IGBT MODULATOR FOR X-BAND KLYSTRONS

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Abstract

The Solid State Induction type modulator was developed at KEK for the JLC project. This modulator was designed for tunnel installation. The modulator consists of two oil-filled tanks; the first is for two klystrons and the second for the pulse transformer. The pulse transformer consists from 42 cores made from Finmet3 material, each core is driven by voltage of 3.2 kV by two IGBT plates in parallel, and one of them has core reset circuits. The total numbers of IGBT plates are 84. Each core has one turn at the primary and transformer has four turns for secondary. This modulator can drive: short up to 1.6 microsecond, high voltage up to 500 kV pulse with current up to 540 A for two X-band 75 MW klystrons. The pulse top flatness is 2%. The expected modulator efficiency is about 75%. The step #1 of the modulator test was done in the summer of 2005 [1], 300 kV of output voltage and full current at 1 pps was achieved.

INTRODUCTION

For a future linear collider machine, LC, 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 [1]. The main requirements for this modulator are high reliability and compact vertical size. In KEK there was proposed induction type modulator which can put power in two klystrons it has a six times less volume than conventional one.

Table 1. Technical Specification of Induction Modulator

Number of Klystrons	2
Total Current	560A
Cathode Voltage	500kV nominal; 530kV max
Repetition Rate	100pps
Pulse top Flatness	2 %
Efficiency	85 %
Pulse width (HV)	1.7 micro sec

The specifications of KEK's Induction modulator are Given in Table 1. The modulator was designed and prepared in KEK before ITRP (International Technology

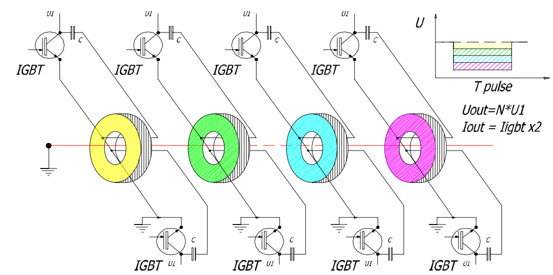

Figure 1: Simplified concept of induction type modulator.

Recommendation Panel) made its decision in order to select the technology of ILC accelerator as cold technology. After solution of ITRP we decided to demonstrate the feasibility of our construction and to make a test, but only for present set of cores (step#1). We obtained test results of about 300 kV with a resistive load, a pulse width of 1.1 μs, a repetition rate of 1 Hz. The repetition rate was restricted by the power supply, which was not an essential matter [2].

PRINCIPLE AND STRUCTURE

The principle of the LIM is simple, as shown in Fig. 1. The number of the cores is N, current of the each IGBT is I_{IGBT}, and each IGBT commutates a voltage of U_1, the final voltage (U_{OUT}) is to be $N*U_1$ and a total current (I_{OUT}) is $I_{IGBT}*2$. Although the principle is simple, there are several points have to be carefully considered: IGBT protection, weight of the core material, the electrical field strength in oil, a type of IGBT, the type of capacitors, and the system of modulator control and monitoring.

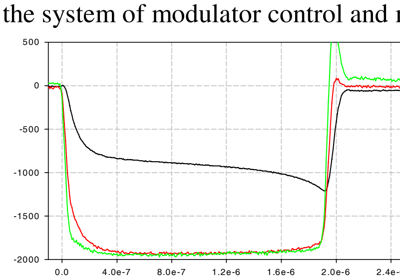

Figure 2: Waveform from the IGBT plus core test. Black magnetization current, green IGBT output voltage, red secondary voltage.

In this modulator, the IGBT driver was specially designed to have a very fast rise time. Fig. 2 shows the waveform of the IGBT test, CM900HB-90H was used. It is special feature of this model. Finally, a multi-turn induction modulator of the 2-pack type was adopted (four turns for the secondary winding were chosen). The pulse transformer consisted of 42 cores made from Finmet-3 material; each core was driven by a voltage of 3.2 kV by two IGBT plates, and one of the them had core reset circuits. Therefore, the total numbers of IGBT plates are 84. In this case, a length of core is 2 m long and the weight of the cores is 1.4 tons, as shown in the drawing of Fig. 3. For applying a high voltage, it was necessary to consider IGBT protection, the klystron's arcing detection, and the design of a 3.2 kV feed-through from the plate to the core. The rise time and impulse flatness were also important issues. One of the main issues in R&D of this type of modulator was the way to protect these devices from the arcing. We designed all parts of modulator with enough high safety factor, so feedthrough was tested up to 6.5 kV(3.2 kV nominal), the ceramic insulator for keeping secondary was tested up to 350 kV (125kV nominal), the maximum electric field in secondary is only 170 kV/cm. Nevertheless we could not guarantee that we are free of the arc, in additional the klystron gun can have arcing during operation [3]. We tested our protection system. It is enough fast, the measured switch off time is 250 nanosecond this time includes the time we need to detect an arc and time what we need to switch off IGBT, during this test we didn't loss any IGBT though the place of arc was located just before feedthrough. In case of Gun arcing we tried to 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 occurs when the klystron gun arcing takes place [4]. We studied this kind of X-ray

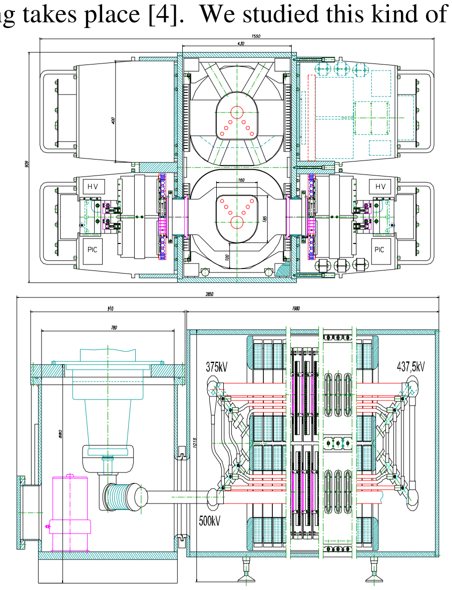

Figure 3: Drawing of the Modulator. Top is cross section of the cores and the installed IGBT boards. The bottom is cross section of both oil tanks.

production from the point of view of the protection system. The results are in [3], the X-ray burst started about 200 ns before gun arcing takes place. This is enough time to switch off the IGBTs.

IGBT PLATE AND CONTROL SYSTEM

Eighty-four IGBT plates, each of which produced 3.2 kV, were carefully designed and all of them were tested before installing to the tank Figure 4 shows pictures of IGBT plates. A block diagram of the IGBT plate is shown schematically in Fig. 5. This figure also shows the IGBT protection schemes. Each IGBT driver plate has a microcontroller, which is connected over the RS485 line to a personal computer, and can be managed. IGBT protection signals come from the following detectors: an over-current detector, an over voltage detector, a dI/dt detector, a temperature detector, a reset current detector, to the gate driver with fast logic. Some of the protection schemes are shown in Fig. 5 along with the waveforms.

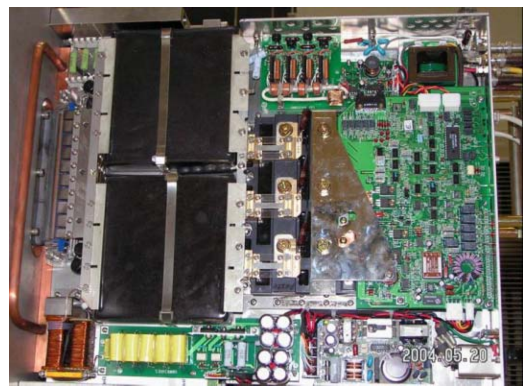

Figure 4: IGBT board.

Temperature information and the status, such as the protection status, HV status, core reset status and p/s status, are sent from the board to the PC if IGBT protection is not ready. The pc sends IGBT various signals related to a delay, the pulse length, estimated current and voltage, a HV control and a board rest.

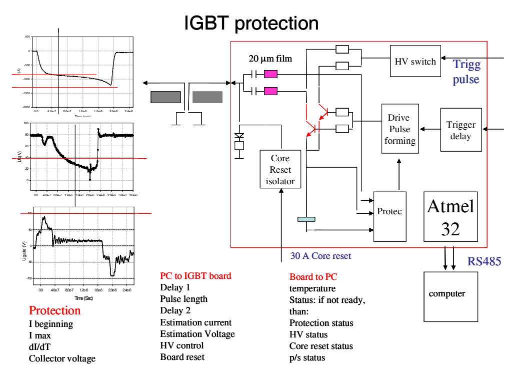

Figure 5: Block diagram of the IGBT plate.

Because our modulator has extreme low stray induction we put additional inductances between each klystrons what can help us to limit the gun arc current. Each IGBT board has a current-limited circuit what consists from thin

20 micron foil made from pure iron. For the 3.2 kV feedthrough from the IGBT plate to the tank, since there was no commercial available, we developed a special feedthrough comprised of a conductor plate molded with rubber packing, which sealed the insulation oil. After production we tested a feedthrough up to 6.5 kV.

FABRICATION AND TESTING

Selection of the core material was an important issue for the LIM, since loss in the core was strongly related to the modulator efficiency and the total weight of the system. We compared the loss of various core materials, such as Finmet™, Metglas™, Amet™ and oriented silicon steel material. From the test of toroidal-core we found that Finmet3 would be the best. We determined to use Finmet3™ as the core material for the pulse transformer. The performance of the first prototype of the Finmet cores was good for the acceptance test. Before manufacturing the modulator, a prototype model was tested in May, 2004 with the configuration of the 2 core setup having 4 IGBT plates. A high voltage was tested in the air and we obtained a voltage of 6.4 kV and a current of 2.4 kA with a pulse width of 1.6 μsec and a repetition rate of 100 Hz. These result confirmed the design validity, and we started to manufacture all boards and cores.

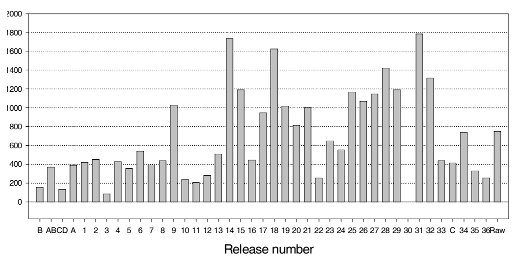

Figure 6: Loss of the Finmet 3 cores for the step#1 test.

During the manufacturing process of the cores several problems were found: the surface insulation of Finmet was sometimes destroyed during the winding process of the foil, which led to a serious loss increase, as shown in Fig.6. Other problem was a core tolerance after epoxy-impregnation process. After the cores was tested we decided to test the modulator with present set of cores, in future we could produce additional cores and replace cores with high losses by the new.

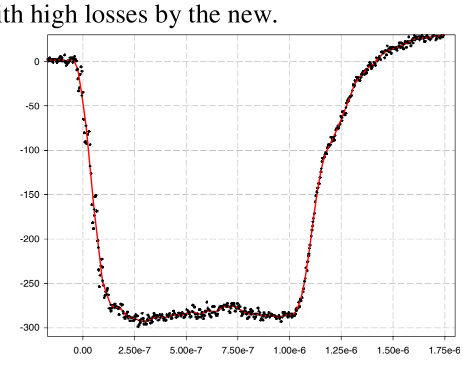

Figure 7: Waveform of the first modulator output pulse.

Fig.8. shows the final assembly of the modulator with resistive load. Fig.7. shows the first waveform of the output voltage from modulator.

SUMMARY

We developed a solid-state modulator and performed the first successful test up to 300 kV. We achieve very short pulse rise time, the level of noise from our modulator was enough low, what makes it possible to control the shape of pulse and to operationally change the settings of protection level. The construction makes it possible to operationally change the active parts of the modulator without requiring detaching of klystrons and the especially prime advantage is its small vertical size, which allows us to decrease the size of tunnel.

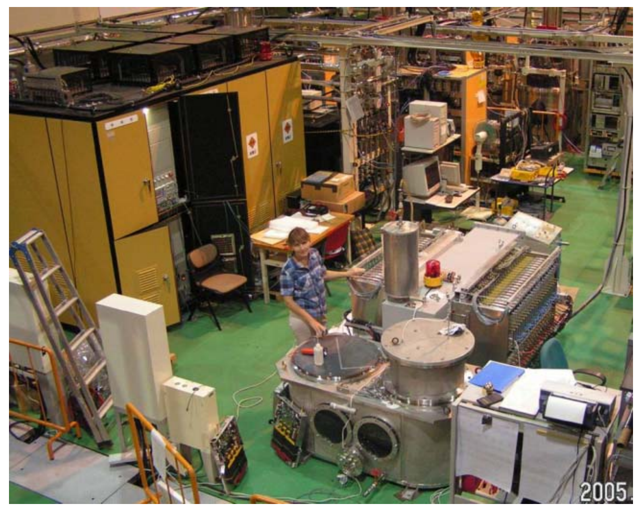

Figure 8: Induction modulator assembly under test, at the left side the view of the conventional PFN modulator.

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