FEASIBILITY STUDY ON SUPERCONDUCTING SYSTEM FOR INTENSE CW ION LINAC

Y.Tanabe, T.Ota, A.Yamaguchi, Y.Wachi, C.Yamazaki, S.Kawatsu, and A.Miyahara(a)

Toshiba Corporation

2-4, Suehiro-cho, Tsurumi-ku, Yokohama, 230 Japan

(a);Teikyo Univ.

359, Otsuka, Hachioji-shi, Tokyo, 192-03 Japan

Abstract

Feasibility study on superconducting(sc) system is carried out for an intense cw ion linac. The system consists of sc cavities and sc quadrupole magnets, which are analyzed and optimized in the study. Moreover, an rf solid state amplifier and an rf control system are investigated. The results show that construction of the proposed system is feasible by existing technology, while intensive R&D efforts are, of course, inevitable.

1 INTRODUCTION

Intense proton or deuterium cw beam has been required for irradiation tests of materials for future fusion devices[1] and transmutation of nuclear waste. For such cw machines, an sc system is considered to be intrinsically suitable because of its superior temperature stability and absence of electric losses. Moreover, the influence of beam halo can be reduced due to its large bore diameter. In this paper, an sc ICL(Independent Cavity Linac) system with sc cavities and sc quad. magnets is presented and the feasibility of the system is studied.

2 SUPERCONDUCTING MAIN LINAC

Main components of an sc linac system are investigated, assuming in case that it accelerates ion beam from 8 MeV to 40 MeV.

2.1 Optimization of Superconducting Cavity

In this system, an sc cavity is determined to be made of niobium(Nb) and a $\lambda/2$ coaxial type with two gaps because of rather low frequency and low β. The cavity has a large bore radius in order to avoid a severe problem of beam spill. To achieve a high accelerating efficiency at low β region, configuration of the cavity is optimized using the three-dimensional electromagnetic analysis code MAFIA. When the thickness of the inner conductor is smaller, the effective shunt impedance becomes larger at low β. However, electric field of the cavity with a thin inner conductor concentrates over 1 kp.(Kilpatrick's criterion, 14 MV/m at 175 MHz) on the corner of the inner conductor. The smaller thickness requires the larger gap length not to exceed 1 kp..

Cavities of 60 mm inner conductor thickness are analyzed changing those gap length 50, 60 and 70 mm. As a result, the cavity with 60 mm gap length is selected as an optimum configuration considering following reasons. (1) The number of cavities to accelerate the beam from 8 MeV to 40 MeV is small. (2) The rf input power is lower. It means that an antenna can be operated in relatively smaller loading. (3) Effective shunt impedance(Rsheff) is relatively large at low β.

The schematic drawing of the optimized cavity is shown in Fig. 1. A Nb bellows is attached as a tuner on the top of the cavity. The resonant frequency is adjusted by changing the length of this bellows. The frequency tuning rate is approximately 102 kHz/mm. Main specifications are summarized in Table 1.

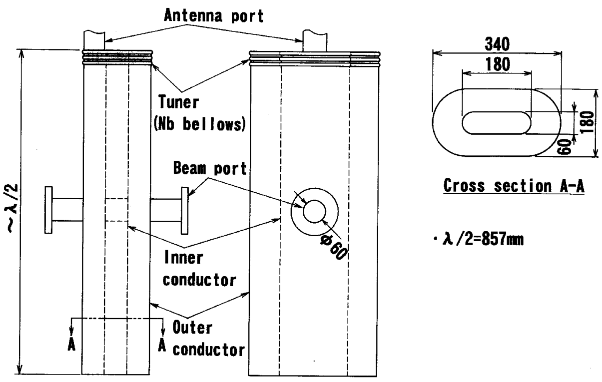

Fig. 1 Optimized sc cavity

Table 1 SC cavity specifications

Material	Nb
Frequency	175[MHz]
Maximum transit time factor	0.83(at β=0.168)
Maximum accelerating field	2.9[MV/m]
Unloaded Q*	7.5×10^{8}
Beam loading	43 ~ 91[kW]
RF loss on wall*	7.0[W]
Maximum electric field	14.0[MV/m]
Maximum magnetic field	405[Gauss]

* The surface resistance of Nb is assumed as 50[nΩ]

2.2 Magnetic field Analysis of SC Quadrupole Magnet

The sc quad. magnet with a saturated iron core is analyzed using three-dimensional code TOSCA. An iron core is employed to reduce the stray field. An excitation curve is shown in Fig. 2, which is nonlinear over 20 A/mm^2 due to the magnetic saturation. The sc quad. magnet can generate the field gradient of 50 T/m at 180 A/mm^2, which is enough below the average critical current density(Jc) of NbTi. However, the distribution of the field gradient is not so good that it should be included in the analyses of beam dynamics. Main specifications are summarized in Table 2.

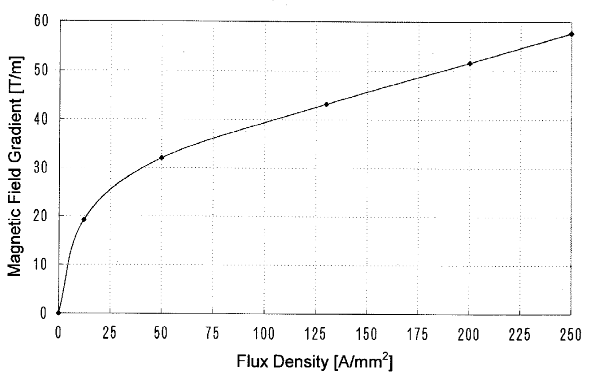

Fig.2 Excitation curve

Table 2 SC quad. magnet specifications

Bore diameter	60 mm
Magnet length	50 mm
Magnetic field gradient	max 50T/m
Good field region	± 16 mm at 50 T/m
Average Jc of NbTi*	430 A/mm^2 at 2.5 T

* The copper ratio is assumed as 6

2.3 Linac System

A schematic drawing of one cryounit is shown in Fig. 3. An antenna has a coaxial structure and can move through stainless steel bellows to adjust its coupling coefficient to the cavity. It should be so compact as to be installed in narrow space and to reduce its heat leakage as small as possible, while it should allow 100 kW power rating. The cryounit is cooled until 4.2 K by LHe and thermally shielded by LN_2. This LN_2 shield is also used as a magnetic shield for the terrestrial magnetism.

The sc quad. magnets and the sc cavities are located alternately as shown in Fig. 3. The stray field of the quad. magnet is shielded by a magnetic shield located outside the cavity. The magnetic shield is located 70 mm apart from the magnet center, where the magnetic field is 2.5 kGauss at 180 A/mm^2. Therefore it is possible to shield the stray field by ordinary ferromagnetic materials.

Table 3 shows main specifications of the sc linac system which accelerate the ion beam from 8 MeV to 40 MeV.

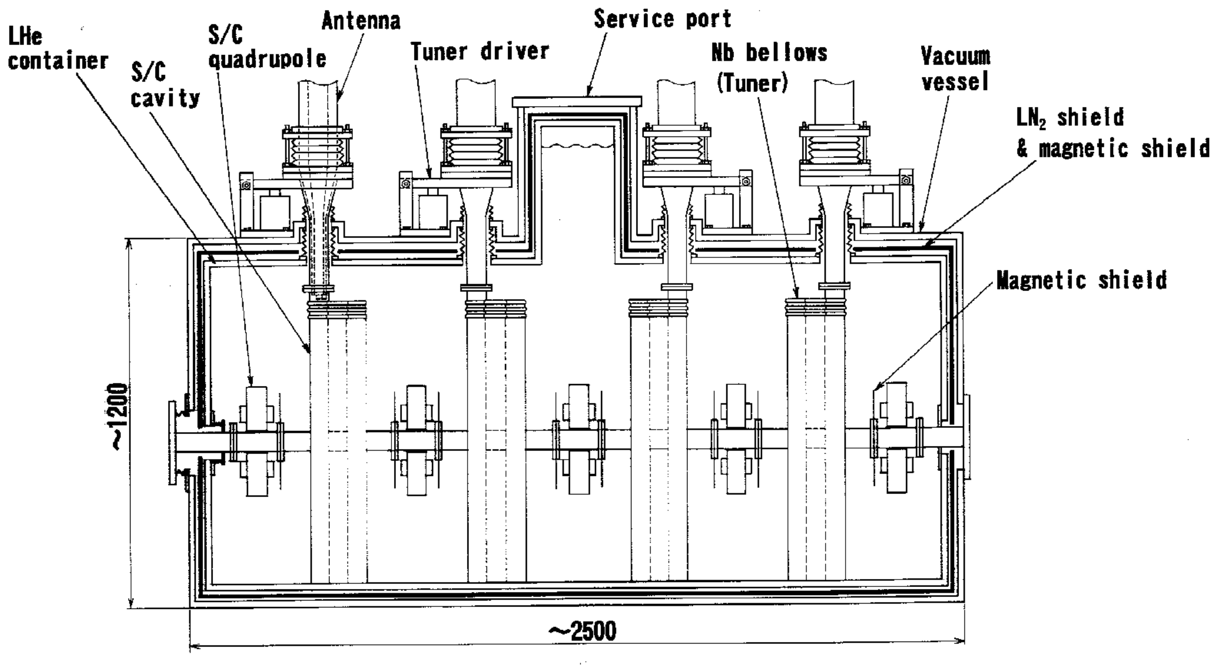

Fig.3 Schematic drawing of the cryounit

Table 3 SC linac system specifications

Number of cavities in a cryounit	4
Number of cryounits	13
Number of sc cavities	52(=4×13)
Number of sc quad. magnets	65(=5×13)
Total length	32.5[m](=2.5×13)
Beam loading	4.0[MW]
Total rf loss on wall	364[W](=7.0×52)

2.4 Cryogenic System

Outline of a cryogenic system is investigated based on the heat load. The total heat load is estimated as about 1.2 kW at 4.2 K. The refrigerator capacity of 1.2 kW at 4.2 K is the same as that of a refrigerator for the LCT(Large Coil Task) domestic test facility at JAERI[2]. A block diagram of the system is shown in Fig. 4. The cryostat is cooled down from 300 K to 20 K using a refrigeration line and then LHe is transferred to the cryostat from a 20000 liter LHe dewar in order to cool down the cryostat up to 4.2 K and to fill it with LHe. LHe level is kept constant in a refrigeration mode during the steady state sc cavity operation.

Required power is about 640 kW for 1.2 kW refrigeration capacity and it means that efficiency is 1.2/640=1/530 at 4.2 K.

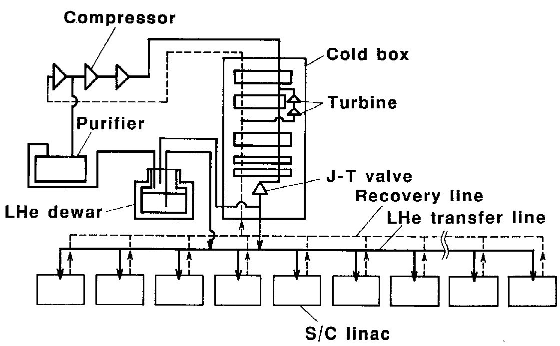

Fig.4 Block diagram of cryogenic system

3 RF SOLID STATE AMPLIFIER

There are two options for an rf amplifier. One is a high power tetrode and the other is a solid state. The solid state rf amplifier is probably more expensive than the tetrode rf amplifier initially, but is very attractive for the sc ICL due to the following reasons. (1) A 100 kW class solid state rf amplifier can be prepared by existing technology which is commercially used for broadcasting power supplies. (2) Easy operation and easy maintenance can be expected. (3) It is probably possible that the high initial cost can be compensated due to the long lifetime of the solid state amplifier. The schematic diagram of 100 kW solid state rf amplifier is shown in Fig. 5.

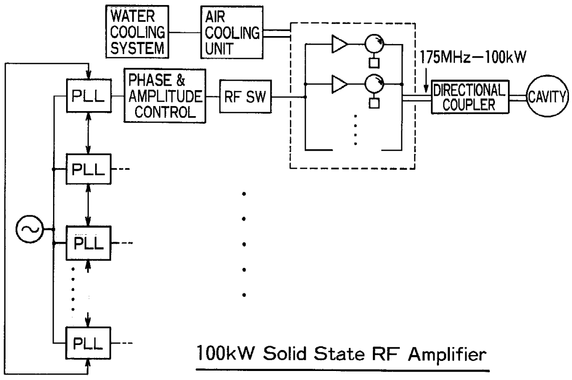

Fig. 5 Schematic diagram of solid state rf amplifier

4 RF CONTROL SYSTEM

A schematic diagram of an rf feedback control system is shown in Fig. 6. A signal from a pickup probe is divided into two feedback loops for the phase control and the voltage control, as well as the frequency tuning. A system which uses the piezoelectric elements like sc cavities in TRISTAN[3] is one candidate for this fine tuning.

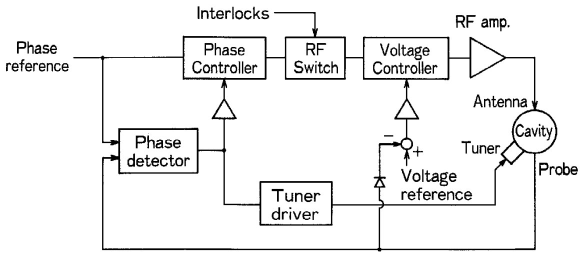

Fig.6 Schematic diagram of rf control system

5 CONCLUSION

The conceptual design of the sc linac system is carried out for an intense cw ion linac. The configuration of the sc cavity is optimized to achieve the high accelerating efficiency at low β region. Even at high β region, since it has relatively high efficiency, the same cavity is applied. It is beneficial from the viewpoint of compatibility to use the same cavity. The total length of the system is about 32 m and the average accelerating gradient is about 1 MeV/m. It is probably possible to reduce the total length through further system design in detail. A 100 kW class solid state rf amplifier is available by the existing technology and is very attractive especially for the sc ICL system.

6 REFERENCES

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[2] E.Tada et al. Cryog Eng (1984)19(2) p69(in Japanese)
[3] K.Akai et al. Particle Accelerators (1990)29 p11