COMMISSIONING OF THE JAERI FREE ELECTRON LASER

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ABSTRACT

We have developed, and constructed a prototype for a quasi-cw, and high-average power free electron laser driven by a 15 MeV superconducting rf linac at Tokai, JAERI.

In designing a high power FEL, there are many available design options to generate the required power output. By applying the superconducting rf linac driver, some of the options relating to the FEL itself may be relaxed by transferring design difficulties to the driver. Because wall losses become minimal in the superconducting accelerator cavity, very long pulse or quasi-cw, and resultant high average power may be readily attained at the JAERI superconducting rf linac FEL.

In 1992 Japanese fiscal year, we have successfully demonstrated better cryogenic(stand-by loss<3.5W at 4.5K) and accelerating fields' performances (Eacc= 7-9.4MV/m and Q =1- 2 x10+9) of four JAERI superconducting accelerator modules, and installed them in the FEL accelerator vault. In 1993, Optical resonators and beam transport systems, which have been already assembled, are now under commissioning.

A description and the latest results of the JAERI super-conducting rf linac FEL will be discussed in comparison with a normal-conducting one, and reported in the symposium.

1. Introduction

A developmental program[1,2] of the free electron laser(FEL) system for a far-infrarèd region from the wavelength of 20 mm to 50 mm or longer has been undertaken at Japan Atomic Energy Research Institute(JAERI), Tokai. The purpose of the present JAERI FEL program lies in constructing a very long pulse or quasi-continuous wave(cw) superconducting rf linac electron accelerator, and demonstrating a high-average power FEL in the far-infrared wavelength region.

Because wall losses and required rf power become minimal in the superconducting accelerator cavity, we may realize a quasi-cw and high-current rf linac driver, and hence a high-average power laser. Each major part of the program including future plans has been reported in other papers[3-8] in detail. Here, we present an outlook of the program including the present status and schedule.

2. Injector

The injector of the JAERI FEL consists of a thermionic cathode electron gun with a pulsing grid, a sub-harmonic buncher(SHB), and a buncher. The accelerating voltage in the single gap electron gun is typically around 230KV, and the gun is usable from 200 to 250 KV. The cathode is mounted horizontally in a stainless-steel pressurized vessel with SF6 gas to 2kg/cm2 in order to prevent break down across a 45 cm-long insulating ceramic tube of the gun. The accelerating gap electrodes are fabricated in a re-entrant geometry to increase the accelerating gradient. Optimization of the geometry was made by computer-modeling of electron beams using E-GUN[9].

The injector has been installed, and was commissioned late August 1991, and is now operated routinely. An extensive study of pulse characteristics as a function of injector parameters has resulted in sets of optimized operating conditions which minimize pulse width at a time focus point while maintaining the beam quality as good as possible. The characteristics typically obtained are as follows: an electron beam of 100mA or more with a 4ns bunch length was extracted from the gun at the accelerating voltage of 180-220KV. The beam was successfully compressed to less than 70 ps at around the time focus point by the bunching system[1].

3. Superconducting rf Linac

The JAERI superconducting rf linac consists of two pre-accelerator modules of the single-cell cavity type and two main modules of the 5-cell cavity type. The resonant frequency of the cavities is 499.8MHz which is exactly the same with the buncher, and the sixth harmonic of SHB in the injector.

We decided to choose a so-called DESY concept of the cavity geometry and fabrication technology refined by Siemens Energieerzeugung KWU for the JAERI FEL superconducting linear accelerator late September,1990. Design values of the accelerating field strength and Q-value for the cavities are 5MV/m, and 2 x 109, respectively. In 1992 Japanese fiscal year, we have successfully demonstrated better cryogenic (stand-by loss<3.5W at 4.5K) and accelerating fields' performances(Eacc =7-9.4MV/m and Q > 1-2 x10+9) of four JAERI superconducting accelerator modules, and installed them in the FEL accelerator vault.

As a main coupler was designed to have a variable coupling coefficient over 3 and half decades, we could inject not only low current but also high current electron beams into the accelerator module. Typical peak RF power for the coupler was measured up to the 150kW without trouble. The coefficient was designed to be adjusted by inserting a center conductor into the cavity.

Three sets of the higher mode couplers were designed, and fabricated to suppress unwanted and harmful TE and TM modes having a higher resonance frequency. Two monitor couplers were designed, and fabricated to use in monitoring and phase detecting in the feedback loop of a fast tuner. Slow and fast tuners were designed, and fabricated to tune a resonance frequency of the cavity in the module. The slow tuner consists of a stepping motor driver and an interface from the control system. The fast tuner consists of a piezo-electric actuator, a high voltage power supply, a feedback loop, and an interface from the phase detector and the control system.

4. Cryostats and Refrigerators

We have newly developed a multi-refrigerators system[5] integrated into the superconducting accelerator module cryostat to realize a highly-efficient system without any liquid coolant. As shown in fig 1, a 4K closed-cycle He gas refrigerator mounted just above a liquid-He supply tower of the module was adopted to cool down and to recondense cold vapor of liquid He around a heat exchanger in the liquid He container. A 40K/80K two-stage closed-cycle He gas refrigerator, which was mounted in a vacuum vessel of the module was adopted to cool down the 40K and 80K heat shields and other major components of the cryostat. These two kinds of the refrigerators are available commercially in Japan and other countries. The 4K refrigerator suspended in a stainless-steel frame can be winched up and down to remove the heat exchanger out of the liquid He container, and to insert the exchanger into the container. Cooling capacity of the 4K refrigerator is 11W at 4.5K and 60Hz.

The 40K and 80K heat shields are used to prevent heat invasion from outside into the liquid He container. In order to minimize heat loads to the container, the heat shields work as a thermal anchor, and make the return route having a temperature higher than 4K for all heat bridges from the outside. The 40K/80K refrigerator used here provides two cooling stages with a typical pair of temperature of 40K and 80K and heat load capacities of 40W and 120W , respectively.

5. RF Power Source

One of the largest merit of a superconducting accelerating cavity is very low power loss, which makes it possible to use all-solid-state RF power amplifiers for all of the cavities[4]. Because the control voltage of the all-solid-state amplifiers is lower than that of a klystron and a tetrode, a more stable RF power is expected to be realized. We choose to use two sets of all-solid-state 50kW RF power amplifiers for the main accelerator modules.

Two sets of the power supply have been already installed, and have been ready to use at the experimental area since the middle of last August. Performance of the rf power supplies has been preliminarily measured to be better than 1% of amplitude and within1 degree of phase stability at an rf power level of 50kW or more.

6. Electron Beam Transport System

The energy of electron beams accelerated by the linac ranges from about 10 to 20 MeV. A conceptual design of the transport system was done by using the beam optics code TRACE-3D [10]. High current beams have to be fed to the undulator under isochronous and achromatic conditions for efficient lasing of FEL. Because of the large amount of charge density, space charge effects would become serious in a long transport line and a beam waist. Since the code could take into account partial space charge effects, the transport system has been investigated by using the code.

A beam dump in preparation will be capable of handling about 40 mA of average current or more, and 1 kW of beam power. Cooling of the dump is provided by air flowing in channels or pipes machined into an aluminum rod. About 30 cm-thick lead surrounds the dump to reduce the radiation levels during routine operation to natural background levels outside the shielding walls made of 150 cm-thick concrete.

7. Hybrid Undulator

A wedged-pole hybrid undulator will be used for the first lasing experiment of the JAERI FEL. The undulator was originally designed and built as a prototype undulator for the SPring-8 project[11]. This device is expected to generate brilliant photon beams of energy ranges around 10 keV by installation into the low emittance high energy storage rings such as the SPring-8[12]. In order to fit the undulator into the JAERI FEL system, the undulator was characterized by three-dimensional field calculation and two-dimensional field mapping.

In order to characterize the undulator, a distribution of the multipoles was derived from the field distributions in the median plane of the undulator. A strip of the three-dimensional field distribution was obtained by using a conventional finite element method(FEM) calculation code ANSYS[13]. An experimental distribution was obtained by field mapping with commercially-available three-dimensionally measuring equipment.

Calculational and experimental distributions of the multipole components along the undulator axis were derived up to dodecapole components from the field distributions by a least-square fitting method. The calculated distributions of the multipoles quantitatively shows very good reproduction of the experimental distributions.

8. Accelerator Vault

A new extension was completed to an old 5.5 MV electrostatic accelerator building as an FEL accelerator vault in March 1992. Two sets of the main accelerator module, the beam transport system, hybrid undulator, and opticals were installed inside the vault in the1992 Japanese fiscal year.

9. Present Status and Schedule

In 1992 Japanese fiscal year, we have successfully demonstrated better cryogenic(stand-by loss<3.5W at 4.5K) and accelerating fields' performances(Eacc= 7-9.4MV/m and Q =1- 2 x10+9) of four JAERI superconducting accelerator modules, and installed them in the FEL accelerator vault. In 1993, Optical resonators and beam transport systems, which have been already assembled, are now under commissioning.

10. Summary

In conclusion, we have presented the status and purpose of the JAERI quasi-cw, high-average power FEL program concerning the superconducting rf linac driver, and other FEL opticals. We reported our successful demonstration on the performances of the injector, rf power supplies, four JAERI superconducting accelerator modules, hybrid undulator, and Liquid He refrigerators, which have been installed for these three years.

In the very near future, we will report upon their results.

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References

[1] M.Sawamura et. al. ,Nucl. Instrum. Method A318(1992)127.
[2] M.Ohkubo et. al. ,Nucl. Instrum. Methods A296 (1990)270.
[3]M. Takao, et al., in the Proceedings of Fourteenth International Free Electron Laser Conference, 1992, Kobe.
[4]M. Sawamura, et al., ibid.
[5]N. Kikuzawa, et al., ibid.
[6]R. Nagai, et al., ibid.
[7]M.Sugimoto, et al., ibid.
[8]K. Sasaki, et al., ibid.
[9]W.B.Herrmannsfeldt, SLAC Report-226, November 1979.
[10]K. R. Crandall, et al., TRACE 3-D Documentation, LA-1054-MS, UC-32 and UC-28, 1987.
[11]H. Kamitsubo, Nucl. Instr. and Meth. A303 (1991) 421.
[12]S. Sasaki, et al., in the proceedings of Particle Accelerator Conference, 1991, San Francisco.
[13]Swanson Analysis Systems, Inc. Reference manual of ANSYS-386 Rev. 4.4.

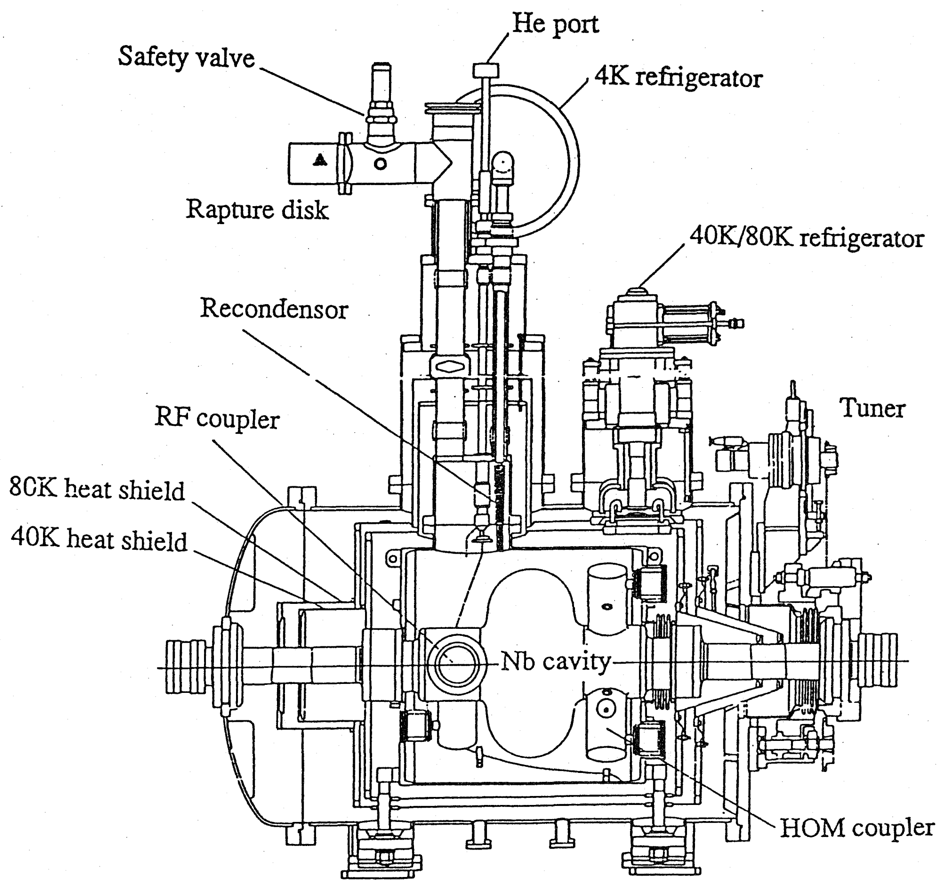

Fig.1.The JAERI superconducting accelerator module cryostat