STATUS OF RF SYSTEM FOR THE JAERI ENERGY-RECOVERY

LINAC FEL

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ABSTRACT

The two types of the RF sources are used for the JAERI ERL-FEL. One is an all-solid state amplifier and the other is an IOT. There are advantages of little failure and wide bandwidth for the all-solid state amplifier, low cost and high efficiency for IOT. The property of low cost with the IOT is suitable for a large machine like an ERL.
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1. INTRODUCTION

The JAERI (Japan Atomic Energy Research Institute) free-electron laser (FEL) began to be constructed from 1990. The high power lasing of kW was achieved in 2000 [1]. This was the first linac that was operated with all-solid-state amplifiers for all RF power sources.

The JAERI FEL linac was reconstructed to the energy recovery linac (ERL) FEL in 2002 [2]. The ERL has an advantage of high current beam acceleration without increasing the RF power of main accelerators because the beam energy after radiation was converted to the RF power to accelerate the following beam. While the RF power of an injector part of the ERL, where no energy-recover works, increases with the beam current.

There are many requirements for operation modes such as high power or long pulse from the view of various applications. The repetition rate of the micro pulse from the electron gun of the JAERI ERL-FEL is 10.4125 MHz. A high repetition operation of the gun is planned to increase the beam current and the FEL power. The RF power sources for the injector were replaced with inductive output tubes (IOTs) for high power and/or long pulse operation.

Here we describe the performance of the two amplifiers such as tolerance, bandwidth etc., which will be useful for the RF system design for a new accelerator.

2. RF SYSTEM FOR THE JAERI ERL-FEL LINAC

2.1 Configuration
The JAERI ERL-FEL superconducting accelerator (SCA) consists of an injector, an injector merger, two main modules of 499.8 MHz 5-cell superconducting accelerators, two 180-degree bending arcs, an undulator and a half-chicane before the undulator. The injector consists of a 230 kV thermionic electron gun driven by a grid pulser, an 83.3 MHz normal conducting subharmonic buncher (SHB) and two modules of 499.8 MHz single-cell superconducting accelerators.

Electron micro bunches with a charge of 0.5 nC at repetition of 10.4125 MHz are produced and accelerated to 230 keV in a DC electron gun. The average current corresponds to 5 mA. The bunches are compressed by the SHB, pass though the two single-cell modules and are accelerated to 2.5 MeV. The output beam is injected into the two 5-cell main modules where it is accelerated up to 17 MeV. The beam then passes through the first arc, the half-chicane and the undulator. Afterward it is recirculated through the second arc, returned into the main modules in the decelerating RF phase and dumped at the injection energy of 2.5 MeV.

2.2 RF System

Three types of all-solid-state amplifiers for RF power sources for SCA were used, whose powers were 5kW for the SHB, 6 kW for the single-cell cavity, and 50 kW for the 5-cell cavity. These RF power sources were operated in pulse mode of macro pulse width of 1-2 msec and repetition of 10 Hz.
The output of 50kW amplifier was achieved by combining 32 amplifiers of 1.8kW with a coaxial 32-way combiner [3]. The combiner used suspended microstrip lines and subsequently converted them to a coaxial line. The insertion loss was less than 0.2dB, the isolation was more than 17dB, and VSWR was more than 18dB. The output of 6kW was also achieved by combining six 1kW-amplifiers and 5kW by twenty 700W-amplifiers.

In order to increase the beam power and the macro pulse width, IOT amplifier systems of 50 kW CW operation were replaced for the two single-cell cavities, which required more power to increase the beam power because of the non-recovery parts. The other two power sources for the 5-cell cavities are under preparing to be equipped.

3. PERFORMANCE

3.1 Tolerance

The all-solid-state amplifiers have been used for more than 10 years and the IOT amplifiers for a few years. Though there were some troubles for both types of amplifiers, no major breakdown occurred for the all-solid-state amplifiers. The minor failures for the all-solid-state amplifiers occurred as followings.

1) Discharge in the power combiner for the 6kW amplifier.

2) Burnout of matching resistance of the power combiner for the 50kW amplifier.

3) DC power source failure in the control unit of 5kW amplifier.
The all-solid-state amplifiers are easy to operate because of almost maintenance-free and simple instructions.

On the contrary there was a critical failure for the IOT amplifiers. The output ceramic window was cracked during the initial tuning. It happened due to the lack of airflow and improper tuning. It therefore requires careful treatment such as vacuum, heater control, and temperature management.

3.2 Bandwidth

The bandwidth of the all-solid-state amplifier and the IOT amplifier were measured as shown in Figure 1. These bandwidths were measured at the pulse mode by setting the output power to 50kW at 499.8MHz and detecting the output power by sweeping the frequency. Since the power was not maximal at the main frequency of 499.8MHz, the bandwidth defined by the range over the half output power of 50kW was 55MHz for the all-solid-state amplifier and 6.5MHz for the IOT amplifier. While the power spectrum of the IOT amplifier is simple shape, that of the all-solid-state amplifier was more complicated. This seems to come from the difference property of each all-solid-state amplifier module.

3.3 Cost

The production cost of the all-solid-state amplifier for 50kW pulse mode operation was about $0.7M when it was produced in 1992. The production cost of the all-solid-state amplifier for 50kW CW operation is estimated to be about $2M. The production cost for the
50kW CW IOT amplifier is about $0.26M including a vacuum tube, an assemble unit and a high voltage power supply. The currency exchange rate is assumed to $1=100 JPY.

The all-solid-state amplifier has an advantage of little fatal failure and a disadvantage of high production cost. This high production cost could become the determining factor to pass over the all-solid-state amplifier because the total cost of the IOT amplifier in which 35 vacuum tubes were replaced due to breakdown is less than that of the all-solid-state amplifier with no breakdown.

4. CONCLUSION

The two types of amplifiers of the all-solid-state and IOT were compared. The all-solid-state amplifier has advantages of little fatal failure and large bandwidth, and an disadvantage of high production cost. The IOT amplifier has advantages of low cost, and disadvantage of careful handling. The all-solid-state amplifier could be used for a small machine with a few operators because it requires only initial production cost with little maintenance. The low cost RF source like IOT is suitable for large machines like ERLs.

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FIGURE CAPTIONS

Figure 1. Bandwidth of the all-solid-state and IOT amplifiers.
REFERENCES


Soild-state

IOT

Frequency (MHz)
Figure 1