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Conductor Fabrication for ITER Model Coils. Status of the EU Cabling and Jacketing Activities

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The conductors for the ITER magnets are being defined according to the operating requirements of the machine. To demonstrate the technological feasibility of the main features of the magnets, two model coils (central solenoid and toroidal field), with bores in the range 2-3 m, will be manufactured. This is the first significant industrial production of full-size conductor (a total of about 6.5 km for these coils). One cabling and one jacketing line have been assembled in Europe. The former can cable up to 1100 m (6 tons) unit lengths; the latter,which can also handle 1000 m conductor lengths, has been assembled in a shorter version (320 m). A description of the lines is reported, together with the results of the trials performed up to now.

1. INTRODUCTION

In the present ITER EDA design, forced-flow-cooled conductors of the cable-in-conduit type have been proposed for the central solenoid (CS) and toroidal field (TF) coils. The reference conduit material is Incoloy 908 and the strand material Nb_3Sn. The CS and TF model coils have been introduced in the development programme to test conductor and coil performance. Thick-walled round-in-square conductors have to be manufactured for the CS model coil (about 5.5 km), while thin-walled round conductors will be used for the TF model coil (about 1.1 km). One cabling and one jacketing line have been assembled in Europe for this purpose. The first will manufacture a total of 5 km of cable (of CS and TF types) and the latter will jacket the total amount of conductor for the CS model coil.

2. THE EU CABLING LINE AT EM-LMI

The EU cabling line at EM-LMI has been designed to handle cabling for the ITER coils i.e., for a cable length of the order of 1 km and for a weight exceeding 5 tons. The EU will carry out all the cabling for the TF model coil conductor and about 75% (3.8 km) for the CS model coil.

The present ITER design for the model coil conductors is a circular cable around a central tube. Six last-but-one subunits are used. Wrapping of the last-but-one subcable and final cable with a thin high-resistivity metallic foil is required to reduce coupling losses and provide better protection of the outer surface of the cable.

In addition to standard cabling equipment for the initial cabling steps, two separate lines have been set up for cabling and wrapping the last-but-one subcable and final cable. The cabling line for the final cable is schematically shown in Fig 1.

The main components are a large cabling machine, a Turk's head, a caterpillar and a spooling machine. The cabling machine has been designed to hold 6 last-but-one subcable spools and can cable unit lengths up to 1100 m (approx 6 tons in weight). It is equipped with 6

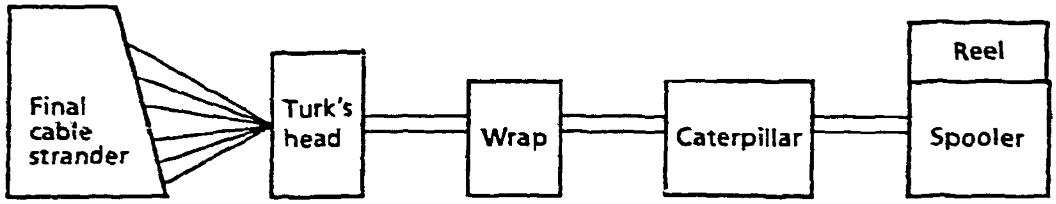

Figure 1. Block diagram of the cabling line

intermediate Turk's heads to allow pre-shaping of the subcables, if required. Back-twist can be adjusted up to full detorsion. A tube or spring positioned in the centre of the conductor may be introduced from behind the cabling machine. The two-cylinder motorised Turk's head is situated next to the cabling machine to compact and shape the cable according to the specifications. The caterpillar of the main line can generate a maximum pulling force of 500 kg. The cable is collected on a modular spool (core diam > 2.4 m) on which up to 1 km of cable is pancake-type wound.

The spool can be directly installed as pay-off spool on the jacketing line.

A preliminary testing of the main line components was done using dummy Cu strands. The line is currently being used for the production of dummy and superconduting cables in preparation to cabling for the model coil conductors. About 150 m of dummy Cu cable and 45 m of superconducting cable will be manufactured within August '94 and delivered to Ansaldo for jacketing test trials.

3. THE EU JACKETING LINE AT ANSALDO

The line (Fig. 2) is based on three main sequential operation steps: prefabrication of the full unit straight length of the oversized jacket by butt-welding sections of tubing; pull-through insertion of the cable into the jacket; compaction of the conductor (jacket + cable) by rolling to its final dimension.

The jacketing line has to be at least as long as the required conductor length, some hundred meters for the model coil conductors. The plant can be divided into three parts: the line and the two end plants. The secondary end plant consists only of the winch used to pull the cable. All the other equipment is located in the main end plant.

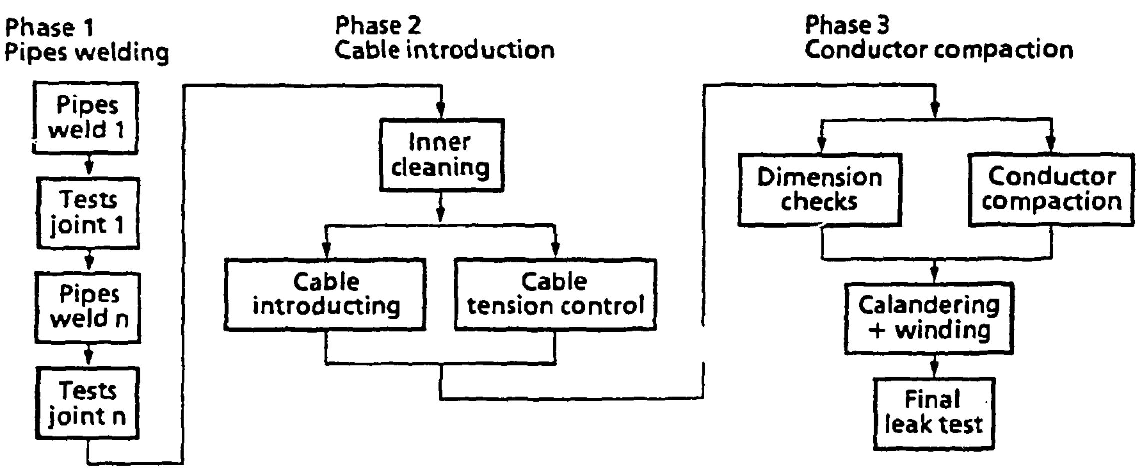

Figure 2. Block diagram of the jacketing line

The line length is presently 320 m, but the end plants have been designed for a length of 1 km. Thus, a feasibility test for a cable insertion of over 1000 m, a typical unit conductor length for ITER magnets, will be possible without changing the main components of the line.

A brief description of the equipment used for welding, insertion and compaction follows.

3.1 Welding

The welding process has been developed for an AISI 316 LN steel jacket. This was the reference jacket material for the ITER CDA design: in the present ITER EDA design, a steel jacket is considered only for the outer poloidal field coils and is a possible candidate for the TF coils. The reference jacket for the model coil conductor, the central solenoid and the high-field layers of the toroidal field coils in the EDA design is Incoloy 908. The jacket lengths and the welding specifications will be delivered by the U.S. ITER Party.

Qualification of the welding process for Incoloy 908 will be carried out at Ansaldo.

The welding equipment is suitable for rectangular, round-in-square and circular jacket sections. The jacket pieces, already prepared (with the proper chamfer), are aligned using the internal profile as reference. An internal tool provides inert gas shielding and back-pressure. The butt welding of the jacket is performed with an automatic orbital machine (400 A, DC).

The welding system is TIG without filler material for the first pass and with filler for the successive passes. The variations in wall thickness are obtained by changing the welding parameters during the process.

There are three principal axes to perform the square profile (X, Y and a rotation around an axis parallel to the jacket axis). Three additional automatic movements are added for better regulation: angle between torch and the welding line, tangential setting of the torch and a radial movement of the torch to keep the distance to the piece constant. The torch movements and the cycle sequence are guided by a numerical control system.

After any single welding, the external and internal surfaces are hand machined. A helium leak test is also performed, taking advantage of the tools used for the back-pressure. The internal tooling is then removed and an optical internal inspection performed using a TV camera. X-ray inspection of this welding is carried out, inside a protection box, using a proper source (300 kV, 6 mA) and three exposures: vertical, horizontal and at 45 °C (corner to corner).

After the tests, the jacket section is pushed forward by 4 pinch-roll stations placed along the 320-m line and a new piece is positioned on the welding machine. The roll line has horizontal rolls with rims (one every 20 cm) and, around the jacket, complete sets of four rolls (one every 12 m) whose distance can be adjusted from 15 mm to 60 mm for both the jacket section dimensions. The roll line is aligned within ± 2.5 mm over a 24-m length.

3.2 Insertion

When a jacket length has been completed, the stainless steel rope of the winch is pushed into the jacket hole and attached to the superconducting cable coming from its reel. The jacket is well fixed and the insertion can start.

The winch, driven by a hydraulic motor, can produce a tension force of 30000 N and its rope is more than 1 km long. It is possible to control it by the velocity of the rope and/or by the tension force.

The cable reel is also able to produce a tension force of 3000 N on a maximum diam of 5.5 m and is controlled like the winch. The inner diameter of the cable pay-off spool is 2.4 m.

The spool has to work in the reverse direction in case the cable sticks in the jacket during insertion. Pancake winding on the pay-off spool has been adopted to avoid damage to the cable in the case of reverse operation. The spool can house up to 333 m of cable.

Three standard spools will be fixed together for the insertion test with 1 km of cable. Just before insertion in the jacket, a free roll calibration unit will reduce the cable to its original dimensions, after which it will be continuously measured. During insertion, a feedback-controlled pre-tension of the cable (2000-3000 N) will be given by the cable reel.

The winch is speed regulated in the range 2-25 m/minute.

All these operations can be performed manually or automatically with the aid of a PLC system. All the data are recorded on a PC and a continuous display of the friction force (given by the winch tension minus the s.c. cable pretension) is shown as a function of the length of cable inserted in the jacket.

Several alarms (software and hard wired) warn of overtension, etc.

About 50 m of dummy Cu cable length, delivered by EM-LMI at the end of August, will be soon used for insertion tests in 316 LN jacket sections.

5. ROLLING

After the insertion, the conductor is pushed against the Turk's head using the pinch rolls, which are then disengaged and the rolling process can start.

The Turk's head has four rolls pivoted on a four-lever switch. Using a power-driven threaded cylinder, the roll can be moved to compress the tube.

During rolling, the rolls (diam 300 mm) are driven by 4 DC motors (3.7 kW each) with a maximum torque of 9000 Nm each. The lateral force on each roll will be of the order of 30 tons. The velocity can be adjusted to a max of 2.87 m/min.

The calibration rolls placed behind the Turk's head consist of two facing plateaux, each with four rolls for correcting the profile and independent manual regulation.

The measurement station comes after the calibration section and transmits the two external dimensions of the final conductor to the data acquisition system.

A pre-calander machine is used to bend the conductor to reach the last power-driven calander placed near the last reel.

The last calandering machine is driven by an orbital-type hydraulic motor and allows hydraulic adjustment of the bending rolls. The bending rolls have a 315-mm-diam and a rolling speed variable from 0 to 5 rpm. A torque limiting device has been installed and the bending roll position is constantly monitored to an accuracy of 0.1 mm.

After calandering, the conductor will be wound on the final reel, which consists of a 6-m-high central column with a jack driven by reduction gear (pitch 12 mm) to change the spool height, a movable frame driven on two sides of the column by idle pins that carry a gear wheel and a motor (10 kW) for the rotation. The cable spool (4000 mm diam) is fixed to the gear wheel and can rotate around a movable frame using the motor. This tooling weighs 12 tons void and will increase to 30 tons with 1000 m of conductor wound on it.

The spool is 4100 mm in diam, and 1235 mm high for 320 m or 3880 mm high for 1 km of conductor.

A PLC system controls the rolling and winding operations: the Turk's head is the master and the calander and the reel the slaves. All the parameters are recorded.

The spool will be removed and put into a vacuum chamber to perform the final helium leak test on the conductor according to the specifications.

Compaction and calandering tests have been carried out on a 316 LN jacket length with a butt-welded joint. After compaction, the vertical side was slightly larger, by 0.2 mm, than the horizontal side. Calandering at a 4-m-diam has produced a key-stoning of 0.4 mm on the vertical side and an inside curvature of the horizontal side of 0.05 mm. The measured free-turn diameter ranged from 4910 mm to 4575 mm. No important deviations in the joint area were detected. It has been noted that the corner radius of the jacket tubes has to be larger than 4 mm to avoid sharp corners after compaction.

The next jacketing stage will concern about 500 m of dummy cable and a few 20-m pieces of superconducting cable, provided by the EU, US and JA.

The conductor jacketing for the CS model coil, for a total of 5.5 km, will then be carried out. The conductor will be used by the US and JA to wind the CS model coil.

4. CONCLUSIONS

The EU cabling line at EM-LMI has started manufacturing full-size dummy Cu cables and short lengths of superconducting cables

The EU jacketing line at Ansaldo is ready to jacket cables in AISI 316 LN tubes and has only to be adapted to use Incoloy jacket sections.

The experience on the long-cable jacketing is expected to provide important information about the maximum length achievable by the pull-through jacketing process.