Overview of Progress on the EU DEMO Reactor Magnet System Design

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***Abstract*—The DEMO reactor is expected to be the first application of fusion for electricity generation in the near future. To this aim, conceptual design activities are progressing in Europe (EU) under the lead of the EUROfusion Consortium in order to drive on the development of the major tokamak systems. In 2014, the activities carried out by the magnet system project team were focused on the toroidal field (TF) magnet system design and demonstrated major achievements in terms of concept proposals and of consolidated evaluations against design criteria. Several magnet system R&D activities were conducted in parallel, together with broad investigations on high temperature superconductor (HTS) technologies. In this paper, we present the outcomes of the work conducted in two areas in the 2014 magnet work program: 1) the EU inductive reactor (called DEMO1) 2014 configuration (power plant operating under inductive regime) was the basis of conceptual design activities, including further optimizations; and 2) the HTS R&D activities building upon the consolidated knowledge acquired over the past years.**

***Index Terms*—DEMO, fusion, HTS, LTS, Nb_3Sn, superconducting magnets.**

I. INTRODUCTION

ALONG the European Horizon 2020 roadmap [1] a pre-conceptual design activity is conducted on the DEMOnstration (DEMO) reactor, as the first generation of fusion power plant implemented after International Thermonuclear Experimental Reactor (ITER) tokamak operation and its first period of exploitation used as validation for a certain number of technologies, including magnets. DEMO is currently in conceptual design phase and a broad activity is ongoing in Europe (EU) in this regard. The EUROfusion Consortium took over the former framework, establishing a project structure to carry out the DEMO activities. A project team dedicated to Magnet System was established, having members from 19 European laboratories, and carried out a wide range of design activities in 2014–2015, ranging from the dimensioning of reactor coils to longer term R&D.

A large part of the 2014 work was dedicated to the dimensioning of the Toroidal Field (TF) coils, using Low Temperature Superconductor (LTS) materials; the project level objective being to evaluate the potential performance of the different coil concepts within the allocated space. The conclusions drawn from these studies will steer future work. A study of the Central Solenoid (CS) system was also initiated.

In parallel to the conceptual design and dimensioning of the LTS TF coils, High Temperature Superconductor (HTS) R&D activities were pursued, in continuity with the former program. A broad range of upstream (tapes irradiation, characterization and modelling) and downstream (cable manufacture and tests) issues were explored, with the overall mid-term goal of facilitating the emergence of the best HTS cable concept for fusion magnets.

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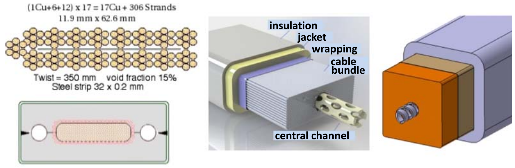

Fig. 1. Schematic views of the three initial conductor concepts proposed for the EU DEMO1 2014 TF coil. (Left) WP#1 is a flat cable composed of twisted sextuplets separated by a steel foil, confined in steel profiles with segregated cooling channels. (Middle) WP#2 is a low aspect ratio classically transposed cable, with a perforated tube central channel (design then optimized, see Section IV-B). (Right) WP#3 is a square transposed cable with spiral central channel.

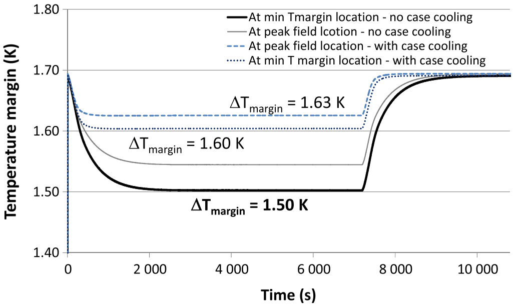

Fig. 2. $\Delta\mathrm{T}_{\mathrm{MARG}}$ variation with time for WP#3 in burn conditions. The impact of casing cooling is evaluated in a parametric approach.

II. DEMO LTS Magnet System

A. TF Conductor and Winding Pack (WP) Design

Regarding TF system, three TF WP concepts using Nb_3Sn material (since $B_{\mathrm{MAX}} \sim 13.5$ T) were issued in the project team, covering a rather large technological surface. Two of them were derived from past conceptual studies [2] and updated to match the 2014 newly issued DEMO1 central CAD configuration [3] defined by considering outputs [4] of PROCESS code, and periodically updated. The most significant change was the TF WP cross-section reduction by about 15% to match remote maintenance access ports constraints, which led a substantial effort to optimize design within the allocated space.

First, the methodology for dimensioning the TF WP (criteria, thermohydraulic laws, etc.) were agreed within the project team [5] (e.g., $\Delta T_{\mathrm{margin}} > 1.5$ K, copper-only hotspot $T_{\mathrm{MAX}} < 250$ K, insulation dimensions, etc.) into a code and standard-like approach for the assessment of the design performance. Three LTS conductor options were proposed (see Fig. 1) to be used for three different TF WP layouts.

WP#1 (proposed by SPC) follows the design basis of [2], i.e., high aspect ratio rectangular section, react & wind manufacturing route, and a graded layer winding approach.WP#2 (proposed by ENEA) is also along the design laid out in [2], i.e., high aspect ratio rectangular section, wind & react manufacturing route and graded layer winding. WP#3 (proposed by CEA, see [6], [7]) has a square cross section, a wind & react manufacturing route, and a pancake winding.

From WP#1 to WP#3 the degree of technological similarity with respect to the ITER TF design gradually increases, retaining a relatively broad spectrum of approaches in DEMO, from more innovative to more established. They carry pros and cons regarding integration in the DEMO machine, e.g., savings on material amount (superconductor, steel) and thus on machine cost, or affect some manufacturing steps (electrical junctions, winding tolerances…) and thus risks in either fabrication or exploitation phases.

An important first round of performance evaluation lies in extended simulations in both thermohydraulics and mechanics to get a first quantitative assessment.

B. Thermohydraulic Analyses

First, a reference methodological approach was established (e.g., friction factor scaling laws) and documented [8], [9] to serve as common guidelines for all analyses. Then, after a benchmarking step between the codes [10], detailed analyses were conducted on both normal and off-normal scenarios (burn and quench regimes, respectively). Update of loads (magnetic field map [11], [12] and nuclear heat map [13], including heat transfer from casing to WP [14]) were applied to the different configurations. An initial analysis was carried out with an analytical tool to spot large deviations [15]. Then more detailed analyses applying numerical codes (THEA, 4C) showed that in burn regime (2 hours full power plateau), most of the configurations passed the $\Delta\mathrm{T}_{\mathrm{MARGIN}}$ criterion of 1.5 K ([11], [17], [18]) except a few layers in WP#2 ([10], [19], [20]), that can likely be optimized in a future version. An illustrative example of the results is shown in Fig. 2, where the casing cooling was also considered and its positive impact on T margin assessed as non-negligible. An integrated study of the cooling scheme was also conducted with 4C code [21], [22] with same conclusions.

In the quench regime, the studies showed that the hotspot criterion considering all material of 150 K maximum temperature in the WP could be satisfied under certain conditions (e.g., considering heat diffusion effects inside the WP [19], [20]), however further consolidations of the assumptions are expected in the future to more robustly qualify any conclusions on this point.

The above thermohydraulic studies, showing mitigated conclusions and raising some issues had to be complemented by mechanical analyses to get a full picture of the WP performances from simulations.

C. Mechanical Analyses

Similar to the thermohydraulic analyses, the mechanical analyses were focused on the TF system. Since both PF scenarios and structure concepts were not mature enough, the study was confined to the load scenario including cool-down and inplane forces. The analysis approach is based on a first step with a global model using smeared WP properties (see e.g., Fig. 3) followed by a detailed stress map reconstruction through consideration of ad-hoc critical paths on the mesh.

Evaluation was conducted according to agreed criteria on primary, primary + bending, or shear stress maximum values [23]. Further to the reference case, the effect of friction was investigated through a parametric approach, providing a deeper view on possible sources of mitigation.

The main outcomes of the TF structural analyses [24], [25] draw the following conclusions:

- The behaviors of the three WPs are varied, consistently with their differences in geometry and in material distribution (steel, insulation).

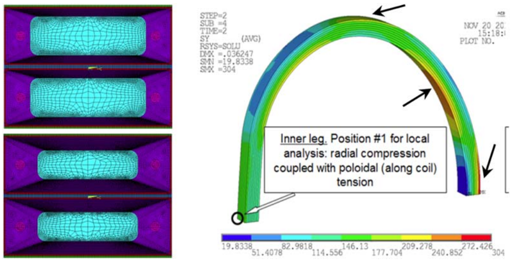

Fig. 3. (Left) Smeared model used for the two innermost layers of WP#1. (Right) Output of the global model for WP#2, showing where a local analysis is carried out to evaluate maximum stress (see black arrows).

- Depending on the criterion, the ranking of sensitivity to load between WPs can change, likely due to detailed WP features (jacket corners, jacket alignment, etc.) that can influence e.g., local bending effects.
- On average, the most resilient is WP#1, with cumulated benefits of highest steel proportion derived from graded architecture and react & wind approach while WP#3 shows the highest sensitivity to mechanical load, for inverse reasons (pancake + wind & react approaches).
- For all WP options at least one mechanical design criterion is found violated in the WP, showing the need for all concepts to be further improved, or for more space to be allocated to the WP.
- Aside from the WP, volumetric weaknesses were also found in the casing on both inboard and outboard legs.

The issue should be solved mainly by increasing the proportion of steel, but also by considering introduction of attractive alloys (e.g., Haynes 242) or consequences of manufacturing route (e.g., R&W vs. W&R) on mechanical behavior. As a consequence of the above studies, a dedicated mechanically-oriented macroscopic design tool was developed, derived from a semi-analytical approach based on fundamental principles [26], [27]. It was first used to check tentative optimizations of WP designs and led to identical conclusions on mechanical insufficiencies. In parallel, detailed analyses also assessed the outputs sensitivity to local geometry parameters. Finally, this work demonstrated that in the EU DEMO1 configuration considered, the radial build space allocated to the TF coil was insufficient and, in general, brought the issue of the mechanics to the forefront in the system-level conceptual design approach.

III. MAGNET AUXILIARY SYSTEMS

Preliminary assessments of the cryogenic plant and quench protection system (QPS) were conducted, drawing some initial reflections. As a summary:

- The QPS study [28] allowed steering the future work towards two main QPS options: one similar to ITER and a more hybridized system as used in JT-60SA [29].
- Regarding the cryoplant, the work [30] consisted of an initial parametric study, which made emerge a methodology and a tool to be further improved for complementing the magnet design loop.

In both the above systems, subsequent analyses are expected to include fabrication considerations and some feedback to magnet designers.

TABLE I
DEMO TF SAMPLES MAIN SPECIFICATIONS

Parameter	RW1 sample (React & Wind)	WR1 sample (Wind & React)
Pattern	(1Cu+6+12)x17	4[2]x3x3x4x(5+core1 [spiral]+core2)
Strand ∅ (mm)	1.5 mm	1 mm
Twist pitches (mm)	90/350	110/125 /145/175/500
Cable dimensions (mm)	68.5x 17.8	66.8 x 25
Void fraction	19%	25-27%

IV. LTS CONDUCTOR R&D

The 2014–2015 R&D activity was focused on TF system and investigated both strand and conductor levels. The main scope was to build two conductor samples (SULTAN-type) relevant to the WP#1 and WP#2 concepts (respectively RW1 and WR1, named after their manufacturing route) in order to investigate the feasibility aspects of the concepts in question.

A. *TF Strand*

A batch of 200 kg of Nb_3Sn strand was provided by WST (CN) in 2014, split into two strands diameter. The production was extensively tested in bath (production-like) conditions at SPC [31] and for one diameter in a broad operation domain (variable field, strain, and temperature) at the Univ. of Twente [32]. It showed a constant electro-mechanical behavior against past WST production at lower diameters. This database will be of importance when conductor samples tests are analyzed.

B. *TF Conductor*

The design of the two conductor samples essentially derive from the past work on DEMO conductor [2], including further modifications related to e.g. feasibility constraints. The samples design characteristics can be seen in Table I.

Regarding the RW1 sample, the design concept is the replacement of the flat profile two-channeled jacket by a single-wall tube in order to simplify the fabrication. Furthermore, a dedicated welding R&D program on short jacket lengths was successfully carried out on a remaining cable length, leading to some shape optimization with respect to the initial design.

The WR1 sample conversely underwent a major change in design, as the first dummy prototypes showed serious structural integrity issues for the central channel. As a consequence, the WR1 design now incorporates distributed cooling channels in two of the six petals, and a central copper core (more on updated conductor design features in [21], [22]), in analogy to the Korean DEMO approach [33].

From a fabrication perspective, the RW1 short lengths were completed (see Fig. 4) following a substantial internal R&D stage with a few non-conformities, which are expected to have negligible impact on the DC performances. Regarding the WR1 sample (Fig. 4), the conductor was completed without non-conformities and the sample assembly is underway and should be completed within 2015.

The RW1 was assembled at CRPP and the electrical tests were conducted in EDIPO in July 2015, leading to valuable conclusive assessments on RW1 [34], [35]. For the WR1 the likely test period is early 2016, with associated analyses. The R&D activities were also complemented by preparation of the non-destructive tomographic examination set-up [36] in conditions relevant to thick jacket samples to be used in 2016.

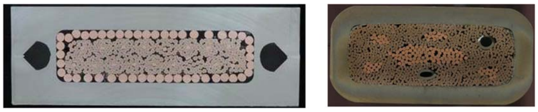

Fig. 4. Cross sections of the two samples. (Left) RW1 as prepared for jacketing tests, and (Right) WR1 sample. The WR1 copper cores and spirals-in-petals (6.6 mm diameter before compaction) are clearly visible.

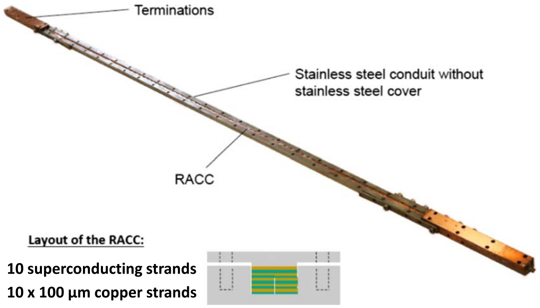

Fig. 5. Assembled RACC subsize cable sample with reinforcing jacket for FBI test facility.

Overall, the 2014–2015 R&D activities generated insight on the TF conductor samples performances but also valuable industrial feedback on manufacturing feasibility, that was compiled in the design process. These studies will be further complemented in 2016 with wider considerations at the full TF coil scale (winding process, joints etc…).

V. Investigations on HTS Technology

Alongside the previously mentioned DEMO power plant magnet dimensioning activities, investigations were conducted on the possible use of HTS material for fusion magnets.

Firstly, an experimental campaign was applied on commercial tapes aiming at evaluating their baseline performances and in addition their resilience to irradiation [37], [38]. Many laboratories of the project team were involved in these activities and provided valuable information to identify promising commercial tapes for future samples.

Additionally, R&D activities were conducted to tentatively qualify feasibility aspects of HTS cable concepts, e.g. Roebel Assembled Coated Conductor (RACC), Rutherford cable with RACC strands and Conductor On Round Core (CORC). The RACC cable was manufactured by KIT after an intensive development programme, addressing e.g. forming and assembly. A subsize sample is shown in Fig. 5 prepared with mechanical jacket to balance Lorentz Forces.

Two RACC cable samples were tested and showed promising results, with a negligible I_C degradation versus a single tape [39]. A motivation for a new program are internal results of KIT on cables with up to 31 strands instead of 10 with full width (RACC) and promising current capabilities [40], [41] which prove the scale-up potential of this type of cable concept. Besides, promising results are obtained for a Rutherford cable equipped with Roebel strands.

The CORC cable (managed in commercial context by ACT) was designed and manufactured internally at IEE, together with an extensive test campaign on the associated tapes. The cable was tested in 2015 with no evident issues, but the data are still being analyzed, the final results being subject of a future communication.

The R&D showed that the two investigated HTS cable concepts could be attractive for use in fusion applications and investigations will be continued. It should be noted that this might include alternative concepts that showed attractive potentialities for further use in fusion, like stacked concept cable recently manufactured within the HTS R&D program by SPC [42], [43] or other types recently developed ([44]–[47]).

A conceptual design activity [48], [49] proposed a TF inner leg design with HTS material, showing attractive aspects, namely a secured temperature margin well above 10 K.

Furthermore modelling work was advanced, with a particular focus on the cable concepts previously mentioned, aiming to provide robust tools for the interpretation of test results. Tentative validation of electro-mechanic models was also carried out [50] in the aim to be used in the near future as predictive tools and to facilitate decision-taking on technological choices.

VI. Conclusion-Perspectives

The EU DEMO1 TF magnet dimensioning was carried out on an updated radial build for three different LTS WP concepts proposed by the EU team. The extensive evaluation of these concepts in thermohydraulics and mechanics revealed design criteria deviations on many aspects and clearly highlighted the importance of the space allocation to TF coil at plant level. Following the analyses on the TF coil, ad-hoc tools and associated methodologies were developed [26], [27], [51] in order to efficiently address future configuration changes. The tools and methodologies have been applied for an initial assessment of the newly established 2015 TF baseline [6], [7], [52], [53], the outcomes of which need further refinement. More generally, the tools and methods will be further upgraded, in the view of designing the updated TF system and also the CS and PF systems in the near future (CS studies having been started [52], [53]). LTS DEMO R&D showed good achievements: one TF sample manufactured and tested and a second one almost completed and an extensive strand characterization. Further work includes the electric test of the second TF sample, but also wider investigations on both samples (hydraulics, electromechanics, tomography, etc.).

As per investigations on HTS, extensive irradiations and tests on commercial tapes were conducted and two mid-size cables samples were manufactured, exploring the potential of RACC and CORC technologies. The test results were satisfactory and will continue in the future, with the overall goal of identifying the best cable concept for fusion magnets and possibly aim to demonstrate winding of a HTS cable.

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References

[1] F. Romanelli *et al.*, “Fusion electricity. A roadmap to the realisation of fusion energy,” Eur. Fusion Develop. Agreement, Garching, Germany, 2012. [Online]. Available: https://www.euro-fusion.org/wpcms/wp-content/uploads/2013/01/JG12.356-web.pdf

[2] P. Bruzzone *et al.*, “Design of large size, force flow superconductors for DEMO TF coils,” *IEEE Trans. Appl. Supercond.*, vol. 24, no. 3, Jun. 2014, Art. no. 4201504.

[3] " DEMO 1 CAD," Eur. Fusion Develop. Agreement, Garching, Germany, 2014. [Online]. Available: https://idm.euro-fusion.org/?uid=2ASSGL

[4] "DEMO 1 PROCESS configuration output," Eur. Fusion Develop. Agreement, Garching, Germany, 2012. [Online]. Available: https://idm.euro-fusion.org/?uid=2LQT74

[5] L. Zani *et al.*, "Setting common operating values, analysis tools, and criteria for DEMO TF WP design," EUROfusion, Garching, Germany, 2014. [Online]. Available: https://idm.euro-fusion.org/?uid=2LNLLB

[6] A. Torre, D. Ciazynski, P. Hertout, and L. Zani, "Design tools developed at CEA for large fusion toroidal field magnets," presented at the 24th International Conference Magnet Technology, Seoul, South Korea, 2016.

[7] A. Torre, D. Ciazynski, P. Hertout, and L. Zani, "Design tools developed at CEA for large fusion toroidal field magnets," *IEEE Trans. Appl. Supercond.*, to be published.

[8] B. Lacroix *et al.*, "Proposal of scaling laws for thermal-hydraulic analyses in burn conditions," EUROfusion, Garching, Germany, 2014. [Online]. Available: https://idm.euro-fusion.org/?uid=2LCLKZ

[9] K. Sedlak *et al.*, "Proposal of scaling laws for thermal-hydraulic analyses in quench conditions," EUROfusion, Garching, Germany, 2014. [Online]. Available: https://idm.euro-fusion.org/?uid=2M6DW4

[10] R. Zanino *et al.*, "Assess thermal-hydraulic properties of WP#2 with 4C & code comparison," EUROfusion, Garching, Germany, 2015. [Online]. Available: https://idm.euro-fusion.org/?uid=2L7TV3

[11] K. Sedlak *et al.*, "Thermohydraulic analysis of TF winding pack 1 (WP#1) option and "CRPP" LTS cable," EUROfusion, Garching, Germany, 2015. [Online]. Available: https://idm.euro-fusion.org/?uid=2MENCP

[12] A. Torre *et al.*, "Magnetic field maps calculations at CEA With TRAPS code," EUROfusion, Garching, Germany, 2015. [Online]. Available: https://idm.euro-fusion.org/?uid=2LDQP8

[13] L. Zani *et al.*, "Advanced definition of neutronic heat load density map on DEMO TF coils," EUROfusion, Garching, Germany, 2014. [Online]. Available: https://idm.euro-fusion.org/?uid=2MFVCA

[14] F. Nunio, "Thermal analyses on TF system," EUROfusion, Garching, Germany, 2015. [Online]. Available: https://idm.euro-fusion.org/?uid=2LJ8AK

[15] M. Lewandowska, K. Sedlak, and L. Zani, "Thermal-hydraulic analysis of the Low Tc Superconductor (LTS) winding pack design concepts for the DEMO Toroidal Field (TF) coil," presented at the 24th International Conference Magnet Technology, Seoul, South Korea, 2015.

[16] M. Lewandowska, K. Sedlak, and L. Zani, "Thermal-hydraulic analysis of the Low Tc superconductor (LTS) winding pack design concepts for the DEMO toroidal field (TF) coil," *IEEE Trans. Appl. Supercond.*, to be published.

[17] R. Vallcorba *et al.*, "Thermo-hydraulic analyses associated to a CEA design proposal for DEMO TF conductor," presented at the CHATS Applied Superconductivity, Bologna, Italy, 2015.

[18] R. Vallcorba *et al.*, "Thermo-hydraulic analyses associated to a CEA design proposal for DEMO TF conductor," *Cryogenics*, to be published.

[19] L. Savoldi, R. Bonifetto, and R. Zanino, "Quench propagation in the European DEMO TF coil winding pack: A first analysis with the 4C code," presented at the Symposium Fusion Engineering, Austin, TX, USA, 2015.

[20] L. Savoldi, R. Bonifetto, and R. Zanino, "Quench propagation in the European DEMO TF coil winding pack: A first analysis with the 4C code," *IEEE Trans. Plasma Sci.*, to be published.

[21] R. Zanino *et al.*, "Development of a comprehensive thermal-hydraulic model for the European DEMO TF coils," presented at the 12th European Conference Applied Superconductivity, Lyon, France, 2015.

[22] R. Zanino *et al.*, "Development of a comprehensive thermal-hydraulic model for the European DEMO TF coils," *IEEE Trans. Appl. Supercond.*, vol. 26, no. 3, Apr. 2016, Art. no. 4201606.

[23] F. Nunio *et al.*, "Reference basis for mechanical & thermal analysis of TFC," EUROfusion, Garching, Germany, 2015. [Online]. Available: https://idm.euro-fusion.org/?uid=2MC8T4

[24] A. Panin, "TF system under cool-down and in-plane EM loading," EUROfusion, Garching, Germany, 2015. [Online]. Available: https://idm.euro-fusion.org/?uid=2ANVM7

[25] M. E. Biancolini *et al.*, "Mechanical analysis of TF system," EUROfusion, Garching, Germany, 2015. [Online]. Available: https://idm.euro-fusion.org/?uid=2MBVLN

[26] A. Panin *et al.*, "Analysis approaches to resolve structural issues of the European DEMO toroidal field coil system at an early design stage," presented at the 24th International Conference Magnet Technology, Seoul, South Korea, 2015.

[27] A. Panin *et al.*, "Analysis approaches to resolve structural issues of the European DEMO Toroidal Field Coil system at an early design stage," *IEEE Trans. Appl. Supercond.*, vol. 26, no. 4, Jun. 2016, Art. no. 4200805.

[28] E. Gaio and A. Maistrello, "QPS studies on TF system," EUROfusion, Garching, Germany, 2015. [Online]. Available: https://idm.euro-fusion.org/?uid=2LMS9X

[29] A. Maistrello *et al.*, "Experimental qualification of the hybrid circuit breaker developed for JT-60SA quench protection circuit," *IEEE Trans. Appl. Supercond.*, vol. 24, no. 3, Jun. 2014, Art. no. 3801505.

[30] C. Hoa, "Cryogenic studies on TF system," EUROfusion, Garching, Germany, 2015. [Online]. Available: https://idm.euro-fusion.org/?uid=2LNS32

[31] P. Bruzzone and K. Sedlak, "Fabrication of two short length TF conductor sections, RW1 and WR1," EUROfusion, Garching, Germany, 2015. [Online]. Available: https://idm.euro-fusion.org/?uid=2MDFPU

[32] A. Nijhuis, "TF conductor samples strand thermo mechanical critical performances tests," EUROfusion, Garching, Germany, 2015. [Online]. Available: https://idm.euro-fusion.org/?uid=2MBSFK

[33] K. Kim *et al.*, "Conceptual design study of the K-DEMO magnet system," *Fusion Eng. Des.*, vol. 96/97, pp. 281–285, Oct. 2015.

[34] P. Bruzzone *et al.*, "Design, manufacture and test of a 82 kA, react&wind TF conductor for DEMO," presented at the 24th International Conference Magnet Technology, Seoul, South Korea, 2015.

[35] P. Bruzzone *et al.*, "Design, manufacture and test of a 82 kA, react&wind TF conductor for DEMO," *IEEE Trans. Appl. Supercond.*, to be published.

[36] I. Tiseanu, "Tomographic examination of a DEMO TF conductor-relevant sample," EUROfusion, Garching, Germany, 2015. [Online]. Available: https://idm.euro-fusion.org/?uid=2LJSE8

[37] D. X. Fischer *et al.*, "Effects of fast neutron irradiation on the critical currents in GdBCO coated conductor tapes," presented at the HTS4Fusion Conductor Workshop, Pieve Santo Stefano, Italy, 2015.

[38] D. X. Fischer *et al.*, "Effects of fast neutron irradiation on the critical currents in GdBCO coated conductor tapes," *IEEE Trans. Appl. Supercond.*, to be published.

[39] C. M. Bayer, P. V. Gade, C. Barth, A. Preuß, and K. P. Weiß, "Mechanical stabilisation for RACC cables in high magnetic background fields," *Supercond. Sci. Technol.*, to be published.

[40] F. Grilli, M. Vojenciak, A. Kario, and V. Zermeno, "Estimation of self-field critical current and transport-magnetization AC losses of Roebel cables," presented at the 24th International Conference Magnet Technology, Seoul, South Korea, 2015.

[41] F. Grilli, M. Vojenciak, A. Kario, and V. Zermeno, "Estimation of self-field critical current and transport-magnetization AC losses of Roebel cables," *IEEE Trans. Appl. Supercond.*, to be published.

[42] D. Uglietti, "Test of a prototype large current HTS cable for fusion," presented at the HTS4Fusion Conductor Workshop, Pieve Santo Stefano, Italy, 2015.

[43] D. Uglietti, "Test of a prototype large current HTS cable for fusion," *IEEE Trans. Appl. Supercond.*, to be published.

[44] A. Augieri, "HTS slotted core cable-in-conduit-conductor for high current-high magnetic field applications," presented at the HTS4Fusion Conductor Workshop, Pieve Santo Stefano, Italy, 2015.

[45] A. Augieri, "HTS slotted core cable-in-conduit-conductor for high current-high magnetic field applications," *IEEE Trans. Appl. Supercond.*, to be published.

[46] N. Yanagi *et al.*, "100-kA HTS STARS conductor for the helical fusion reactor," presented at the 24th International Conference Magnet Technology, Seoul, South Korea, 2015.

[47] N. Yanagi *et al.*, "100-kA HTS STARS conductor for the helical fusion reactor," *IEEE Trans. Appl. Supercond.*, to be published.

[48] R. Heller, P. V. Gade, W. H. Fietz, T. Vogel, and K. P. Weiss, "Conceptual design improvement of a toroidal field coil for EU DEMO using high temperature superconductors," presented at the 24th International Conference Magnet Technology, Seoul, South Korea, 2015.

[49] R. Heller, P. V. Gade, W. H. Fietz, T. Vogel, and K. P. Weiss, "Conceptual design improvement of a toroidal field coil for EU DEMO using high temperature superconductors," *IEEE Trans. Appl. Supercond.*, vol. 26, no. 4, Jun. 2016, Art. no. 4201105.

[50] K. Ilin *et al.*, "Experiments and FE modeling of stress-strain state in ReBCO tape under tensile, torsional and transverse load," *Supercond. Sci. Technol.*, vol. 28, no. 5, Mar. 2015, Art. no. 055006.

[51] M. E. Biancolini *et al.*, "A new meshless approach to map electromagnetic loads for FEM analysis on DEMO TF coil system," *Fusion Eng. Des.*, vol. 100, pp. 226–238, Nov. 2015.

[52] R. Wesche *et al.*, "Winding pack proposal for the TF and CS coils of European DEMO," presented at the 12th European Conference Applied Superconductivity, Lyon, France, 2015.

[53] R. Wesche *et al.*, "Winding pack proposal for the TF and CS coils of European DEMO," *IEEE Trans. Appl. Supercond.*, vol. 26, no. 3, Apr. 2016, Art. no. 4200405.