RF POWER OPERATIONS FOR JAERI FEL LINAC

M.Sawamura, E.J.Minehara, R.Nagai, M.Sugimoto,, M.Takao, R.Kato, N.Kikuzawa, and M.Ohkubo
Free Electron Laser Laboratory, Japan Atomic Energy Research Institute (JAERI)
Tokai-mura, Ibaraki-ken 319-11, Japan

Abstract

All of the JAERI FEL linac has been installed and the beam tests have begun. Improvements of the rf system have made the acceleration stable.

Adoption of the method of dividing to generate harmonic frequencies makes the phase fluctuation small. The all-solid-state high power amplifiers are improved to equip the high power isolators. These improvements make the fluctuation of the phase and the amplitude less than several degrees and 1%, respectively. The electron beam has been accelerated successfully up to 15 MeV.

Introduction

Construction of the superconducting linac driven FEL system for far infrared oscillation has been continuing at JAERI. An outline of the JAERI FEL program has been reported elsewhere [1,2].

The JAERI FEL linac consists of a sub-harmonic buncher (SHB), a buncher, two single-cell superconducting modules (pre-accelerator), and two five-cell superconducting modules (main accelerator). All of the cavities have been installed.

The superconducting accelerators are operated with pulse mode of 2 ms macro pulse and 10 Hz repetition rate. Two kinds of the closed-loop helium gas refrigerators, 11 W at 4 K and 20 W at 20 K, have been installed to each module for cooling of the superconducting accelerator cavities.

The cooling tests [3] and the rf tests of the superconducting cavities have been done [4], the beam accelerating test has begun.

In this article, improvements of the rf system and the rf characteristics of the beam acceleration were reported and discussed briefly.

RF system

RF control

The linac are operated with three kinds of frequencies, 499.8 MHz, 83.3 MHz and 10.4125 MHz, which are related each other and generated from the fundamental rf source of 499.8 MHz as shown in Fig. 1 and used as follows.

1) 499.8 MHz is used to operate the five cavities such as the buncher, two pre-accelerators and two main accelerators.

2) 83.3 MHz is generated by dividing 499.8 MHz into the one-sixth sub-harmonic frequency and used to operate the SHB. The rf power fed into each cavity is independently under the control of the phase-and-amplitude controller and amplified by the high power all-solid-state amplifier [5].

3) 10.4125 MHz is generated by dividing 83.3 MHz into the one-eighth sub-harmonic frequency. This frequency is used to generate the grid pulse signals controlling the electron beam emission from the cathode of the gun, and makes the beam synchronized with the accelerator cavities. As 10.4125 MHz is the repetition rate of the electron bunch, the length of the optical resonator of the FEL coincides with 10.4125 MHz.

Frequency divider

In the case of using the harmonic frequencies at the operation of the accelerators, there are two methods to generate the frequencies. One is multiplying the low frequency into the high and another is dividing the high frequency into the low.

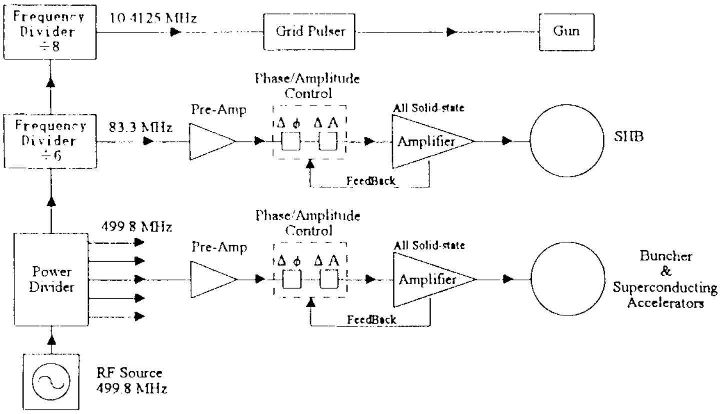

Fig. 1 Block diagram of rf system for JAERI FEL linac.

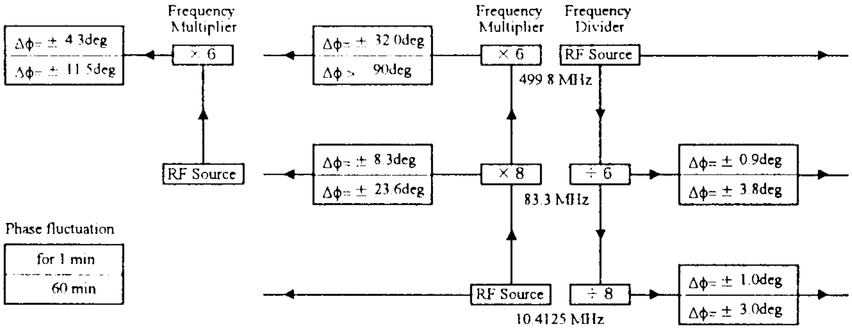

Fig. 2 Phase fluctuation caused by the frequency multipliers and dividers.

In the method of multiplying, the sine curve signal of the fundamental frequency is transformed distortedly and the desired frequency among the various harmonic frequencies is picked up through the band-pass filter. The phase fluctuation of the multiplied frequency is estimated to depend on the rising of the distorted signal and to be multiplied by that of the fundamental frequency.

On the other hand, in the method of dividing, the pulse signal of the same cycle of the desired frequency is generated by counting the number of the wave of the fundamental frequency and the desired frequency is transformed by passing through the low-pass filter. Although there is the merit of decreasing the phase fluctuation through the process of dividing, it might be difficult to choose the suitable counter working certainly at such high speed as the fundamental frequency and dividing by the desired divisor.

A quality of the accelerated beam such as the energy spread depends on the fluctuation of the phase and the amplitude of the rf power. When there is the rf phase fluctuation, the accelerating phase in the cavity becomes unsteady to spread the beam energy. The phase fluctuation generated by the methods of multiplying and dividing the frequency is shown in Fig. 2. The phase fluctuation of multiplying is larger than that of dividing. It shows some demerit of the multiplying that the fluctuation is also multiplied by the previous fluctuation.

Improvement of the rf amplifiers

The five high power amplifiers of 499.8 MHz have the similar structures. Each of them consists of a power divider, several or a few tens of low power amplifier modules, a power combiner and a directional coupler. The divided input power by the power divider is fed into the low power amplifier modules, whose power is combined to make the high power output. Each low power amplifier module has an isolator to protect itself from the reflected power. The directional coupler picks up the power for monitoring and controlling.

The rf coupler of the superconducting accelerator is set at the most suitable position when the rf power is fed into the beam loaded cavity. The dissipated power by the beam occupies so large a percentage of the total dissipated power that the rf coupling becomes considerably over-coupling in the absence of beam load. Therefore, when the power is fed into the superconducting accelerator in the pulse mode, the reflected power from the accelerator to the rf amplifier varies drastically due to over-coupling.

The reflected power was thought to be divided by the power combiner and to be absorbed at the isolator of the low power amplifier module. Due to mismatching of the power combiner the reflected power was reflected again at the power combiner, and affected the feed-back control signal, so that the output power became unstable. To solve this, a high power isolator was inserted between the power combiner and the directional coupler in order that the reflected power could not invade the control signal from the directional coupler as shown

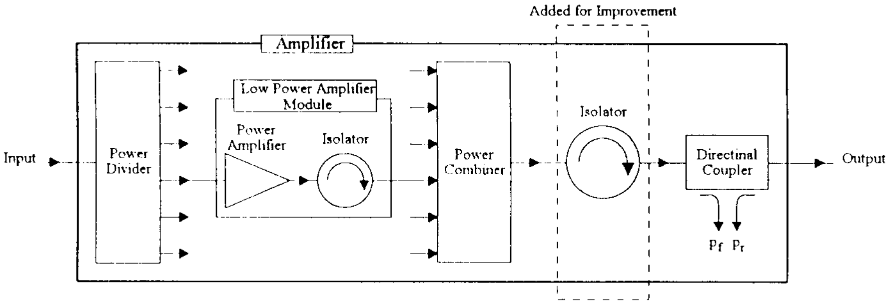

Fig.3 Block diagram of rf high power all-solid-state amplifier and isolator equipped for improvement.

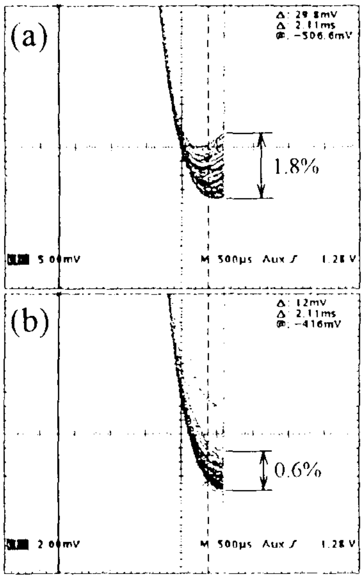

Fig. 4 Field fluctuations in the pre-accelerator cavity fed the power from the amplifier (a) before and (b) after inserting the isolator.

in Fig. 3. Field fluctuation in the cavity fed by the amplifier with or without the high power isolator is shown in Fig. 4. It indicates large improvement of the field stability by 3 times.

Beam accelerating tests

The JAERI FEL linac consists of the electron gun, the SHB, the buncher, two single-cell superconducting pre-accelerators and two 5-cell superconducting main accelerators. The first merit of using the superconducting accelerators is to be able to operate the accelerators at the continuous wave (CW) mode. Despite this merit, the reasons for the pulse mode operation of the JAERI FEL linac are as follows.

1) It is necessary to shield the accelerators much more heavily in order to protect the radiation caused by the beam loss at the CW mode than at the pulse mode.

2) A closed-loop helium gas refrigerator is adopted for cooling the superconducting accelerators. There are two kinds of the heat loss such as the rf power loss on the cavity wall and the heat invasion from outside of the cavity. The former is estimated to be about 30 W at the field of 5 MV/m and the latter about 3 W for the 5-cell accelerator module. The performance of the 4 K refrigerator is 11 W, so that it is necessary to reduce the power loss by operating the rf power at the pulse mode.

The pulse mode of 2 ms macro pulse and 10 Hz repetition rate is chosen to operate the superconducting accelerators. This macro pulse is long enough to get the FEL oscillation.

As the JAERI FEL linac has both the superconducting and normal conducting cavities, it is necessary to delay the timing of feeding the rf power and emitting the beam according to the filling times of the cavities as follows.

1) The rf coupler of the superconducting cavity is set with almost maximum coupling coefficient. In this coupler position the loaded Q-value is about 0.5×10^6 at the field of 4.5 MV/m, so that the filling time of the cavity is about 0.3 ms. The rf power is fed into each superconducting cavity with the pulse length of 2 ms.

2) After 1 ms the rf power starts to be fed into the SHB and the buncher with the pulse length of 1 ms

3) After 0.2 ms the electron beam starts to be emitted with the pulse length of 5 - 800 ms.

The beam accelerating tests have started and beam has been accelerated successfully to the end of the undulator. The voltage of the electron gun is about 250 kV. The bunch length at the exit of the gun was about 2 ns. The accelerating field of the superconducting accelerators is about 4.5 MV/m with the unloaded Q-value more than 2×10^9. The energy spread at the exit of the pre-accelerators was about 3 %. The energy at the exit was about 15 MeV. The beam accelerating tests is continued to improve the peak current of the beam and the energy spread, and the beam will be passed through the undulator to get the FEL oscillation.

Conclusion

The stability of the rf system is improved by adopting the frequency dividers to generate the sub-harmonic frequencies, and by inserting the isolators to the high power rf amplifiers. Improvement of the rf system makes the fluctuation of the phase and amplitude in the field less than several degrees and 1 %, respectively and the beam acceleration more stable. The beam has been accelerated successfully up to 15 MeV to the end of undulator. The experiments of the FEL oscillation will begin in the future.

References

[1] M.Sawamura et al., Proc. 13th Int. Free Electron Laser Conference, Santa Fe, NM, USA, 1991, Nucl. Instr. and Meth. A318 (1992) p. 127.

[2] E.J.Minehara et al., Proc. 14th Int. Free Electron Laser Conference, Kobe, Japan, 1992, Nucl. Instr. and Meth. A331 (1993) p. 182.

[3] N.Kikuzawa et al., ibid., p. 276.

[4] M.Sawamura et al., Proc. 15th Int. Free Electron Laser Conference, The Hague, The Netherlands, 1993, Nucl. Instr. and Meth. A341 (1994) p. 391.

[5] M.Sawamura et al., Proc. 14th Int. Free Electron Laser Conference, Kobe, Japan, 1992, Nucl. Instr. and Meth. A331 (1993) p. 323.