Large Superconducting Radio Frequency Construction Projects

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Abstract—The SRF achievements of the last two decades will be reviewed; concentrating on the CEBAF, LEP, and SNS projects. The near term new SRF initiatives will also be presented.

Index Terms—Superconducting, CEBAF, LEP, SNS

I. INTRODUCTION

THIS paper will cover the major SRF projects using elliptical cell cavities. It will not try to cover the many projects using low and medium velocity structures (Beta < 0.5).

Pre 1989 there had been four significant worldwide efforts:

- HEPL in the early 1970's
- Cornell cavity beam test in 1984, five-cell 1500 MHz
- HERA 16 cavities, five-cell 500 MHz
- KEK 32 cavities, five-cell 508 MHz

This was followed by two major construction projects: CEBAF at Jefferson Lab and LEP II at CERN. Fig. 1 shows the growth of accelerating voltage with an order of magnitude increase each of the last two decades.^[1]

The break thru that made this possible was the elliptical cavity, which reduced “multipacting”, resonant electron loading of cavities that plagued HEPL.^[2] Fig. 2 shows how cell shapes are being optimized for specific applications. A) is the original 1989 CEBAF/Cornell shape; B) is optimized to minimize the peak electric field in order to reduce field emission, C) is optimized to minimize the peak magnetic field in order to reduce refrigeration losses. If field emission can completely be eliminated, the latter also would provide the highest accelerating gradient.

Fig. 1. Growth of accelerating voltage.

Fig. 2 Three inner cell dumbbells

Manuscript received October 5, 2004. This work was supported by the U.S. Department of Energy under contract #DE-ACO-584ER40150.

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II. MAJOR SRF PROJECTS

A. CEBAF @ JLab

In 1989, construction started on a SRF re-circulating linac,

building on the Cornell effort. CEBAF was originally designed as a Cu water-cooled accelerator, but switched before construction started. It uses 338 cavities at 1500 MHz in a five turn re-circulating linac.^[3] The cavities are housed eight to a cryomodule (CM). Each CM has quick disconnects that permit it to exchange at liquid He temperatures.

The gradient specification was 5.0 MV/m @ $Q_0 = 2.4 \times 10^9$; it achieved 7.2 MV/m.

In 1996, JLab started construction of a second much smaller accelerator, the JLab FEL, Fig. 3. In its initial configuration, it used $\frac{1}{4}$ CM for the injector and one for the linac. Two additional CMs have been added to the linac to raise its energy to 160 MeV. Over the last eight years it has increased the world FEL records by more than 3 orders of magnitude up to 8.5 kW average power at 6 microns.^[4]

Fig. 3. JLab 10 kW IR FEL upgrade

We are continuing to increase performance an order of magnitude every 3 to 4 years. The current specifications are:

- a) 10 kW average, 1 to 14 microns
- b) 3 kW average, 0.3 to 1 microns
- c) 100w broadband 2 to 50 cm^{-1}

B. LEP II @ CERN

In 1989, LEP, the water-cooled Cu electron-positron collider was commissioned. At the same time, superconducting cavity installation started, which eventually led to LEP II. The initial plan was to supplement the accelerating voltage, but by 2000, when it shut down for LHC installation, all of the Cu cavities had been removed to make room for the much more powerful SC cavities.

LEP II used four-cell 350 MHz SRF cavities; four to the CM. Over the 12 years, the upgrade reached 208 GeV in the center of mass. The total accelerating voltage was 3,600 MV at 4 mA (465m at 7.7 MV/m).^[5]

C. TESLA, TTF, VUV-FEL, & X-FEL @ DESY

In 1990, DESY started an international effort to design a TeV superconducting linear collider. The first meeting was held in July-90 at Cornell in conjunction with the bi-annual SRF workshop. A TDR was produced in Mar-01.^[6]

As part of this program, a beam test facility was constructed, TESLA Test Facility (TTF). In 1998, it accelerated electrons with a 100 MeV CM. This facility has continued to grow over the last decade and is becoming an important research tool renamed VUV-FEL. Currently it is being recommissioned for 30 nm FEL ops with 5 CMs. In

2006, a 6th CM will be added to upgrade to 6 nm operation (1GeV).

Fig. 4. VUV-FEL

These efforts have lead to the approval of the European X-FEL.^[7] This is a 3 km long ~ 1000 cavity 17.5 GeV electron accelerator.

D. SNS @ ORNL

SNS, similar to CEBAF and LEP, also started as a water-cooled Cu linac, which in 2000 switched to SRF, six months after CD#3 (construction start). The linac produces 1 msec 1.0 GeV pulses to produce 1MW of neutrons. JLab was asked to join as the sixth member of the national lab collaboration and provide the cryogenics and CMs.^[8]

Fig. 5. SNS Linac

The protons are accelerated to 186 MeV using a RFQ, a six tank DTL, and a four tank CCL. The SRF starts with 11 CMs each with three 10.2 MV/m Beta=0.61 cavities. This is followed by 12 CMs each with four 15.6 MV/m Beta=0.81 cavities. The design permits adding of nine additional Beta=0.81 CM to increase the linac energy to 1.4 MeV and neutron power to 2-4 MW.

III. DOE 20 YEAR PLAN

In 2003, DOE's Office of Science started to develop a new 20-year plan for future facilities⁹. The previous plan, known as the "Trivelpiece Plan", ended with the construction of the SNS.

Approximately 80 proposals were evaluated for "science merit" as well as "readiness" for construction. Twenty-eight projects made the list, which was broken into 12 near-term, 8 mid-term, and 8 far-term, Fig. 6.

Fig. 6. 20-year Facility

A minimum of 7 out of these 28 projects require SRF technology. Including two in the near-term, both of which have been given the go to start design (CD#0).

A. Rare Isotope Accelerator

In a four-way tie for third place is the Rare Isotope Accelerator (RIA).

This fully SRF facility will accelerate ions up thru Uranium with a minimum 400 MeV/u with a beam power of 100 kW CW upgradeable to 400 kW. Protons are specified to reach 1.0 GeV.

Two different designs are being proposed by Argonne National Lab and Michigan State University. For Uranium, one first accelerates two charge states ($q=28$ & 29) to ~ 10 MeV/u and the first stripper. Five charge states ($q=\sim 70$ to 75) are then accelerated to ~ 80 MeV/u and the second stripper. Four charge states ($q=87$ to 90) of an almost fully stripped beam are then accelerated to 400 MeV/u.

Due to the fact that this is an ion accelerator, both designs require about 8 different Betas. The cavity types being proposed include: Fork, Quarter Wave, Half Wave, Multi Spoke, and Elliptical.

B. CEBAF 12 GeV Upgrade

In a five-way tie for seventh place is the CEBAF 12 GeV upgrade. Similar to SNS, the existing facility only fills 20 of the 25 CM slots in each linac. By installing five new CMs each four times more powerful than the original CM, we are

able to double the energy (three times the original 4 GeV specification).

C. Linear Collider

Heading the mid-term list in 13th place is the Linear Collider. This is an electron – positron collider with a length of about 25 km. The International Technology Recommendation Panel (IRTP) just completed its review of the warm and cold technologies and unanimously recommended the SRF option.

This would be a TeV in the center of mass using about 20,000 cavities.

D. Other Projects

The two other mid-term project are upgrades of 1) the SNS, which adds nine CMs in empty slots similar to CEBAF, and 2) the RHIC, which uses e-beam cooling to improve luminosity.

In the far-term is the Super Neutrino Beam; one candidate is the Fermilab 8 GeV proton SRF linac. Another project is RHIC converted into an electron – ion collider; where the e-beam is provided by an SRF linac.

IV. CONCLUSION

With the large number of SRF projects worldwide, in the near future there three major challenges that face us:

1) We need to train an increased workforce

Without the Linear Collider, we need to at least double the number of SRF experts. With it tripling them, they will not be

adequate.

2) *For pulsed Accelerators, we need to improve gradients*

Over the last 15 years, gradients have improved from specifications of 5.0 MV/m to goals of 35-45 MV/m

3) *For CW Accelerators, we need to improve Quality Factor*

Over the last 15 years, Q_0 have improved from specifications of $2.4 * 10^9 @ 5 \text{ MV/m}$ to goals of $1 * 10^{10} @ 20 \text{ MV/m}$. Without this improvement, the refrigeration costs are prohibitive.

Accelerator Conference, Portland, OR, May 12-16, 2004.

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