STATUS REPORT OF SUPERCONDUCTING RF ACTIVITIES IN KEK

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Abstract

In KEK there are three groups which concern with superconducting rf. The superconducting accelerating cavity group and the superconducting crab cavity group belong to KEKB (KEK B-factory). The L-band superconducting cavity group works for domestic and international collaborations of KEK. Introduction on these groups and their activities is presented in this paper. Main part is devoted for the introduction of crab cavities, which are new type superconducting rf cavities and are planned to install into KEKB to increase luminosity.

1 INTRODUCTION

Comprehensive activities on radio-frequency (rf) superconductivity have been carried out in three groups in the High Energy Accelerator Research Organization (KEK). Two of them belong to the KEK B-factory (KEKB), an asymmetric electron-positron collider at 8 GeV and 3.5 GeV, respectively. The superconducting (sc) accelerating cavity group has constructed 8 single-cell sc accelerating cavities to accelerate electrons in the High Energy Ring (HER) of KEKB. Another of KEKB is the sc crab cavity group, which makes efforts to develop and construct sc crab cavities to increase luminosity and then to improve the performance of KEKB.

The third group works on various subjects with L-band high gradient sc rf cavities as collaborations with domestic and foreign institutes and companies.

In this paper their activities are introduced briefly, especially with focusing on KEKB sc crab cavities, which are new type cavities using rf superconductivity.

2 KEKB SC ACCELERATING CAVITY GROUP

This group has responsibilities on designing, constructing and operating sc accelerating cavities in HER of KEKB.

2.1 KEKB SC Accelerating Cavities

Based on the experience of the TRISTAN sc cavities in KEK, sc accelerating cavities were designed and fabricated for HER of KEKB. This cavity has single-cell structure and is made of pure niobium. A cryostat contains one cavity as shown in Fig. 1. In the first construction phase of KEKB, 4 sc accelerating cavities were installed in HER of KEKB. To increase the beam current, the next 4 sc accelerating cavities were added in HER, and then totally 8 cavities have been installed to accelerate an ampere-class electron beam of KEKB [1] (Fig. 2). A pair of higher order mode (HOM) dampers made of ferrite is attached to each cavity to absorb higher order modes.

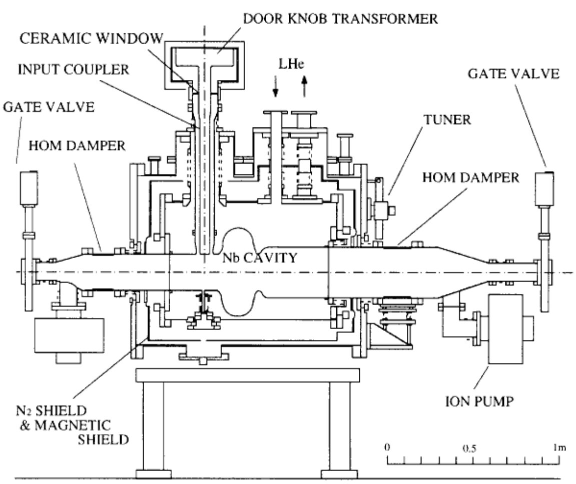

Figure 1: A schematic view of the KEKB sc accelerating cavity and its cryostat.

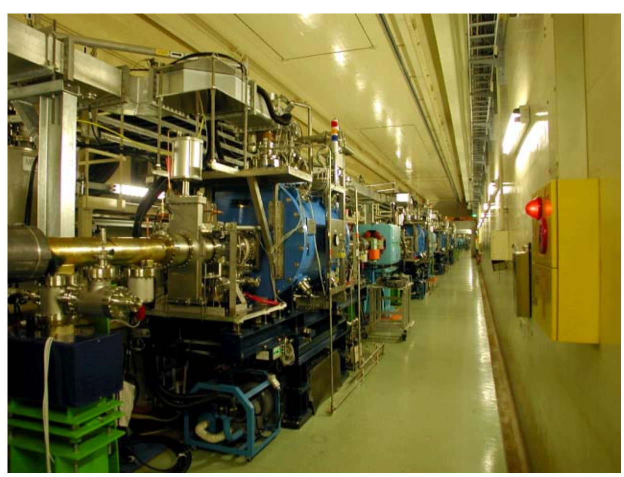

Figure 2: A photo of KEKB sc accelerating cavity cryostats installed in the KEKB tunnel.

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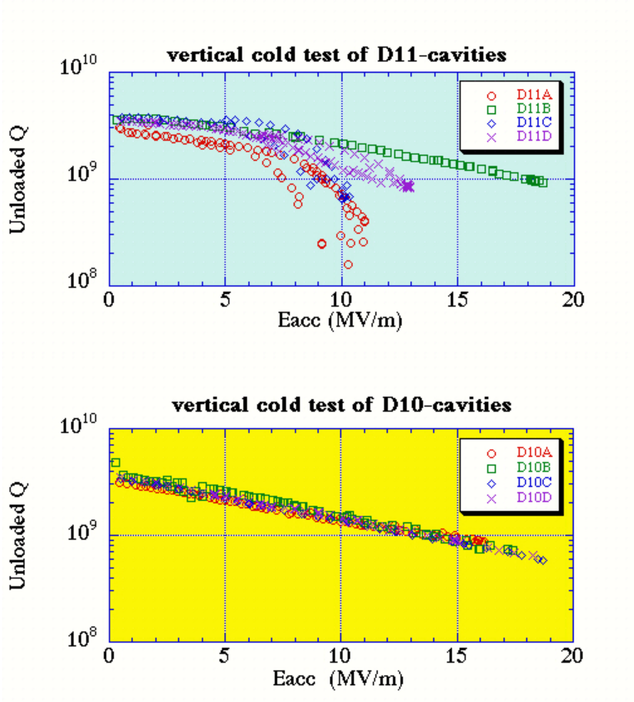

Fig.3: Results of vertical cold test of 8 KEKB sc accelerating cavities, 4 of which are installed at D11 section of KEKB at first (upper), and the next 4 at D10 section (lower).

Table 1: Summary of figures achieved in KEKB-HER operation

	Design	Achieved
Number of SC cavities	8	4 at the commissioning 8 since Sept. 2000
Beam current	1.1 A in 5000 bunches	0.87 A in 1537 bunches
Bunch length	4 mm	6 – 8 mm
RF voltage without beam	–	>2.5 MV/cavity
RF voltage with beam	1.5 MV/cavity	1.2 - 2.0 MV/cavity
Q value	1×10^9 at 2 MV	$1 - 2 \times 10^9$ at 2 MV $0.3 – 1 \times 10^9$ at 2.5 MV
The max. power transferred to the beam	>250 kW/cavity	370 – 380 kW
HOM power	5 kW/cavity at 1.1A	7.4 kW/cavity at 0.78A

2.2 Performance

The maximum accelerating field of sc accelerating cavities measured in vertical cold test was 19 MV/m as seen in Fig. 3. After the installation into the KEKB beam line, accelerating field of cavities has been conditioned to 10 MV/m at least. During long-term operation of KEKB, the sc cavities trip several times a day. However, most of them are not caused by breakdowns of the cavities themselves, but by the voltage drop induced by sudden beam damping because of heavy beam loading. Except such fake breakdowns, the cavities can continue their stable operation with rare true breakdowns (only a few times a month). In Table 1, the sc cavity performances achieved in KEKB operation are listed.

3 KEKB SC CRAB CAVITY GROUP

To increase luminosity of a particle collider which has a finite crossing angle, a crab cavity is proposed for a B-factory [2]. This kind of sc crab cavities is planned to be installed into KEKB, and R&D program on this cavity has been carried out by the KEKB sc crab cavity group.

3.1 Crab Crossing

Since KEKB is an asymmetric electron-positron collider, which has two beam lines and one colliding point, two beams intersect with a finite angle at the colliding point. This crossing scheme has advantage to reduce the back ground rates and to simplify the beam optics at the colliding region, while this reduces luminosity because of the geometrical effect and the synchrotron-betatron instability. To avoid this instability and to increase luminosity, beam bunches can be tilted by rf deflectors, i.e., crab cavities and can make head-on collision. This scheme is schematically shown in Fig. 4.

After collision, bean bunches should be tilted again to the original direction by crab cavities to be accelerated properly. Hence two crab cavities are needed for one beam line before and after the colliding point. Since KEKB has two beam lines for electrons and positrons, totally 4 crab cavities should be installed in KEKB as seen in the figure.

3.2 SC Crab Cavities

In order to tilt beam bunches, the crabbing mode should be generated in a crab cavity. The cavity has a squashed cell as shown in Fig. 5. KEKB sc crab cavities are made of pure niobium. Half-cells of crab cavities are shaped by hydro-forming from 4.5 mm thick niobium sheets, and electron-beam welded into squashed cells. The inner surface of the cavity is barrel-polished, electro-polished, annealed at 700 °C, and finally rinsed with ultra-pure water (~18 MΩ·cm) at high pressure (~7.8 MPa).

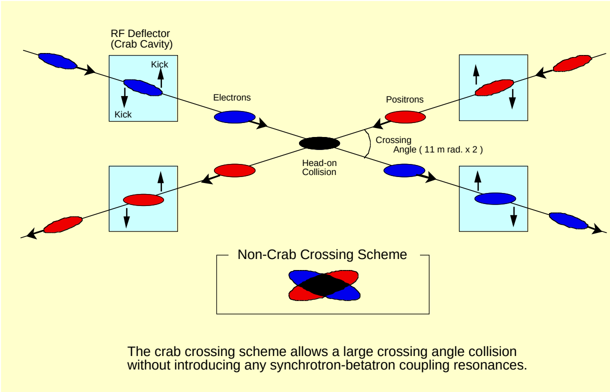

Figure 4: Crab crossing scheme.

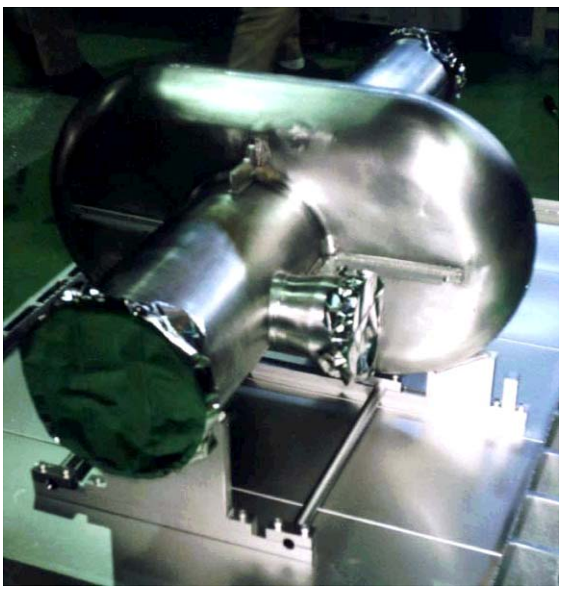

Figure 5: A photo of a KEKB sc crab cavity.

3.3 SC Crab Cavity Structure

As shown in Fig. 6, a crab cavity is equipped with a coaxial coupler, a notch filter and rf absorbers. The coaxial coupler is adopted to conduct unnecessary modes to the rf absorber. The coupler will be made of niobium-sputtered copper to utilize superconductivity and to have high thermal conductivity. Since the coupler is long and placed inside the beam pipe, stub supports are employed to support the coupler. Since the crabbing mode is also conducted by the coupler from the cavity cell to the rf absorber, the notch filter is employed to return back the crabbing mode toward the cavity cell again.

3.4 Vertical Measurement with Simplified Coaxial Coupler at 4.2 K

Following to the successful establishment of the cavity fabrication procedure verified with good performance of the crab cavity, the effect of a coaxial coupler inside a beam pipe on the cavity performance is the next subject to be investigated [3]. Since it can be assumed that only the tip of a coaxial coupler affects the cavity performance, a simplified coaxial coupler made of pure niobium was fabricated to measure the cavity performance with it, as shown in Fig. 7. The outer surface of the coupler was electro-polished and rinsed with high-pressure ultra-pure water.

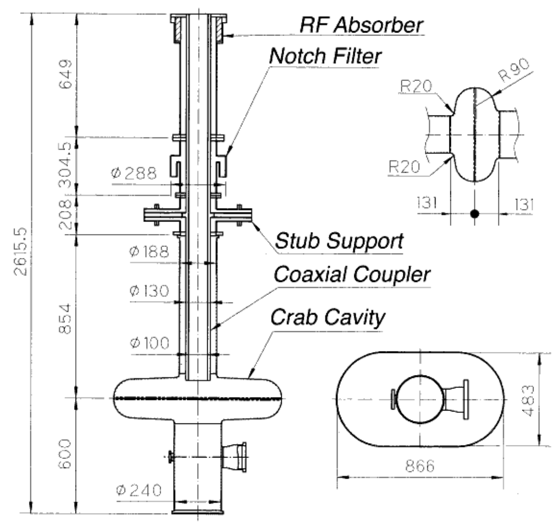

Figure 6: Schematic structure of a crab cavity attached with some rf components. Dimensions are in mm.

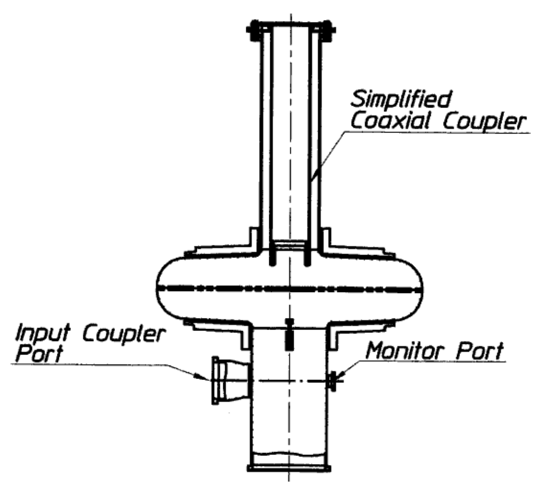

Figure 7: A crab cavity with a simplified coaxial coupler inside it.

Since the coupler was not experienced any thermal process, the total cavity performance was largely degraded at first because of the breakdown of the coupler. After several trials such as rf processing and cool-down procedure modification, the total cavity performance is recovered [4] as shown in Fig. 8. For comparison with this result, the cavity performances measured previously without the coupler at 4.2 K and also at 2.8 K are plotted together in the figure. The crab cavity has reached the peak field up to ~32 MV/m at 4.2 K and ~40 MV/m at 2.8 K. Now the crab cavity can generate enough surface peak field up to ~28 MV/m, higher than the design field even with the simplified coaxial coupler. If the coupler is annealed, better performance of the cavity can be expected.

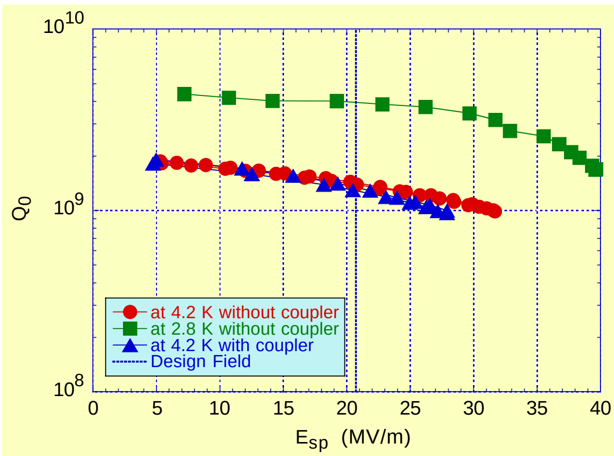

Figure 8: Performance of the sc crab cavity.

3.5 Horizontal Cryostat of Crab Cavity

A jacket-type liquid helium vessel is proposed for accommodating a crab cavity in liquid helium, since the space for crab cavities is limited in the KEKB tunnel. Fig. 9 shows a preliminary cryostat design. Another issue to be solved in design of the crab cavity cryostat is how a long coaxial coupler is supported horizontally inside a beam pipe in the cryostat, while the coupler should be movable axially and in the cross-sectional plane to adjust the frequency and the mode. Hence, a stub support is introduced into the cryostat to support the coaxial coupler. The stub supports are also in liquid helium to keep the coupler in superconducting state. The outer conductor of the coupler is connected with a bellow to the extended beam pipe of the cavity.

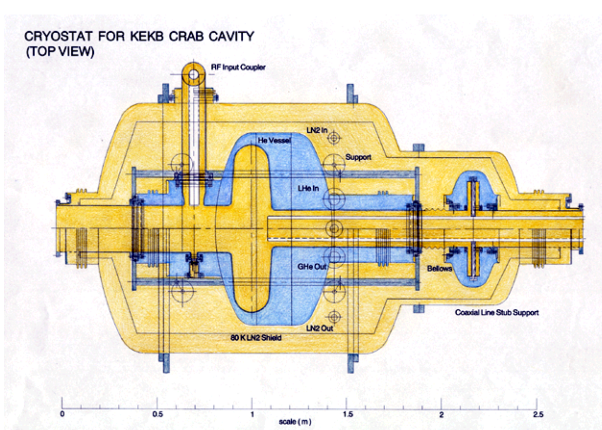

Figure 9: A preliminary design of a horizontal cryostat of the crab cavity.

4 L-BAND SC CAVITY GROUP

As increases the opportunity to adopt sc cavities in various accelerators in Japan and also around the world, such as TESLA, high gradient sc cavity fabrication procedure should be established. This group is executing some R&D programs on high gradient sc cavities in collaborations with various international and domestic projects.

4.1 High Gradient Cavities

As shown in Fig. 10, high gradient up to ~40 MV/m was achieved in sc cavities made with the fabrication procedure, especially with the surface preparation procedure, established by this group. This high gradient can be realized in various cavities having different shapes according to various β for heavy particle acceleration.

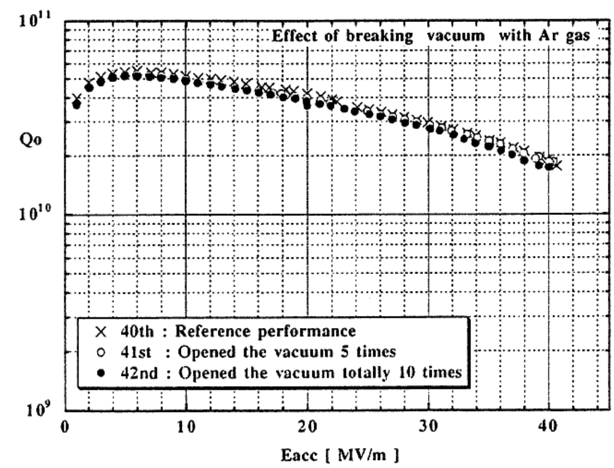

Figure 10: L-band high gradient sc cavity performance and the effect of argon gas exposure on the cavity performance [7].

4.2 Fabrication Cost Reduction

A new type sc accelerating cavity is proposed, i.e., a niobium/copper (Nb/Cu) clad seamless cavity [5] (Fig. 11). This cavity is shaped by hydro-forming and conventional electron-beam welding is not needed. The necessary amount of niobium to fabricate Nb/Cu clad seamless cavities is much less compared with that of pure niobium cavities. Hence the fabrication cost and the material cost of Nb/Cu clad seamless cavities are greatly reduced. In addition to the development of Nb/Cu clad seamless cavities, this group has developed aluminum seal applicable to stainless-steel flange bonded to niobium tube, instead of widely used indium seal [6]. This seal can help to reduce the total cost of sc cavities.

It is well known that the cavity performance is degraded during the assembly of cavities into cryostats and the installation into the beam lines of accelerators. It is found by the study of this group that pure nitrogen, which is ordinarily used to break the cavity vacuum, becomes a cause of the performance degradation of sc cavities [7]. From this result, it is possible to avoid the performance degradation during the assembly of cavities into cryostats and the installation of cryostats into the beam lines by using argon gas, for example, to break the cavity vacuum (Fig. 10).

4.3 Stable Operation of SC Cavities

The major reason of the performance limitation of sc cavities is multipacting. Once multipacting occurs in the cavity, it becomes impossible to generate higher field in the cavity. A criterion of multipacting is found in comparison among performance data accumulated for various cavities [8]. This criterion can be applied to suppress the occurrence of multipacting and to realize the stable operation of sc cavities.

Figure 11: A photo of a Nb/Cu clad seamless sc cavity.

5 SUMMARY

Superconducting rf activities being conducted by 3 groups in KEK are summarized as follows.

- Stable operation of 8 sc accelerating cavities is realized in KEKB, and large current beams are successfully accelerated.
- R&D activities on sc crab cavities are in firm progress and a horizontal cryostat design is already proposed.
- Concerning with international and domestic collaborations, high gradient sc cavities can be fabricated for various shapes and frequencies, R&D programs are carried out to reduce cavity fabrication cost and to achieve stable operation of cavities in accelerators.

6 REFERENCES

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