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RECENT DEVELOPMENT OF THE JAERI FEL DRIVEN BY A SUPERCONDUCTING RF LINAC ACCELERATOR

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ABSTRACT

A prototype for a quasi-cw, and high-average power free electron laser(FEL) driven by a 15 MeV super-conducting rf linac has been developed, and constructed at Tokai, JAERI. Expected cryogenic(stand-by loss<3.5W at 4.5K) and accelerating fields' performances(Eacc ~ 7MV/m and Q ~ $2 \times 10^{+9}$) of four JAERI superconducting accelerator modules have been demonstrated, and installed them in the FEL accelerator vault. A beam test and commissioning of the JAERI superconducting rf linac as an FEL Driver have been successfully performed to get an electron beam ranging from 10 to 20 MeV with nearly full transmission. FEL opticals and beam transport elements around the undulator, which have been already assembled, are now under commissioning. Spontaneous emission in the wavelength of 20 μm to 80 μm or longer have been observed by using the Ge(Cu) detector and fast current amplifier system, and 20m long light pipe.

1. Introduction

As well known, a laser consists of three major parts, i.e., a laser driver, gain media, and an optical resonator. Since the invention of the laser in 1950's, their efficiency, and average power level have been limited to very low by their huge heat losses in the laser driver and gain media. If we could use an FEL, we could neglect the heat loss in the gain media. Unfortunately, as long as the normal conducting accelerator were used to produce high energy electron beam as the laser driver, we could not realize the high efficiency and high average power level due to the heat losses in the accelerator as the FEL driver. In order to make a highly-efficient, and high average powered FEL, we resultantly have to minimize the heat losses in the accelerator.

A developmental program[1,2] of the free electron laser(FEL) system for a far-infrared region from the wavelength of 20 μm to 80 μm 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.

2. Status of the JAERI FEL Facility

(1)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 SF_6 gas to $2 kg/cm^2$ 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.

(2)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. Design values of the accelerating field strength and Q-value for the cavities are 5MV/m, and 2×10^9, respectively. In 1992 Japanese fiscal year, we have successfully demonstrated expected cryogenic(stand-by loss<3.5W at 4.5K) and accelerating fields' performances(Eacc~7MV/m and Q~$2 \times 10^{+9}$) of four JAERI superconducting accelerator modules, and installed them in the FEL accelerator vault.

(3)Cryostat and Refrigerator

We have newly developed a multi-refrigerators system[5] integrated into the super-conducting accelerator module cryostat to realize a highly-efficient system without any liquid coolant. 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. Cooling capacities of the 4K and 40K/80K refrigerators are about 11W at 4.5K and 40W/120W at 40K/80K, respectively.

(4)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]. Two sets of all-solid-state 50kW RF power amplifiers for the main accelerator modules have been already installed, and have been ready to use at the experimental area. Performance of the rf power supplies has been preliminarily measured to be better than 1% of amplitude and within 1 degree of phase stability at an rf power level of 50kW or more.

(5) 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 [9]. 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.

3. Present Status and Schedule

Since 1992 Japanese fiscal year, we have successfully demonstrated expected cryogenic(stand-by loss<3.5W at 4.5K) and accelerating fields' performances(Eacc >5MV/m and Q>2 $\times 10^{+9}$) of four JAERI superconducting accelerator modules, and installed them in the FEL accelerator vault. In 1994, Optical resonators and beam transport systems, which have been already assembled, are now under the beam test.

In 1994, a preliminary beam test of the JAERI superconducting rf linac FEL has been successfully performed to get an electron beam of ten and several

amperes of peak current after the main accelerator at around 15 MeV. Measured energy resolution of a pre-accelerated beam is about 3% of FWHM, and that of a fully-accelerated beam about 0.8% or less. Maximum transmission of the beam from the gun is now at around 100%. We are now active in transporting electron beams in the JAERI FEL and in performing some lasing experiments in the optical resonator. FEL opticals and beam transport elements around the undulator, which have been already assembled, are now under commissioning. Spontaneous emission in the wavelength of 20 μm to 80 μm or longer have been observed by using the Ge(Cu) detector and fast current amplifier system, and 15m long light pipe.

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