The Status of RF Superconductivity R & D in China

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Abstract

The recent research and development activities in the field of RF superconducting technology in China are reviewed. New proposed projects are also presented.

Introduction

The study of RF superconductivity for accelerating cavities was initiated by Prof. DingYu at the Institute of High Energy Physics (IHEP) of China early in 1972, unfortunately it has not been carried on until a new project of superconducting cavity of L-band was started at Peking University sixteen years later. Since 1988, the SC group of Peking University has been quite active in studying RF superconductivity and made a number of progresses. Treatments and tests on an L-band Nb cavity from DESY were accomplished in 1991[1]. In 1994, two superconducting cavities with China made niobium were successfully manufactured and tested.[2]. Two new devices, namely the DC photo-electron gun with a 2-Mev superconducting booster section and Cu-Nb sputtering system have been designed, manufactured and installed in 1997[3][4].

In the mid 1990's, three Institutes are involved in the design studies of RF superconducting accelerators for their new projects. The feasibility of a heavy-ion superconducting boosting accelerator with sputtering QWR cavities was studied by the China Institute of Atomic Energy (CIAE) in collaborating with PKU for their proposed project of radioactive nuclear beam facility[5]. A radio frequency superconducting laboratory is planned to be set up for CW FEL studies in the China Academy of Engineering Physics (CAEP)[6], where the liquid helium facility has been installed. The Institute of High Energy Physics (IHEP) and Peking University will collaborate in the research of superconducting structures for the upgrading of BEPC, the t-Charm factory project[7], as well as for a newly proposed project for the treatment of nuclear waste using high current high energy Linac[8] .

1. The R & D on single cell RF Superconducting Cavity

Thanks to the support of the National High Tech Program of China, a laboratory equipped with low temperature facilities and RF apparatus was established in 1988 in Peking University for carrying out experimental studies in the field of RF superconductivity. With the kind help of Dr. Proch, a Nb cavity from DESY was sent to the laboratory to enable us for the first experiment. It was an L-band cavity and was successfully processed and tested. The field gradient reached more than 11 MV/m in 1991 without Q degradation after a number of cycling[1]. Great efforts were then made by the SC group of PKU to develop the superconducting cavity with China made niobium materials from 1992 to 1994. Two 1.5GHz Nb cavities were designed and manufactured in China. Special technologies such as the electron beam welding and heat treatments for the Nb sheets were developed at this stage. One of the difficulties associated with the China made Nb sheet is the low RRR value ranging from 50 to 60. The performance of the material was considerably upgraded with the help of Dr. P. Kneisel of CEBAF that the RRR value was raised to 470 after it was treated with high temperature (~1400 ^{0}C). Fig. 1 shows the thermal conductivity of the Nb sheet before and after the treatment. Based on the above experience, one of the cavities was then treated in KEK with the help of Dr. Y. Kojima, and Dr. K. Saito in Sep. 1994. The RRR of this cavity reached more than 270 and the field gradient increased from 4.5MV/m to 10MV/m, while the Q_0 value from $3x10^8$ to more than 10^9, as shown in the low temperature tests[2]. Main parameters of the cavity are shown in table 1, and Figure 2 is the photo of the cavity, where as Fig. 3 shows the Q versus E peak value verified under 1.8K by CEBAF.

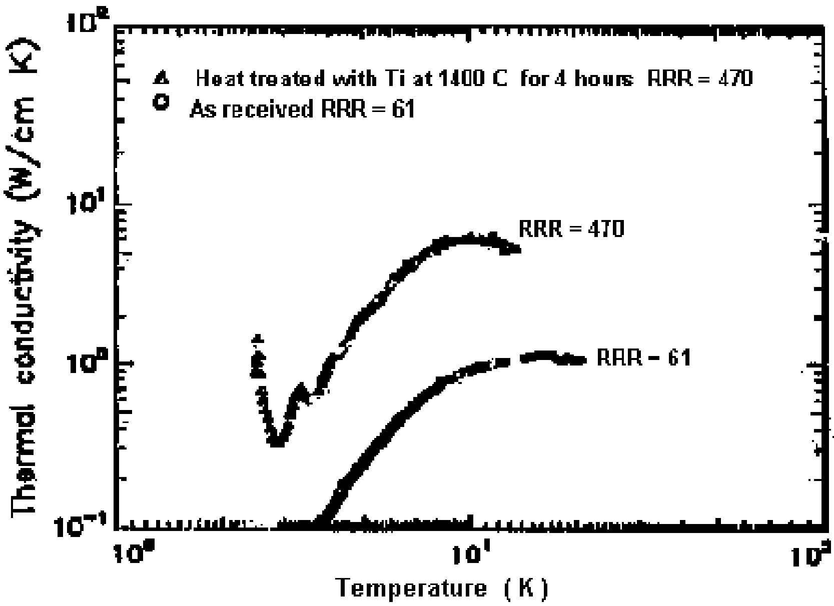

Fig 1 The thermal conductivity of Chinese Nb sheet

Table 1 Main parameters of the SC cavity

F_0	R/Q	G	H_{sp}/E_{acc}	E_p/E_{acc}
1.487 GHz	102	286	41	2.1

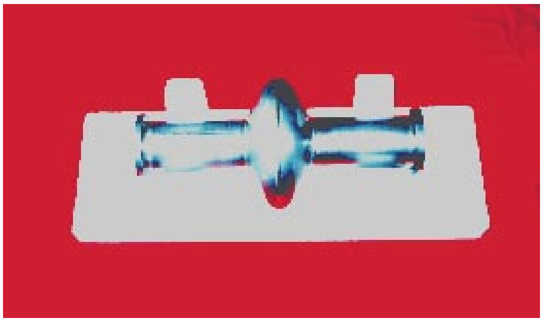

Fig.2 SC cavity made of Chinese Nb

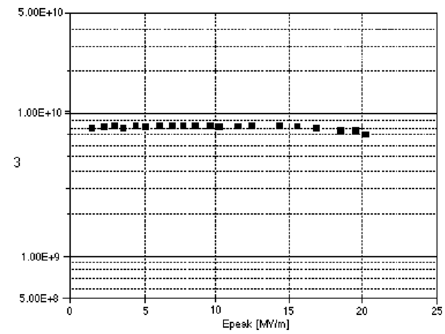

Fig. 3 Q versus E peak value

2. High Brightness Electron Beam Source with an SC Accelerating Section

During the last 10 years, photo-cathode injectors developed rapidly to meet the requirements of high brightness e-beam for the Free Electron Lasers, Linear Colliders, wake field accelerators etc.. A High Brightness and Super-short Pulse Electron Beam Source was developed by the SC Group at PKU. The electron beam is generated by a laser driven photo-cathode and then extracted by a high-gradient DC field followed by an SC accelerating section. In this way, it is expected to provide ps or fs high brightness electron beam either in CW or pulsed mode. Polarised beam can also be provided with special photo-cathode. There are three main energy sections: 10-200KeV, 1-2MeV, and 15-20MeV in the laser-driven source. In the middle of 1997, a laser driven DC photoelectron gun and a superconducting section were set up at PKU. Fig. 4 is the photo of the source, including a cathode-preparing chamber, a DC accelerating chamber and an SC section[3]. Provisions have been made to enable the preparation of the cathode either by ion implantation, CVD or beam enhanced deposition. A number of experiments such as the photo-cathode preparations, the electron beams extraction, and the beam quality diagnoses are being carried out. Preliminary results are rather encouraging.

An SC high brightness electron gun similar to that of PKU is being developed at the China Academy of Engineering Physics for the development of their CW FEL. PKU SC group will collaborate with them on SC cavities. Parts of their low temperature facilities were installed

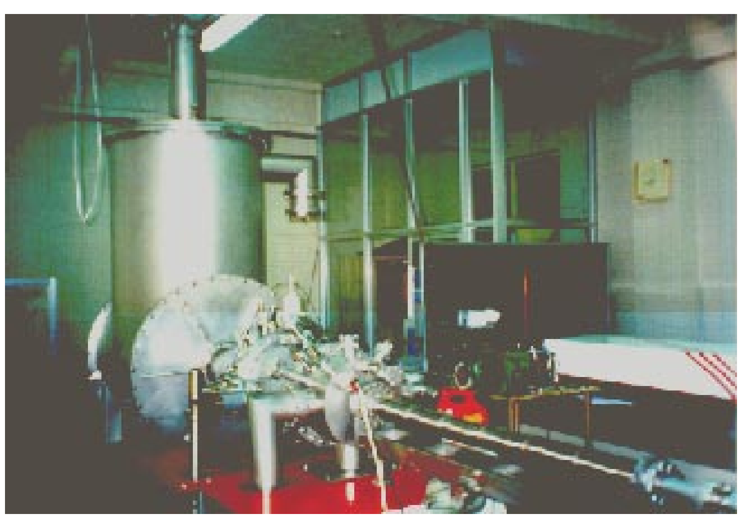

Fig. 4 Photo of High Brightness & Super-short Pulse Electron Beam Source at PKU

3. SC for the Beijing Radioactive Nuclear Beam Facility (BRNBF)

The research and application of radioactive nuclear beams is one of the main future directions of nuclear physics in China. CIAE has proposed to build the BRNBF based on their HI-13 tandem accelerator, and a superconducting heavy ion linac will be used as the post-accelerator[5]. Fig. 5 is the layout of BRNBF. SC group of PKU will take part in the development of the superconducting booster linac. The niobium-sputtered copper quarter wave resonator (QWR) is the first choice for the accelerating structure, since it has good RF superconducting performance and low construction and running cost.

Great progress has been made in the technology of the niobium-sputtered resonator in Europe. Niobium has good mechanical properties but low thermal conductivity, which might induce thermal instability of the resonator and thus increase the danger of quench. One effective way to tackle with the problem is to sputter a layer of high pure niobium, about several microns thick, on to the surface of the OFHC copper cavity, so as to increase the thermal conductivity by about ten times at low temperature.

The SC group of PKU started exploring Cu-Nb sputtering QWR technology by the end of 1995. A DC diode sputtering system was installed at the middle of 1997[4] The main part of the system is a UHV chamber, 120 cm in height and 60 cm in diameter. A background vacuum of $2x10^{-9}$ torr can be reached inside the chamber and a residual gas analyser is set up for the chamber. A 12.5 KW DC constant current power supply is used and Fig.6 is the photo of the sputtering system. Recently a series of Al-Cu sputtering experiments have been carried out. The effect of sputtering parameters, such as gas pressure P, voltage U and current I, as well as temperature T, was studied. By the end of August some good result was obtained on an Al-Cu QWR model.

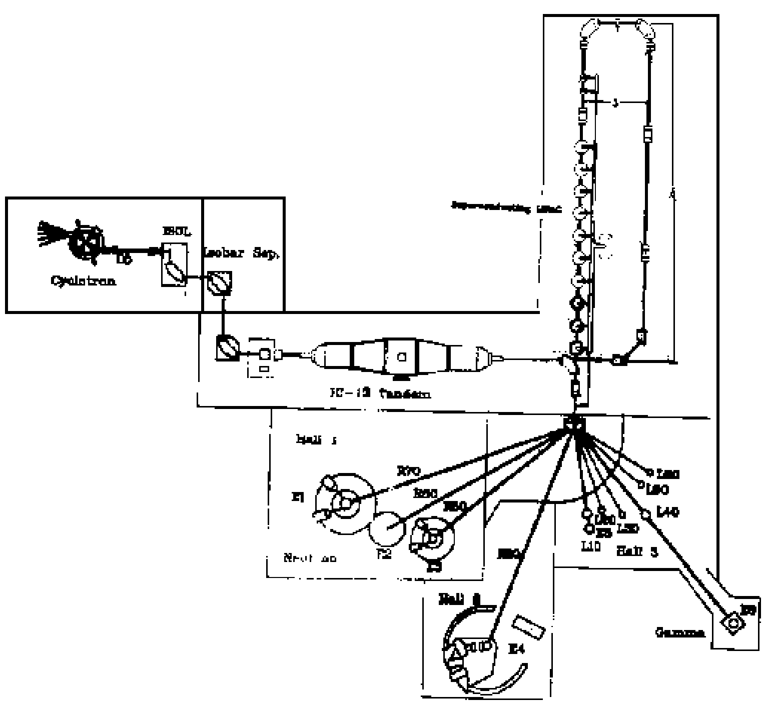

Fig. 5 Layout of BRNBF

For the next step, we shall examine the uniformity of the inner sputtering film so as to determine the shape of the target electrode. The Cu-Nb sputtering experiment is scheduled at the beginning of 1998.

Now, the research on the superconducting LINAC is well under way. With good collaborations between CIAE and INFN at Legnaro, Dr. Palmieri gave a detailed talk on the sputtering technology of SC QWR in Beijing. The study groups of CIAE and Peking University have worked out jointly the conceptual design and the layout of the SC booster LINAC based on the sputtering QWR.

Fig. 6 The Cu-Nb sputtering system

4. Superconducting technology for high-energy accelerators

The feasibility study of BTCF has been accomplished by IHEP. The machine will be a double ring multi-bunch collider in the energy range of 1.5-3.0 GeV, with a luminosity of $10^{33}cm^{-2}s^{-1}$. To meet the requirements of high current and low impedance, superconducting cavities are to be used. Each ring will install three single cell superconducting cavities of 476MHz, each cavity will provide 2.3MV peak voltage under 0.6 A[7]. The quality factor Q of HOM should be damped to less than 100. Fig. 7 shows the layout of BTCF. In 1995, the feasibility of using superconducting cavities as the accelerating structure for the proposed Beijing Tau-Charm Factory (BTCF) was Studied by the SC group of PKU in collaborating with IHEP. The main challenge would be the instabilities caused by beam-cavity interaction, since the RF SC cavities are the main source of the ring impedance, which would cause single and coupled bunch instabilities.

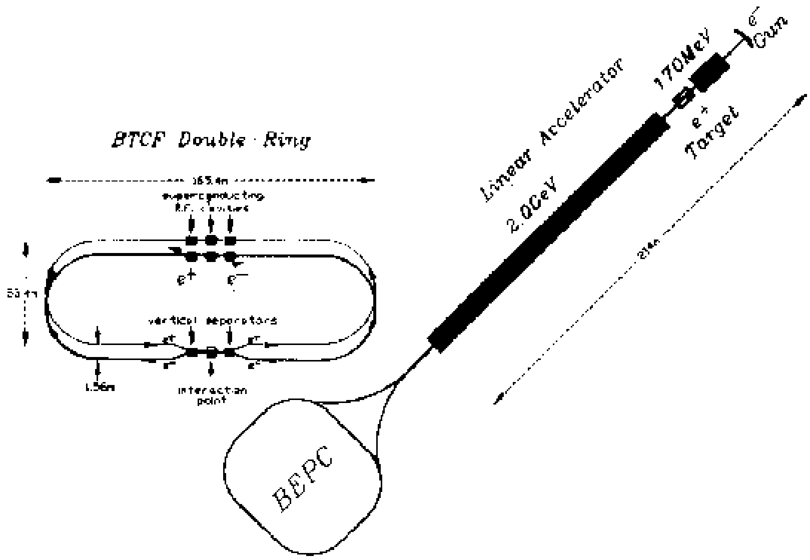

Fig. 7 The Layout of Tau Charm Factory

According to the experience of Dr. T. Furuya, KEK, the main problem of SC cavities in the B-Factory remained to be the sufficient damping of higher order modes (HOMs). They got satisfactory results with ferrite pipe damper in the beam pipe connected to the cavity. As the beam current is very high, a multi-bunch longitudinal instability due to the fundamental accelerating mode could be very serious. The cavity tuning should be set to minimise the input power and to compensate for the reactive component of the beam loading. Usually, the resonant frequency is detuned towards the lower side for this purpose, and so the detuning frequency and other related parameters were carefully examined and calculated [9].

Although three cavities are to be used, the operation of using only one or two cavities with the same Q_L is sometime inevitable and should be considered. In case something goes wrong during the operation, the other two or even one cavity should be able to keep working so as to maintain the beam. The results calculated at PKU is shown in Table 2, where only the number and the voltage of cavities are varied, and the Q_L remains the same in all cases. It turns out that the detuning frequency is rather small compared with the revolution frequency, and is eight times smaller than the normal conducting cavities. It means that the SC cavity is safe enough to eliminate multi-bunch instabilities in the accelerating mode.

Table 2 (QL=$1.760X10^7$)

Number of Cavities	1	2	3
Vc (MV)	6.800	3.400	2.267
Va (MV)	.167	.083	.056
Δf (KHz)	-1.913	-3.826	-5.739
ψ	-85.756	-87.875	-88.583
Vb (MV)	6.783	3.399	2.267
Arg (Vg)	2.834	.715	.007
Vg (MV)	.670	.210	.112
Vgr (MV)	9.055	5.655	4.522
Pg (KW)	125.247	48.852	31.234
Pb (KW)	93.520	46.760	31.173
Pc (W)	497.204	124.301	55.245
Pref(KW)	1.230	1.968	.006
τ (sec.)	1385.519	346.368	153.930

BEPC is to be upgraded to BEPC-II in the future. With the same mono-ring tube, the luminosity range of 5×10^{31}—1×10^{32} $cm^{-2}s^{-1}$ is anticipated for a 150mA single bunch beam at the energy range of 1.5-2.5Gev[10]. Two 500 MHz superconducting cavities, with an operating voltage of 1.5 MV, will be installed in this machine, and the Q of HOM will be damped to less than 100. Four superconducting magnets will be used in the area of collision for both BTCF and BEPC-II, so that the β function in the vertical direction will be 1.0-1.5cm at the colliding point.

Recently, IHEP, CIAE and Peking University are proposing to start the studies on the accelerator driven radiological clean nuclear energy system. High current proton linear accelerators are to be used to drive the subcritical reactor. To reach a beam power of 25-30 MW, CW proton linear accelerator of 1 GeV , with a current of 25-30mA is intended to be used. In order to control strictly the factor of beam loss in the high-energy segment and to raise the electric power, superconducting cavities will be used favourably in the high-energy (0.1-1.0Gev) segment[8].

5. Microwave property of High-Tc Superconductor

The measurement of microwave surface resistance and penetration depth of superconducting film was studied by the SC group of PKU, using parallel plate resonator technique[11]. The method allows the evaluation of small, flat samples over a broad range of temperate. In addition to the high resolution, it has several other advantages.

The overall test arrangement is shown in Fig. 8. The resonant frequency f and quality factor Q of a certain parallel resonator was first measured versus different thickness of sapphire under 77K to determine the surface resistance, which turned out to be R_s= 695 μΩ for our case, and then the temperature dependence of Q and f was obtained and plotted. With these data, the penetration depth of a $YBa_2Cu_3O_7$ sample was obtained as 2900A at the frequency of 5 GHz under 77 K.

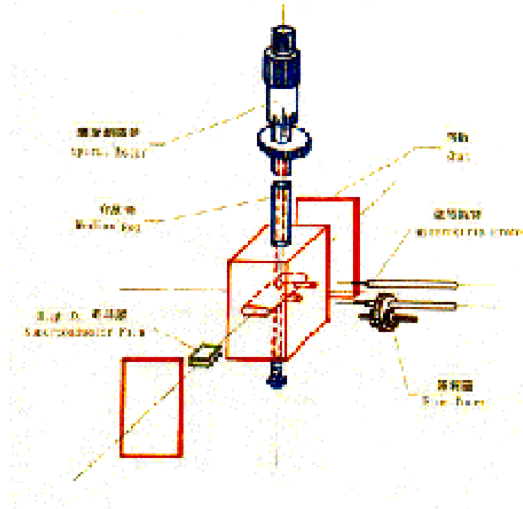

Fig. 8 Expand view of the configuration

6. Conclusion

SC group of PKU, IHEP of CAS, CIAE, and CAEP are very much interested in the R&D of RF superconductivity for developing superconducting accelerators and FELs. Practical studies are well in progress.

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