New Technology Complex for ITER TF and PF Cables and TF Conductors Production

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***Abstract*—Complex through technology, developed in JSC VNIIKP for serial production of ITER PF and TF cables and TF conductors, is described. This technology was developed as a result of performing some R&D programs on selecting cabling parameters, definition of automatic TIG welding of seamless jacket section, elaboration of cable insertion, compaction and winding process. Fitting of the complex with technological equipment and control devices are also described. Two short qualification TF conductor samples (on the base of internal-tin superconducting strands and with strands manufactured by bronze technology) were made and successfully tested on "SULTAN" test facilities. New technologic complex was developed within JSC VNIIKP for realization of this technology. It consists of:**

— Departments for copper and superconducting strands surface cleaning and Cr- and Ni-plating;

— Cabling workshop;

— Jacketing line equipped with full production machinery and test devices.

First dummy conductor with copper strands cable was jacketed and tested this year on modified jacketing line.

***Index Terms*—Cabling, conductor, insertion, jacketing, superconducting strands.**

I. Introduction

JSC "VNIIKP" has been taking part in ITER Program since 1993 year and is responsible for cabling of TF and PF cables, Cr- and Ni-coating of copper and superconducting strands and jacketing TF conductors in RF. Initial experiments and investigations were made in VNIIKP pilot plant and on jacketing line in Lvovskaja. First 860 m conductor was jacketed there. New technological Complex for ITER TF and PF cables and TF conductors jacketing was made at the stage of preparation for serial cables and conductor production by the ITER construction program. It consists of two main departments:

— Workshop for strands surface preparing and Cr- and Ni-coating and 5-stages PF and TF cables manufacture. It located in Podolsk superconducting cables and conductor division JSC "VNIIKP".

— Jacketing line was demounted and transferred to technical territory of High Energy Physics Institute (HEPI) in Protvino. It is fitted with all technological equipment and test devices for manufacturing and control of all cables and conductors parameters in accordance with Procurement Arrangement 1.1.P6A.RF.01.0 requirements.

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II. Cabling

A new technological complex for mass production of superconducting PF- and TF- cables for the ITER project is developed and constructed in the premises of the Podolsk site of JSC "VNIIKP" which comprises a complete production process beginning with initial components to the final product.

As a part of that complex, the chemical and technological site is prepared for production. It includes the processing equipment for chemical and electrochemical pre-treatment of copper wire and superconducting Nb_3-Sn- and Nb-Ti strands [Fig. 1(a)] and their subsequent Cr- and Ni-plating (Figs. 1(b) and 1(c), respectively). The parameters of each production process were obtained on the base of R&D investigations ensure the required quality (thickness of coating 1.5–2.0 mcm, cohesion—no cracks and foliation-, diameter tolerance), and the rate of production within 3–5 km per hour. These installations are equipped with apparatuses for flow control and continuous measurement of length and diameter of wire.

All these processes are based on a soft technology, consume no more than 100 liters of distilled water for a fourteen- hour working day and have no leakages or discharge to a main drain. More than 1000 km of Ni-plated wire 0.73 mm in diameter and 1500 km of Cr-plated wire 0.82 mm in diameter as well as the specimen for qualification test have been produced with the use of the new equipment.

One of the important preparation stages for serial cable production was developing and creating of the production line for continuous formation of central spiral. Special R&D program was prepared and realized. Two main aims of this program were:

— technology of long length spiral production,

— spiral design, excluding the damage of superconducting strands and copper wires in a zone of their contact with a spiral in cable.

As a result the special production line for manufacturing the spiral of infinite length has been created (Fig. 2):

— diameter of spiral from 8 up to 12 mm,

— material—stainless steel strip,

— thickness of strip—1,0 mm.

About 5,000 meters of a spiral (both for the company itself and for the other participants of ITER project IO, EU, US teams) have been produced by means of this device.

The design of PF and TF-cables considers 5-stage cabling of strands:

— $((2\mathrm{SC} + 1\mathrm{Cu}) \times 3 \times 5 \times (5 + \text{the core } 3 \times 4\mathrm{Cu})) \times (6 + \text{spiral})$—TF-cable;

— $3\mathrm{SC} \times 4 \times 4 \times 5 \times (6 + \text{spiral})$—PF-cable.

Fig. 1. The processing equipment for (a) cleaning, (b) chromium, and (c) nickel plating.

Fig. 2. Central spiral.

First stages of the cabling (up to manufacture of a subcable) and the core of a cable do not provide serious difficulties. The technology of their manufacture can be considered completely developed. The cabling machines of different types are used on the various stages of cabling, so:

- — High-speed tubular standing machines for the 1-st and 2-nd stages of the cabling and on both stages of copper core production (for TF-cable);
- — Cabling machines of planetary type—for 3-rd and 4-th stages of cabling.

The cabling machines of planetary type are equipped by the special devices for wrapping of subcables by stainless steel tape in line with their cabling. All planetary machines provide 100 percent back twisting.

The basic and perhaps the most complicated problem in all technological process of manufacture of cables for conductor of magnet system of ITER is the cabling of subcables around of central canal-forming element (spiral) with its subsequent wrapping by a stainless steel tape. For realization of this operation the planetary machine is fitted with specially developed devices to compact a cable and two-coordinate laser measuring instrument to check the finish product diameter. The main difficulties appearing on this cabling stage are connected with extremely strict requirements to a local void fraction of cable space. It must not be more than 30% for the option-2 of TF-cable. Such strict requirements are called by necessity to save cable design and strands coatings, and minimize deformation of strands. Similar difficulties were met by all cabling teams of ITER project. Two compaction device sets are used on the final stage of cabling now. Special duo rolling three-sets compacting devices are used in combination with the system of wire calipers in the first variant (Fig. 3). Roller rotating and compacting calipers are used for the second variant. Both of these variants are successfully tested during the output of pilot and qualifying samples of TF and PF-cables (Fig. 4). The choice of the optimal of them depends on a completion of extra tests.

Then cable is wrapped by the SS tape and measured by two-coordinate laser diameter meter. Two-wheel pulling device (wheels diameter—1.5 m) is located between wrapper and take-up unit. Cable is taken up on a drum with diameter up to 3 m.

TABLE I
TECHNICAL PARAMETERS OF WELDING HEADS

Parameters	Weld head model	
	8 – 2000	9 – 2500
Welded tubes diameter, mm	6,35 – 52	19 – 63,5
Power supply:	Microprocessor controller model 207	
welding process:	GTAW (TIG)	
arc start system:	Injection pulse start	
current pulse rate, pps:	0,05 to 50	
Welding current, A	100 – 150	

III. TF CONDUCTOR JACKETING

Completed and tested cables are transported on jacketing line. Technological process of conductor jacketing on new jacketing line is nearly the same as on previous one [1]–[6]. Technological equipment and control and test devices are located in workshop (hangar) with length 54 m, width 18 m, high 8 m. 800 m rollgang with protective gallery adjoins to hangar [Fig. 5(a)]. Force winch is located at the end of rollgang and operated from hangar.

Two winders (pay-off/take–up units), welding equipment, control zone, belt pull, 4-sets rolling mill are installed in hangar [Fig. 5(b)]. Second rolling mill was made and is in test stage now.

Jacketing of cable includes the following technological operations. The whole length jacket is assembled by automatic butt welding of 10–12 m jacket sections in inert gas (argon). Orbital weld heads (models 8-2000 and 9-2500) with programmable power supply model 207 Arc machines, Inc. are used for fusion TIG (GTAW) welding of jacket sections. Parameters of weld heads and supply are presented in Table I.

Welding process is shown on Fig. 6.

After welding completion each welded joint is transferred to the control zone, where the appearance of every weld both outside and inside of the tube (television system TCKT-30) is checked, as well as radiographic testing (X-ray tube Baltospot GFD165, x-ray films automated processing unit), local leak testing (exhaust pumping post DRY TEL 102SAS, Lay-on camera and helium leak detector ASM 142 under inside helium pressure 3 MPa) are caring out.

Sound welds are transferred on rollgang by means of belt caterpillar. Defective welds shall be cut. Tube sections after edge re-preparation are welded together again.

Welded jacket is pushed to 800 m rollgang. Cable is inserted in full length welded jacket by means of steel rope and force

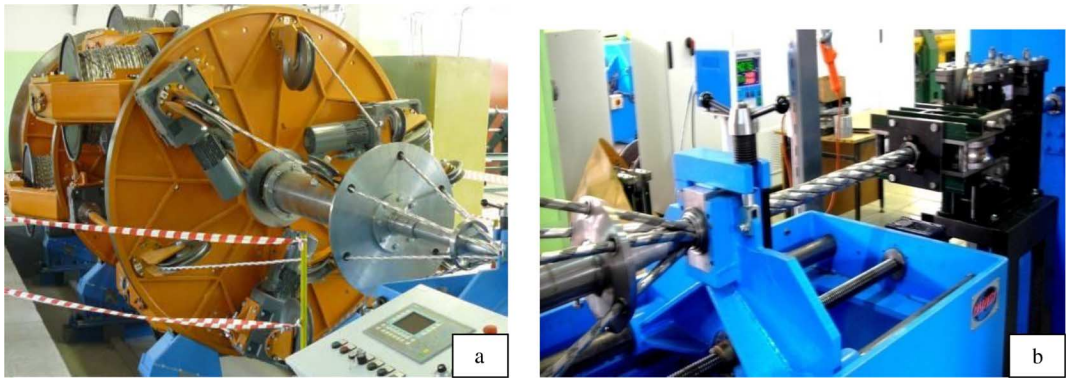

Fig. 3. Part of a cabling complex: (a) planetary strander; (b) cable compaction unit.

Fig. 4. Appearance of a cable after compaction.

Fig. 5. Jacketing line outlook: (a) hangar and protective gallery; (b) inside of hangar.

Fig. 6. Tubes welding process.

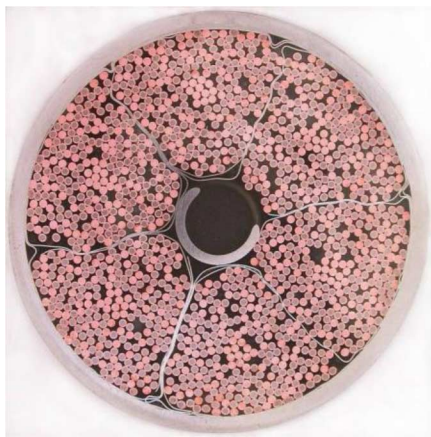

Fig. 7. Cross section of superconducting TF conductor.

winch. Pulling force is controlled during insertion. Reduction of jacket up to required diameter is performed by compaction in four-stage rolling mill. Conduit diameter is reduced to 43.7 mm. Cross section of compacted superconducting TF conductor is shown on Fig. 7.

Two qualification TF conductor samples were made. First is on the base of internal-tin superconducting strands, second—with superconducting strands manufactured by bronze technology. Both types of strands were produced by Bochvar Institute. Samples were successfully tested on "Sultan" test facilities.

Current sharing temperature for samples of "bronze" strands (Fig. 8) is higher that required (5,7 K) and conductor parameters did not degrade after cycling up to 400 cycles.

First 100 m dummy conductor with copper cable was jacketed and tested on new jacketing line for verification of jacketing process (Fig. 9). 120-meter copper dummy cable was used for this purpose. A jacket was welded of SS Õ18Í10Ò tube sections of 6 meter length. 20 welding joints were made. All of them were sound. Conductor was tested by the following methods: outside and inside surface check (visual and with endoscope),

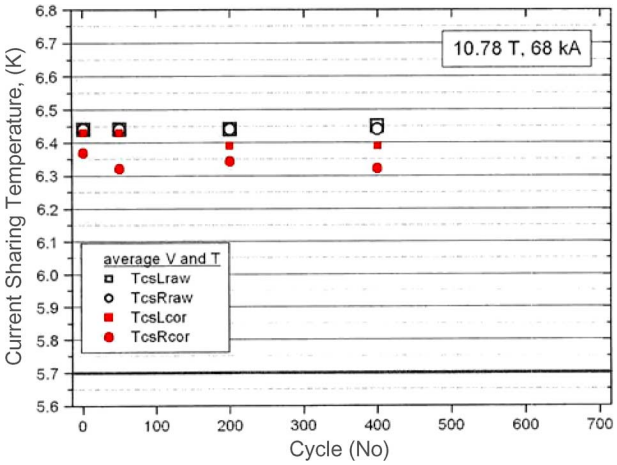

Fig. 8. Current sharing temperature as a function of cycle numbers at 10,78 T, 68 kA for "bronze" strands TF conductor.

Fig. 9. Dummy conductor, 100 m, winded on the drum.

radiographic test, local leak testing with 2 MPa helium pressure inside.

760 m copper dummy cable was made. Qualification of jacketing process using 760 m copper dummy cable is in preparation stage now. Second 760-meter copper dummy cable is in preparation stage too.

The following questions are in a stage of development now:

— manufacture of a winder for completed conductor winding in one-layer solenoid with 4.0 m diameter;

— up-grade of vacuum chamber for total TF conductor pressure and leak testing.

IV. Conclusions

New technological complex for TF and PF cables production and TF conductor jacketing is created in JSC "VNIIKP".

Capacity of the complex allows to fulfill Russian obligations for PF and TF cables and TF conductor production in accordance with ITER construction Program and signed Procurement Arrangement.

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