IMPACT OF CARE - SRF ON FLASH / XFEL AND OTHER PROJECTS

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Abstract

CARE (Coordinated Accelerator Research in Europe) [1] describes a collaboration which aimed at improvements of existing accelerator facilities. It was supported by the European commission in the framework of FP6. The dominant R&D activities within CARE were related to superconducting accelerator systems, especially TTF / FLASH [2]. This report will describe the different SRF activities (cavity fabrication technologies, surface treatments and inspection, industrialisation of electro-polishing, coupler and tuner developments, Low Level RF concepts and beam diagnostics). The most important advances will be high lighted and the impact to new or future SRF accelerator systems will be concluded.

INTRODUCTION

The JRA-SRF [1] has been active from 1.1.2004 until 31.12.2008. The purpose was to enhance the performance of superconducting cavities and related auxiliaries for the operation of a superconducting electron linac. Also innovative and promising technologies were investigated. A direct impact is expected for the operation and performance of FLASH. But new, e.g. XFEL [3] or future superconducting accelerators (e.g. ILC [4] or energy recovery linacs) will benefit from the R&D efforts in JRA-SRF.

In total 8 partners were involved in the JRA-SRF: CEA, CNRS-Orsay, DESY, INFN (INFN-LNL, INFN-Mi and INFN.Ro2), TUL (Technical University of Lodz), IPJ (Swierk), WUT-ISE (Warsaw University of Technology) and PSI. In addition four industrial partners were attached to JRA-SRF (ACCEL, WSK, ZANON and Henkel). The total cost of this activity was around 20 M€ including a support of 5 M€ by the European Commission (EC).

The development of superconducting electron linacs has been pushed in Europe for more than 10 years. A major milestone of this activity was the foundation of the TESLA collaboration [5]. The aim of this collaboration was to prepare the technical competence for the construction of a possible high energy physics collider with an energy reach of 500 GeV with possible extension to 1 GeV. This collaboration joined laboratories from Europe, USA and Asia. The central R&D superconducting linac installation was the TESLA TEST Facility TTF at DESY.

In 2004 the International Technical Recommendation Panel ITRP has recommended the superconducting solution for the linac technology for a future High Energy Physics linear collider. As a direct consequence the International Linear Collider effort ILC was founded. Based on the technical expertise of TESLA ILC initiated a global design effort for a 1 GeV collider.

Although the TTF/FLASH linac at DESY has become a FEL user facility, it also serves as test bed to gain operating experience for new linac components. The TTF test infrastructure is a unique installation for preparation and testing of superconducting 1.3 GHz cavities. In the last years the main activity at DESY was devoted to prepare the technical knowledge for the construction of XFEL, a superconducting based new light source. The construction of XFEL started in 2008.

SUMMARY OF MAIN ACHIEVEMENTS

JRA-SRF activities covered a large field of R&D areas for design and performance improvements of superconducting cavities as well as upgrades of additional components related to the operation of superconducting RF accelerating systems. The main advancements are

- An electropolishing (EP) system for processing of 9-cell cavities has been designed, built and operated at DESY
- The technology of EP has been successfully transferred to industry (two companies in Germany)
- Two different tuning systems for SC cavities has been optimized and were finalized by adding fast tuner mechanisms
- A new beam position monitor for operation at cryogenic temperatures was designed, built and successfully tested in Flash
- A new non intercepting beam emittance monitor, based on Optical Diffraction Radiation ODR, was designed, built and successfully tested at FLASH
- New strategies for high power coupler conditioning were developed which dramatically reduce the effort of coupler training
- Several new hard and software components for the low level RF control (LLRF) were developed, built and successfully implemented in FLASH
- A superconducting SQUID scanner for quality control of Niobium sheets was built and demonstrated superior sensitivity as compared to the standard normal conducting Eddy current device.

- The technology of seamless cavity fabrication was developed and a first 9-cell prototype could be built and was successfully tested
- The technology of large grain and single crystal cavities has been advanced and several prototypes were built and tested
- Dry ice cleaning was applied to cavities and RF guns as a novel method to purify surfaces without the need to use water
- An novel electrolyte for electropolishing without use of hydrofluoric acid has been proposed and was successfully explored on samples

MAIN IMPACTS OF THE JRA-SRF ACHIEVEMENTS

The impact of the JRA-SRF achievements can be grouped in two categories:

A) The design, functionality, treatment and performance of hardware or software have reached a mature state. In these cases components or treatments can directly be used or applied for infrastructures which are operating (such as FLASH), are under construction (such as XFEL) or are under planning (such as ILC). Examples are:

- The cavity / helium vessel design was optimized in respect to cost effective fabrication and for high mechanical stiffness (in order to minimize the effect of Lorentz detuning). This design will be used for possible upgrade of FLASH and also partially for the fabrication of XFEL cavities and for the design of ILC modules. For any new pulsed superconducting electron linac this design will be first choice.

- The standard electro polishing (EP) procedure for multi-cell cavities was finalized and is in operation at DESY for more than 150 cavities. This technology was successfully transferred to industry and can be "ordered" now by any present or future project. The European industry now is leader in the industrial EP technology.

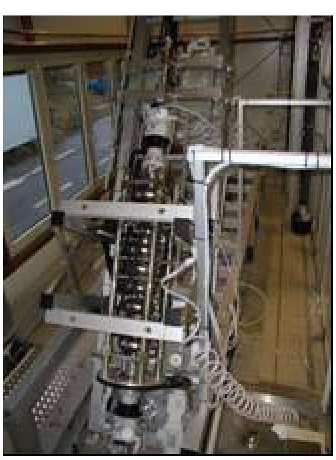

Figure 1: Electro polishing installation at DESY. This system has been copied by industry (ACCEL, Henkel).

- Niobium sheets are scanned for material defects by Eddy current devices. A superconducting SQUID detector should result in a higher sensitivity as compared to the normal conducting pick up coil presently under use. In cooperation with the company a novel SQUID scanner was designed, built and tested. The sensitivity of the SQUID scanner about a factor of 4 higher when comparing the depth of detection of a 50 µm size calibration defect in the Niobium sheet.

Figure 2: SQUID scanner

- The design and optimization of slow and fast cold tuning systems for cavities is finalized and was approved by prototypes. Two versions are available: tuning mechanism is placed at the end or at the middle of the helium vessel. The first one is the standard solution for FLASH and XFEL type accelerators. The second one is first choice for accelerators where the absolute length is critical, e.g. ILC.

Figure 3: New tuning system for ILC type applications.

- A new type of beam position (re-entrant type of cavity) was designed, built and successfully tested at FLASH. This monitor complies with the requirements of class 100 clean-room assembly conditions and also meets the resolution specification of the XFEL. It was decided to use this monitor in FLASH. At present this monitor is the only choice for use in superconducting accelerators similar to XFEL.

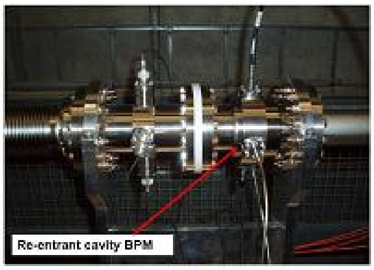

Figure 4: New re-entrant cavity beam monitor for XFEL

- The technology for production of seamless cavities has been finalized. A patent has been granted for this new fabrication technology. Seamless tubes are fabricated by a combination of back extrusion and flow turning. A computer controlled hydraulic machine forms cavity cells from these tubes. The material properties, specification and the forming parameters are well understood and defined. A first 9-cell hydroformed cavity has been successfully tested at a high accelerating gradient of 30 MV/m. This fabrication method is ready to be used in cases where welding defects limit the performance of superconducting cavities. Europe is definitely the leader of this technology.

Figure 5: Hydro-forming apparatus for the production of seamless Niobium cavities

- The objective of the Low Level RF Control (LLRF) has been to advance RF Control Technology in the areas of hardware and software to meet the requirements for linear collider and linac based free electron lasers (FEL and XFEL). The work has been focused on the following topics:

o Pushing the envelope of technical performance such as field regulation close to the operational limits of the cavities and high power systems

o Compatibility with tunnel installation including low maintenance and radiation tolerance

o High degree of automation for large scale system for adequate operability of large scale systems

o Reliability and availability optimization in connection with cost reduction

Overall the LLRF hardware and software currently implemented at the RF Gun and at the first cryomodule at FLASH as the result of the LLRF work in FP6 are considered pioneering work in this field. While several other labs and industry just started to follow the hardware development in this area, the software developed and evaluated in this framework has not only improved the field regulation but also paved the way to high availability, simplicity of operation, and exploration of operation close to the performance limits of cavities and high power systems.

- Input coupler conditioning can be time consuming and has the risk of breaking the RF window. New strategies have been developed and resulted in considerable reduction of conditioning time. This achievement is based on three components: stringent quality control during fabrication, applying clean-room technology

B) There are interesting and promising achievements which need additional R&D effort beyond CARE or cooperation with new partners or industry. Examples are:

- The standard fabrication technology of Nb cavities is to form and weld sheet material of small grain structure. The intrinsic superconducting materials parameters of Niobium might be reduced by the many intermediate steps of forging, baking and etching. Large grain or even single crystal cavities are formed by starting with Nb sheets being cut from the highly purified ingot row material. JRA-SRF has fabricated and tested very successfully several large grain 9-cell resonators and also single cell single crystal cavities. A patent has been granted to the fabrication technology of single crystal single cell cavities. The breakthrough of this novel technology requires R&D effort by the Niobium industry for large scale production of appropriate ingot raw material. This would revolutionize the Niobium cavity fabrication with respect to fabrication cost and cavity performance. JRA-SRF has created one of the world leading centers of excellence in this field.

Figure 6: Single crystal Niobium cavity.

-Dry ice cleaning is an alternative method to high pressure water cleaning. An experimental set up for dry ice cleaning has been built and was operated in order to determine the optimum parameter set. Sample investigations demonstrated that the dry ice cleaning effect is superior to the high pressure water process. But this benefit could not be verified with Niobium cavities. However dry ice should be an optimum choice where the use of water is not recommended. This is the case for the normal conducting copper RF gun cavity where the water jet would oxidize the copper surface. As first experiment the RF gun of FLASH has been cleaned by the dry ice method. The dark current of the RF gun could be substantially reduced by this procedure. This positive proof of principle experiment will initiate an activity to optimize the dry ice cleaning apparatus for RF gun cleaning. This effort will be beyond CARE but is an example of spin off technology from CARE activities.

Figure 7: Nozzle of the dry ice cleaning apparatus.

- The standard electropolishing electrolyte is based on hydrofluoric acid (HF) which is very toxic. JRA-SRF has investigated HF free electrolyte. The most promising alternative is based on Chocline which forms an ionic liquid. Intensive studies with samples explored the parameter space of this solution (one PhD work). The surface of samples is very shiny, which is considered to be a necessary condition for good RF performance. The transfer of this technology to cavity application is rather complex and could not be finished within the scope of CARE. TTC (TESLA Technology Collaboration) has recently started a global activity to further investigate this novel EP technology. This is another example of global impact of the R&D work in CARE.

- The characterization of the transverse phase space for high charge density and high energy electron beams is demanding for the successful development of the next generation light sources and linear collider. The interest in a non-invasive and non-intercepting beam diagnostics is increasingly high due to the stringent features of such beams. Optical Diffraction Radiation (ODR) is considered as one of the most promising candidates to measure the transverse beam size and angular divergence, i.e. the transverse emittance. JRA-SRF has developed a prototype of such monitor. An experiment has been set up at DESY FLASH Facility to measure the electron beam transverse parameters based on the detection of the ODR angular distribution. The experiment confirmed that ODR can be used as a non intercepting beam size diagnostics, allowing also the simultaneous measurement of the beam angular spread. The remaining difficulty is to lower the background of synchrotron radiation from bending and quadrupole magnets.

CONCLUSION

The "Joint Research Activity (JRA)" CARE-SRF is an excellent example of a joined R&D activity by several laboratories. It is important to note that the success of SFR-JRA is based on a very active and fruitful collaboration between all partners from laboratories, universities and industries.

The aim of CARE SRF was to improve existing or to develop new components for superconducting radio frequency accelerator systems. There is direct impact to FLASH and XFEL, but many proposed or planned SRF accelerator projects will benefit from the findings of CARE SRF.

The list of CARE SRF documents includes 90 contributions to conferences, 44 CARE reports, 30 publications, 19 CARE notes and 2 patents. All documents are available on the CARE webpage [1]. A compact documentation of all CARE SRF reports and talks is under preparation by the author and should be available end of 2009 on request [6].

The advancements of JRA-SRF further strengthen the European leadership in the field of superconducting electron linacs. Synergetic benefits of the partners will continue even after JRA-SRF ended. The success of CARE in FP6 was a helpful pre requisite for the approval of EuCARD [7], a similar joined R&D activity in the 7th frame work program of EC.

Table 1: Summary of the main JRA-SRF Achievements and their impact on the Scientific Infrastructure.

Selected Achievements	Main improvement	Direct impacted infrastructure	Future impacted infrastructures	Industrialisation
Helium vessel / cavity design	low cost, high mechanical stiffness	FLASH, XFEL	any pulsed SC linac for electrons	
Standard electro-polishing, EP	Industrialisation finished	XFEL	all SC linacs world wide	Tranfered to industry
Tuner design	two designs completed	XFEL	ILC, ALICE, RIB,ERL linacs	
Beam position monitor	high resolution	FLASH, XFEL	ILC, ALICE,ERLs	
SQUID scanner	Higher sensitivity than EDDY current device			Built by industry
Seamless cavity design	no performance limitations by welds	FLASH,	ERLs	Patent granted
Low level RF, LLRF	Advanced design	FLASH, XFEL	ILC, ALICE, RIB,ERL linacs	
Input coupler	Short conditioning time	FLASH, XFEL	ILC, ALIC, ERLs	
Large grain / single crystal cavity	Cost reduction & performance upgrade	FLASH	XFEL,	Patent granted
Dry ice cleaning	New cleaning method without water	FLASH	XFEL, ERLs	
Electro polishing without Hf acid	Avoids chemical hazard	FLASH	all SC linacs world wide	
Beam emittance monitor	Non intersepting monitor	FLASH	ILC, XFEL,	
Cry-Ho-Lab	New SCRF test facility	FLASH	ILC, XFEL, any SCRF project	

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