DETECTION OF X-RAY DUE TO GUN ARCING OF HIGH POWER KLYSTRON

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Abstract

X-ray due to a klystron gun arcing was monitored by a detector consists of a plastic scintillation fiber and a photo-multiplier. Observation of the X-ray was done during the processing run of an X-band klystron. A clear signal of X-ray burst is observed when the gun arcing occurs. Possibility of the fast protection system for a pulse modulator from the gun arcing is discussed.

INTRODUCTION

For a future linear collider machine, GLC, some of novel machine components are proposed. One of these is a new kind of pulse modulator, which uses solid state switching devices, IGBT (Insulated Gate Bipolar Transistor), instead of conventional thyratron tube. One of the main issues on R&D of this type of modulator is the way to protect these devices from the arcing in klystron gun [1]. The protection should be fast enough after detecting a signal of the arcing. One possible protection system is a combination of an X-ray detector and a fast logic control in gate driver of IGBT.

It is naturally understood that a burst of X-ray appears when the klystron gun arcing takes place. We study this kind of X-ray production in a point of view of the future protection system. In this report, we will give the observation result of such X-ray during the processing of a PPM X-band klystron and discuss the possibility of the fast protection system.

EXPERIMENTAL SETUP

The detector system consists of a plastic fiber and a photo-multiplier (PMT). The system is as same as the ones currently used as beam-loss monitors in KEK-PS (Proton Synchrotron) [2]. The plastic fiber is doped with scintillation material. We use Kurarey SCSF-81M, 2mmϕ. The decay time of the scintillation material is a few nano seconds (ns). Once an X-ray hits the fiber, it is converted into a light pulse in the fiber and this light runs along the fiber. At the end of the fiber, a PMT is set. By observing the output signal of the PMT, we can know the arrival of X-ray. We use PMT Hamamatsu R-1635. Figure 1 is a picture of the detector.

The klystron is a PPM-focussed X-band pulse klystron, which is a prototype for GLC klystron. Its operation parameters at AR-South Test Stand in KEK are in Table 1. In order to check the basic performance of the X-ray detector, we did a pilot observation, a survey of X-ray against whole of the klystron, at the test stand where we set the fiber along the klystron and monitored the PMT signal on a scope. Clear signals of X-ray were seen within every high voltage pulse when the klystron being in operation. Thanks to the fast time response of the fiber and the PMT, we can identify the individual hit of X-ray on the scope. We confirmed that the sensitivity and the time resolution of the detector are good enough for our purpose.

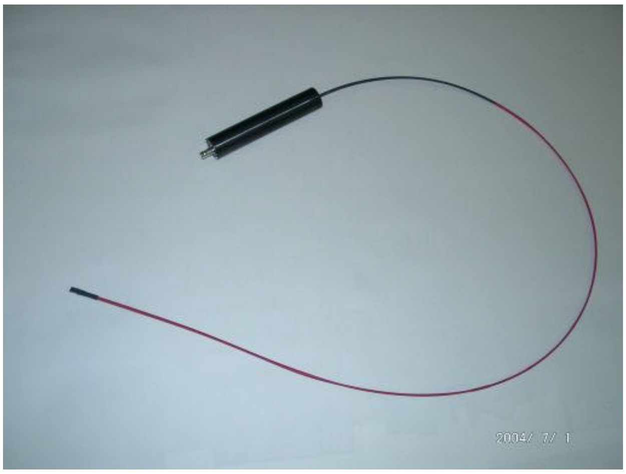

Figure 1: Picture of the X-ray detector. The plastic fiber (2mmϕ) is covered by rubber tube for shielding of light. The PMT is covered by lead (for radiation shield) and laid in an iron cylinder (shield from magnetic field). The length of the fiber may be changed from one measurement to another.

The observation of the X-rays from the gun is done during the processing of the klystron. The fiber is set in the gun coil housing. Figure 2 shows its location. The fiber is set along the coil which surrounds the gun structure. The fiber is turned three times around the gun and its both ends are extracted outside and they are guided into a single PMT. The X-rays from the anode can come to the fiber after penetrating through the gun housing wall (stainless steel) and the return yoke of the gun coil (iron). Lead shields are properly set to prevent the background X-rays for better observation.

Table1. Operation of GLC prototype PPM klystron at AR-South test stand.

Cathode Voltage	500kV nominal; 530kV max
Cathode Current	283Amps (@500kV)
Pulse width (RF)	1.6 micro sec
Repetition	50pps
Operation Frequency	11.424GHz
Output Power	75MW

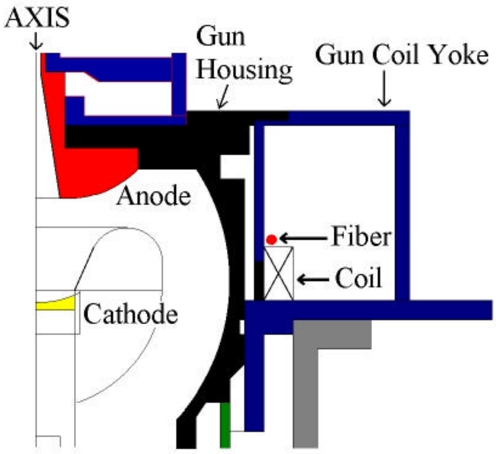

Figure 2: A cut view of the klystron gun region. The left end of this figure is the central axis of the klystron. The location of the fiber is indicated.

RESULTS

Examples of the wave forms appeared on the scope are compiled in Figure 3, those in normal operation and in a case of arcing. The waveforms of cathode current, the collector current [3] and the PMT signal are shown.

Figure 3C shows that the collector current drops to zero within about 100ns while the cathode current goes up and falls off in a rather slow way. This means “the current from the cathode is missing” during almost latter half of the pulse duration. This missing current should run through another path, possibly, directly to the anode in the gun and we may call this the arcing. The sudden change of these currents (decay of the collector current or rise of the cathode current) indicates the start of the gun arcing. The cathode voltage starts to drop at the same moment although it is not explicitly shown here.

Once the arcing starts, the electrons emitted from somewhere (probably other than the cathode) appear and hit the anode wall eventually. This should cause the production of X-rays much more than normal. As shown in Figure 3D, we have an X-ray burst. One can see the burst of X-ray starts somewhat earlier than the currents start to change (compare Figure 3C with 3D).

Time response of the collector current pickup (Current Transformer) or the collector current pickup (resistors) is supposed to be fast enough. The response of the fiber or the PMT is also fast (a few ns). Even though taking into account of the time delay due to the cables between those pickups and the scope, the PMT signals still comes rise earlier than actual change in the signals of currents.

The PMT signal starts increasing 200-300ns before the increase of the cathode current starts. One can conclude that some X-rays emitted in advance of the arcing. There is a discussion on these X-rays in a vacuum tube although the cathode voltage is much lower than our case [4]. At any rate, we can utilize those X-rays as the precursor of the arcing.

If we observe those waveforms over longer duration, they look like as those in Figure 4. An additional minor burst of X-ray is seen. The pulsed power from the modulator is moving back and forth in an oscillatory way between the klystron and the modulator.

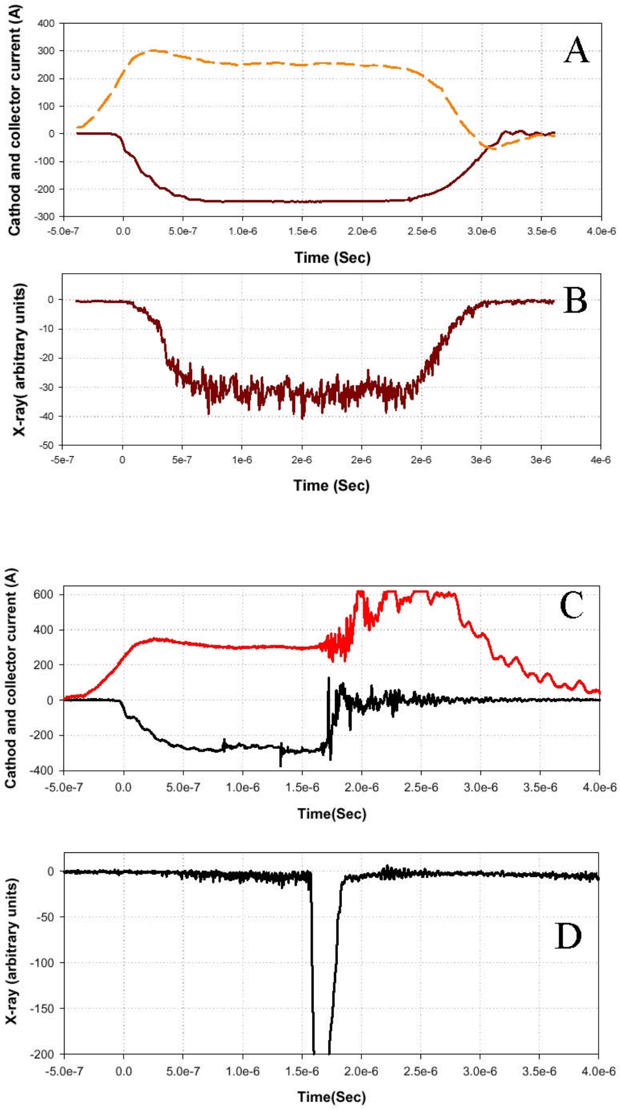

Figure 3: The observed waveforms in case of the operation being normal (A and B) and the gun arcing (C and D). The length of the pulse flat-top is about 1.6 micro seconds. The cathode voltage is 480kV. Figure A shows the cathode current (dotted line) and the collector current (solid line) whereas Figure B shows the X-ray signals in normal operation. As for Figure B the data accumulated over many normal pulses. Figure C shows the current signals too in a case of the arcing. Figure D shows a burst of X-ray due to the arcing. Single pulse.

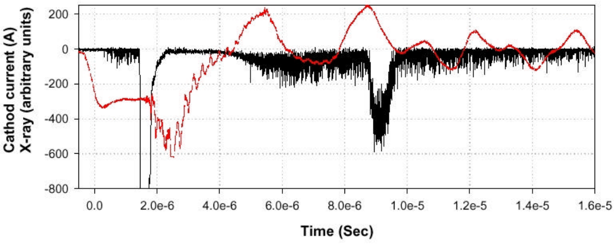

Figure 4: The cathode current and the X-ray (PMT) signal in case of the gun arcing. Waveforms for longer duration than that of Figure 3.

DISCUSSION

The protection of the components in the RF system from the damage due to the klystron gun arcing is an important issue to make the system stable and reliable [5]. The X-ray detection of klystron gun arcing may be applicable for the fast protection. It is possible to consider a variety of protection schemes with a proper control trigger signal prepared from the X-ray detector signal.

In case of a PFN modulator, for example, one may use an additional thyratron tube together with dummy load for the protection of the klystron. The second thyratron works as a switch of the bipass line to the PFN, which is terminated with the load. Once extra X-rays from the gun are detected, the second thyratron is fired. An appropriate trigger for the thyratron is made from the detector signal. The dummy load absorbs the energy stored in PFN, which would be consumed at breakdown point in the klystron gun if this kind of protection system being absent. We should consider the protection of klystron more seriously when we operate the machine in high repetition rate.

In PFN modulators, the maximum peak current due to the arcing is naturally limited to factor 2. However this is not true for the modulator which is now developing at KEK. It utilizes IGBT each of which handles the peak power of 3MW (3kV and 1kA). There are 40 circuits in series to feed power to the klystron. One of the circuits is schematically represented in Figure 4. The power from the each circuit is combined together through the magnetic cores and the circuits produce the peak power of 120MW(3kV 1kA 40) as a total.

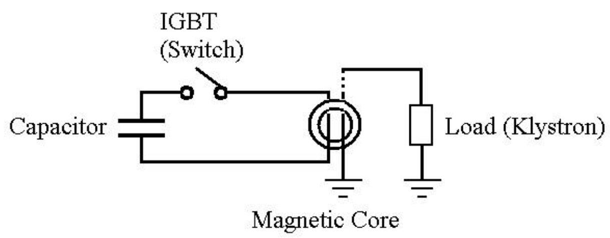

Figure 5: Schematic representation of a single IGBT circuit.

In our spark gap experiment, we found that the current through IGBT CM600-90 type increased as 12-15kA/1µs when the breakdown takes place. From this experiment, we can conclude that we need to switch off the IGBT immediately after the gun arcing, otherwise we would have huge current through IGBT and it is surely harmful or danger for IGBT.

The protection from the arcing can be accomplished by switching off the IGBT immediately after the arcing is detected. Such a fast protection system is possible to be designed based on the X-ray detection system. If we have the precursor X-rays and we can use its signal to make a trigger to control the switching gate, the protection can be efficient. It is necessary to study more in detail the time structure of the X-ray burst due to the gun arcing in order to accomplish this work.

Note that we have already utilized the gun X-ray detector signal as the one of the interlock signals at the test stand. The X-ray interlock is not the fast one considered above but it use (meter) relays. Once the extra X-ray is detected, it makes the relay signal and stops the next coming pulse. This works as a new additional protection from the gun arcing at our test stand. We have had the protection by monitoring the peak of the cathode current.

REFERENCES

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[2] T.Kawakubo, T.Ishida, H.Yamaguchi, "High Cost-performance Fast-response Beam-loss Monitor using a Photo-multiplier", in Proc. of 2nd Asian Particle Accelerator Conf. (APAC01), Beijing, China, Sep. 17-21, 2001.

[3] The collector of the klystron is not electrically grounded directly but so through some resistors. Thus we can monitor the collector current by measuring the induced voltage on the resistors.

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