DEVELOPMENT OF RF CAVITIES FOR THE SHB SYSTEM OF THE L-BAND ELECTRON LINAC AT OSAKA UNIVERSITY

R. Kato, S. Kashiwagi, Y. Morio, S. Suemine, G. Isoyama#
Institute of Scientific and Industrial Research, Osaka University, Ibaraki, Osaka 567-0047, Japan

Abstract

Two 108 MHz and one 216 MHz RF cavities are developed for the subharmonic buncher system of the L-band electron linac at Osaka University. They are quarter-wavelength coaxial RF cavities made only of oxygen-free copper. Special care is taken to make their operation stable by keeping their temperature constant with cooling water. The cavities are successfully fabricated and commissioned.

INTRODUCTION

A sub-harmonic buncher (SHB), which operates at a sub-harmonic of the RF frequency of a linac, is used to produce a single-bunch electron beam by preliminary bunching of electrons. The 40 MeV L-band linac at Osaka University operating at a 1.3 GHz frequency in the L-band is equipped with a three-stage SHB system and it is optimized to produce a high-intensity single-bunch electron beam. When constructed in 1978, it was equipped with a single 216 MHz quarter-wavelength coaxial RF cavity, frequency of which is a sixth sub-harmonic of 1.3 GHz, and afterward two 108 MHz, or 12th sub-harmonic RF cavities of the same type were added between the electron gun and the 216 MHz cavity, comprising a three-stage SHB system. The charge in a single bunch beam is higher than 30 nC/bunch in ordinary operation and the maximum charge so far realized reaches 91 nC/bunch with the SHB system.

The SHB system is turned on in the single bunch mode and the multi-bunch mode of operation of the L-band linac. The single bunch mode is used for laser-synchronized pulse radiolysis experiments in the time range down to femto-seconds and for basic study on Self-Amplified Spontaneous Emission (SASE) in the far-infrared region, and the multi-bunch mode is used for free electron laser experiments in the same wavelength region. These experiments require stable operation of the linac. Problems of the linac in these experiments were that it took three to four hours to warm up the linac after start-up in the morning and that a beam condition suddenly and sometimes changed, and their causes are found to be due to the SHB system. The RF cavities of the SHB system are made of clad plates of copper on stainless steel and they are cooled with water flowing through a copper pipe wound on the outside wall of the cavity, which is the stainless steel side of the outer conductor. The area of heat generation and the cooling part are away and cooling is made only by heat conductivity through a thin clad plate of copper and stainless steel, which makes the warm-up time longer, and when temperature of the clad plate varies, the cavities slightly change their shapes and sizes due to difference in thermal expansion coefficients of the two metals, which produces sudden changes of the beam condition. To solve these problems, we have fabricated new RF cavities for the SHB system that have higher temperature stability; two 108 MHz cavities and one 216 MHz cavities, which are designated from the upstream side as cavity #1 through #3. We will report design, fabrication, and commissioning of the RF cavities.

#isoyama@sanken.osaka-u.ac.jp

DESIGN

Basic design concept of the new RF cavities is as follows. The new cavities will be substituted for the present ones, so that physical sizes must fit with the present environments. Longitudinal lengths of the cavities between the entrance and the exit flanges should be same as the present values and transverse sizes should be smaller than the inner size of the Helmholtz coils, 253 mm. The physical aperture for the beam should not be smaller than the present value, 50 mm in diameter. The new cavities should be made of pure copper to realize higher temperature stability. The cavities will be cooled with water, temperature of which is precisely controlled to be 38 ± 0.03°C, so that water channels should be equally distributed over bodies of the cavities, including the outer and the inner conductors, in order to make the temperature of the cavities uniform and constant and not to rely on thermal conductivity of copper too much. Routes of the water channels should be designed so that heat is taken away by water at the place it is generated.

The mechanical design of the cavities are made by referring to a similar SHB cavity used for the electron and positron linac at KEK, which is a quarter wavelength coaxial cavity of a resonance frequency of 114 MHz made of copper. The physical design is made using the computer code, SUPERFISH. The main parameters calculated for the cavities #1 and #2, and the cavity #3 are listed in Table 1.

Table 1: Calculated Main Parameters of the Cavities

	Cavity#1, #2	Cavity#3
Resonance freq. (MHz)	108.4	216.8
Unloaded Q-value Q_0	8765	11642
Shunt impedance R (MΩ)	1.45	2.07
RT^2 (MΩ)	0.844	0.871
RT^2/Q (Ω)	96.3	74.8
Transit time factor (β=0.55)	0.764	0.649

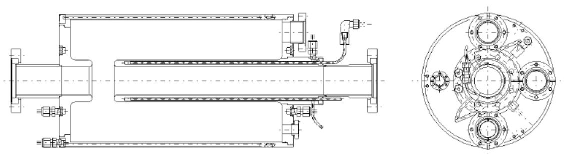

Figure 1: Mechanical design of the 216 MHz cavity.

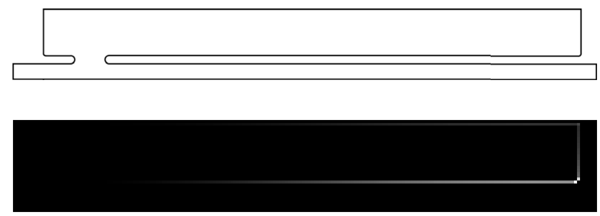

Figure 2: Cross section of the 114 MHz quarter-wavelength RF cavity of the KEK linac (top) and calculated heat generation on its wall (bottom). The brightness of the white line in the bottom figure shows intensity of heat generated on the surface of the inner conductor and the end plate of the RF structure illustrated above.

Fig. 1 shows a mechanical design of a 216 MHz RF cavity. It has the circular symmetry around the central axis. The diameters of surfaces of the inner and the outer conductors are 76 mm and 220 mm, respectively, and the longitudinal lengths between the inner surfaces of the end plates are 733 mm for 108 MHz cavities and 386 mm for the 216 MHz cavity. The gap between the two electrodes is 40 mm. The inner and the outer cylinders are 13 and 10 mm thick, respectively, while the end plates are 20 mm thick. Fig. 2 shows a distribution of heat generated on the surface of the cavity calculated for the KEK cavity. The heat is generated mainly around the conjugation between the end plate with the long inner conductor and the heat generation quickly falls off as it goes away from the conjunction to both directions, so that the conjunct part as well as the end plate and the inner conductor should be efficiently cooled. To realize this and the other requirements for cooling, four long holes of 6 mm in diameter are drilled along the inner conductor from the base towards the gap but not to the end. A stainless steel pipe of 4 mm in diameter is inserted in each hole to make a water circuit. Water comes in through the pipe and goes out through the hole and the four water channels for the inner conductor are connected in series. A circular trench from the outside of each end plate is made near the inner conductor and it is covered with a plate to make a water channel in order to effectively cool the area of heat generation. Similar to the inner conductor, 16 long holes of 6 mm in diameter are drilled along the outer conductor from the base towards the gap side but not to the end. These holes are connected with trenches from outside of the outer conductor, and the trenches are covered with copper plates to make a water channel serially connecting 16 holes.

The end plate on the gap side is equipped with four ports for an input coupler, a tuner, a pick-up monitor, and a vacuum pump, and the other end plate is occupied by piping and connection for cooling water. The input coupler is a loop for magnetic coupling, the tuner is a copper block, and the pick-up monitor is a thin rod plated with copper.

FABRICATION

The cavity consists of three major parts, that is, an inner conductor with an end plate, an outer conductor, and an end plate with a short electrode, as shown in Fig. 3. They are machined from oxygen-free copper cylinders and plates. The outer conductor is made slightly longer than a design value to make the frequency tuning afterwards. All the welding is made with silver brazing, including welding between copper and stainless steel. After smaller parts are welded to the three main components, they are temporarily assembled with O-rings and the resonance frequency is measured at room temperature. Then it is evacuated with a scroll pump or rotary pump and a shift of the resonance frequency is measured at room temperature and then it is measured at the temperature determined by cooling water, 38°C. The frequency drift ceases in 13 minutes after opening valves of the cooling water system, which means that the cavity temperature becomes uniform and constant in the time. These frequency shifts for the 216 MHz cavity are $\Delta f = +55$ kHz by evacuation and $\Delta f = -70$ kHz with cooling water, and those for the 108 MHz are +30 kHz by evacuation and -30 kHz with cooling water. When the resonance frequency is tuned, the input coupler and the tuner are installed. The cavity is evacuated to make RF contact between the major parts firm and the frequency is measured at room

Figure 3: Three major components of the 216 MHz cavity. From left to right: short electrode with the end plate, inner conductor with the end plate, and the outer conductor.

temperature. By taking the frequency shift due to cooling water into account, the resonance frequency is tuned to be the designed value under the normal operating conditions. The resonance frequency is determined mainly by the length of the long inner conductor and weakly by the gap, so that there are four possible places to be machined to change the frequency. For a larger change, shaving of the inner conductor end makes the frequency higher while saving of the inner surface of the end plate with the long inner conductor makes it lower. For fine frequency tuning, shaving of the outer conductor end makes the frequency low and shaving of the short nose at the gap makes it higher. At first, the inner conductor is made longer than a design value to save margins for frequency tuning because it is easier to shave the end of the inner conductor than to do the inner surface of the end plate, and then the resonance frequency is measured. The measured frequency is corrected for the shift owing to the cooling water and compared with a calculated frequency. The amount of machining is determined by the calculation and it can be repeated until the target value is realized. However, one trial is usually enough to reach the design frequency by a little help of the tuner except for the case where a mistake is found in machining of the nose cone of the long inner conductor. After the frequency tuning, the three major parts are welded to be a coaxial RF cavity by silver brazing.

The 216 MHz cavity was fabricated first, because the cavity is short and easier to fabricate. Then two 108 MHz cavities were fabricated by making good use of experience gained in the first cavity.

COMMISSIONING

After completing fabrication of the cavity, we measured characteristics of the cavity at the low RF power level. The measured characteristics are listed in Table 2. The calculated values of the unloaded Q-value listed in Table 1 are 8765 for the 108 MHz cavities and 11,642 for the 216 MHz cavity, while the measured values listed in Table 2 are ~8,200 for the 108 MHz cavities and ~10,300 for the 216 MHz cavity, which are 94 % and 89 % of the calculated values, respectively. These measured Q-values should be compared also with those measured for the previous cavities, which are ~5,500 for the 108 MHz cavities and ~5,900 for the 216 MHz cavity, indicating that the new cavities have RF characteristics better than the previous ones and close to the ideal ones. The unloaded Q-values of the cavities are too high to obtain constant RF voltage in the pulse duration of the RF power 40 μs produced with the independent RF amplifiers. The rise time of the RF voltage in the cavity has to be reduced while the same peak voltage is produced with the RF amplifier. This is realized by setting input couplings to be ~4 for the 108 MHz cavities and ~4.4 for the 216 MHz cavity, as can be seen in Table 2, which make filling times of the RF power 4.8 and 2.4 μs, respectively. Owing to space limitations, we can use linear motion feedthroughs with a stroke of only 20 mm for the tuners. A copper cylinder of 29 mm in diameter is attached on the rod of a linear motion feedthrough. Lengths of the cylinders are adjusted so that the resonance frequencies become close to the design values, 108.42 MHz and 216.88 MHz, as listed in Table 2 when they are inserted by 10 mm. The cylinder lengths are 30, 22, and 34 mm for cavities #1, #2, and #3, respectively.

Table 2: Measured Parameters of the Cavities

	Cavity#1	Cavity#2	Cavity#3
Res. freq. (MHz)	108.423	108.426	216.881
Tuning range (kHz)	83	73	327
Loaded Q-value Q_L	1626 ± 6	1612 ± 6	1899 ± 17
Unloaded Q-value Q_0	8232 ± 35	8187 ± 35	10297 ± 128
Input coupling β_1	4.06	4.08	4.42
Filling time (μs)	4.8	4.8	2.8

After completing the measurement and tuning of the cavities at the low RF level, we proceed to the high power test and conditioning of the cavities. A cavity is mildly baked with tape heaters and then evacuated with an ion pump through the beam pipe. The RF power is fed to the cavity at a very low repetition rate like 0.1 Hz while the monitor waveform and the vacuum level are being watched. We are afraid of multipactoring but it does not occur when the high power RF power is fed at once instead of increasing the RF power gradually from a low level. The condition of the cavity is made by gradually increasing the repetition frequency while keeping the vacuum high, until normal operation conditions of the 60 Hz repetition rate and the 20 kW input RF power with the pulse duration up to 100 μs are realized.

The high power test and the conditioning of the cavities are conducted one by one and then the three cavities are installed on the linac in place of the previous ones. The linac is successfully operated with the new cavities for the SHB system without any problems. The overall start-up time of the linac with the SHB system is reduced from some hours to one hour, which is same as the time necessary for the other operation modes without the SHB system and the linac can be operated long time without readjustment.

ACKNOWLEDGEMENTS

The authors would like to thank Professors S. Ohsawa, M. Isawa, H. Hayano, and J. Urakawa of KEK for their valuable suggestions and advice about this work. The mechanical design and fabrication of the cavities are conducted by Meisho Kiko Co. Ltd. This work is partly supported by the program of KEK, "Comprehensive Support Program for the Promotion of Accelerator Science and Technology".