STUDY OF POSITRON PRODUCTION SYSTEM USING SUPERCONDUCTING LINAC

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Abstract

National Institute of Advanced Industrial Science and Technology (AIST) succeeded in producing a low energy positron microbeam, and continues to develop the technique of the positron annihilation spectroscopy with high spatial resolution for samples mounted in a vacuum. We have two improvement plans for this positron microbeam system. The first is to increase the positron beam intensity by introducing a supercoducting linac for an electron beam injector. We could receive the conveyance of the superconducting accelerator modules and reassembled those dismantled for transportation, and the vacuum test and the cooling test into 4 K proved successful. The second is the development of the atmospheric scanning positron microscope. Then, the positron microbeam has to be accelerated up to 50-100 keV to be extracted from the vacuum chamber to the atmosphere through a thin film. As the first phase, a 2856 MHz normal-conducting RF cavity was fabricated to accumulate a necessary technology. The accelerator system for each improvement has been studied and the situations are described.

INTRODUCTION

Electron-positron annihilation occurs when a positron and an electron collide in a substance. The positron lifetime and Doppler broadening depend on the sizes of material defects and their density. Therefore, the positron annihilation spectroscopy using this principle is effective method to analyze the material defects without destruction.

National Institute of Advanced Industrial Science and Technology (AIST) succeeded in producing a low energy positron microbeam, and continues to develop the technique of the positron annihilation spectroscopy with high spatial resolution for samples mounted in a vacuum [1-4]. As shown in Figure 1, the positron beam produced with an electron linac injector and a tantalum target is regulated through a moderator and it is formed to the beam size of 0.03-0.1 mm at the measurement point of the end. This analysis system is called a positron-probe microanalyzer or a positron microscope.

However, we have two improvement plans for this system. The first is to increase the positron beam intensity and the achievement of one order will be expected through the new installation of a supercoducting linac system for an electron beam injector. The second is the development of the atmospheric scanning positron microscope. In the current system, the samples have to be mounted in a vacuum; therefore, the measurable material is restricted. This new system being realized, the defect imaging with positron beam will be possible for samples not easy to set in the vacuum environment such as liquid and powder. Then, the positron microbeam has to be accelerated up to 50-100 keV to be extracted from the vacuum chamber to the atmosphere through a thin film. Therefore, we have developed an RF acceleration cavity and the single-cell type was fabricated as the first phase.

The accelerator system for each improvement has been studied and the situations are described.

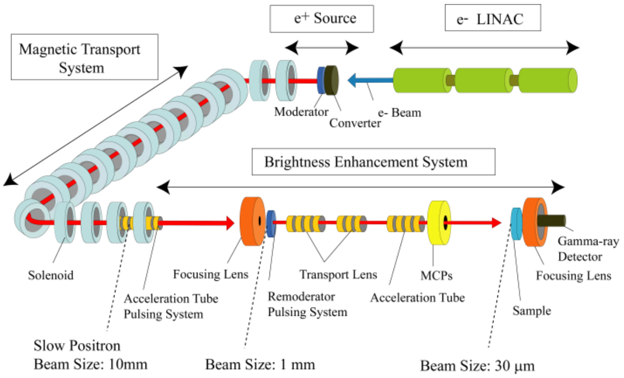

Figure 1: Schematic drawing of the low energy positron microbeam analysis system in AIST.

SUPERCONDUCTING INJECTOR

The positron microbeam system in AIST produces a positron beam by bremsstrahlung and pair creation induced after electron beam irradiates a tantalum target. The current injector accelerator is a conventional normal-conducting electron linac, which is operated at 2856 MHz and has the final acceleration energy of 500 MeV and a peak current of 100 mA. For the positron production, this supplies 70 MeV electron beam with a macro pulse width from 1 μs and a repetition of 50-100 Hz. However, the number of produced positrons is not sufficient and one of the reasons is of low duty cycle of the electron injector.

In order to solve this problem, we considered the use of a superconducting linac, a microtron and Rhodotron as a cw or a high duty injector. The superconducting linac and the microtron can operate under cw or high duty condition, and the power loss of the former especially is very small. The Rhodotron is a commercial accelerator of IBA Corporation for industrial electron beam processing of sterilization etc. This realizes cw operattion with a tetrode amplifier in a VHF band and generates a high

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power beam over 300 kW. However, the standard acceleration energy is 10 MeV because of industrial use.

A positron yield converted from an electron beam increases when the injection energy is above 15-20 MeV. Although the high power beam is fascinating, the increase of the acceleration energy and the change of the operating frequency are special request for the Rhodotron. The superconducting accelerator having outstanding energy-saving performance is suited for a sustainable accelerator system in the future, and the expandability of beam energy is higher by adopting the recirculating acceleration. Fortunately, we could receive the conveyance of the superconducting accelerator (SCA) system which had been used as main accelerator modules in the JAEA ERL-FEL facility [5-8].

These consist of two five-cell SCA modules as shown in Figure 2, two 50 kW solid-state RF amplifier systems and several refrigerator systems. The SCA modules have the performance that can operate in the cw condition; however the RF amplifiers and the refrigerators were made as pulsed operation type, and the duty factor is 3 % in a steady state. The operating frequency is 499.8 MHz and the acceleration energy of each cavity is 7.5 MeV in the pulsed mode; the total energy is 15 MeV. As the maximum allowable beam current is 5 mA, being able to use the full pulse width for beam acceleration, the average beam power will be 2.3 kW of about three times of that using the current injector. Therefore, we consider quasi-cw operation by changing the pulse repetition in the capacity of the RF amplifier and the refrigerator.

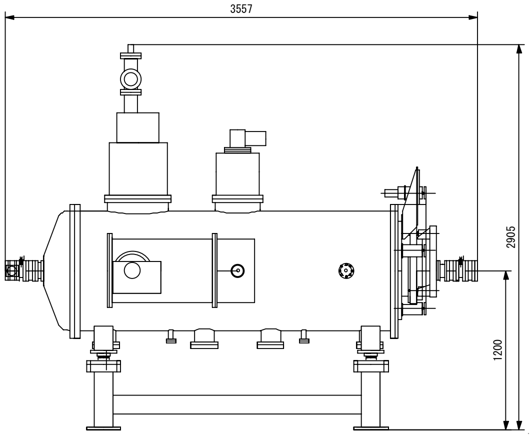

Figure 2: Superconducting accelerator (SCA) module.

The SCA system dismantled for transportation was reassembled and the vacuum test and the cooling test into 4 K proved successful. Figure 3 shows the current layout plan of the SCA injector system that will be constructed in the accelerator tunnel at AIST. The two SCA modules will be set in series and there is the long electron beam line for the positron experimental room in parallel with the current linac.

LOW ENERGY POSITRON ACCELERATOR

We have developed an RF cavity for an atmospheric scanning positron microscope in parallel with the preparation of the SCA injector system. When the positron beam is extracted from the vacuum chamber into the atmosphere, the larger acceleration energy is desirable to obtain high transmission factor for the vacuum window. It became a conclusion that the practicable acceleration energy was 50-100 keV as a result of evaluate the stopping power of some vacuum window materials. Although a 30 kV electrostatic acceleration tube was used in the current system, the development of the RF cavity was started to realize the new acceleration energy. For this cavity as well as the SCA injector, the cw operation is ideal to shorten the measurement time of the positron annihilation spectroscopy; however, we have carried out a phased development because of the restrictions of the usable resource. As the first phase, a 2856 MHz normal-conducting RF cavity was fabricated to accumulate a necessary technology.

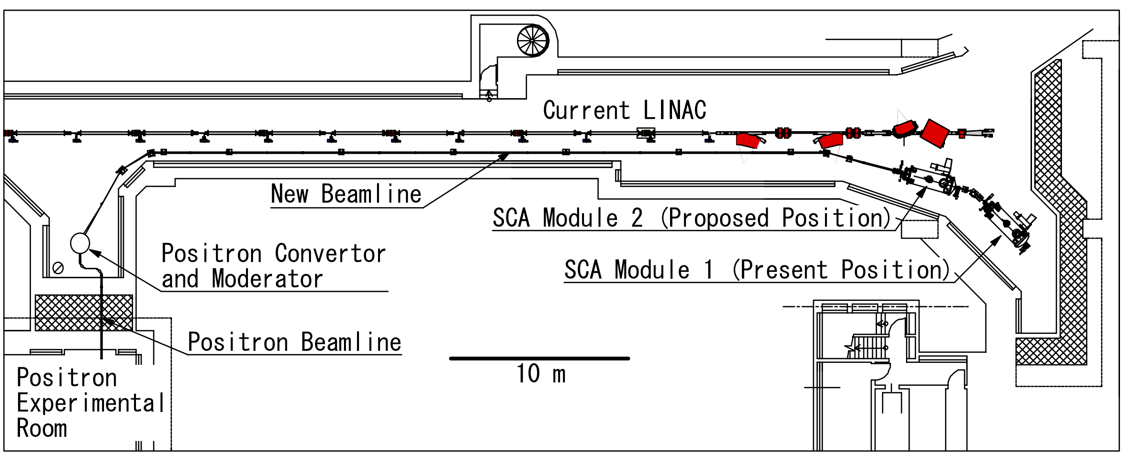

Figure 3: Layout plan of the new electron beam injector system using the SCA modules.

Cavity Design

Low cost and simple design taken, the new cavity is a similar type to a single-cell one with the development results at TokyoTech, and the overall dimension was 160 mm in diameter and 140 mm in length. It is configurated by two half-cell parts made of OFC (oxygen free copper) and assembled with O-ring, bolts and nuts. The indium wire is used as an RF contactor. Each half cell has two ports to install an RF coupler or a frequency tuner. The vacuum is created by evacuating from the beam port. The port flanges being ConFlat-type of stainless steel are attached on OFC through silver brazing.

This cavity uses the RF electric field excited of the TM_{010} mode for the beam acceleration. The configuration was designed with the electromagnetic field simulation software SUPERFISH and MW-Studio, which were used for basic design and for the influence evaluation of the RF ports, respectively. The tuning of the resonance frequency is performed by cutting the edge that remained around the circumference region within the cavity. Moreover, it is possible to correct the frequency by installing a fixed tuner of a copper rod in the port, if there is a necessity. The RF power is fed using an N-type coaxial cable.

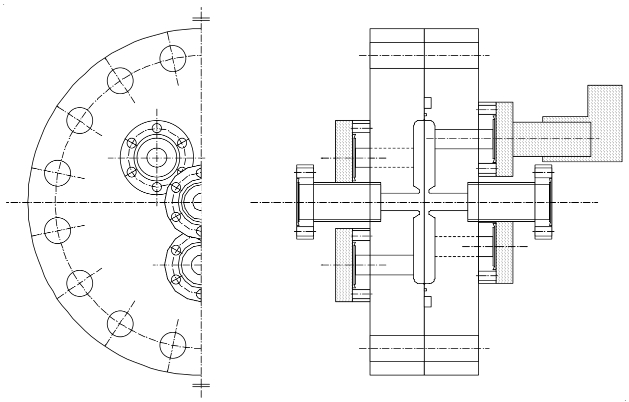

Figure 4: Configuration of low energy positron cavity.

Fabrication and RF Measurements

After the cavity was machined and brazed, the resonance frequency and the Q-value were measured with a network analyzer. The experimental temperature was controlled to 25-27 °C like becoming near the actual use condition. The resonance frequency was tuned to 2855.4 MHz by cutting the tuning edge, which shifted to the designed frequency after evacuation.

As the preliminary test, it was confirmed that the fabricated cavity operated without trouble by inputting the pulsed power of 240 W, 4 μs and 10 Hz using a solid-type amplifier. A positron beam acceleration experiment will be carried out after other components under development will be completed. Therefore, we are planning the first acceleration test using an electron beam and preparing the experimental components such as an electron gun and a klystron.

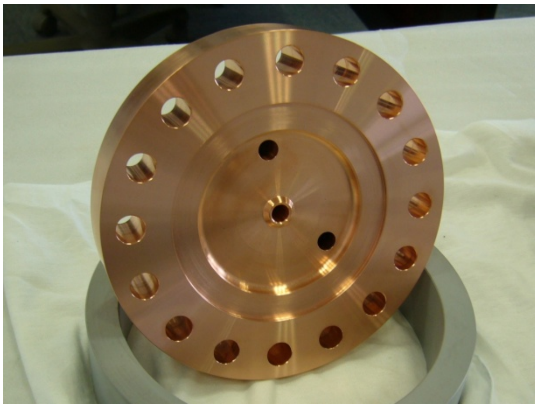

Figure 5: Low energy positron cavity half-cell for the atmospheric scanning positron microscope.

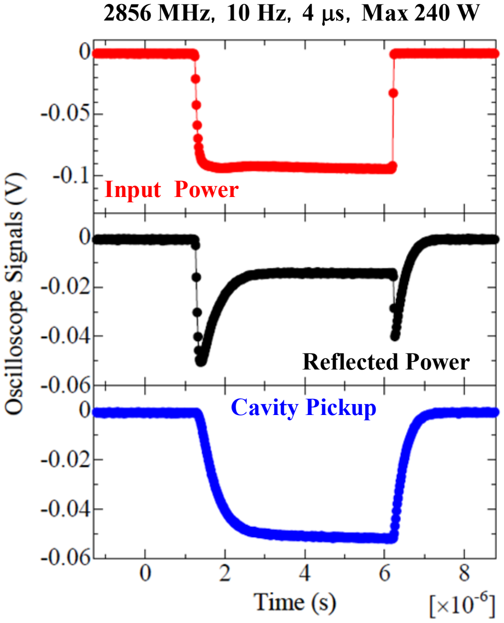

Figure 6: Results of the preliminary RF test with a solid-state RF amplifier.

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