STUDY OF PPM-FOCUSED X-BAND PULSE KLYSTRON

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Abstract

The R&D of PPM (Periodic Permanent Magnet)-focused X-band pulse klystrons has been conducted since 1999, originally for Global Linear Collider (GLC) project. So far six prototype tubes have been tested. Some of them successfully produce the power required in GLC (75MW, 1.6 μs pulse width). However their performance was not perfect as a GLC tube. The problem lies in the stability of RF output and the gun performance. Since GLC programs were terminated in 2004, some limited work on the improvement of the PPM tubes continues at X-Band Test Facility (XTF) in KEK. The work includes the test to evaluate the performance of revised (rebuilt) tubes as well as disassembling these tubes after the test for further inspection.

PPM TUBE AS GLC POWER SOURCE

Our PPM (Periodic Permanent Magnet)-focused klystron tube was originally proposed as the power source of the main linacs of Global Linear Collider (GLC)[1]. The most significant character of this tube is its high peak power (75MW) and high efficiency (55%). The former is the direct conclusion of the need of high gradient acceleration in the main linacs while the latter is caused by the fact that more than four thousands tubes would be used. By the choice of relatively low perveance and high cathode voltage (480kV), the tube is designed to produce 75MW. Major specifications are listed in Table 1.

Table 1: PPM tube design specifications

Frequency	11.424GHz
Peak Power	75MW
Pulse width	1.6μs
Repetition	150pps
Cathode Voltage	480kV
Cathode Current	266A
Perveance	0.8uK
Efficiency	>55%
Main Focus	PPM
Max B / period	0.32T / 30mm
Magnet Material	NdFeB

R&D work of the PPM tube was initiated at KEK in 1999 after our solenoid-focused X-band klystron (called XB72K) R&D program as an LC power source for a decade. We did not design our PPM klystron by a simple replacement of solenoid into PPM for XB72K klystrons. We prepared a new design for the gun, for the RF circuit and for the focusing magnet system. We adopted some of key concepts developed in XB72K such as a travelling wave output cavity with two output ports for the high power stability. The details of the design work are found in Ref. 2.

STUDY AT XTF

In August 2004, the decision was made that all of the worldwide efforts for LC R&D should be integrated into an L-Band based superconducting LC (the International Linear Collider). The GLC R&D programs at KEK have been already reorganized along this decision. Our X-Band activities are now concentrated into XTF (X-Band Test Facility, formerly GLCTA). PPM klystron tests are ongoing at its Klystron Test Stand. A series of the tests on high gradient accelerator structures (and some RF components) continue also at XTF. Two of the PPM tubes are running as workhorses to power the accelerator structure since 2004. Each tube could run up to 50MW x 0.4μs x 50pps. The power from the two tubes is combined and some 100MW RF power is available for the structure tests.

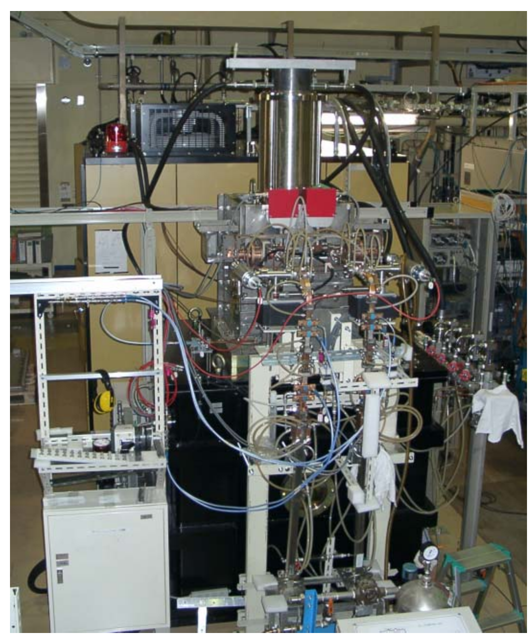

Figure 1: XTF Klystron Test Stand.

REVIEW OF TUBE TEST RESULTS

So far six prototype PPM tubes, as named PPM1-PPM6, have been built. Some of them have successfully

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attained to 75MW or more with 1.6µs RF pulse width at their maximum performance. Let us summarize some details of the test results up to now.

- The first PPM tube, named PPM1, was designed as a 50MW tube. This tube is water-cooled but minimum for the design simplicity. This tube reached 54MW x 1.5µs x 5pps. (The final peak power was 63MW, 0.3µs pulse width.) The beam transmission from the gun to the collector was practically perfect. No parasitic oscillation was observed. The RF design and the magnetic field design of PPM1 were to be the baseline for the next tube. This tube verifies the PPM-focused klystron is feasible. (Year 2000.)
- The next tube, PPM2, reached 73MW x 1.4µs (2001). Though the repetition rate was 3pps, the peak power and the RF pulse are almost what we need in GLC. With this result, this tube is regarded as the first Proof-of-principle tube for GLC.
- PPM4 reached 77MW x 1.6µs x 50pps (2003). PPM5 reached 70MW x 1.6µs x 25pps (2004). During these years, the operations of the tube over 50MW under 50pps at the test stand were common.
- The peak power of PPM3 and that of PPM6 have not reached to 75MW due to parasitic oscillations. PPM3 mounts second harmonic cavities. The parasitic oscillation appeared around these cavities. PPM6 has different TW output cavity from others. The HOM of the TW cavity was responsible for the oscillation.
- The maximum time-averaged RF power available was 13.7MW (=67MW x 1.7µs x 120pps) by PPM2B (second repaired tube of PPM2) (2004).

Window Failures in Early Tube Tests

In our early tube tests, most failures appeared in the TE11-TM11 Mixed-Mode (MM) windows[3] mounted on the tubes. Their ceramic plates were seriously damaged (crack or puncture). The failures occurred when the tubes were at their maximum performance.

The high power test of MM window has shown that the window was promising: it could run up to 80MW 1.6µs [4]. In order to establish the processing technique for the window, the light emission from the ceramic was carefully observed by a photomultiplier (PMT) in our later high power tube tests. During these tests, the RF output power was controlled to keep the light emission to be gone or at least to be moderate. Based on the experience of these tests, we recognize the processing technique for the MM window has been established.

Our recent tubes install the newest windows which utilizes the circular TE01 as the transmission mode[5]. It has been confirmed in our recent tests that this type of window is robust (better than MM windows). The RF window issue has been practically gone.

REMAINED PROBLEM: RF STABILITY

Since the window issue has been gone, the problem of the tube, the "RF pulse shortenings" (PS), came out. The phenomenon, which was already observed in the test of PPM1, is characterized as a loss of output power that develops over several hundreds ns (nano seconds). See Figure 2.

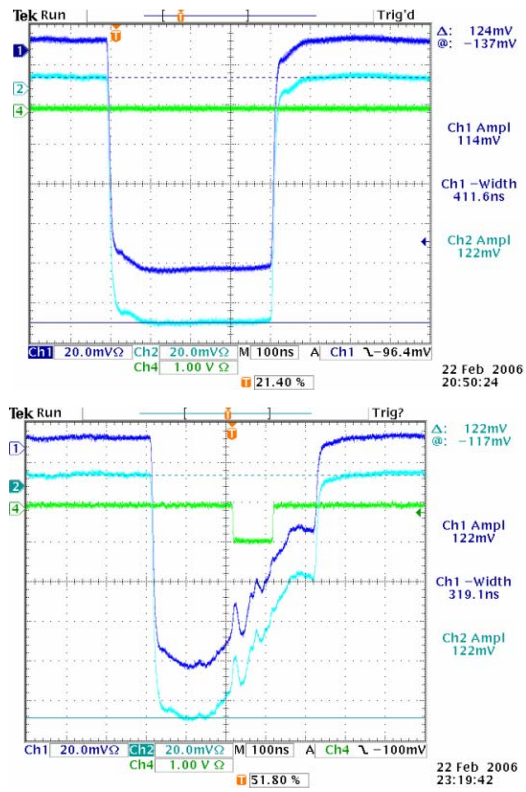

Figure 2: Examples of the RF output waveforms: a normal case (upper) and RF pulse shortening event (bottom). 45MW x 400ns x 50pps. The event rate was about 5 per hour. Ch1 and Ch2 in the figure are the output power signals from each one of two output ports. (The tube has two symmetrical output ports.) Ch4 is the trigger signal from a fault counter which monitors the waveforms (It makes a trigger when the waveforms are deformed.)

If one marks the points on the peak power vs. pulse width plane where PS becomes significant, the result will look like Figure 3. PS appears in a very similar way in our every PPM tube. The rate of the events increases as higher output power and/or longer pulse width. In the case of the operation at XTF for the accelerator structures, the maximum power and pulse width are 50MW and 0.4µs. This position is on the border in Figure 3 and the operation is practically no problem. However, if we operate the tube under GLC specification, PS events are common. Based on the processing experience so far, the PS events are not likely to be gone completely by usual processing techniques.

By the observation with X-ray monitors and acoustic sensors, we found PS is owing to the breakdown event in the output cavity. The study on the nature of PS is ongoing.

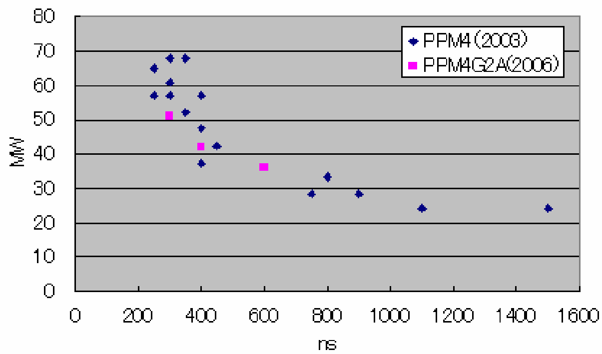

Figure 3: Each point represents the locations where PS was observed. Pulse width (horizontal in nano sec) vs. peak power (vertical in MW).

TOWARD A ROBUST TUBE

The inspection of the disassembled tubes, we found recently various parts of the tube got damaged. One of the remarkable damage was found on the surface of the beam pipe located slightly upstream of the input cavity. The damage is likely caused by the pulse heating from the beam loss due to the stopband of PPM. See Figure 4.

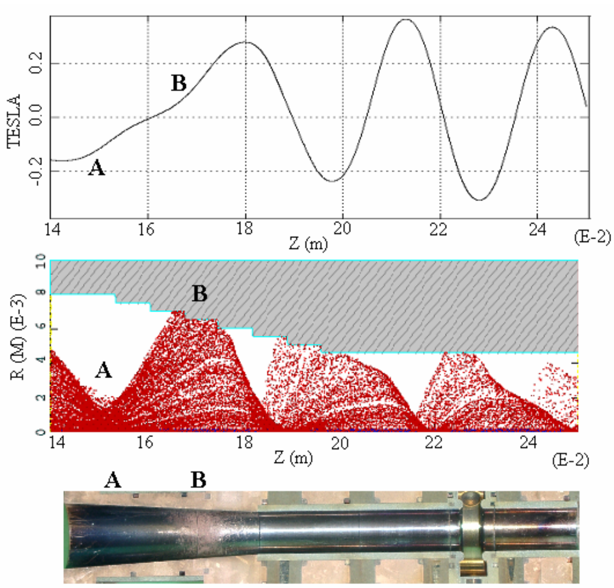

Figure 4: The profile of focusing magnetic field (Upper), beam trajectory simulation result at 100kV beam (Middle) and the picture of the tube cut after operation (Bottom). There is a damaged region on the beam pipe (Location B in the bottom picture). Location B is the beam loss region shown in the simulation.

Under the stopband voltage, the beam is soft to be squeezed much by the strong magnetic field (location A in the figure). The beam is sprayed out as going downstream since the magnetic field goes to zero. The some of the beam are lost at location B as shown in the figure. It is estimated from the simulation that the heat deposit on the surface around location B is some 0.7Joules/cm^2, if we assume the raising and falling time of the high voltage pulse is 200ns.

Figure 5 shows the images of microscope of location A and B. The machining marks by the lathe is clearly seen at A while these marks disappear and the surface looks rough at B.

Since the loss is inevitable in the pulse operation of a tube, all of our latest tubes are with Molybdenum sleeve to cover this "hot region".

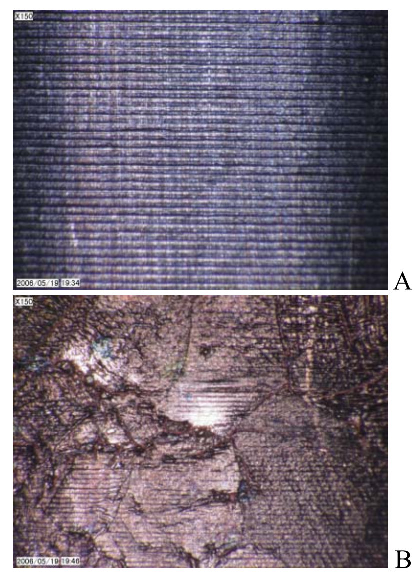

Figure 5: Microscopy images on the surface of the beam pipe location A (Top) and B (Bottom). Magnification x 150.

ACKNOWLEDEMENT

Authors are grateful to T. Kriya, H. Urakata and S. Miyake of Toshiba Electron Device Co. for their efforts in design and fabrication of X-Band PPM klystrons. One of the author (S.M.) is grateful to Y. Watanebe of KEK Machining Center for the microscope observation.

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