Performance evolution of 60 kA HTS cable prototypes in EDIPO test facility

N. Bykovsky, D. Uglietti, K. Sedlak, B. Stepanov, R. Wesche, P. Bruzzone

EPFL-SPC, Superconductivity group, CH-5232 Villigen PSI, Switzerland

E-mail: `nikolay.bykovsky@psi.ch`

Abstract. During the first test campaign of the 60 kA HTS cable prototypes in the EDIPO test facility, the feasibility of a novel HTS fusion cable concept proposed at EPFL Swiss Plasma Center (SPC) was successfully demonstrated. While the measured DC performance of the prototypes at magnetic fields from 8 T to 12 T and for currents from 30 kA to 70 kA was close to the expected one, an initial electromagnetic cycling test (1000 cycles) revealed progressing degradation of the performance in both the SuperPower and SuperOx conductors. Aiming to understand the reasons of the degradation, additional cycling (1000 cycles) and warm up-cool down tests were performed during the second test campaign. I_c performance degradation of the SuperOx conductor reached ∼20 % after about 2000 cycles, which was the reason to continue with a visual inspection of the conductor and further tests at 77 K. AC tests were carried out at 0 and 2 T background fields without transport current and at 10 T / 50 kA operating conditions. Results obtained in DC and AC tests of the second test campaign are presented and compared with appropriate data published recently. Concluding the first iteration of HTS cable development program at SPC, a summary and recommendations for next activity over the HTS fusion cable project are also reported.

Keywords: Coated conductors, HTS fusion cable, cyclic load degradation

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1. Introduction

Based on a novel design of HTS strand proposed at SPC [1] (a twisted stack of HTS tapes encased and soldered between two semi-circular copper profiles), geometry parameters for high-current HTS fusion cable were elaborated and presented in [2]. Then, almost one year was needed to manufacture the cable prototypes made of SuperPower and SuperOx tapes for the test in the EDIPO test facility at SPC [3]. Each prototype is made of 20 strands twisted at 1 m; each strand contains 16 tapes twisted at 320 mm. During the manufacturing process, several intermediate verification tests were performed on strands and short tapes. Individual strand measurements were carried out at 77 K with all the 20 strands of each prototype before they were placed on the cable core and after – with

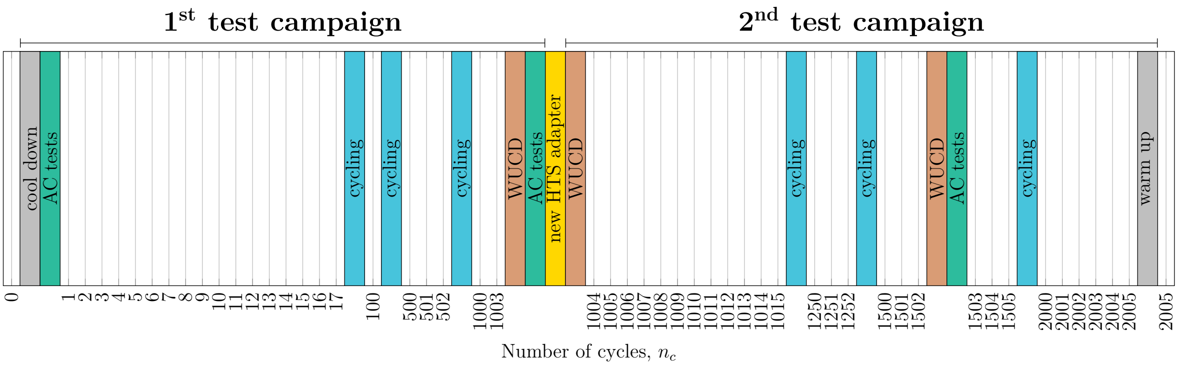

Fig. 1: Sequence of the tests performed in the EDIPO test facility. WUCD stands for Warm Up-Cool Down test. Each line corresponds to a DC test.

sets of 7 SuperPower and 10 SuperOx strands [4]. This allowed us to assess performance of the prototypes at high magnetic fields (> 8 T) and low temperatures (< 40 K).

In order to fulfil challenging requirement of EDIPO superconducting transformer for the total sample's resistance of less than 10 nΩ, special attention was given to joints and terminations of the prototypes. The sample composed of HTS adapter and two cable prototypes made of SuperPower and SuperOx tapes was tested in the EDIPO facility in June'15 during the 1st test campaign. Results of DC, AC and electromagnetic tests together with details of the sample design and fabrication have been published recently in [4]. The 1st test campaign was ended with an unexpected quench in the HTS adapter at 33 K and a current of 99.35 kA, when the adapter was burnt (see details in [5]).

There were two main reasons to justify the 2nd test campaign – commissioning of a new HTS adapter and investigation of reasons of the performance degradation during the electromagnetic cycling loading. All the measurements performed with the HTS sample in the EDIPO test facility are summarized in figure 1 as a function of number of operating current cycles at high magnetic field, n_c (number of cycles). Definitions of the 1st and 2nd test campaigns are given in the figure. During a cycling test, the operating current is ramped up and down from 2 kA to 50 kA at 12 T. Warm up-cool down tests correspond to a slow temperature increase of the sample up to 270 K and then cooling back to 5 K ($\sim$12 hours). Design of the new HTS adapter is based on the former one [6], but the stacks of 12 mm SUNAM tapes were additionally equipped with thin brass strips (0.15 mm thickness) and soldered along the whole length together in order to improve thermal and electrical properties.

This work summarizes all the DC and AC test results obtained during the two test campaigns. It will be shown that roughly $\approx 10\,\%$ and $\approx 20\,\%$ of I_c performance degradation was found for the SuperPower and SuperOx cable prototypes respectively. Thus, aiming to perform a further investigation, SuperOx conductor was disassembled and opened. We repeated the critical current measurements in liquid nitrogen bath with the 10 SuperOx strands, which were measured after the cabling, plus 1 extra one for reasons explained below. Results of the measurements and visual inspection of the

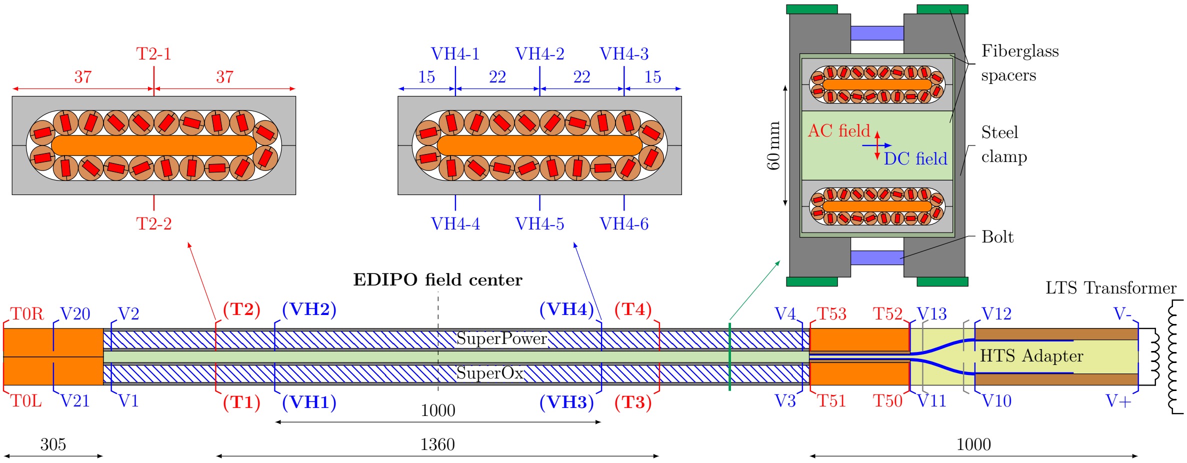

Fig. 2: Instrumentation scheme of the EDIPO sample consisting of HTS adapter and SuperPower / SuperOx cable prototypes. Temperature sensors are shown in red, voltage taps – in blue and gray. Bold labels correspond to multiple sensors. Cross-section of the sample and orientations of DC and AC fields with respect to the sample are also indicated.

SuperOx prototype are reported as well.

2. Electrical and cryogenic circuits

Detailed discussion over the design and fabrication of the cable prototypes and its joints has been published recently in [4]. A full instrumentation scheme and cross-section of the sample is presented in figure 2. Cable prototypes ('legs') are connected in series with each other at the bottom joint and with each side of the HTS adapter at the top joints. Legs are positioned at 60 mm distance using fiberglass spacers and oriented such that the DC field of EDIPO is parallel to the wide side of the cable prototypes, the AC field – perpendicular.

Compared with the 1st test campaign, additional pairs of voltage taps on the sample (V2–VH2-4, V1–VH1-9, V3–V4) and on the HTS adapter (V+–V- and gray ticks in figure 2) were installed. Eventually, 3 pairs of voltage taps were used on the bottom joint, and 5 pairs – for each side of the sample between the prototypes and transformer. Electric field developed in the sample is measured by six 1-m long pairs of voltage taps on the each prototype, which are centered with respect to a high field zone of EDIPO. Temperature sensors are marked red in figure 2, allowing to measure inlet (T0R/T0L), outlet (T52/T50) and middle region (T2-T4/T1-T3, centered around the high field zone) temperatures in the prototypes.

In DC tests of the sample both I_c and T_{cs} measurements were performed, corresponding to the *fixed temperature–ramping current* and *fixed current–ramping temperature* operating conditions respectively. In order to obtain I_c or T_{cs} values from the DC test, average values from the six pairs of voltage taps VH2-VH4/VH1-VH3 and from the set of four temperature sensors T2-T4/T1-T3 are used.

The cryogenic circuit of the EDIPO test facility is described in figure 3. For each

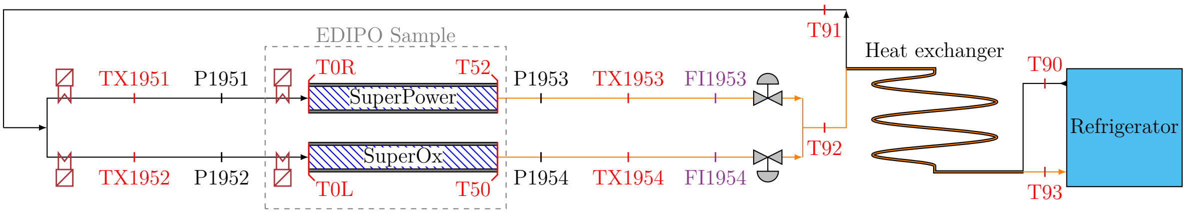

Fig. 3: Cryogenic circuit of the EDIPO facility for HTS sample test. Temperature sensors are shown in red, pressure drop – in black, mass flow-rate – in violet. Valves ( ) and built-in / sample heaters ( ) are also indicated.

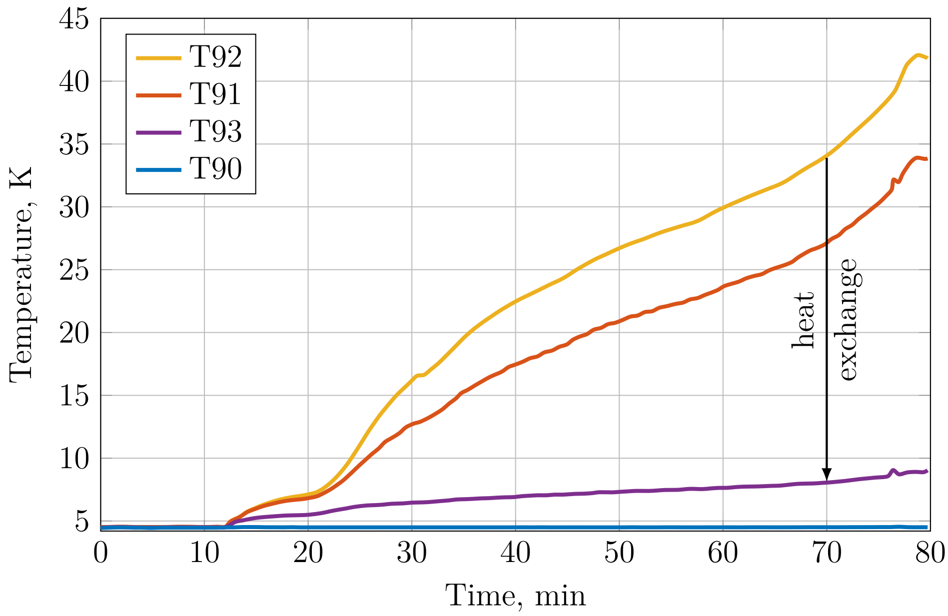

Fig. 4: Inlet and outlet temperatures of the heat exchanger in the T_{cs} test at 12 T and 20 kA.

conductor of the sample there are temperature, pressure and mass flow-rate sensors. Built-in heaters and valves are for the temperature and helium flow control respectively. Inlet pipes of the sample were additionally equipped with 2 extra heaters just upstream of the inlet, in order to establish different operating temperature in the two conductors.

Heat exchanger (HEX) is required for a high temperature operation of the facility in order to reduce the heat load on the refrigerator. HEX commissioning was recently published in [5]. In figure 4, the evolution of the temperatures of helium gas at locations of T90, T93, T91 and T92 for the T_{cs} test at 12 T background field and 20 kA operating current are shown. In that measurement the temperature of the sample was increased above 40 K, while the inlet temperature of the return flow to the refrigerator T93 is well below 20 K. Initial offset of 12 minutes is due to the current ramp.

3. Resistances of the sample

Due to an electrical requirement dictated by the transformer of the facility, a total resistance of the secondary loop including the sample should be lower than 10 nΩ. In

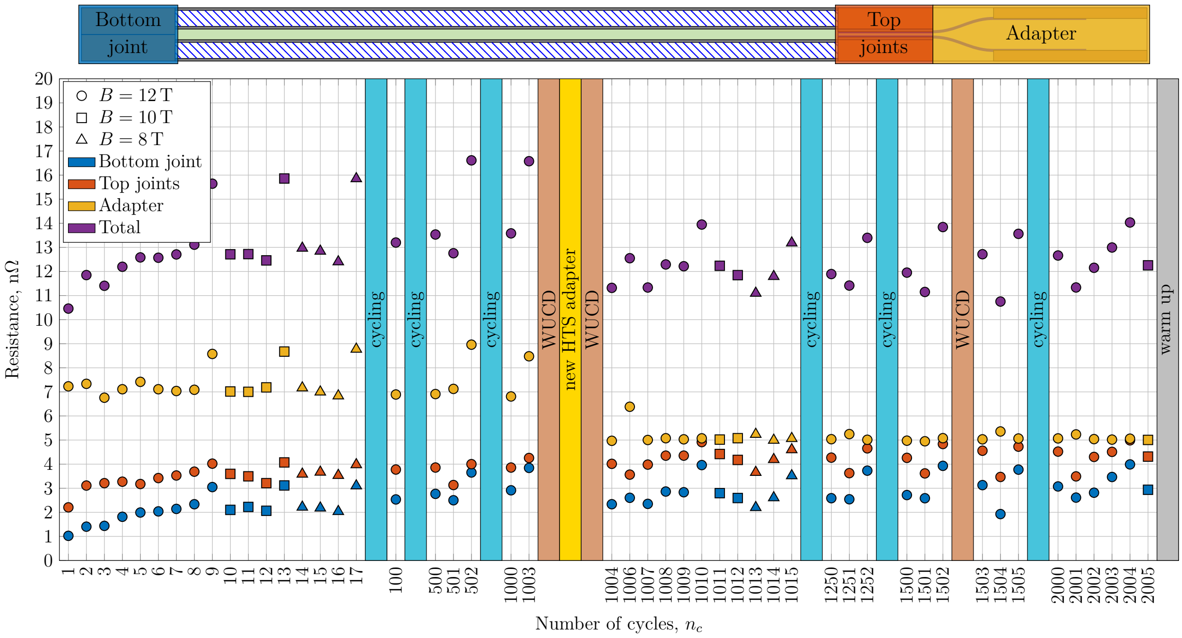

Fig. 5: Resistances of the sample as a function of number of cycles n_c.

order to achieve this, all the HTS tapes of the prototypes were connected in parallel at top and bottom terminations by using tapes staggering at the ends of the strands (see [4] for the details).

Total resistance of the sample can be splitted in three parts: (1) bottom joint, consisting of SuperPower / SuperOx terminations and joint between them (correspond to V2-V20, V1-V21 and V20-V21 voltage taps in figure 2), (2) top joints (V4-V13 and V3-V11) and (3) HTS adapter, divided along the length of each side in four regions with voltage taps in the 2nd test campaign.

For every DC test of the sample, resistance of each part was evaluated during the current ramp. Evolution of the sample resistances as a function of number of cycles n_c is presented in figure 5. Symbols in the figure correspond to different DC fields explained in the legend. While the current ramp for most of the measurements was done at ≈ 5 K, in some of them (such as $n_c = 502, 1003$ etc.) initial temperature was higher, up to 18 K, leading to essentially higher resistance values.

Resistances of the bottom and top joints tend to increase with n_c. Initial values of 1 nΩ and 2 nΩ have changed up to 3 nΩ and 4 nΩ at the end of 2nd test campaign for the bottom and top joints respectively. For the bottom one, this behaviour was caused by the joint between two terminations, measured with V20-V21 pair of voltage taps, while the resistances of terminations, measured by V20-V2 and V21-V1 pairs, were from 0.3 nΩ to 0.4 nΩ and not affected during the test. This trend can be explained by a long high-field zone: non-zero background field at the location of joints leads to forces pulling two terminations apart and slightly worsening the electrical connections between them.

Note that resistance of the new adapter is essentially lower than of the one used in the 1st test campaign. For the 1st adapter there was also a noticeable difference in the resistance of left and right sides. When that adapter was burnt during the quench at the end of 1st test campaign, the side with higher resistance was the one which initiated this process. With the new HTS adapter resistances of the both sides are almost identical, what reflects a higher manufacturing quality of the new adapter.

Total resistance of the secondary loop was a bit higher than the target value of $10\,\mathrm{n\Omega}$. It was typically in the range from $11\,\mathrm{n\Omega}$ to $13\,\mathrm{n\Omega}$. As a result, operation in steps for the transport current and temperature, conventionally used for measurements of LTS cables in SULTAN test facility, was not possible; continuous ramp was used instead.

Since the HTS adapter is necessary for high temperature operation of EDIPO, $\approx 5\,\mathrm{n\Omega}$ are already reserved out of total $10\,\mathrm{n\Omega}$ requirement. This means that bottom and top joints of future HTS cable prototypes should be designed to meet $\approx 5\,\mathrm{n\Omega}$ resistance allowing to use operation in steps for transport current and temperature in EDIPO.

4. Assessment of the DC cable performance

Basically, two types of DC measurements were performed with the SuperPower and SuperOx cable prototypes:

1) Individual strand verification tests in liquid nitrogen bath (77 K, self-field)
2) EDIPO sample tests at high-field (from 8 T to 12 T) and low temperature (from 5 K to 40 K)

For the first type of tests, performance of the strands was evaluated as described in [7]. Compared to the sum of the I_c of the individual tapes, the current capacity of the 16-tape strand is reduced by $\approx 30\,\%$ due to the self-field effect. This effect was taken into account by iterative calculation of the magnetic field of the stack (using the Biot-Savart law in a straight-tape approach), which influence the distribution of the critical current density along the width of each tape in the stack (using the Kim-like model). After several iterations, a consistent distribution of the field and critical current could be obtained. The results of the calculation and their comparison with the measured I_c of the straight and cabled SuperPower / SuperOx strands were published in [4].

A first step in the assessment of DC test with the EDIPO sample is the calculation of magnetic field distribution including background field and self-field of both conductors, which have opposite directions of the transport current (again, in the straight tape approach of Biot-Savart law). Then, every tape's element in the cable cross-section can be numbered using 3 counters (i, j, k) as i-th position (from 1 to N_{mesh}) along the width of j-th tape (from 1 to n) in the k-th strand (from 1 to N) of the cable. This allows to express electric field along the cable E as a function of the transport current I and temperature T in the following form:

$$\frac{E(I,T)}{E_c} = \frac{1}{N_{\mathrm{mesh}} n N} \sum_{(i,j,k)=1}^{N_{\mathrm{mesh}} n N} \left(\frac{I}{I_c^{\mathrm{tape}} \left(B^{(i,j,k)}(I), T \right) f \left(\theta^{(i,j,k)}(I) \right)} \right)^{n\left(B^{(i,j,k)}(I),T\right)} \tag{1}$$

where the definitions of critical current scaling law $I_c^{\text{tape}}(B,T)$, function of the critical current anisotropy $f(\theta)$ and $n(B,T)$-value for SuperPower / SuperOx tapes correspond to those presented in [4]. Electric voltage criterion is $E_c = 1\,\mu\text{V/cm}$, which is typical for HTS tapes characterization. Nevertheless, it should be noted that a more sensitive criterion E_c is desirable (i.e. $0.1\,\mu\text{V/cm}$, typical for LTS wires), since it may drastically increase the accuracy of the test results.

Finally, using equation (1), current sharing temperature T_{cs} and critical current I_c of the cable can be calculated in a similar way: condition for the I_c test, when background field and temperature are fixed, is $E(I_c,T) = E_c$; condition for the T_{cs} test, when background field and transport current are fixed, is $E(I,T_{cs}) = E_c$. For the both T_{cs} and I_c parameters there are error margins in the calculation caused by uncertainties in the critical current of single tapes (±3.3 % for SuperPower; ±2.4 % for SuperOx) and by the temperature gradient ±0.25 K during the EDIPO tests (i.e. temperature gradient between T2 and T4 sensors for SuperPower; T1 and T3 – for SuperOx, see figure 2).

5. DC performance evolution

As it was discussed in details in [4], initial test results of the 1st test campaign of T_{cs} and I_c measurements are in good agreement with predicted values (see previous section) for both the SuperPower and SuperOx prototypes. These tests were performed at 8 T, 10 T and 12 T background DC magnetic fields and in temperature range from 5 K to 40 K. It allowed to conclude that tape's transport properties were fully retained in the both prototypes at initial test phase, i.e. feasibility of the proposed designs of the HTS strand and cable for fusion magnets was experimentally demonstrated.

After that, during the cycling operation of transport current from 2 kA to 50 kA at 12 T ('cycling test'), performance of the both conductors started to continuously degrade with increasing number of cycles n_c. This behaviour was preserved in the next measurements performed during the 2nd test campaign. The comparison of voltage-temperature curves for all the T_{cs} tests performed at 50 kA and 12 T for SuperPower / SuperOx prototypes is shown in figure 6. In this plot temperature is an average value for T2, T4 sensors for SuperPower and T1,T3 – for SuperOx; electric field is an average between the six pairs of voltage taps (VH2-VH4; VH1-VH3) normalized by 1 m length (see figure 2). In the 1st test campaign, corresponding to n_c up to 1003, there was an instrumentation problem with voltage taps for the SuperPower leg resulting in a high signal noise. As one can see from figure 6, it was fixed in the 2nd campaign, corresponding to n_c from 1004 to 2005. A strong performance drop of the SuperOx leg was observed at $n_c = 1004$. For this and the following T_{cs} tests, superconducting transition starts in the leg already at the base temperature during the current ramp up to 50 kA.

Values of T_{cs} and I_c were obtained from the measured voltage-temperature or

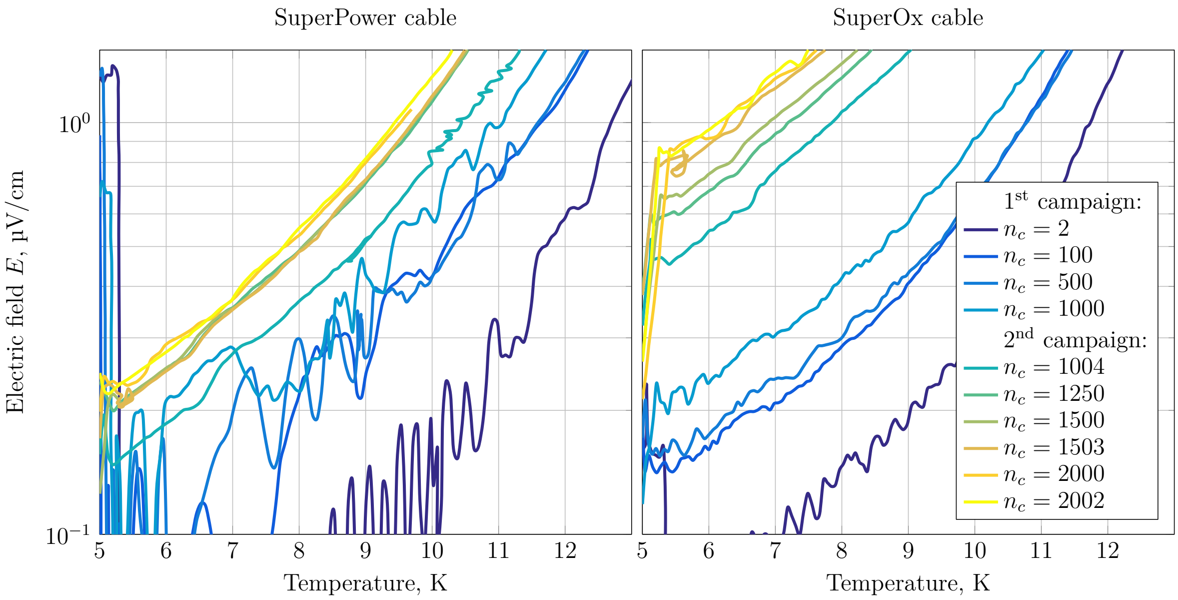

Fig. 6: Smoothed voltage-temperature curves of SuperPower and SuperOx prototypes at 50 kA and 12 T for various number of electromagnetic cycles n_c.

voltage-current characteristics using the standard power-law fit:

$$E(T) = E_0 + E_c \left(\frac{T}{T_{cs}}\right)^m, \quad E(I) = E_0 + E_c \left(\frac{I}{I_c}\right)^n \qquad (2)$$

Finally, in order to characterize performance of the cables, expected value for the I_c test was calculated at appropriate T and B and for the T_{cs} test – at appropriate I and B as it was explained in the previous section. Then, both the numerical and experimental data were considered as $I_c(B,T)$ data disregarding the type of test, what allows to consider simultaneously evolution of the cables performance as a function of number of cycles n_c. In this way, results for the SuperOx prototype are presented in figure 7. Same as in figure 5, different symbols correspond to magnetic fields, while the colours represent a temperature range in which the E_c criterion was reached. Important that evolution of each symbol-color combination has a roughly parallel trend, i.e. degradation of the cable performance is almost independent of the operating conditions. The high values of the purple points (temperature range from 30 K to 40 K) are due to the low accuracy of the scaling law for SuperOx at high temperature.

Average results of individual strand test at 77 K are also presented in figure 7 at $n_c = 0$ and $n_c = 2005$. These measurements were performed before the EDIPO test (see [4] for details) and afterwards (will be discussed in section 7). The cable performance at 77 K / self-field follows the same trend as the one at lower temperatures and high magnetic fields. Roughly 20 % of the performance degradation was observed with the SuperOx prototype at the end of the 2$^{\text{nd}}$ test campaign.

The same data analysis was performed for the SuperPower prototype. As it was already stressed in our previous publication [4], chosen scaling law parameters for

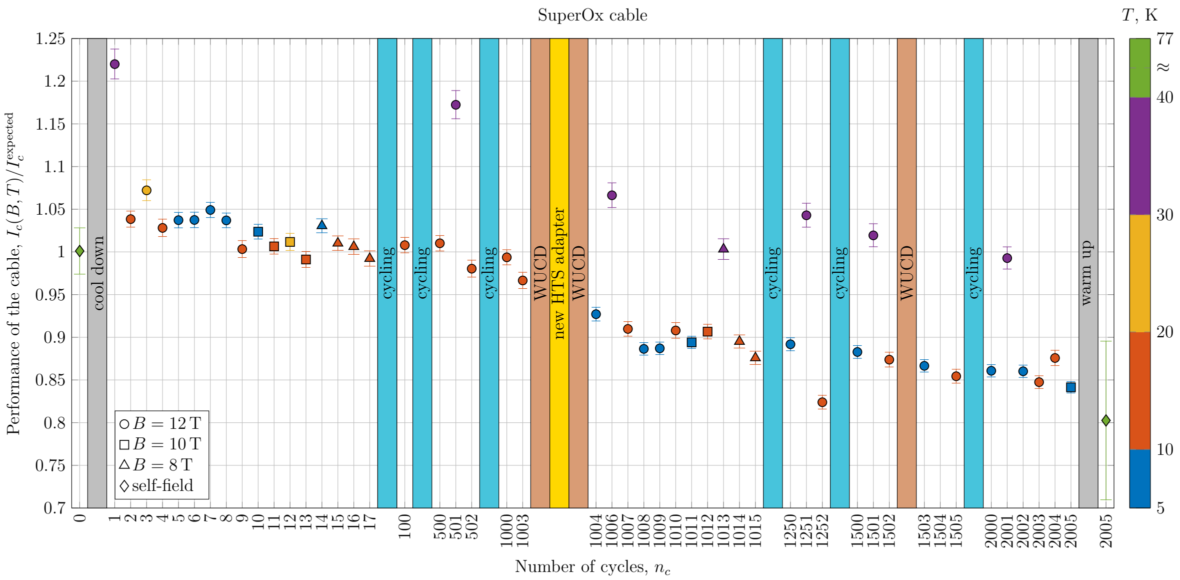

Fig. 7: Evolution of the SuperOx prototype performance as a function of number of cycles n_c.

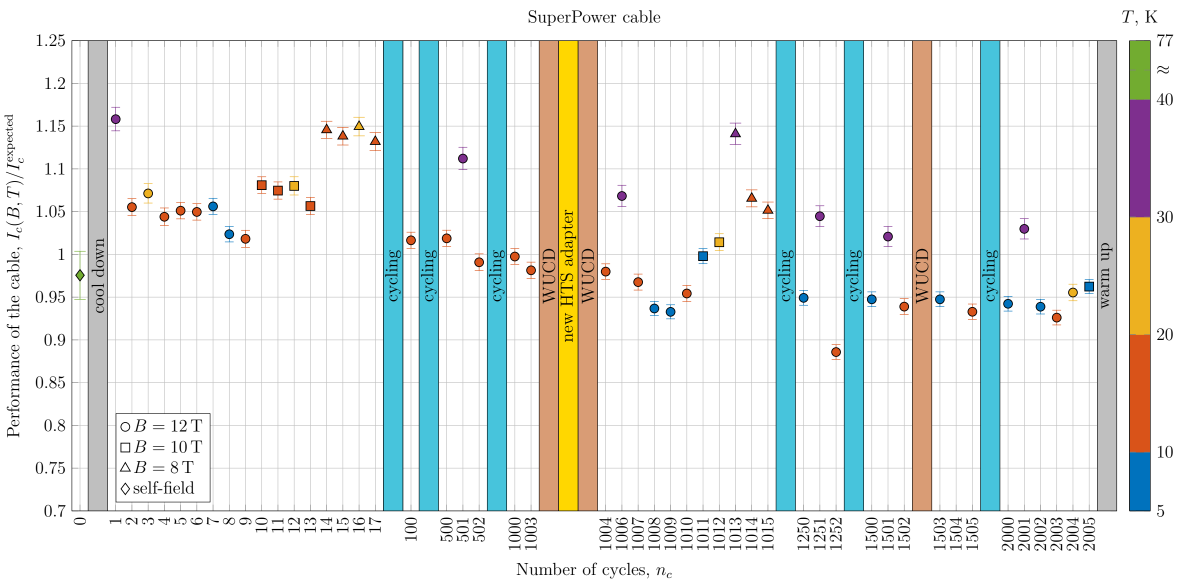

Fig. 8: Evolution of the SuperPower prototype performance as a function of number of cycles n_c.

SuperPower tapes are not well representative for the prototype: measured T_{cs} and I_c values are typically higher than the expected ones (especially at $B < 12\,\mathrm{T}$). Nevertheless, this scaling law was used in the calculation for the consistency. As a result, obtained evolution of SuperPower prototype presented in figure 8 is much more scattered than that of SuperOx. In spite of this, it is still possible to make the same conclusion: degradation of the SuperPower cable performance is almost independent of the operating conditions. Average degradation observed at the end of tests is about 10 %.

6. AC performance evolution

Using calorimetric method for an estimation of AC loss of the prototypes in applied magnetic field, we calculate first an average power loss P according to the following expression:

$$P = (h(T_{\text{out}}, p) - h(T_{\text{in}}, p))\, \dot{m}/l \qquad [\text{W/m}] \tag{3}$$

where T_{in} and T_{out} are inlet and outlet temperatures – T1/T2 and T3/T4 in figure 2; $\dot{m}$ and p are helium mass flow-rate and absolute pressure – FI1953/FI1954 and P1951/P1952 in figure 3. Distance between temperature sensors is $l = 1.36\,\text{m}$. Tabulated data from [8] was used for the dependence of helium enthalpy over the temperature and pressure $h(T, p)$.

Energy loss per cycle per unit length Q is obtained as P/ν, where ν is the frequency of AC field. Q is proportional to energy of AC field Q_0 for different amplitudes B_{ac} used in the measurements (0.1 T, 0.2 T and 0.3 T). This energy per unit length can be estimated simply as $Q_0 = \frac{B_{\text{ac}}^2}{2\mu_0} S$, where $S = 74\,\text{mm} \times 26\,\text{mm}$ is the rectangular cross-section of the prototypes. Therefore, normalizing Q by Q_0 allows to exclude dependence over B_{ac} in the data representation.

Summary of results obtained during the AC test of the 2nd test campaign for the both cables is shown in figure 9. There are 3 operating conditions that were studied: (a) $B = 0, I = 0$, (b) $B = 2\,\text{T}, I = 0$ and (c) $B = 10\,\text{T}, I = 50\,\text{kA}$, where I is the transport current, B is the DC magnetic field parallel to wide side of the cables (see figure 2). The DC joule power loss in the (c) condition was approximately 0.41 W/m and 1.49 W/m for the SuperPower and SuperOx prototypes respectively. These DC contributions were subtracted from the total power loss (3) in the AC energy loss calculation.

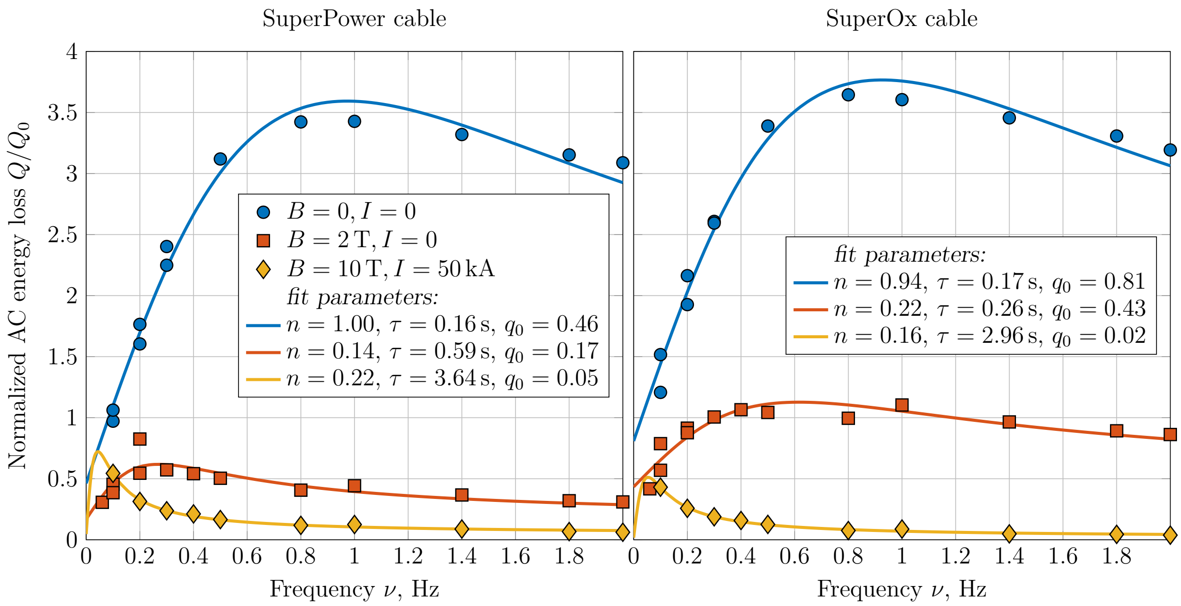

Fig. 9: Normalized energy loss of SuperPower and SuperOx prototypes versus frequency ν. Indicated fit parameters correspond to the equation (4).

Fit curves presented in figure 9 correspond to an analytical function obtained from general AC loss considerations presented in [10]. Applying the same normalization by Q_0 as described above, we use the following form of the fit function:

$$q(\nu) = q_0 + \frac{4\pi^2 \nu n \tau}{1 + 4\pi^2 \nu^2 \tau^2} \tag{4}$$

where q_0 corresponds to the normalized hysteresis loss, n is the shape factor, τ is the time constant. For fit reasons only, q_0, n and τ are considered as free fit parameters (even disregarding that n is only a geometry parameter). Maximum value of the fit function (4) corresponds to $\nu^* = 1/(2\pi\tau)$ and equals to $q_0 + \pi n$. As can be seen from figure 9, chosen fit provides satisfactory accuracy. For $B = 10\,\mathrm{T}, I = 50\,\mathrm{kA}$ case, peak loss was not identified in the measurements down to $\nu = 0.1\,\mathrm{Hz}$.

Comparing (a) and (b), we conclude that SnPb solder is responsible for the noticeable difference: for temperatures below 7 K, SnPb is superconducting at 0 T (see section A3.9 in [9]), while at 2 T is already at normal state. In the case (c), when the higher DC magnetic field and transport current were applied, corresponding transverse Lorentz force ensures a better contact between the strands and the copper cable core, i.e. the lower inter-strand resistivity ρ_{is}. This explains that the peaks of the curves (c) are shifted to the left compared with (b), because the time constant τ is inverse proportional to ρ_{is}.

Finally, AC loss results obtained during the 1$^{\mathrm{st}}$ and 2$^{\mathrm{nd}}$ campaigns are summarized for both cables in figure 10. Note that measurements at $B = 10\,\mathrm{T}, I = 50\,\mathrm{kA}$ were performed only in the 2$^{\mathrm{nd}}$ campaign. For the other two operating conditions data points for the 1$^{\mathrm{st}}$ campaign have lighter colors. There is only a small influence of warm up-cool down and cycling tests (sequence of the tests is in figure 1) on the AC performance of the cables. As already discussed in [4], the cables demonstrated relatively high AC loss – from 2 to 10 times higher than ITER TF cables. Estimating various possible AC

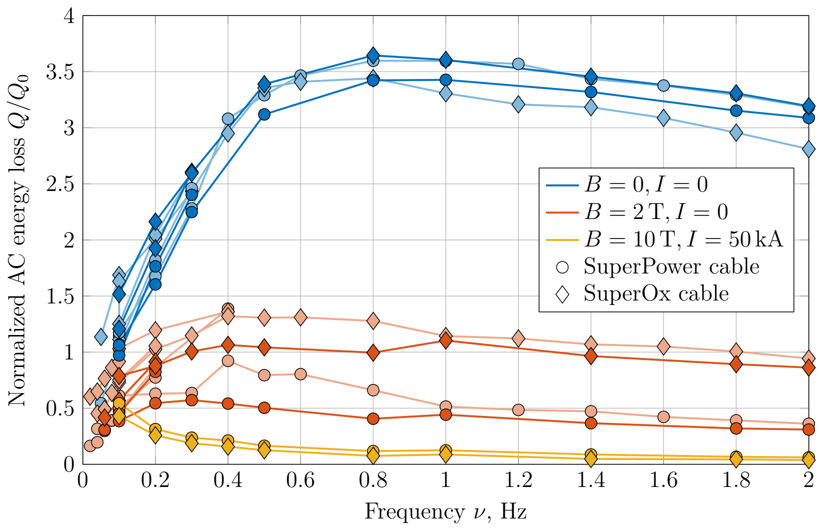

Fig. 10: Comparison of AC test results obtained during the 1$^{\mathrm{st}}$ (lighter colors) and 2$^{\mathrm{nd}}$ (darker colors) test campaigns.

loss mechanisms in the cable (hysteresis loss, inter-tape and inter-strand coupling loss, eddy currents loss), contribution from the inter-strand currents is the dominant one.

7. SuperOx cable after the EDIPO test

After the measurements in EDIPO it was decided to investigate further the reasons of DC performance degradation of the prototypes. The SuperOx conductor was chosen for disassembling since it has twice higher degradation than the SuperPower one. After an opening of the cable jacket, we performed visual inspection of the cable and repeated individual strand measurements at 77 K.

Several cracks were observed between copper profiles of the strands at the cable edge, as illustrated in figure 11. This indicates the effect of transverse Lorentz force acting when transport current is applied at high magnetic field. The corresponding transverse pressure in the strand's midplane is estimated to be roughly ≈ 10 MPa, which is smaller than the critical pressure measured on a single strand [11]. In other words, it's not only amplitude of Lorentz force that matters but also its cycling action is another important aspect. On top of that, copper profiles used for fabrication of the strands are preliminary annealed. While annealing improves significantly strand's bending properties, it also reduces elastic limit of copper. In order to better understand the influence of cycling load a dedicated experimental setup is under development now. The measurements will be performed at 77 K because, as shown in figure 7, the degradation at 77 K and at 4.2 K in field is comparable.

After the test in EDIPO and the disassembling, critical current measurements at 77 K, self-field were carried with a set of 11 strands: the same 10 strands that were measured before the EDIPO test, plus an additional one, which visually has the most damaged region (right picture in figure 11). Test results normalized to the expected I_c value (as described in section 4) are presented in figure 12 as 'cycled strands'.

The data for 'straight strands' were obtained just after the manufacturing of strands; 'cabled strands' – after the strands were placed on the cable core. Average values for the I_c distribution of cabled and cycled strands were already presented in figure 7 at

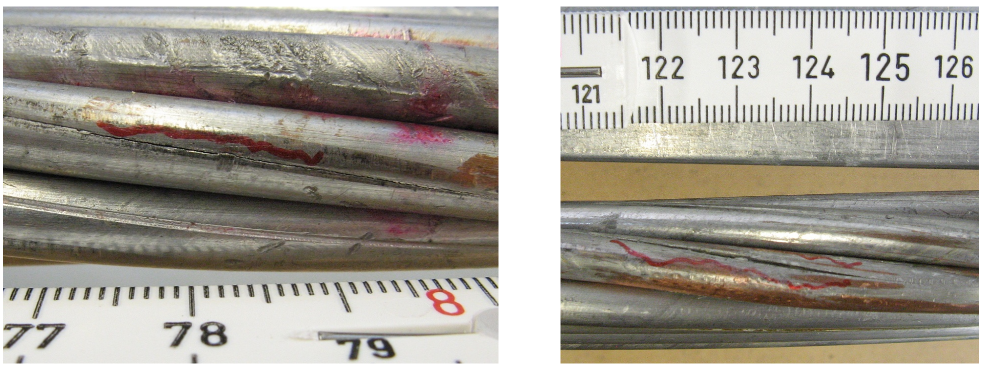

Fig. 11: Photos of the damaged regions at edges of the SuperOx cable after the test in EDIPO.

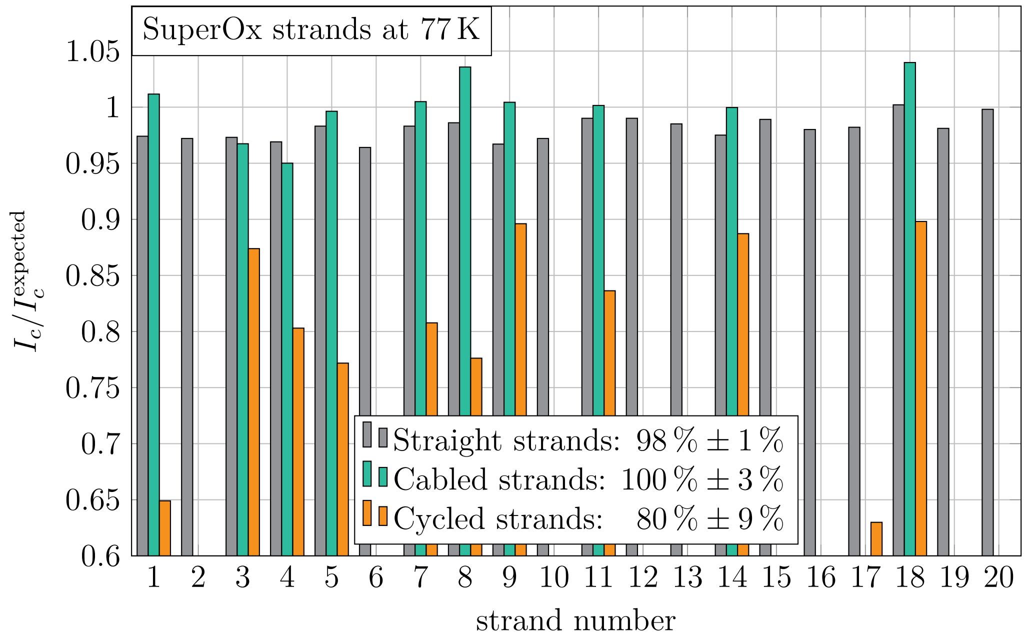

Fig. 12: Critical current of the SuperOx strands normalized by expected values before (straight and cabled) and after (cycled) the EDIPO test. Average value and standard deviation for each distribution are indicated in legend.

$n_c = 0$ and $n_c = 2005$ respectively. As it was obtained during the test in EDIPO, there is approximately 20 % degradation of I_c also for the set of strands measured at 77 K.

8. Conclusion

Two main tasks of the 2nd test campaign with 60 kA HTS cable prototypes – commissioning of the new HTS adapter and investigation of the cables performance degradation – were successfully performed.

Measured resistances of the new adapter in the DC tests, summarized in figure 5, demonstrate a high quality of the new device. For the high temperature operation of the EDIPO test facility ($T > 10$ K), need of HTS adapter (basically, for preventing a heat load on LTS transformer, see figure 2) results in a more challenging requirement for the resistance of cable prototypes. Since ≈ 5 nΩ are already presented with the adapter's resistances, not more than 5 nΩ are allowed for total sample's resistance in order to use operation in steps of current or temperature in the DC test.

Performance evolution of the SuperOx and SuperPower cable prototypes with increasing number of cycles (see figures 7, 8) indicates that it is independent from the operating conditions: comparable results were obtained with the background magnetic fields 12 T, 10 T, 8 T and 0 T (self-field) in the temperature range from 5 K to 77 K. Accumulated I_c degradation after 2005 electromagnetic cycles is 20 % for SuperOx and 10 % for SuperPower. From the visual inspection performed with the SuperOx cable after the EDIPO test, we concluded that transverse Lorentz force is the key factor of the degradation.

Results of AC tests performed in the 1st and 2nd test campaigns reveal a weak influence of the cycling and WUCD tests on the AC performance of the cables. It was concluded that the dominant AC loss contribution is due to the inter-strand coupling currents. For the next HTS cable prototypes we will attempt to reduce it using shorter twist-pitch of the cable, lower number of strands and by increasing the contact resistance between the strands and the copper cable core.

Before producing the next cable prototypes, a study of cycling load influence on strand's performance will be carried out at 77 K. By varying parameters of the strand design, mechanical limit on the transverse pressure p_c can be significantly increased [11]. The main aim of the planned study is to figure out an evolution of p_c with the number of mechanical load cycles (up to some thousands of cycles) for the two E_c criteria 0.1 µV/cm and 1 µV/cm.

9. References

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