IMPROVEMENT OF THE LONG PULSE OPERATION OF THE FEL LINAC AT NIHON UNIVERSITY

T.Tanaka, K.Hayakawa, I.Sato, K.Sato, Y.Hayakawa, K.Yokoyama, K.Kanno, T.Sakai
Atomic Energy Research Institute, Nihon University, Funabashi, 274-8501, JAPAN
S.Fukuda, S.Anami, S.Ohsawa, A.Enomoto
High Energy Accelerator Research Organization (KEK), Tsukuba, 305-0801, JAPAN

Abstract

Some improvements to the high power RF system of the 125 MeV linac have been performed to realize a stable long pulse operation of the linac. The breakdown of the klystron RF window occurred in 8 klystrons at early phase of the linac operation. However, the problem has been avoided by the improvement to the vacuum conductance around the RF windows and by a careful conditioning. The Mitsubishi PV3030 type klystrons, which were moved from KEK, have been operated successfully at the peak output RF power of 20 MW, the RF pulse width of 20 μs and the repetition rate of 12.5 Hz.

1 INTRODUCTION

The 125MeV FEL linac at LEBRA (Laboratory for Electron Beam Research and Application) in Nihon University has been operated since 1997[1]. The 2856 MHz RF has been supplied with two Mitsubishi PV3030 klystrons. Difficulties in the high power RF system, the dielectric breakdown around the heater transformers in the klystron assembly tanks and the breakdown of the klystron output RF windows, were quite serious problems in accelerating a long pulse electron beam. The specifications required of the high power RF from each klystron are the peak power of 20 MW and the pulse width of 20 μs for infrared to visible region FEL in LEBRA.

Some improvements to the devices in the high power RF system were made to suppress the above troubles. The details of the improvements are discussed in the following sections.

2 PROBLEMS IN KLYSTRON ASSEMBLY TANK

2.1 Dielectric Breakdown in Transformers

Each klystron pulse modulator offers the pulse with FWHM of 30 μs and a flattop of 20 μs. The peak voltage applied to the klystron cathode is about 240 kV at routine operation for infrared FEL. The klystron is mounted together with the focusing coil on the klystron assembly tank. The klystron assembly tank contains the 1:12 pulse transformer, the heater isolation transformer and the klystron socket, and is filled with the high voltage insulating oil.

In the early phase of operation, there occurred frequent dielectric breakdowns in the tank. Many tracks of the dielectric breakdown were found in the pulse transformer and in the heater transformer. Notably serious damage was found in the secondary winding of the heater transformer.

2.2 Renewal of Transformers

The tracks of breakdown in the pulse transformer were concentrated around the corner of the windings. This has implied that the radius of windings at the corner was not sufficiently large to avoid a strong electric field. Therefore, at the renewal of the pulse transformer, coils have been wound with a larger corner radius than the previous one.

The structure of the heater isolation transformer is shown in a) of Figure 1. The transformer, together with the pulse transformer, was fabricated by Nihon Denji Kogyo Co. ltd. The corona was found around the edge of

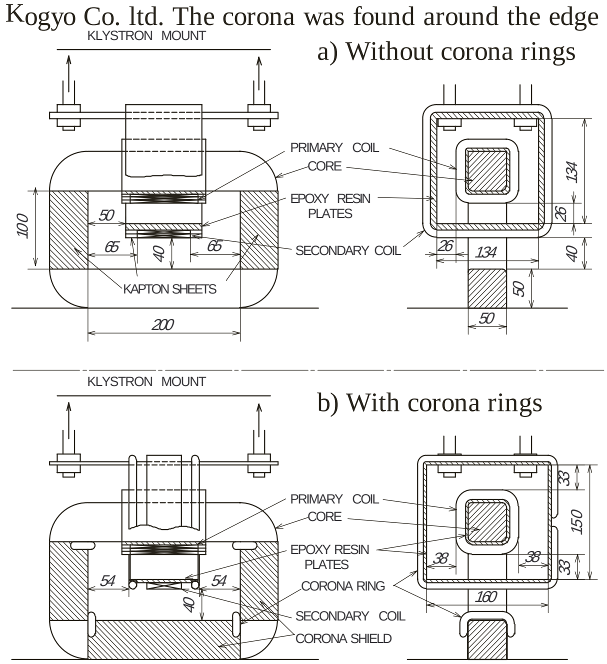

Figure 1. Layout of the heater isolation transformer.

the secondary winding inside the cut core in every pulse. The breakdown was found to occur between the edge and the polyimide (kapton) sheet wrapping the cut core, which was observed with a TV camera through a viewing window in the assembly tank.

Generally, high quality insulating oil has a dielectric strength greater than 30kV/mm. Minimum separation of 26mm between the primary and the secondary coils was enough if the electric field distribution was the same as those between plane electrodes. However, it was evident that the electric field on the thin edge of polyimide sheets wrapping the secondary winding or on the edge of the epoxy resin plates was greater than the dielectric strength.

When the transformer was disassembled, a significant carbonization was found extensively on the surface and the inner layer of the epoxy resin plates.

At the renewal of the heater transformer, the following improvements have been made to the structure of the transformer, as shown in b) of Figure 1:

1) The inner size of the secondary coil frame has been extended from 134×134mm to 160×150mm, while the thickness of the epoxy plates has been reduced from 8mm to 4mm. Then minimum separation between primary and secondary coils has been extended to 33mm.
2) The ordinary epoxy resin plates used as the coil frame have been replaced with the void-less ones. Also the polyimide sheets that were used to wrap the coils have been replaced with the kraft papers.
3) In order to avoid the strong field around the coil edges, copper corona rings have been added at both side edges of the epoxy resin plates of the secondary coil frame.
4) The whole edge of the cut core has been rounded off. In the previous cut core, only the inside edge was rounded off.
5) The polyimide sheets that were used to wrap the cut core have been removed. The rounded copper sheets have been substituted as the corona shields.
6) The corona ring has been added at each inside corner of the cut core.

These improvements were performed by Nihon Denji Kogyo Co. ltd.

2.3 Results of Improvements

The pulse transformer and the heater transformer in the #2 klystron assembly tank were renewed in December 1998. The running test of the klystron at the diode-mode operation proved that no dielectric breakdown occurs in the tank even with the pulse modulator peak output of 24 kV, which corresponds to 288 kV at the klystron cathode and peak output RF power greater than 30 MW.

The transformers in the #1 klystron assembly tank were also renewed in February 1999. Since then, there has been no incidence of dielectric breakdown in the assembly tank, though the operation time is over several thousand hours. Therefore the improvements to the transformers as mentioned above are considered to be quite effective for the increase of the dielectric strength.

3 PROBLEM IN KLYSTRON RF WINDOW

3.1 Dielectric Breakdown of the RF Window

The RF pulse width of 20 μs is out of the design specification for the PV3030 klystron. The most serious problem in the long pulse operation of the PV3030 klystron was the breakdown of the output RF window. As the result of the diode-mode operation with the pulse width of FWHM 30 μs, no problem was found with the collector or the electron gun up to peak voltage of 288 kV and repetition rate of 12.5 Hz.

Eight klystrons were broken in early phase operation of the linac because of the damage of the output RF windows. All these klystrons were moved from KEK after being used for a long time in the injector linac of Photon Factory. Therefore the klystrons were well aged, but the outer surfaces of the RF windows were exposed to air for a while before reused at LEBRA.

The vacuum in the waveguide was pumped with a 60 l/s ion pump located about 2.6 m downstream the RF window, which is illustrated in Figure 2. The vacuum conductance at the RF window was estimated to be approximately 8.2 l/s[2]. During the aging of the klystrons at LEBRA the long pulse output RF from the klystron, even at quite low power level, led to a considerable degradation of vacuum around the outer surface of the RF window.

At high power output operation, though the klystron was aged carefully, the dielectric breakdown that sometimes occurred at the RF window surface caused degradation of vacuum instantly by 1 to 2 orders of magnitude. Because of low vacuum conductance, the vacuum near the RF window had not sufficiently

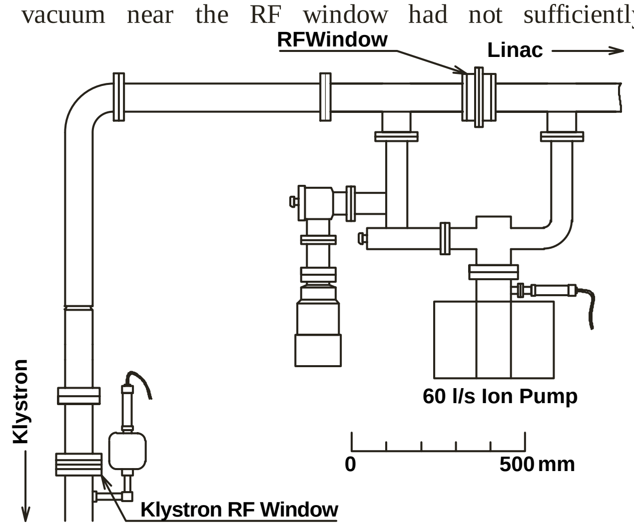

Figure 2. Layout of the waveguide and the vacuum pumping system with a low vacuum conductance.

recovered before the next RF pulse, which caused the dielectric breakdown again. After these conditions were repeated many times in the operation of the linac, the window was finally broken.

The rapid degradation of the vacuum after the dielectric breakdown was never resolved even by a careful aging for a long time.

3.2 Increase of Vacuum Pumping

The second RF window on the way to the linac accelerating tubes is shown in upper side of Figure 2, which is placed because of convenience in the maintenance of the linac. Although there was no essential difference from the klystron RF window on the material or the RF power suffered, the window was never damaged. The important difference seemed to be the distance from the ion pump, which means the difference of the vacuum conductance.

The vacuum conductance at the second RF window was estimated to be approximately 20 l/s, which is about 2.5 times greater than that at the klystron RF window. It suggests that a quick recovery from the degraded vacuum at the window surface is essential to avoid the damage of the klystron RF window.

Figure 3. The photograph of the waveguide with two additional vacuum pumps downstream the klystron RF window

Considering these factors, additional two vacuum ports were put to the waveguide at about 40cm downstream the klystron RF window as shown in Figure 3. The vacuum conductance at the RF window associated with these ports is estimated to be 43 l/s. For easier installation ANELVA 8 l/s ion pump has been connected to each port.

3.3 Effect of additional pumps

A vacuum recovery simulation suggests that a fast recovery of the vacuum is expected around the klystron RF window as shown in Figure 4, where the simulation has been performed with an assumption that the vacuum at the surface of the klystron RF window changes instantly from 1×10^{-6} Pa to 1×10^{-4} Pa by the dielectric breakdown.

The dielectric breakdown in successive RF pulses has been considerably suppressed since the vacuum system was improved. The peak output RF power of 20MW from PV3030 klystrons has been achieved at the pulse width of 20 μs and the repetition rate of 12.5Hz. The klystrons have been operated more than 1000 hr at 2 Hz without damage to the RF windows since the vacuum pumping was increased.

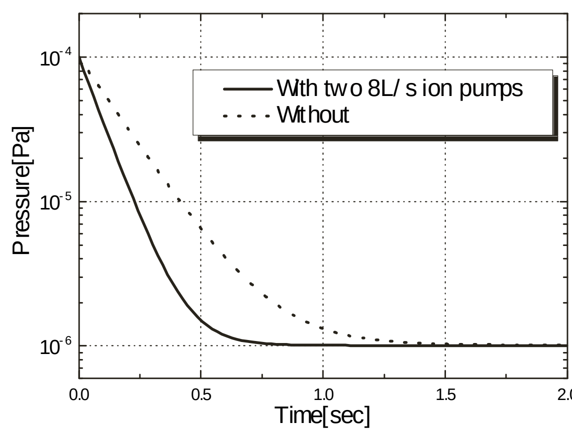

Figure 4. The result of simulation for the vacuum recovery after the dielectric breakdown at the klystron RF window.

4 SUMMARY

The problems in the high power long pulse RF system have been solved by the improvements to the pulse transformer, the heater isolation transformer and the waveguide vacuum system. Specifically, the vacuum pumps closed to the klystron RF window are quite effective for the protection against damage to the window.

REFERENCES

[1] T.Tanaka et al., “Performance of the FEL Linac at Nihon University”, APAC’98, Tsukuba Japan, March 1998. KEK Proceedings 98-10 (1998)722.
[2] ULVAC Corporation Center, “Vacuum Handbook III”, 1989.