OVERVIEW OF REGIONAL INFRASTRUCTURES FOR SCRF DEVELOPMENT

Carlo Pagani, University of Milano and INFN Milano - LASA, Italy

Abstract

The perspective of building the International Linear Collider, ILC, as a global project based on the SCRF technology, which has been pushed in the last decades mainly in Europe by the TESLA Collaboration, imposed to the other two Regions, America and Asia, the investment of consistent resources to locally develop with industry the capability of handling the "cold" technology. Following the success of TTF at DESY, and before of LEP II at CERN and CEBAF at TJNAF, large dedicated infrastructures are being created at Fermilab and KEK. The new regional infrastructures, together with the existing ones, will form the basis for the realization of a global machine, with a single design and distributed production of the key components. In this paper the importance of the SCRF infrastructures is discussed, and their status and plans are outlined.

INTRODUCTION

Since the early 70s, Superconducting RF, SCRF, has been introduced in the particle accelerator community as a promising technology to efficiently transmit energy to a variety of particle beams.

When a superconductor is exposed to a time varying electromagnetic field the electrons which are not coupled as Cooper pairs lead to energy dissipation in the shallow London penetration depth. Nonetheless it was soon realized that in the practical frequency range of RF accelerators the theoretical surface resistance is order of magnitude lower than in a normal conductor, widely compensating for the required cryogenics and leading to an increase of the overall plug to beam power conversion efficiency [1].

A few laboratories and universities started fundamental investigations and experiments to demonstrate the technical feasibility of SCRF acceleration. Very rapidly the results reached severe technological limitations, mainly due to the modest purity of the superconducting material being used to produce the cavities prototypes. Moreover, to approach the theoretical limits, it also turned out that all the cavity fabrication process and handling were not adequate to preserve the purity of the few tenths of nanometres layer at the cavity surface.

In spite of these limitations, in the middle 80s two major laboratories, TJNAF in US and CERN in Europe, planned to build large accelerators based on SCRF technology. To overcome the limitations faced so far by this technology, an impressive effort was performed in setting up large dedicated infrastructures to define and control the production parameters at the basis of the modest performances.

The construction and operation, in strict collaboration with industry, of hundreds of moderate gradient (5-8 MV/m) cavities at TJNAF for CEBAF [2] and at CERN for LEP II [3] has been the basis for setting a new level of quality control and industrialization. In particular the successful technology transfer was possible because of the large effort dedicated in defining reproducible production parameters making use of the large dedicated infrastructures set up for this specific purpose.

A deeper understanding of the limiting factors contributed then to revise the SCRF technology further, in order to be compatible with the new challenging demands emerging from the High Energy Physics community.

The TESLA challenge to use SCRF as the basic technology for the future TeV e+e- Linear Collider impressed the momentum to move SCRF Technology to a new frontier, opening a new era

- Accelerating fields exceeding 35 MV/m
- Quality factor higher then 10^{10}

As for the past experience, the great success of the TESLA Collaboration was mainly determined by the consistent investment, in term of both resources and experienced persons, in setting up at DESY, the host laboratory, a dedicated infrastructure that was designed to include all the past experience. This infrastructure - called TESLA Test facility, TTF - combined most of the existing know-how and has been the "school" were most of the new SCRF scientists have been formed.

The success of TTF opened the way for a consistent proposal of the TESLA Liner Collider, presented to the International Community in March 2001 [4]. To perform a realistic costing of TESLA, industry has been included in the process, initiating the technology transfer in view of a large scale production. Process parameters defined in the TTF infrastructure went through a deep analysis made by industry for cost estimation and a few suggestions became part of the baseline design.

In August 2004, the ITRP (International Technology Recommendation Panel) unanimous recommendation of basing the next International Linear Collider, ILC, on the TESLA "cold" technology has been the successful end of the TESLA experience, while opening a new era where the SCRF technology is considered the right choice for most of the new accelerator projects.

The TESLA Collaboration achievements, together with the experience on large existing cryogenic infrastructures, brought most of the accelerator community to be confident that SCRF Technology can be reliably applied for a cost effective accelerator design. In fact, at the present technology level, the SCRF is respecting the original promise of being competitive in term of investment cost, while giving better conversion efficiency and lower operating costs.

Since the decision for the TESLA technology, the Global Design Effort, GDE - which was established for the design and costing of the ILC - is the driving force for the coordination of the worldwide initiative addressed to the regional distribution of the SCRF know-how and its development to the level required for ILC. In this context the new regional infrastructures in construction at Fermilab and KEK are expected to play the central role.

TTF AT DESY

The origin and rationales

In July 1990 the first TESLA Workshop was organized at Cornell by H. Padamsee and U. Amaldi. Two years later the TESLA Collaboration was set up at DESY with the aim of demonstrating that a SCRF-based TeV e^+e^- Linear Collider could have been superior.

The baseline idea was simply that pushing to the limit the niobium SCRF technology, accelerating field up to 50 MV/m could be conceived, with efficiency from plug to beam power much higher than any other NC competitor [9].

Three were the major challenges of this scheme:

- Push the gradient to at least 25 MV/m, at high Q.
- Reduce by a factor of 20 the linac cost per MV.
- Develop the technology for pulsed operation.

Taking advantage of the experience of all the major laboratories investing in this technology, an optimum cavity design was developed and a large infrastructure was set up at DESY, TTF, for the cavity processing and test. Stiffening rings were included in the cavity design to minimize the effect of Lorentz-force detuning in the high power pulsed regime. The major contributions came from CERN, Cornell, DESY, CEA-Saclay and INFN, but important inputs from TJNAF and KEK were essential.

To prove the TESLA concept long cryomodules were required for high filling factor. INFN, supported by FNAL and DESY, developed with the Italian industry a new concept of an eight-cavity cryomodule with outstanding cryogenic efficiency. Module assembling facilities and a shielded area to operate the linac prototype were then included in the TTF Infrastructure.

Infrastructure descriptions

The schematic layout of the TTF infrastructure is presented in Fig.1. It was designed on the basis of the experience from the preceding infrastructures, mainly from CERN, to cover the following four major functions:

- Cavity inspection and processing.
- Cavity test.
- String and module assembly.
- System test in a prototype linac with beam.

The infrastructure design and construction has been performed to control and define all the process parameters in order to optimize the SCRF technology while preparing the required documentation for a smooth technology transfer to industry. A reproducible mass production according to the highest standards in term of QC (Quality Control) and QA (Quality Assurance) was mandatory.

Limiting the short description to the cavity inspection and processing, the most significant steps and apparatus are listed in the following.

- Niobium material inspection with an Eddy-current scanning system to detect major inclusion and forcing producers to a higher level of quality control.
- Inspection laboratory for control and acceptance of the SCRF cavities shapes and EB (Electron Beam) welds by the industry, according to a detailed specified procedure.
- Cavity tuning equipments to reliably converge to a straight tuned cavity, with a flat field distribution.

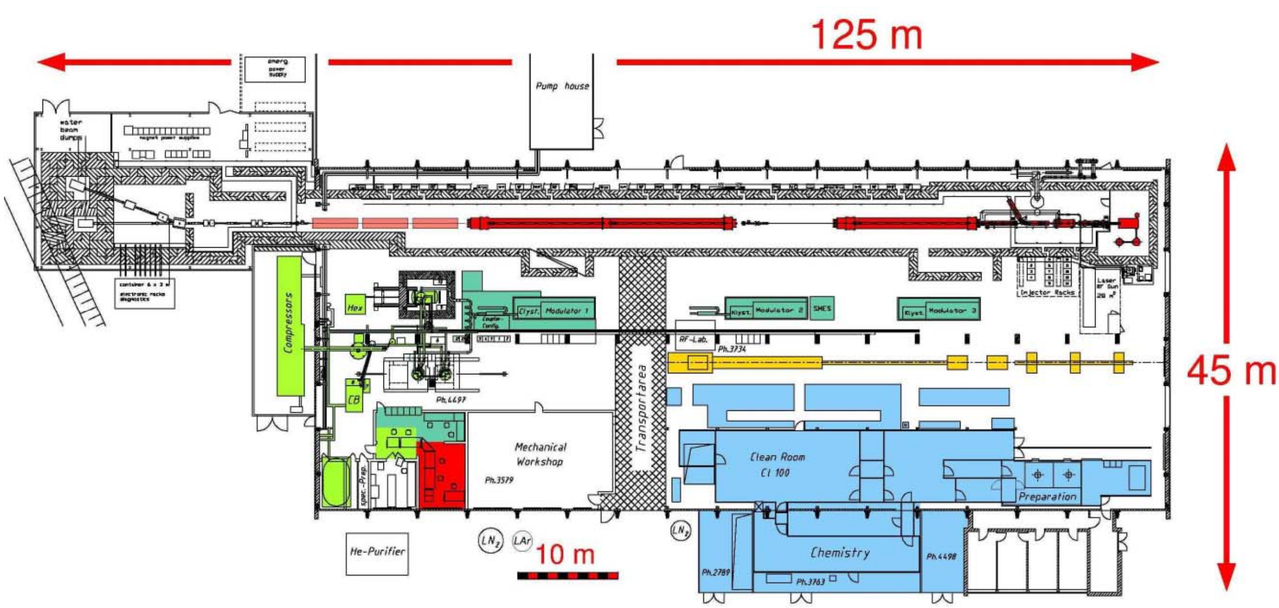

Figure 1: Schematic layout of the TTF original infrastructure at DESY, dedicated to the development of the TESLA SCRF Technology for the realization of an e+e- Linear Collider. The major components are shown in the drawing for size and location wile their short description is given in the text.

- Large class 100 clean room infrastructure for treated cavity preparation, ancillary integration and cavity string assembly. Class 10 areas are also included.
- Closed loop chemical plant connected to the clean room and the ultra high pure (18 MΩ cm) water purifier.
- High pressure ultra pure water rinsing in the clean room area for the subsequent clean drying.
- High temperature vacuum furnaces for hydrogen desorption and stress release (800 °C), and for niobium post-purification for thermal conductivity enhancement (up to 1400 °C).

While not described in this paper, I want to point out that also the other three functions of the infrastructure proved to be essential for setting the SCRF technology. A complex superconducting linac as ILC requires the same level of QA and QC all over the process, which includes cavity tests, ancillary integration, module assembly and linac operation.

Test results and open questions

More than 120 TESLA type cavities have been so far produced by the European industry and have been processed in the TTF infrastructure at DESY. The learning curve has been quite fast, demonstrating the success of the international effort dedicated in the infrastructure design and operation.

Figure 2 shows the vertical test results from the 3rd production batch, i.e. at the end of the learning curve. A very low residual resistance (few nΩ) was measured and the field emission onset was pushed up to around 20 MV/m. The Q drop at high fields was still not cured [5].

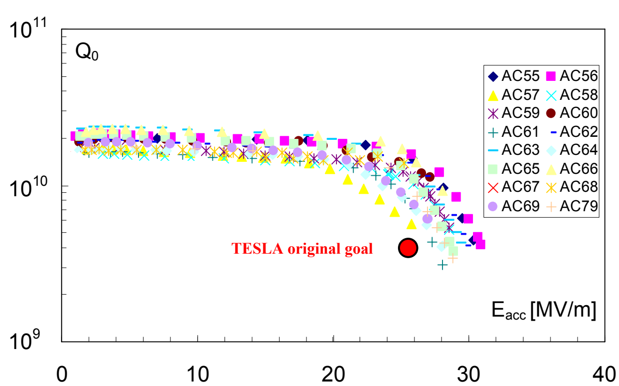

Figure 2: Vertical test results of the TESLA 9-cell cavities from the 3rd production. Standard BCP was applied.

The following steps to approach the physical limits for niobium were mainly determined by the combined introduction of two new ideas originated by the ongoing R&D effort at KEK and CEA-Saclay:

- Electro-polishing (EP) instead of BPC to process the cavity active surface in order to smooth out asperities and improve the effect of HPR [6].
- Moderate temperature baking (100-140 °C) in ultra-high vacuum to re-distribute oxygen in the surface, to mitigate resistive effects [7].

The application of EP raised the onset of field emission, while the moderate temperature baking cured the Q drop. These two very important results from the R&D activity for high gradient were independent but, because of the better quality of the electro-polished surface, baking is simpler and more reproducible for the EP cavities.

Figure 3 shows the tests results of one of the best TESLA EP cavities, as an example of the cure of the Q drop at high field by 120 °C baking. This cavity was electro-polished at DESY in an infrastructure upgrade that was built according to the experience and parameters developed at KEK. The outstanding results of this cavity, AC70, were obtained avoiding the 1400 °C heat treatment, thus giving a proof that the niobium quality has been substantially improved by industry [8].

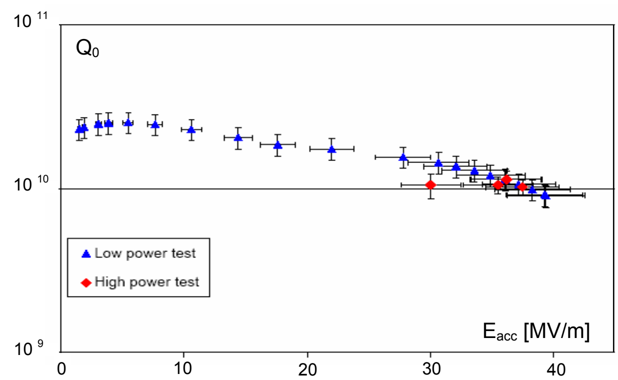

Figure 3: Low and high power tests of AC 70 at DESY.

In spite of the very successful results that have been at the basis of the "cold" decision for the ILC, a lot of work has still to be done for reproducibility. Figure 4 gives an impression of this problem sowing all the TESLA cavity test results. On each cavity several tests have been performed, slightly modifying process parameters.

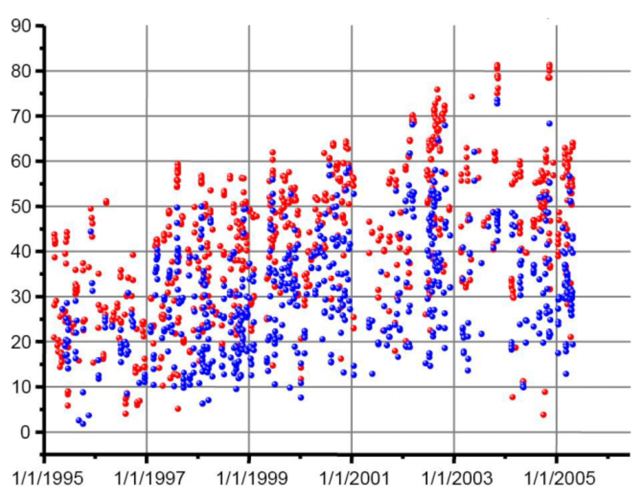

Figure 4: Plot showing the results of all the cavity vertical tests performed in the TTF infrastructure up to mid 2005. Vertical scale is the surface peak electric field [units of MV/m]. For each test the red dot is the maximum field achieved by the cavity and the blue one the field emission onset.

NEW CMTB AT DESY

The decision to transform the TTF linac into a VUV FEL user facility left a limited space for cryomodule test in TTF. Moreover, the preparation phase of the European XFEL was asking for a more continuous availability of tests to define details and gain experience before the construction phase. A new dedicated infrastructure has then been built at DESY, named CMTB (Cryo-Module Test Bench). Commissioning started in mid 2006 and the first complete cryomodule, the so-called #6, has been installed in the following October. The testing program, which includes 10 cool-down / warm-up cycles, is successfully under way in these days.

Figure 5 shows a picture of the CMTB bunker during the installation of the cryomodule #6. By February 2007, 10 cool-down / warm-up cycles will be completed.

Figure 5: CMTB at DESY during the installation of the first cryomodule in October 2006.

Testing a cryomodule in CMTB instead than in TTF turned out to be very efficient. The fact that in the CMTB no beam is available surely limits the completeness of the tests, but conversely CMTB is the right place were the behavior of one complete module, with all the active components installed, can be checked with more diagnostics and in a much shorter time.

SMTF AT FERMILAB

Following the decision of basing the ILC on the TESLA Technology, DOE funded US laboratories to create a large regional SCRF infrastructure at Fermilab, the chemical treatment plants being implemented at ANL to take advantage of the existing facilities and expertise. DESY, INFN and KEK are collaborating to this effort [9].

The new SCRF infrastructure is being located in the Fermilab Meson area. Its mission is going beyond ILC and includes the development of the technology required for a possible high intensity proton linac, also based on SCRF. The sketch of this facility, called SMTF, is presented in Fig. 6 in the version proposed to the DOE for funding.

Limiting the discussion to the ILC related activities, this new regional infrastructure will be including all the functionalities implemented in TTF, apart from chemistry at ANL. The TTF experience is at the basis of the Fermilab design and the technology transfer inside the TESLA Collaboration is being very fruitful.

As for TTF, the ILC Test Area (ILCTA) will include an accelerator called ILCTA_NM. In the first phase, the accelerator will be composed of an electron photo-injector (TTF type) and one ILC RF Unit. An ILC RF unit consists at present of three cryomodules housing 24 cavities powered by a single large klystron and modulator. The electron beam will be provided by an RF gun. The first cryomodule for the ILCTA_NM will be built from a "kit" of parts supplied by DESY and INFN. The kit will include eight fully dressed cavities from DESY and a cold mass built by the Italian industry using the INFN support and drawings. Assembly of the kit will take place at FNAL in the MP9/ICB Cryomodule Assembly Facility. The current schedule envisions this cryomodule to be ready for testing in June 2007. The second cryomodule for the ILCTA_NM will be built using TESLA cavities, processed with US facilities, and housed in a TTF Type III cold mass, produced in Italy by INFN. Coaxial blade tuners will be used for coarse and fast cavity tuning.

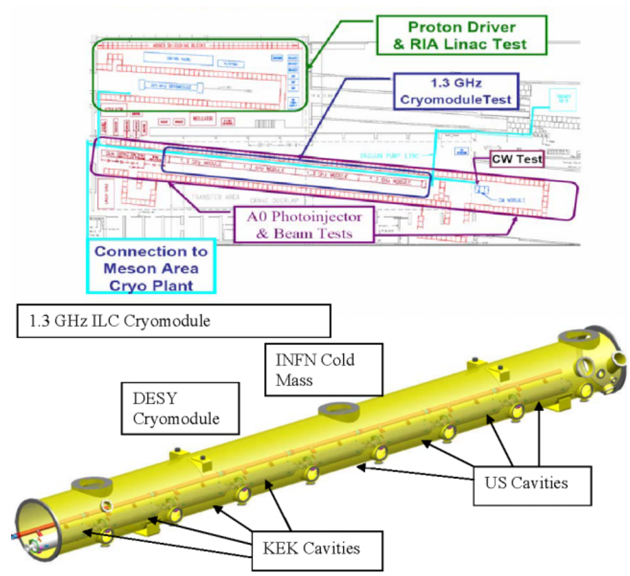

Figure 6: SM&TF Layout Concept at the Fermilab Meson Area, as presented to DOE for funding.

In addition, Fermilab is completing two other test areas: the Vertical Test Facility (VTF) for the testing of "undressed" superconducting cavities at low power, and the Horizontal Test System (HTS) for the high power testing of the "dressed" cavities. These two facilities will be fully operational very soon.

STF AT KEK

The Superconducting Test Facility, STF, under construction at KEK is also similar to TTF. A large dedicated area has been refurnished to allocate the clean room, the module assembly tools and the cryomodule test area with beam. Cavity processing is basically performed in collaboration with industry, following the same scheme successfully applied for TRISTAN. The existing R&D facility, famous for its outstanding achievements, has been partially renewed for research on single-call cavities, support to industry, cavity tumbling and vertical tests [10].

In the first phase, to speed up the learning process, the Type III TESLA cryomodule has been taken as reference for an independent development with industry of two short cryomodules allocating 4 cavities each. These two modules have been recently assembled and tests will start in spring 2007. For the first test just one cavity has been installed in each module, the first of the standard TESLA design and the second of the low losses "Ichiro" type. The status at the time of this conference if presented in Fig. 7.

Figure 7: Installation of the first two short cryomodules in STF at KEK, as in January 2007.

After the experience with the short cryomodules KEK is expected to actively joint Fermilab and INFN in the common development of the Type IV cryomodule that should be the first global prototype for the ILC. The importance of this Japanese strategy is going beyond the national interest. In fact with this strategy KEK could anticipate the system test of different solutions for the cavity design and for their major ancillaries, namely power couplers and tuners. The strong connection with industry is in progress and the participation of other group from Asia is growing, moving the system in the direction of the creation of a fully regional Infrastructure.

OTHER MAJOR INFRASTRUCTURES

Among the many other infrastructures for SCRF development it is worthwhile to quote at least the ones that are substantially contributing on the optimization of the ILC cavity design and processing and/or on the design and test of the cavity major ancillaries. The, although partial, list includes certainly, in alphabetic order CEA-Saclay, Cornell, INFN-LASA, Jefferson Lab and LAL-Orsay.

Through the ILC-GDE a better coordination among the different infrastructures and activities is in progress and the proposal for a second large regional SCRF infrastructure, to be located at CERN, is under discussion for an EU funding request.

CONCLUSIONS

As TESLA in the past, ILC is now leading a consistent worldwide coordinated effort to move the SCRF technology to the level required to build a "cold" Linear Collider, fully fabricated by industry and with the production of the major technologically appealing components distributed among the three Regions (Europe, America and Asia).

In spite of the fact that most of the recent accelerator projects, under construction or being proposed, are extensively using SCRF technology, the TESLA/ILC driven activities are still leading the R&D process for a high quality industrialized product at a moderate cost.

Industry is already producing turn-key reliable systems, including SCRF cavities and cryogenic ancillaries, but their cost and performances are not fully compatible with the requirements for the new large accelerators. The European X-FEL could possibly represent the first large scale applications based on the high gradient technology developed for the Linear Collider. Its realization would represent for Europe the best possible Regional Infrastructure for the ILC.

REFERENCES

[1] H. Padamsee, J. Knobloch and T. Hays, "RF Superconductivity for Accelerators", John Wiley & Sons, 1998.
[2] C. Reece, Proceedings of SRF Workshop 1999, Santa FE, NM, November 1999.
[3] P. Brown et al., Proceedings of SRF Workshop 2001, Tsukuba, Japan, November 2001.
[4] R. Brinkmann, et al. (editors), TESLA - Technical Design Report, volume II. DESY, March 2001. ECFA 2001-209, TESLA Report 2001-23.
[5] B. Aune et al. Phys. Rev. ST-AB, 3(9), September 2000. 092001.
[6] K. Saito et al., Proceedings of SRF Workshop 1997, Abano Terme, Italy, October 1997.
[7] B.Visentin, Proceedings of EPAC 1998, Stockholm, Sweden, May 1998, p. 1885.
[8] L. Lilje et al., Nucl. Inst. Meth., A 524 (1-3); 2004;
[9] S. Mishra, This Conference
[10] H. Hayano, This Conference