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DELIVERABLE REPORT

[MAGNETS AND GRADIENTS]

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	Name	Partner	Date
Authored by	S. Stapnes	[CERN]	01/02/18
Reviewed by	M. Stanitzki [DESY representative] Thomas Schoerner-Sadenius [Scientific coordinator]	DESY] [DESY]	10/02/18
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Month 25 Magnets and Gradients: Report on common R&D results on high field magnets and high gradient structures.

Executive summary:

The work related to high field magnets is primarily focussed on development of the D1 separation dipole for High Luminosity LHC. This work has progressed steadily over the last 3 years and is expected to be completed 2018. The goal is to turn the construction of the D1 magnets into a Japanese in-kind contribution to the LHC machine upgrade, and currently such a contribution is being discussed at founding agency level in Japan. More generic common high field magnet R&D is also on-going.

The common studies for high gradients are focused on X-band technology. A test facility at KEK has been used to characterize accelerator structures in a collaboration with CERN, also testing structures built in SINAP (Shanghai Institute of Applied Physics) and Tsinghua university, Beijing. The common programme between CERN and KEK is very successful and closely coordinated.

1. INTRODUCTION

WP1 covers the LHC exploitation and upgrades in particular linking to the planned Japanese contributions to these projects, as well as R&D for future hadron machine at higher intensity or energy. LHC will run near its full energy from 2015 and Japanese researchers participate in operation, analysis and upgrade projects for both accelerator and detectors. R&D on high field magnets and wideband magnetic alloy RF systems carried out in Japan is a key ingredient for upgrading the LHC itself as well as its injectors - through the LHC Injectors Upgrade project - and for reaching the performance goals of the High Luminosity LHC (HL- LHC) project. This is also relevant for the J-PARC upgrades and, at a later stage, for a potential very large collider as studied in the Future Circular Collider (FCC) programme. The main objective for this work-package is integration of the European and Japanese efforts (involving also other regions) on the LHC High Luminosity upgrade into a construction project for the upgrade hardware.

2. WP1 TASKS

Task 1.1: LHC operation and analysis (CERN, KEK & UoT): Integrate Japanese efforts in operation of LHC machines and detectors at full energy; expected to provide important guidance for future accelerator developments in Europe and Japan.

Task 1.2: The HL-LHC project (CERN & KEK): Engineering design and validation of two short prototype separation superconducting dipoles (D1) followed by construction preparation, construction and test of the 4 final (plus two spare) D1 dipoles for the upgraded LHC insertion regions. Studies for the crab cavities (CC) for the LHC luminosity upgrade, benefitting from operational experience of CC at KEK.

Task 1.3: High field magnet R&D and preparation of future hadron injectors and colliders (CERN & KEK): R&D on the viability of HTS magnets of accelerator/collider quality. Enhance the exchange of staff between CERN and KEK in the context of the LIU project and the J-PARC intensity upgrade studies. Technologies of special interest are Wideband Cavities using Magnetic Alloy, Solid State Amplifiers and Low Level RF.

3. R&D ON HIGH FIELD MAGNETS

The R&D on High Field Magnets is central for the LHC luminosity upgrade (HiLumi) and later higher energy hadron colliders. HiLumi is aimed at allowing set of beam parameters for LHC to reach the following targets: $L_{peak} = 5\times10^{34}$ $cm^{-2}s^{-1}$ with levelling, allowing and an integrated luminosity of 250 fb^{-1} per year, enabling the goal of L_{int} = 3000 fb^{-1} twelve years after the upgrade.

The key development project at KEK for HiLumi is the beam separation magnet D1 (MBXF). The magnet is a 150 mm single aperture, 35 Tm (5.6 T x 6.3 m), Nb-Ti technology dipole.

The development of the beam separation dipole magnet D1 in Japan is focused on a 2 m long model magnet. Three 2 m long model magnets (MBXFS) are planned. This effort is supported by visits from CERN to Japan; the coordination of practical and technical issues profited strongly from the E-JADE secondments. An important milestone was reached with the construction of a mechanical short model of the magnet and subsequent tests. After initial tests in 2016 the D1 prototype was re-assembled for further colds tests in 2017.

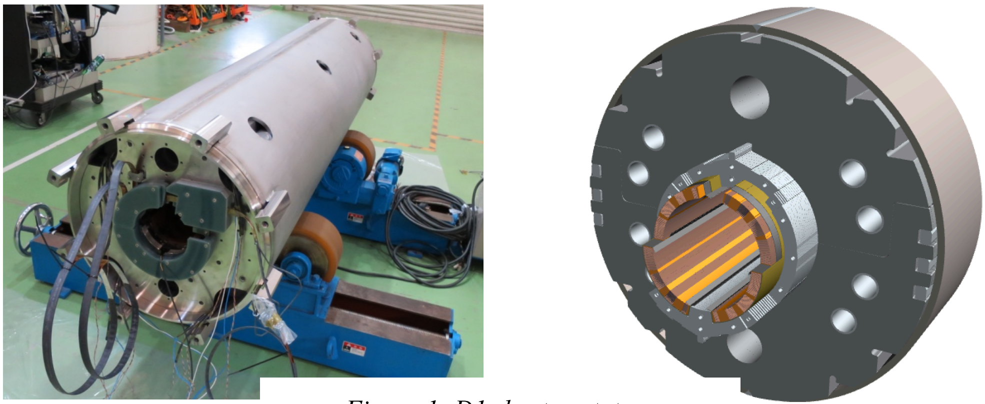


Figure 1: D1 short prototype

The MBXFS1b tested in 2017 successfully demonstrated improved training performance [1] reaching both nominal and ultimate current levels.

Development of a 2nd model magnet (MBXFS2) has been carried out. It includes several design updates (enhanced coil pre-stress, 4 HX holes, improved coil end shape & wet-winding, new QPH, etc.) and these are being implemented. Coil winding started in November 2017 and cold test will be performed in May 2018. This work will be followed by a 3rd model magnet (MBXFS3).

An in-kind contribution from Japan of MBXF magnets for HiLumi LHC is in consideration, consisting of one prototype and a series production of 4 magnets and 2 spares as shown in Fig. 2 below.

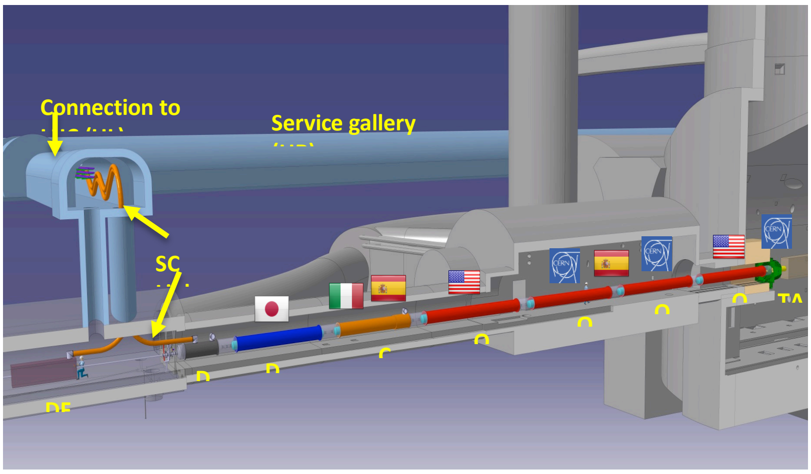
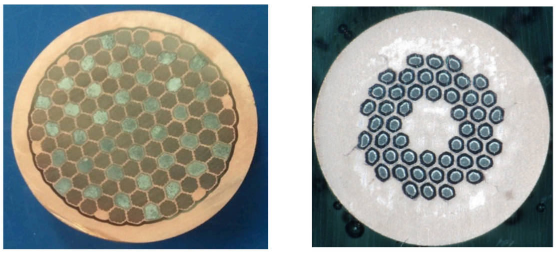
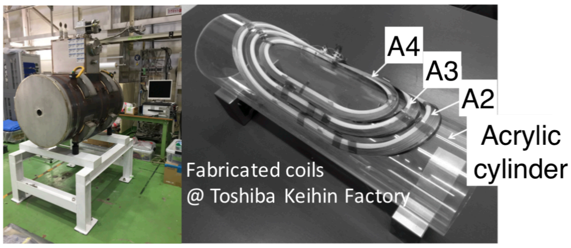


Figure 2: The HiLumi LHC interaction region with contributions from partners

In addition to the project specific R&D described above Japanese E-JADE partners, with industry, carry out more generic magnet technology development. The most prominent programmes are related to Nb3Sn developments as a joint R&D activity between CERN, KEK and Tohoku & Tokai Universities with Japanese companies, as well as R&D on radiation resistant HTS magnets.



Nb3Sn conductor by JASTEC & Furukawa



HTS 3T Dipole with COSθ windings

Figure 3: Examples of superconducting magnet R&D

The former programme is planned over 4 years and the two manufacturers are already active. Conductors are provided to KEK, CERN and Tokai University for further characterization. The HTS programme covers use of new materials, process R&D and irradiation for qualification and tests. More information can be found in [2].

4. HIGH GRADIENT STRUCTURES

High accelerator gradient is pursued for all accelerators, being circular or linear. Related to ILC the use of Super Conducting RF is studied and developed in great detail (E-JADE WP3). In this report we briefly summarize common work between European groups and KEK-Japan on normal conducting RF structures at X-band frequencies (~12 GHz is used), where KEK has been and remain a key partner and developer. Normal conducting structures can reach 100 MV/m gradient with usable pulse-lengths (~200ns) and acceptable breakdown rates. R&D in such structures are carried out to further optimize the basic design, reduce constructions costs, and understand the basic mechanism limiting further increases of the acceleration gradient.

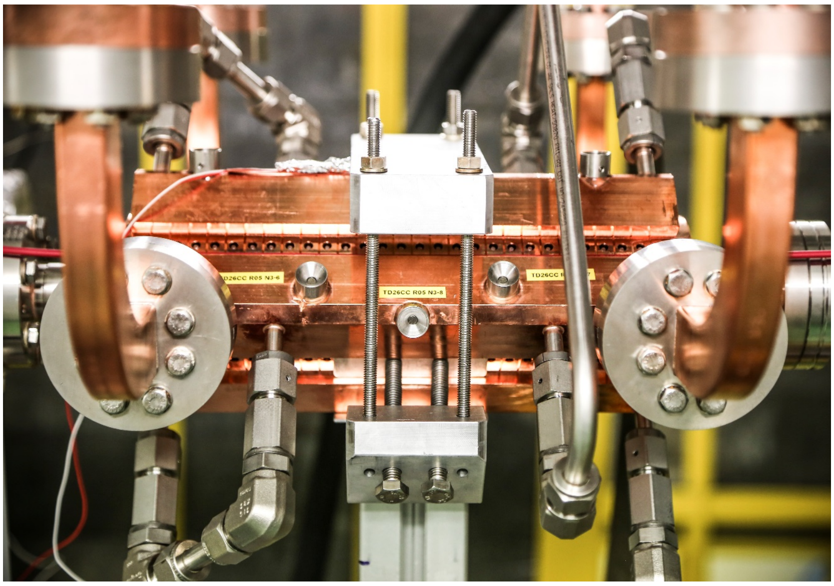


Figure 4: Xband RF structure

The KEK NEXTEF facility carries out a test programme for X-band single cell and complete structures. The samples tested are developed in-house, in Japanese industry or with international partners, most notably SINAP (Shanghai Institute of Applied Physics) and Tsinghua University in Beijing. The overall programme is carefully coordinated with similar tests and sample developments at CERN and SLAC (Stanford). The E-JADE programme is used extensively and consistently to support the necessary exchange of personnel to carry out the common R&D programme. More details about the R&D can be found in [3].

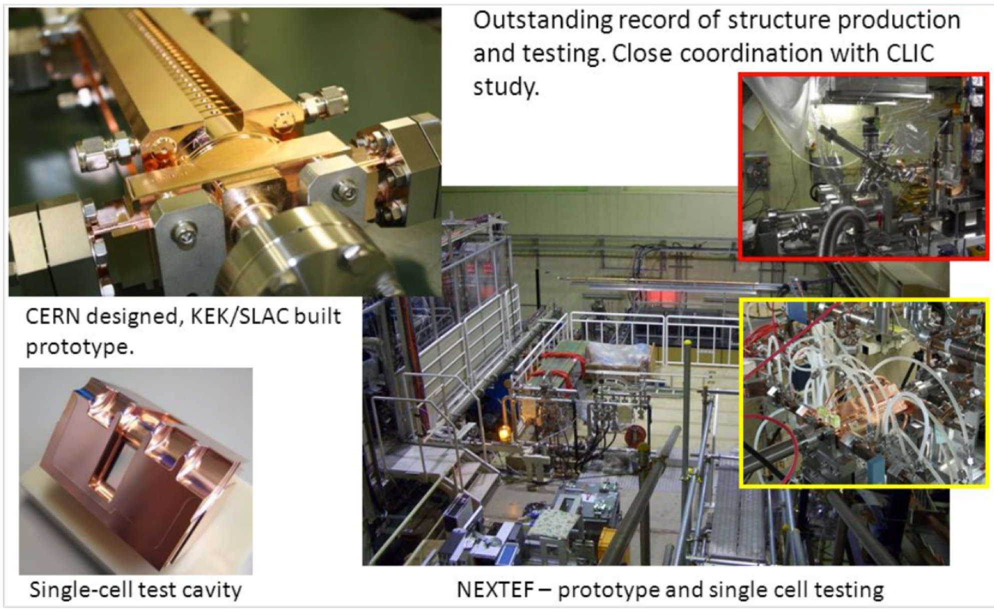


Figure 5: The NEXTEF test-system at KEK has been, and remains, one of the most central development centers for X-band technology for a decade, see summary of test results in next figure.

The results of X-band structures tests at KEK and CERN showing the importance of the collaborative R&D between the partners are summarized in figure 6. The results are combined to provide an overall picture of the performance of the technology and how R&D can be used to optimize design, processing and test-procedures for X-band high gradient structures.

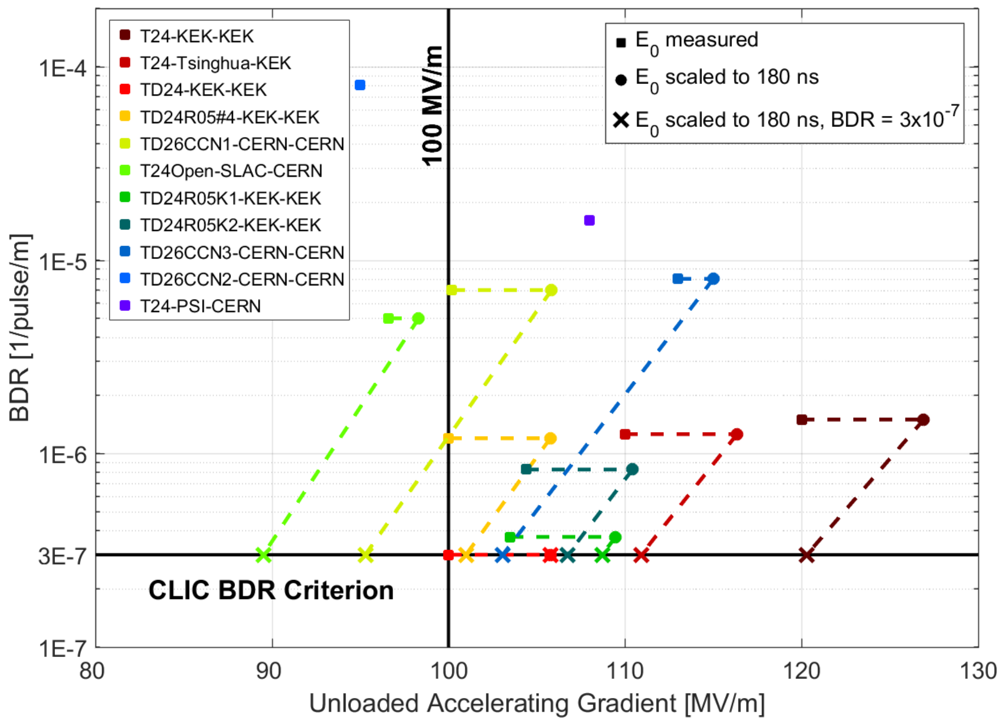


Figure 6: The performance of X-band structures can be characterized as achieved gradient (MV/m) at a given breakdown down rate (BDR/pulse/m) at the appropriate pulse-length (180ns)

REFERENCES

Ref [1]: KEK report on the separation dipole work, Nov 2017
Ref [2]: KEK report on R&D on magnets, Nov 2017
Ref [3]: CERN and KEK reports on high gradient R&D, Nov 2017