Fabrication Techniques and RF Properties of Niobium Thin Wall Cavities

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The cavities with the designed resonant frequency of 2856 MHz and the wall thickness of 0.42 mm were fabricated by YAG laser welding. Pulsed RF properties of the single cell cavities were measured. To obtain cavity Q values, a evaporation rate of liquid He was measured. The maximum value of the peak surface fields was 67 MV/m at the input RF pulse width of 6 µsec.

INTRODUCTION

We designed the synchrotron radiation facility composed of a superconducting linac(SC linac) and storage rings(1). We fabricated Nb thin wall cavities by YAG laser and measured the peak surface fields and the Q values(Q_0.) of the cavities as a primary examination for the application to the SC linac.

As electron beam welding(EBW) has advantages of deep penetration depth and no oxidation of Nb in welding process, it has been usually used for fabricating Nb cavities(2). We employed laser beam welding(LBW) because of following merits.

(A) Prevention of brow holes of a molten metal at the welding of thin walls.

The molten metal of thin walls has a stronger tendency to make the brow hole than of thick walls. To prevent the brow hole, the molten metal has to cool rapidly. LBW process uses gas and it cools the molten metal. As a result, the cooling speed increases and the brow hole is prevented. The cooling effect is greater in case of the welding of thin walls than of thick walls.

(B) Shorter processing time.

In EBW, almost all the time is spent to evacuate a vacuum chamber. It is possible by LBW to weld without the vacuum chamber and to omit a evacuation processes. In addition, the dimensions of cavities arent limited by the case of the vacuum chamber.

It is clear that more oxygen is included in the gas used in LBW than in the vacuum state in EBW. However, welding points are cooled more rapidly in the case using LBW than EBW. Therefore, LBW has the prospect of welding without Nb oxidation.

The peak surface fields of cavities using short RF pulse were measured by Isidoro E. Campisi and Z. David Farkas(3). Our SC linac is excited within several micro seconds by the pulsed RF with the pulse length shorter than 10 µsec. To obtain the RF properties of a single cell cavity for the research of the properties of the linac, we excited the cavity within several micro second, then it has too small external Q to obtain the value of Q_0 by measuring the decay of the energy stored in the cavity. Therefore, we obtained the Q values by measuring a evaporation rate of liquid He.

FABRICATION

A photo of the single cell cavity is shown in Fig.1 and its cross section of view is shown in Fig.2.

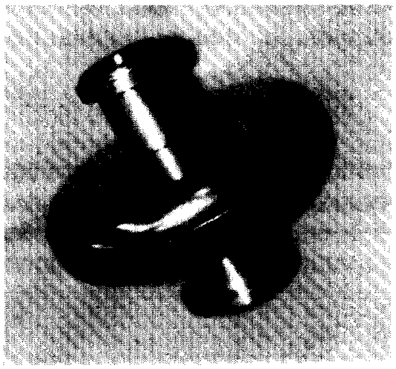

Fig.1 A photo of the fabricated single cell cavity by YAG laser welding.

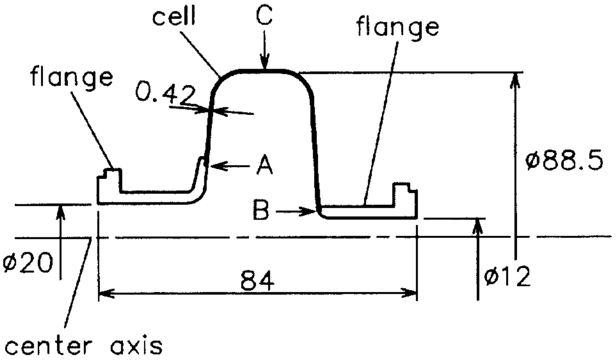

Fig.2 Cross section of the single cell cavity. Points A, B and C are welded.

Nb sheets with the thickness of 0.5 mm were annealed at a temperature of 930 degrees. Two half cells were made by deep drawing from the Nb sheets. The flanges of each side of the cavity were made of Nb rods by machining.

The flange and the half cell were put in Ar gas and were welded together by pulsed YAG laser while blowing Ar gas on

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the welding spot. The two half cells were got butted against each other by a steel band with three long holes opened just on the butted line, and the flanges were attached to fixtures with a hole to flow Ar gasses into the cavity. A seam welding was performed along the butted line after several points of spot welding on the butted line. To prevent temperature rising throughout the cavity, the cavity were welded in few strokes with cooling time for several minutes after each stroke. We welded cavities structured by six cells and the time of welding processes was about 4 hours.

Welded cavities were rinsed in acetone and chemically polished in a solution $HF+HNO_3+H_3PO_4$ in volume ratio 1:1: 1 with 80 µm removal of inner wall and rinsed in pure water.

EXPERIMENT

Experimental setup for the measurement of the peak surface fields and Q_o is shown in Fig.3. The collector of evaporated He gas was set over the cavity. To collect only He gas produced on the surface of the cavity, the entrance of the He gas produced on the surface of a wave guide was prevented by a wall set between the cavity and the wave guide. Collected He gas was transported to a gas flow meter by a narrow tube.

A portion of produced He gas on the surface of the cavity may escape out of the collector. This causes the difference between the produced He gas on the surface of the cavity and the transported to the gas flow meter. To calibrate this difference, we measured the relation between the evaporated He gas and loss yielded by carbon resistances set around the cavity. The results are indicated by boxes in Fig.4. Solid line shows the calculation on the assumption that all of the produced gas collected. The results are good agreement with the calculation in the region from 3 l/min to 40 l/min.

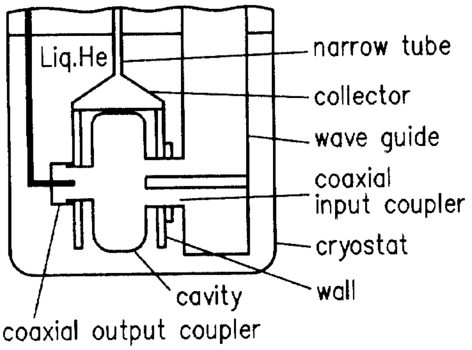

Fig.3 Experimental setup for the measurement of the RF properties.

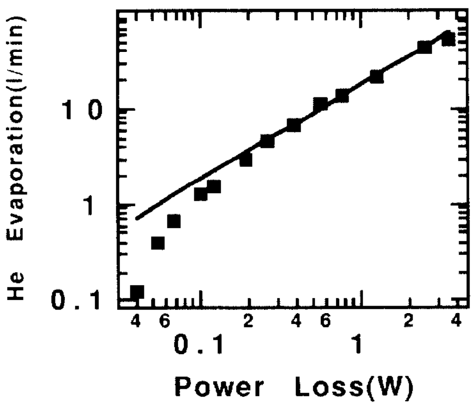

Fig.4 A evaporation rate of liquid He versus the power loss. Measured results are indicated as boxes and calculated value is indicated by solid line.

The powers of the input pulses, the reflected pulses and the transmitted pulses, and a evaporation rate of liquid He were measured at the cavity temperature of 4.2 K. The repetition rates of RF pulse was changed to set a evaporation rate of liquid He in the measurable region, 0.1 to 40 l/min.

ANALYSIS AND RESULTS

The relations between the input pulse power and the peak surface field measured by the reflected and by the transmitted pulse are shown in Fig.5 at the pulse width of 10 µsec.

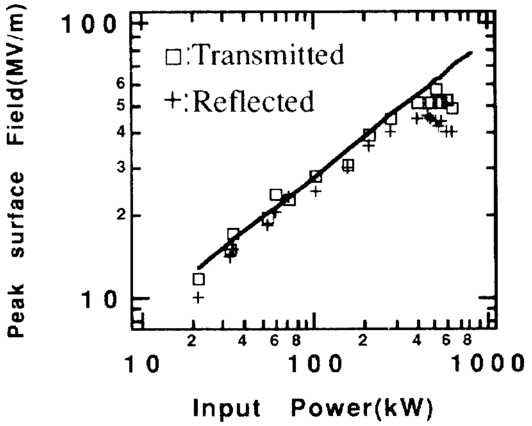

Fig.5 Peak surface field versus input power. The measured values by the reflected and transmitted pulses are shown. The solid line shows the calculated value.

Peak surface fields, E_S, in a cavity can be determined as

$$E_S = k\sqrt{U}$$

where U is a stored energy and k is a coefficient. We determined the coefficient value of 54.84 MV/m/joule of the cavity by using computer programs SUPERFISH.

One can obtain the stored energy at the end of the input RF pulse by measuring the transmitted RF power,$P_{t,f}$ at the end of the input RF pulse as

$$U = \frac{Q_{ext,tra}}{2\pi f} P_{t,f}$$

where $Q_{ext,tra}$ is the external quality factor of the side of output coupler and f is the resonant frequency of the cavity. We obtained the $Q_{ext,tra}$ of $3.3x10^8$ by measuring the spectrum of transmitted power at the cavity temperature of 77.3K because that the Qo value nearly equals the external quality factor in that temperature. In a low loss condition, one can also obtain the stored energy by measuring the reflected RF power, Pe, as

$$U = \int_{t_f}^{\infty} P_e \, dt = \frac{P_p}{2\pi f} Q_l$$

where t_f is the end time of the input pulse, Q_l is the loaded quality factor measured by reflected power, and P_p is the peak of reflected power just after the time t_f. In the case in which the loss is not negligible, this equation gives less energy than the stored energy at t_f by the amount of loss on the inner surface of the cavity after the time of t_f.

The peak surface field is proportional to the square roots of the input power as shown by the solid line in Fig.5, in which the value was calculated from the external quality factor of 1.1×10^4 and Qo of 10^7, where the external quality factor was measured at the temperature of 77.3K. The difference between the calculated value and the measured value by the transmitted pulse is caused by the decreasing of Qo and the difference between the calculated value and the measured value by the reflected pulse is larger because of non negligible loss on the surface of the cavity.

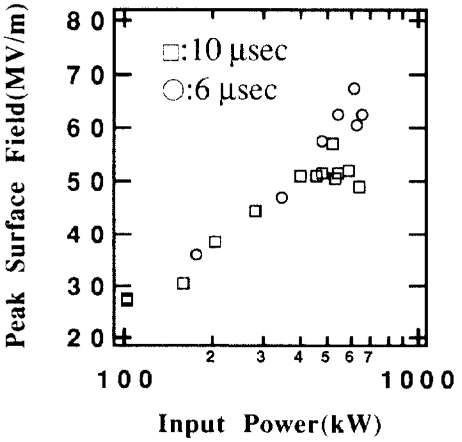

Fig.6 Peak surface field versus input power. The peak surface fields were measured by transmitted power at the pulse widths of 6 and 10 μsec.

We show the relation between the peak surface fields measured by the transmitted pulses and the input powers at the pulse widths of 6 and 10 μsec in Fig.6. Higher surface fields were obtained at shorter pulse widths. The maximum values of the peak surface fields were 57 MV/m at the RF pulse width of 10 μsec and 67 MV/m at 6 μsec. These value are lower than the result by Campisi, et al.., 73 MV/m, but our pulse lengths are longer than of theirs, 1 μsec(3). The peak surface fields depend on the pulse width in higher input power than 400 kW. Approximately the peak surface field was 50 MV/m at the input power of 400 kW.

We measured a evaporation rate of liquid He and obtained a power loss par unit time on the cavity inner surface by using the relation shown in Fig.4. A power loss par one cycle, ΔU, of the input RF pulse is obtained by dividing repetition rate into the power loss par unit time and the mean values of Qo par one cycle were obtained by following equation as

$$Q_0 = \frac{2\pi f U \Delta t}{\Delta U}$$

where Δt is the pulse width of the input RF pulse. The relation between the Qo and the peak surface field obtained by the transmitted pulse is shown in Fig.7 at the input pulse widths of 6 and 10 μsec. In the region of lower input power than one at maximum value of peak surface fields, the Qo values rapidly decreases with the peak surface fields.

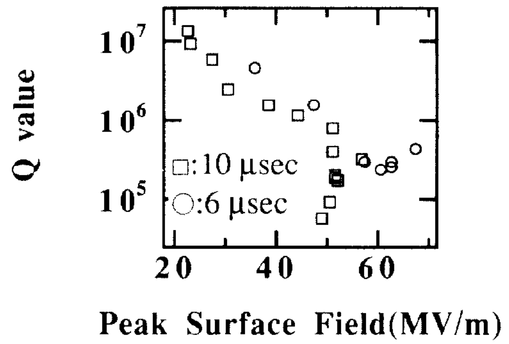

Fig.7 Qo versus peak surface field. Data of pulse width of 6 and 10 μsec are shown.

CONCLUSION

The single cell Nb cavities were fabricated by YAG laser welding. The thickness of the fabricated cavities was 0.42 mm. The value is lower than the typical thickness of L band cavities about one order. Thin wall cavity has the advantage in cooling the breakdown points of superconductivity immediately. Thickness of our cavity was limited by the mechanical break of pressured cavities but it is possible to weld 0.1 mm thickness plates without brow holes. If materials with high heat conductivity can be covered around Nb, Nb cavity with less thickness wall becomes useful.

The maximum values of the peak surface fields were 67 MV/m with the measured Qo of 4×10^5 at the input pulse width of 6 μsec and 57 MV/m with 3×10^5 at 10 μsec. The properties changed at the approximately value of the input power of 400 kW, Qo of 1.5×10^6, and the peak field of 50 MV/m.

Acknowledgment

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Reference

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