing temperature.

## 7.7 VPI and curing

The VPI and curing process shall include the following steps. Parameters to be measured and recorded, along with acceptance criteria, shall be delineated in the MIT.

7.7.1 Leak check and/or rate of rise test

7.7.2 Resin fill volume measurement (recommend expanding a pressurized volume of nitrogen at into the evacuated VPI mold and performing delta PV calculation).

7.7.3 Bakeout/de-gassing of the coil and resin delivery system.

7.7.4 Weighing, mixing and degassing of the resin (to be de-gassed to a pressure less than the vacuum pressure during VPI)

7.7.5 Filling process including fill rates at each inlet and soak times

7.7.6 Milking process (reverse flow under positive pressure) after fill is complete.

7.7.7 Determination of the quantity of resin that was used to impregnate the coil and comparison with expected fill volume based on fill volume measurement.

7.7.8 Oven temperature ramp rates and hold times with each step annotated on the chart and MIT (beginning ramp up, end ramp up, etc.)

Details of the VPI and curing process shall be delineated in the MIT plan which shall include provision for entry of key data and parameters as well as the recording of time and temperature throughout the VPI and curing process.

# 8 ACCEPTANCE TESTS and MEASUREMENTS

## 8.1 Prototypes

All tests performed at the subcontractor's premises shall be delineated on the MIT and all test data shall be recorded the MIT or sub-tier documents referenced by the MIT. IPP will witness tests as indicated on the MIT. If a coil fails any of the tests, IPP shall be immediately notified and a non-conformance report documenting the failure shall be generated and provided to IPP. The subcontractor may elect to perform repairs and additional tests with prior approval by IPP.

Test and inspection results from Phase 1 prototype will be compared to predicted values as a means to judge the adequacy of the fabrication. Care will be taken to ensure that test conditions are consistent across tests on prototype.

**At subcontractor’s premises**

### 8.1.1 Electrical tests

The pre-VPI electrical tests described in section 7.5 shall be repeated except with the insulation resistance test of section 7.5.3 raised to a voltage of 3 kV DC. Measured DC resistance values shall match the pre-VPI values. Measured AC impedance and insulation resistance values shall be consistent with the pre-VPI values, taking into consideration differences arising from the presences of resin in the insulation. No electrical breakdown shall be observed. Ambient temperature and humidity shall be recorded. Test results shall be reviewed and approved by IPP as a prerequisite for shipment.
Test procedures developed for section 7.5 shall address both the pre-VPI and final coil configurations, accounting for differences in test methods that may be required.

### 8.1.2 Dimensional Inspection

Dimensional inspection of the completed coil shall be performed. An inspection report indicating all measured dimensions relative to their nominal shall be generated. Deviations beyond the tolerance shall be reported as a non-conformance.

### 8.1.3 At IPP

#### 8.1.3.1 General quality evaluation

IPP will perform a general inspection of workmanship and dimensions of the delivered prototype. Any defects will be noted, characterized, and recorded.

#### 8.1.3.2 Tests on complete coil

The electrical tests performed at subcontractor’s premises (section 8.1.1) will be repeated.

#### 8.1.3.3 Tests after cutting coil into sections

The prototype coil will be cut into multiple sections. The section ends will be visually examined under magnification. The precision of the conductor locations within the winding pack array will be evaluated. Any voids evident in the turn or ground insulation will be noted including void size and location.
After visual examination the section ends will be encapsulated in an insulating material to increase the dielectric strength between the ends of the cut turns. The following electrical tests will be performed:
- Megger test of turn-to-turn insulation resistance at 0,5 kV DC, performed between adjacent turns
- DC breakdown test of turn-to-turn insulation, performed between adjacent turns
During the DC breakdown tests, if the turn-to-turn insulation is sound, breakdown should occur at the ends of the sections before breakdown through the turn-to-turn insulation, at voltage levels well below the theoretical breakdown voltage of the turn-to-turn insulation.

### 8.1.4 Test & Inspection Matrix

The following table summarizes the tests, measurements and inspections to be performed on the coil. Additional testing and inspections that will be performed at IPP after the coil is accepted are listed as reference. Tests and measurements indicated in the “Accept Criteria” column, must meet the specified values in order for the coil to be considered acceptable to ship.

Test & Inspection Matrix

| Test | ref. | Pre VPI | Post VPI | Accept criteria | location | Notes |
|---|---|---|---|---|---|---|
| Megger 500 DC | 7.5.3 | yes | yes | no | Vendor | |
| Impedance | 7.5.2<br>8.1.1<br>8.1.3.2 | | yes | no | Vendor and IPP | Compare pre and post VPI values |
| Megger 1 kV DC | 8.1.1<br>8.1.3.2 | | yes | yes | Vendor and IPP | Must pass acceptance criteria |
| Terminal DC Resistance | 7.5.1<br>8.1.1<br>8.1.3.2 | yes | yes | no | Vendor and IPP | Compare pre and post VPI values |
| Dimensional Inspection | 8.1.2 | | yes | yes | Vendor and IPP | Conforms to drawing dimensions/tolerances |
| Visual evaluation sectioned coil | 8.1.3.3 | | yes | no | IPP | Evaluate conductor spacing, VPI quality. |
| Hi-Pot of sectioned coil | 8.1.3.3 | | yes | no | IPP | Determination of turn-to-turn voltage standoff |

# 9 SPECIAL PROCESSES

## 9.1 Braze qualification program

The subcontractor shall qualify the braze procedure, equipment and operators prior to use. Braze qualification requirements are as follows.

### 9.1.1 Procedure

The selected coil manufacturer shall develop a braze procedure for performing the torch brazed lead terminals. Procedure shall be reviewed and approved by IPP.

### 9.1.2 Qualification of Procedure/Process

A minimum of three (3) successful braze samples shall be made to qualify the braze process and settings.

### 9.1.3 Qualification of Braze Operator

A minimum of three (3) successful braze samples shall be made by each braze operator to qualify his/her ability to perform successful braze (these may be the same samples used for procedure qualification).

### 9.1.4 Qualification Requirements

A visual inspection of the finished joint shall be made to confirm complete flow of braze material into the joint area. The joint shall be free from all cracks under 10 x magnifications. Qualification shall be documented along with samples provided to IPP for their examination and concurrence before production brazing begins.

# 10 QUALITY ASSURANCE REQUIREMENTS

## 10.1 Inspection, Surveillance, and Audit

The subcontractor shall perform daily inspections and surveillance throughout the manufacturing of the coils as delineated in this specification. Such inspections and surveillances will be documented and available to IPP.
IPP reserves the right to designate selected manufacturing, inspection and/or test operations as mandatory Witness or Hold points. Subcontractor shall provide IPP with notice five working days in advance of such points.

In addition, due to the critical nature of these components, authorized representatives of IPP will be on-site on a regular basis to perform general inspection and surveillance. This IPP on-site representative will serve as a liaison to resolve questions, inform IPP of progress, and will have the authority to halt the fabrication process until issues are resolved.

## 10.2 Subcontractor Quality Assurance Program

The subcontractor shall establish and maintain an effective Quality Assurance Program to assure that the subcontractor’s work meets the required level of quality and is performed in accordance with contractual requirements. Subcontractor's quality assurance function shall be organized to have sufficient authority and independence to identify quality problems, verify conformance of supplied items or services to specified requirements and obtain satisfactory resolution of conflicts involving quality.

IPP will conduct an on-site pre-award assessment of the subcontractors Quality Assurance Program and capabilities of meeting the requirements of this specification.

## 10.3 Submittal of Quality Assurance Program Description

The subcontractor shall submit with the proposal, one (1) copy of its Quality Assurance Program Manual, describing the Subcontractor’s quality capability and general approach to quality assurance. The subcontractor shall also complete and submit at the time of proposal the IPP PQA Supplier Quality Survey, which will be provided separately from this document. The manual and survey shall be subject to IPP's review and acceptance prior to contract award.

## 10.4 Inspection and Test Procedures

Inspections and tests shall be performed in accordance with the MIT plan (section 6.2) with approved (separate or incorporated) procedures referencing criteria for acceptance or rejection. Adequate records shall be maintained and available for IPP reviews.

## 10.5 Document Traceability and Records

The subcontractor shall maintain a system of documentation whereby objective evidence of required operations, inspections, examinations, and tests is systematically compiled, indexed and stored. Such objective evidence will include completed MIT plan (sections 6.2 and 10.7) and relevant data such as materials certifications, material test reports, inspection reports, discrepancy reports, etc. This information shall be complete and legible and validated by responsible personnel and shall be traceable to subject items.

## 10.6 Equipment/Material Identification and Status

Material and equipment identification shall be maintained throughout the program and shall be traceable to the records. Status of acceptability shall be readily discernible through the use of tags, stamps, serial numbers or other positive means.

## 10.7 Manufacturing/Inspection/Test (MIT) Plan

The MIT Plan or referenced traveler shall be used as a signoff/approval document noting that critical manufacturing steps have been completed. Authorized personnel associated with the manufacturing, inspection and test processes shall initial and date the MIT Plan/traveler for this purpose. In addition, the MIT Plan/traveler is to provide witness points as well as references for test results, and measurements.

## 10.8 Witness/Hold Points and Notification of IPP in Advance

IPP reserves the right to designate selected manufacturing, inspection and/or test operations as mandatory Witness or Hold points. Subcontractor shall provide IPP with notice five (5) working days in advance of such points. These default hold points apply, in addition to any others that may be added for this work:

- When welding / brazing qualifications are specified, welding / brazing must not occur until all required welding documentation is submitted and approved by IPP.
- When a Release for Shipment form is specified, shipment must not be made until the shipping release form is signed and returned by IPP.

## 10.9 Non-Conformance & Corrective Actions

Non-conforming items shall be positively identified, and, where possible, segregated to prevent use. The subcontractor shall document each non-conformance. IPP's written approval is required prior to the use of any non-conforming item. The Subcontractor's system shall provide not only for timely resolution of non-conformances but also for analysis of non-conformances to determine root causes and to implement appropriate and effective corrective actions.

## 10.10 Configuration Control

Subcontractor shall completely document the configuration of delivered end items or services, using drawing revisions, specification revisions, unique part numbers, or other suitable means.

## 10.11 Calibration of Test and Measuring Equipment

Inspections and tests shall be performed using properly calibrated measuring and test equipment. Calibration standards shall be traceable to the National Institute for Standards and Technology (NIST) or equivalent. Where such standards do not exist, the basis used for calibration shall be documented. Test and measurement equipment identification numbers and last calibration date shall be recorded on corresponding steps of the MIT plan or procedures referenced by the MIT plan.

## 10.12 Performance and Documentation of Inspections and Tests

Each item to be delivered to IPP shall be inspected and tested by the Subcontractor to verify that they meet IPP's requirements. Results shall be documented and reported to IPP.

## 10.13 IPP Receiving/Inspection

IPP will perform Receiving Inspection on items or services supplied by Subcontractor, using either a sampling plan or 100% inspection. Discrepant items or services may be rejected and returned to Subcontractor or reworked by IPP.

## 10.14 Process History

The subcontractor shall provide a Process History that includes a compilation of documents (digital preferred, in pdf, Microsoft Word, or Microsoft Excel format), detailing the objective evidence of the acceptability of the work performed. The Process History for each coil shall be provided to IPP with the Shipping Release Request. The Process History shall include as a minimum, but not be limited to the following:

### 10.14.1 Material Certifications

Manufacturer’s Certified Material Test Reports (CMTRs) showing relevant chemical, mechanical and electrical properties of materials used, where applicable, shall be submitted to IPP. Certifications for the insulation epoxy, copper material (lead blocks, etc.) braze material, and fillers are required as a minimum. It is recognized that only certificates of grade may be available for materials such as fillers. Certifications shall be provided to IPP when the subcontractor approves the material for use (start of job).

### 10.14.2 Inspection & Test Reports

The completed MIT form, plus reports from all required inspections and tests shall provide the test or inspection parameters, actual results measured, identification and calibration status of the equipment used, and identification of the name the inspector/tester. Reports shall be reviewed by appropriate subcontractor personnel prior to submittal to IPP.

### 10.14.3 Non-conformance Reports

Signed copies of any non-conformance reports generated per section 10.10 shall be included in the process history.

### 10.14.4 Shipping Release

Subcontractor shall not ship (full or partial) without a "Product Quality Certification and Shipping Release" Form signed by IPP’s Representative. Subcontractor shall complete and sign the certification section, deliver the form to IPP Representative, and hold shipment until the form is signed and returned. A copy of the fully executed form shall accompany each full or partial shipment.

## 10.15 Changes to IPP Approved Documents

Revisions or changes by the Subcontractor to documents approved by IPP shall be reviewed and approved by IPP prior to use.

## 10.16 Subcontractor’s Responsibility for Conformance and Flowdown of Requirements to Subtier Suppliers

IPP's review and/or approval of Subcontractor's documents nor IPP's inspection of Subcontractor's items or services shall not relieve the Subcontractor of responsibility for full compliance with requirements of the purchase order/contract. The Subcontractor is responsible for assuring that all requirements and restrictions are imposed on any subtier suppliers.

# 11 SHIPPING STORAGE AND HANDLING

## 11.1 Preparation of cooling passages

Coolant passages will be sealed for storage and subsequent shipment.

## 11.2 Coil identifier

Each coil shall be affixed with a name tag that provides, as a minimum the coil identifier, subcontractor serial number, date the coil was completed, and coil weight in kilograms.

## 11.3 Packing and crating

Subcontractor is responsible for shipment to the IPP site. Each coil shall be prepared for shipment is such a manner as to ensure acceptance by common carrier and to afford protection from normal hazards of transportation.

Packing and shipping details shall be submitted by subcontractor for review and approval by IPP. Each coil shall be wrapped in minimum 0.127 mm thick polyethylene and crated for shipment. The crate shall be wooden and built for handling with slings from overhead cranes and forklifts. The crate shall protect the coil from shock, damage from load shift, and weather conditions, including precipitation. Shock sensors shall be added to the shipping crate. Characteristics of the shock sensors shall be provided with the packing and shipping details. Special care shall be taken to ensure that the lead area is adequately protected. Subcontractor name, customer name, purchase order number, coil identifier, and gross weight shall be marked on the shipping container. Photographs of the packed and crated items shall be submitted to IPP prior to request for shipment.

# 12 DELIVERABLES

## 12.1 Document deliverables

All documents shall be provided in digital (.pdf) format.

| Deliverable item | when required | Specification reference |
|---|---|---|
| QA Plan | Prior to the start of any work specific to the design and manufacturing scope under this specification, and after any revisions. | 6.1 |
| Manufacturing and tooling drawings | Prior to use. | 3.2, 5.2.1 |

| | | |
|---|---|---|
| List of subcontractor-supplied materials | Prior to procurement of materials and whenever list is revised | 5.2 |
| Certified Material Test Reports for coil terminal blocks | Před každou výrobní, inspekční nebo zkušební činností specifickou pro rozsah dodávky této specifikace. | 5.2.2 |
| Certified Material Test Reports for coil lead and transition fillers | | 5.2.4 |
| Design of VPI mold and sealing features | Prior to use | 5.2.8 |
| Procedures identified in the MIT | Prior to any manufacturing, inspection, or test activities specific to the scope of supply of this specification | 6.2 |
| Manufacturing/Inspection/Test (MIT) plan, template | After receipt of order, for IPP approval prior to the start of manufacture | 7.1.5 |
| Protective measures in clean area during operation that could produce chips and filings | prior to work | 7.3.3 |
| Non-conformance reports | Immediately following detection | 7.3.3 |
| Non-conformance on dimensions | Immediately following detection | 7.3.3 |
| Procedure for repair of damaged insulation | Prior to use | 7.4 |
| Impedance test procedure | Prior to use | 7.5.2 |
| Resistance test procedure | Prior to use | 7.5.3 |
| Pre-VPI electrical test results | Immediately following testing | 7.5, 8.1.1 |
| Raze procedure | Prior to use | 9.1.1 |
| Dimensional Inspection of completed coil | Prior to submittal of IPP Shipping Release Form | 8.1.2 |
| Manufacturing/Inspection/Test plan, filled out and signed off, per coil | After completion of all manufacturing, inspection, or test activities specific to the scope of supply of this | 6.2 |

| | | |
|---|---|---|
| | specification | |
| Photographs of packed and crated items | Prior to submittal of PPPL Shipping Release Form | 11.3 |
| | | |

**12.2 Physical deliverables**

| Deliverable item | When Required | Specification reference |
|---|---|---|
| PF coils | After completion and testing and preparation for shipment and approval of PPPL Shipping Release | 5.1 |
| Process history and PPPL Shipping Release Form | Prior to shipment of each coil | 10.15 |