A COMPACT CRYOGENIC ERL-FEL AND LASER CLEANING IN NUCLEAR REACTORS*

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Abstract

A compact cryogenic ERL-FEL (energy-recovery linac based Free-electron laser) should be usable for laser cleaning applications in radio-isotope (RI) contaminated nuclear power reactors in the world. A new compact zero-boil off (ZBO) superconducting accelerating cavity module like the JAEA FEL machines will be discussed and optimized to realize the easy operation and maintenance-free for nuclear power and other industries. We will firstly make such a high peak and high average power ERL-FEL to realize all of them. The ERL-FEL will be used near future for decommissioning nuclear power plants and other purposes in heavy metal industries.

INTRODUCTION

In this paper, we discuss the use of cryogenic ERL-FELs to laser cleaning RI (radio-isotope) contaminated materials and components in nuclear power reactors for nuclear industries. The difficulties in laser cleaning in hot tests inside the Japanese heavy water test reactor named "Fugen" about 3 years ago. We proposed an improved laser cleaning system for old nuclear power plants to overcome the lower performance recorded in the laser cleaning trials about 3 years ago at Fugen.

We thought there were two motivations before we started the laser cleaning works. (1) We have to prevent a so-called global warming, and to reduce CO2 emission by using nuclear power plants. (2) To realize these two targets, we need to clean up and to decommission many old nuclear power plants, and to build many new nuclear power plants. Therefore, before building up many new nuclear power plants, we have to develop well the proven laser technologies to clean up the RI-contaminated ones, by using FELs, and other lasers.

What should we discuss here for preventing global warming and for reducing CO2 emission at FEL society? Two categories of works, or two step actions, we plan to apply the cryogenic ERL-FEL technology to these open problems. First, to develop and to use the compact cryogenic ERL-FEL for laser cleaning. Secondly, RI-contaminated samples tests are needed to finalize or to complete the laser cleaning technology.

Inside the nuclear power plants and other nuclear plants, we plan to install the movable FELs and movable conventional big lasers. The compact and cryogenic ERL-FEL should be equipped long MTBF(mean time between failures), and very reliable, maintenance-free or easy-maintainable refrigerators and cryogenic systems. Therefore, the liquid-less or zero-boil off refrigerator and cryogenic ones for ERL-FELs needed to run reliably.

ERL-FEL

Figure 1 is the old JAERI-ERL-FEL system; this is the one of the oldest ERL system, and the first zero-boil off linac. Eight refrigerators and 4 ZBO cryostats have been performed and fully-operated over about 18 years, and very good performances have been shown up to last year. Their parameters of the cryogenic ERL-FEL are sown in the figure 1. The JAERI ERL-FEL was renamed to be JAEA FEL about 3 years ago, and shut down last May after about 20 years successful operation and research.

Three types of the ZBO cryostat-based ERL-FEL machines have been designed and planned to use for industrial applications. One set of the electron energy and FEL wavelength of these machines are designed to optimized ones for nuclear industrial applications. .

The closed-loop He gas refrigerators used in the JAEA ERL-FEL has been famous for the one of the largest cooling power in the commercially available cryogenic systems. They are the well developed and proven, and widely-used in the linear motor car train systems of Japan Railways, medical MRI imaging systems in the world and other new applications like a proton therapy recently.

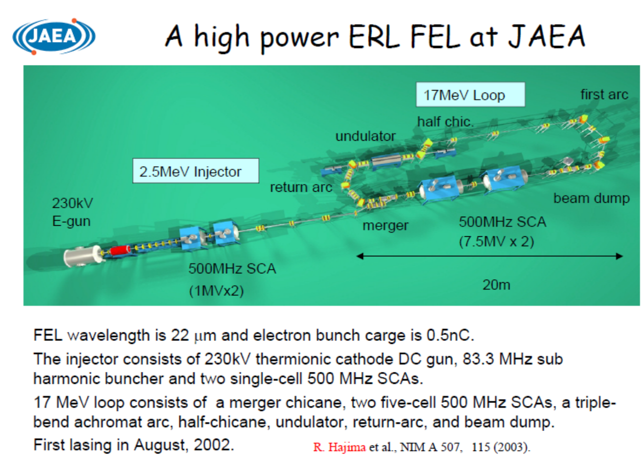

Figure1: The JAEA energy recovery super-conducting linac-based free-electron laser (ERL-FEL) at Tokai.

The refrigerators have been manufactured and repaired regularly by Tanashi Works, Sumitomo heavy industry Co. Ltd. Their limited performance in cooling power forced us to run the cryogenic ERL-FEL in lower duty factor at high macro pulse current. If we can increase the macro pulse current by a multiple factor of the inversed duty one, we can run the lower duty machine with the same and high beam power and the same average beam current.

LASER CLEANING IN REAL WORLD

Many universities, research companies and laboratories have announced many times that they successfully could invent or release the novel product or new instrument to clean up the RI-contaminated components in nuclear power plants and facilities. But these new laser cleaning systems have been never familiar up to now in nuclear power industries and other related ones. The laser cleaning intrinsically has very high, very exotic, and extraordinary performances, that is, "no secondary contamination happened". Many other cleaning methods like a chemical, mechanical and sandblasting removal ones are seriously suffered from the secondary contamination, on the other hands, the laser cleaning method intrinsically has no secondary contamination in the device parts and peripherals. This is the reason why many people want to develop the laser one; therefore, they have been expected to perform very high up to now.

We performed the first trial shown in figure2 using the laser cleaning for the RI-contaminated components used before inside Japanese heavy water test reactor named "Fugen" about a few years ago. In conclusion, Carbon steel components cleaning using the laser were very successful, on the other hand, Stainless steel one very unsuccessful.

Figure2: Laser cleaning trial at Fugen.

In short, Carbon steel case showed the laser cleaning very successful, and the laser cleaner quickly removed the surface and RI-contaminated ones became quickly less radio-active, and the radio-active density became less than the clearance level. But the Stainless steel case was totally opposite, nearly no removal of the activity. The Carbon steel case is typically 100 times more quicker than the Stainless steel case.

Newly-developed and improved laser cleaning method was applied to the cold, that is, no RI-contaminated samples, and we could realize a quicker removal of the sample material.

A vehicle used inside nuclear reactors to clean up mechanically was originally designed to clean up nuclear power plants in the bottom of the nuclear reactor vessel and other ones of the nuclear power plants. We plan to use the vehicle to send laser light to the RI-contaminated parts freely in the bottom of the vessel and other ones, and plan to install the laser-transmittable quartz optical fiber transmission line and other optical focus system in the vehicle. The cleaning laser like FELs, and others should be installed outside of the nuclear vessel and the laser light is transferred to the RI-contaminated parts inside of the vessel.

Quartz optical fiber test experimental have been recently performed to realize a cheap and reliable cleaning by laser, we plan to develop long radiation resistant quartz optical fiber transmission lines for the laser cleaning applications. We expected and thought to extend the fiber life time up to 1000 times longer interval than before.

CONCLUSIONS

The FELs driven by the superconducting RF linac have intrinsically very high average power capability because the linac driver is highly efficient and powerful. Relatively low efficiency converted from the electron beam to FEL power can be overcome, and increased to recover the remained beam power after the lasing by the ERL. The ERL technology can be usable to make the FEL efficient drastically, and to realize the industrial FELs for many major industry fields including the nuclear power industries soon.

Under the above basic understandings, we first reported here some cold and hot tests of ERL-FEL and other laser cleaning for RI-contaminated surface at the nuclear reactors.

Secondly, cold sample experiments show that ERL-FEL, and other lasers may be usable for the laser cleaning.

We finally also add our plan and hope to use or to try ERL-FELs and other lasers to clean-up nuclear power reactors.

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