PRELIMINARY CONSIDERATIONS ON THE ISOTOPE SEPARATION DEDICATED FREE ELECTRON LASER

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Abstract

A free electron laser(FEL) configuration, which is dedicated to the isotope separation, is conceptually proposed as the preliminary considerations. The case of three lines of visible light in simultaneous emission is considered. Some technological items for realizing the system are discussed in conjunction with the current R&D program on the superconducting linac driven FEL at JAERI.

Introduction

In the many FEL applications, isotope separation seems to be the first dominance in the field of nuclear research and industry application, as exemplified in uranium enrichment process for nuclear fuel preparation. As an another case, the isotope separation of ^{90}Zr, ^{91}Zr, ^{61}Ni, ^{57}Fe, ^{53}Cr, and ^{97}Mo, which are used in fuel covering tube(Zircalloy) or as the reactor structural material, can be considered. ^{91}Zr has a large neutron capture cross section, while the remainders(^{90}Zr etc.) have smaller ones. Optimistically, the Zircalloy without the ^{91}Zr can save the fuel consumption as much as 40 %.

There are two ways in laser isotope separation: (1) atomic vapor laser isotope separation (AVLIS) and (2) molecular vapor laser isotope separation (MVLIS), however the AVLIS is believed much superior. It uses either three lines of visible light or two ultraviolet lines, because the ionization potentials of atoms is in the range of 5-7 eV(6.2 eV for U). If we use the conventional lasers, three visible lines can be got from the combination of three copper vapor and dye lasers, and two ultraviolet lines can be got from excimer and dye lasers.

The basic R&D on the superconducting linac driven FEL in minimal configuration (Phase-I) is now underway at Tokai. It will go further to the Phase-II with the several options in near future. The "minimal" means single-pass, mono-light, rather low electron energy(10-20 MeV), and laser wavelength in infrared. It is aimed at the technological achievement of the components and their combination under the several experimental conditions. The discussion below is foreseeing nature of the future plans of experiments or designs.

FEL configurations

Several configurations can be considered to generate two or three laser beams with the different wave lengths, simultaneously, using the rf linac. These are categorized by the scheme of the injection of electron beam and the undulator configuration.

(1) single energy, multi undulator with different parameter, deflecting method:

The consecutive micro bunches of electrons are deflected, one by one, by a fast deflector using a cavity, and injected into the separated undulators which parameters are adjusted to oscillate desirable wave lengths. After passing through the undulators, electron bunches are collected by a merging cavity into an energy recovery line.

Fig. 1 shows the sample layout of this configuration and the injector, accelerator sections described latter.

In this method, the incident electron energy is same for all undulators, so the undulator parameters define the obtainable laser wave lengths. Those wave lengths are tunable by changing the incident energy, but in a dependent manner given in the formula: $\lambda_L = \lambda_W (1+K^2)/2\gamma^2$.

(2) single energy, multi undulator with different parameter, cascading method:

The undulators with the different parameters same as given in the method (1), are configured as a serial or cascading line. The incident electron beam passes through all undulators, sequentially. The exit beam returns into a recovery line.

To maintain the laser oscillation at all undulators, a mechanism to improve the beam quality is necessary between the neighboring undulators, such as a phase space compressor.

(3) multi energy, multi undulator with same parameter, branching method:

The energy dispersion cavity is used to give the energy difference among the electron micro bunches, and the bunches are analyzed and injected into the separated undulators for each laser wave lengths. All electron beams are collected by the funneling magnet and compensated the energy difference by the anti-dispersion cavity to enter the single recovery line.

In this case, the undulators can have the same parameters when the energy dispersion cavity can give enough energy difference for obtaining the desirable wave lengths.

(4) multi energy, single undulator with multi frequency type, merging method:

The energies of the electron micro bunches are modulated as described in the method (3), but these bunches are injected into the single undulator instead of the multi undulator. The laser wave lengths are selected by the resonator's resonance condition. The exit beam is compensated its energy dispersion using the method in (3) and returned into a recovery line.

This method is much difficult to decouple the multi frequency in the single resonator (circular type with a correction for chromatic dispersion) and the tuning mechanism is also a tough problem.

Beam Bunch Structure

Except the method (2), the multi micro bunch structure is necessary to generate the lasers interlaced to each other. The time structure of the beam bunch is usually separated by the round trip time of the light in a resonator, and its repetition rate is rather low compared with the accelerator frequency. So the electron bunches for the other wave lengths are just filled between the basic bunch structure, which should be matched to the accelerator and the deflector (method (1)) or energy dispersion cavity (methods (3),(4)) phases. The time delay of the laser pulses in the order of several tens nsec can be adjusted by the length of the light beam transport line.

Electron Accelerator Section

The electron beam energy is recovered using a decelerator cavity to save the operation cost. This would be done by a separated decelerator tank or by using the decelerating phase of the accelerator tank to save the construction cost and raise the efficiency of energy recovery. The latter can be achieved effectively when the superconducting accelerator(SCA) is used in cw mode operation. The R&D study carried out at JAERI now employs the SCA, so it can be a good basis for such a purpose.

To decelerate the electron beam after passing through the undulators, its deteriorated phase space distribution must be modified or compacted by using some devices before return to the accelerator tank. One of these devices is such as energy compressor, which is a combination of the bunch elongation (using the alpha-type magnet) and the energy compacting cavity.

The accelerator system can be configured as to recirculate the beam to gain the energy doubled or tripled. This would be also done by using the SCA as a main accelerator. The example layout is shown in fig. 1. The electrons are injected at 3MeV and accelerated with energy gain of 39 MeV by a single pass, which is achieved by six sets of the five-cells tank of 500 MHz cavity. The beam is recirculated triple times and the final energy becomes 120 MeV.

In the case of multi turn acceleration, the higher order mode (HOM) waves can be excited by the beams strongly. Particularly, the beam deflecting modes should be avoided to get the low emittance and stable beam. These can be suppressed if the phase space distributions of the neighboring beam bunches are very different. So the phase space adjustment before the injection of each recirculation line is effective to suppress the growing up the HOM power level. In this context, the beam from the energy recovery line contributes almost independently about the HOM excitation because its phase space distribution is very different to that of the accelerated beam.

Another issue in the main accelerator is the control of the rf feeding. The SCA can be operated in cw mode and its power dissipation at cavity structure is very low. If the beam power can be recovered properly, the main accelerator section consumes a little rf power. The small rf power fed at an instance would be stored in the energy of the beam bunches in the recirculation lines and the beam intensity is gradually raised, as in the storage ring. The control of this type operation is a key issue to realize this operation.

Injector Section

The injector provides multi bunch structured electron beam with the energy around 3 MeV. Since the requirements for the multi bunch structure may not be unique, it is desirable to be arranged to produce an arbitrary time structure. The conventional thermionic cathode with grid pulser and sub-harmonic bunching system cannot be used to produce these bunch structures. The possible candidate is a photo cathode gun driven by the mode locked laser system which can provide any sequence of timing pulses. However, the intensive R&D is necessary to realize such injector system.

The pre-accelerator section is important that it must provide a good quality beam with a controlled intensity discussed in the rf feeding problem. The most attractive method is the superconductive rf gun operated in cw mode, but the separated tank scheme (gun + couple of superconductive cavities) is more feasible.

Conclusion

The multi color FEL gives a unique and valuable laser source for many applications in research and industry field, e.g. laser driven isotope enrichment. The several methods can be considered to achieve this. Anyway, the best choice for the main accelerator is the SCA to reduce the operation and the construction cost. Some parts are required to intensive R&D to realize, e.g. multi beam energy recovery line or photo cathode injector system.

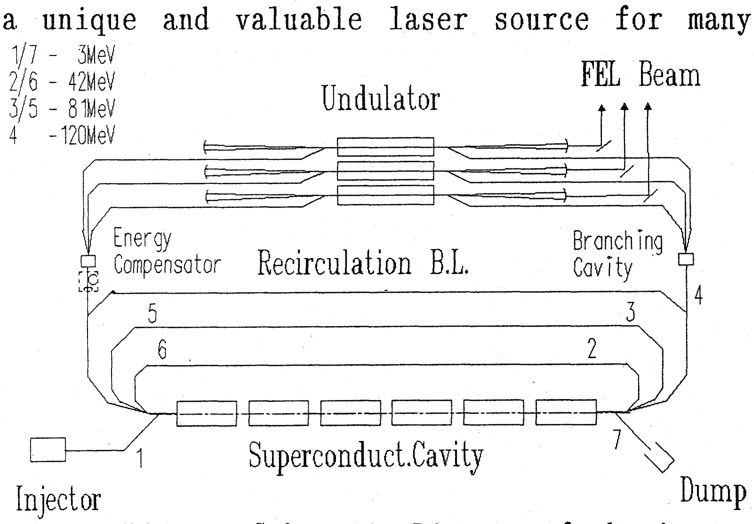

Fig. 1. Schematic Diagram of the isotop sepration dedicated FEL