A NEW SYSTEM TO TRIGGER FAST RISE THYRISTORS

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Summary

Four bump magnets were installed in the KEK booster ring in order to shift the closed orbit toward the stripping foil during the H^- ion beam-injection period. The bump magnet power supplies are of the Pulse Forming Network type. Energy stored in the PFN is delivered to the magnet load via a series array of 32 thyristors. These thyristors must be turned on simultaneously. If there are any differences in the turn-on time, excessive high voltage is added to the thyristor which has the latest turn-on time.

To solve this problem, a new trigger system was developed. Turn-on timing pulses are generated in a low-voltage circuit. Each timing pulse is adjusted independently with an accuracy of 0.1 µsec and converted to optical pulse. These optical pulses are transmitted to the high-voltage circuits through optical fibers. The photo-transistors are exited and deliver the pulse current from the capacitor to the gate of thyristors, which are fired with an accuracy of 0.1 µsec.

Introduction

The multiturn injection of H^-ions into the KEK 500-MeV Booster Synchrotron(1) requires shifting the closed orbit towards the injection stripping foil so as to allow circulating protons to align with injected negative ions at the stripping foil. Fig. 1 illustrates the beam orbit and the arrangement of the magnet. The dotted line and solid line indicate the H^- ion beam and the circulating proton beam respectively. Orbit bump magnets are arranged asymmetrically in order to make the injection angle of the H^-ion beam enlarge, consequently the septum magnet become unnecessary. During the injection period the amplitude of the orbit shift is required to remain essentially constant so as not to excite additional betatron oscillation. After injection, the circulating beam must clear the stripping foil as fast as possible so as to restrict the beam growth due to multiple scattering. The excitation current is shown in Fig. 2, for the case when the duration of the flat top is 100 µs and fall time is 30 µsec. This is a reasonable amount of time to restrict the beam growth and to remove stored energy from the bump magnets. The power supply used to furnish the excitation current to the orbit bump magnets is of the Pulse Forming Network type. Energy stored in the PFN is delivered to the magnet load via a series array of thyristor switches. The working voltage of PFN is 9KV, which is mainly determined from the fall time of the excitation current. The maximum rated voltage of the fast-rise thyristor is about 1.2 KV. Controlling the

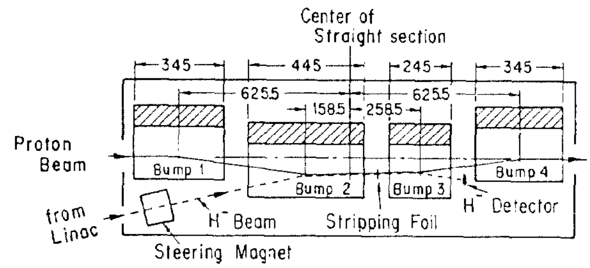

Fig. 1 H^- injection system in the KEK Booster Synchrotron, where the dotted and solid lines are the orbits of H^- ion beam and proton beam, respectively.

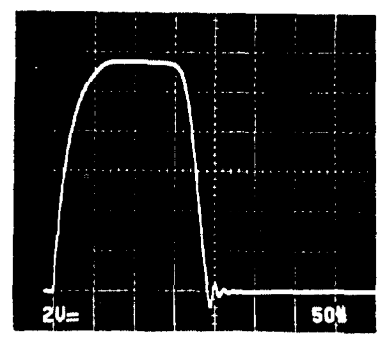

Fig. 2 Current through bump magnet 50µsec/div 2KA/div

series array of many thyristor switches is a difficult problem, but we settled it by the following technique.

Bump Magnet Power Supply Circuit

The circuit of the bump magnet power supply is shown in Fig. 3. A PFN with a characteristic impedance of 0.87 Ω is charged to 9 KV by a D.C.power supply.The series array of thyristors is connected from the PFN output terminal to the magnet load through 23 parallel coaxial cables which have an impedance of 20 Ω. The current through the magnet is shown in Fig. 2 and is restored into the PFN by an inductor and diode.

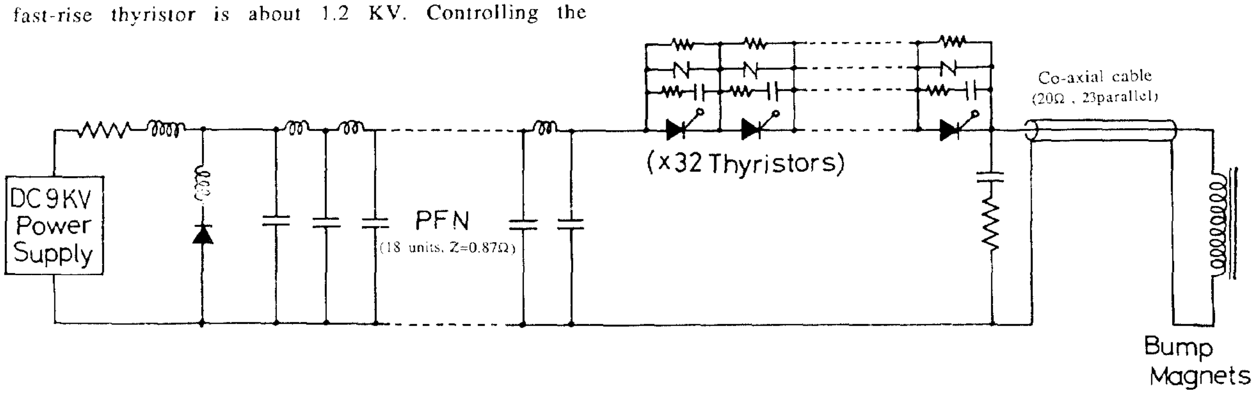

Fig. 3 The circuit of bump magnet power supply

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The characteristics of the thyristor which switches ON and OFF the current from the PFN to the magnet are listed in the Table 1. As the maximum rated voltage of 1.2 KV is too small to 9 KV, the 32 thyristors are used in series. Four thyristors are packed together in a copper-shielded box. In order to observe the voltage between the anode and cathode of each thyristor while in operation, terminals are extracted from the anodes of thyristors to outside.

The conventional trigger system for thyristors

If one of the thyristors has a turn-on time that is later than that of the others, a surge voltage is added to it when it fires. In order to fire all thyristors within 0.5μsec and to remove the surge voltage, the rise time of a trigger current shorter than 1A/μsec is recommended. Therefore, the transformer used in the trigger circuit (Fig. 4) should satisfy two contradictory conditions: response to high frequency and high insulation. In our transformer the response speed is not so good and the rise time is 0.6A/μsec.

In order to fire thyristors within a small timing difference using such a poor rise time of the trigger current, the characteristics among the thyristors should be set to within the values listed in Table 2.

Completely removing of the surge voltage is impossible; the surge voltage added to some thyristors is almost the same value as the regular voltage before firing. Taking the safety coefficient as about four, we used 32 thyristors in series. Almost once every half year, however, a thyristor is shorted from a discharge of the transformer in the trigger circuit.

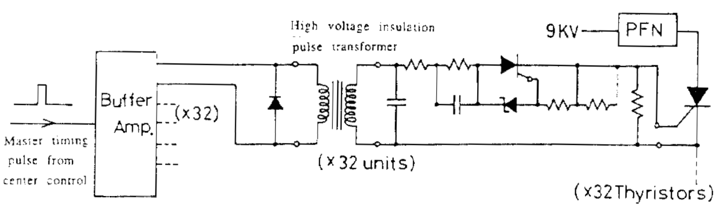


Fig. 4 The conventional trigger system

Table 1 The rated characteristics of thyristor (MITSUBISHI FT1500 EY-24)

peak reverse voltage	1.2 KV
peak off voltage	1.2 KV
averaged on current	1.5 KA
surge on current	30 KA

Table 2 Recommended characteristic of thyrisior to fire all thyristors within time difference of 0.5μs

gate trigger current	80 ~ 130 mA
delayed turn on time	1.0 ~ 1.3 μsec
total inverse charge needed to turn off the current	230 ~ 270 μC

Trigger system of fast rise thyristors using optical method

As mentioned above, the conventional trigger system has a fundamental difficulty to fire all thyristors within 0.1μs, because of the scattering of the characteristics of transformers and thyristors. The new system has taken care of the following subjects:

1) Easy and precise adjustment of individual thyristor firing timing using a low voltage circuit.

2) Reliability of high-voltage insulation

A. Outline of circuit

A block diagram of the system is shown in Fig.5. During operation the master timing pulse of the H^- ion beam injection is transmitted from the central control. This master timing pulse is distributed to the 32 thyristor trigger circuits through individual timing adjustment circuits and optical fibers. This system is consist of two parts; pulse timing control circuit in low voltage and high voltage trigger crciuit, which will be explained in the following section.

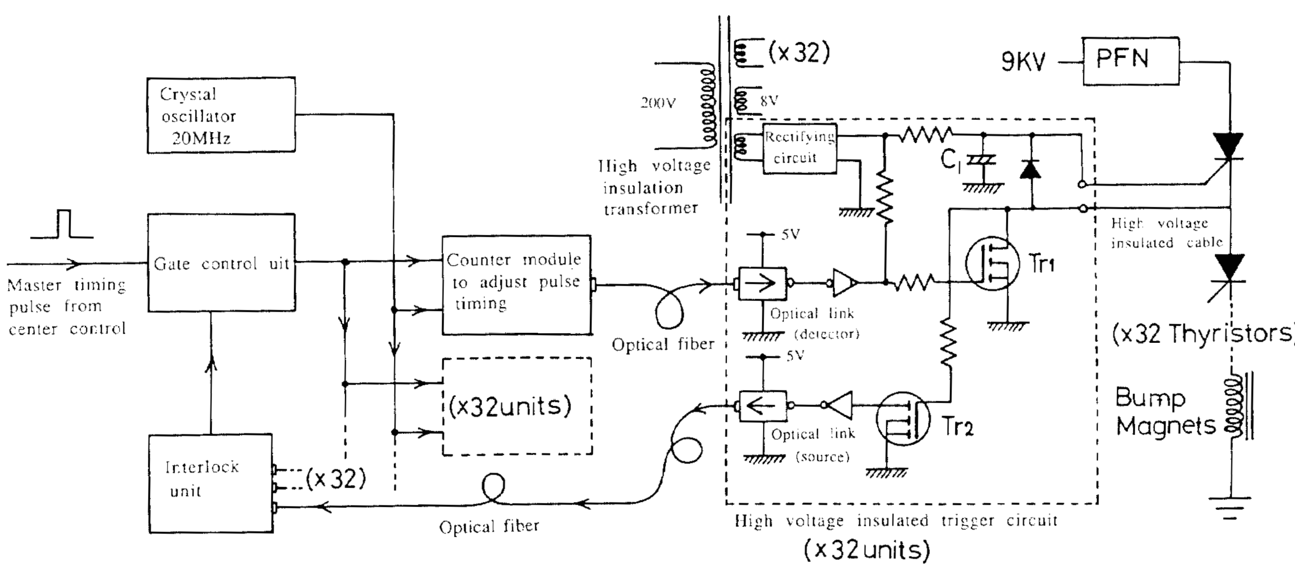


Fig. 5 Block diagram of the optical trigger system

B. Pulse timing control circuit

All of the series array of thyristors must be turned on within 0.2μsec in order to suppress the generation of surge voltage on a particular thyristor caused by a concentration of the applied voltage. The range of characteristic delayed turn-on time is listed in Table 2. The actual range of the scattered values, however, is about 1 μsec. Therefore the timing of trigger pulses of individual thyristors must be adjusted independently with an accuracy of 0.1μsec for simultaneous firing.

As shown in Fig. 5, the pulse timing control circuit comprises a 20MHz crystal oscillator and 32 variable preset counter units to control the output pulse delay. The turn-on time is determined by the value of the preset counter, which is adjustable within the range of ± 5μsec in the accuracy of 0.1μ sec. The counter unit circuit is a standardized module for easy maintenance. These modules have a one-to-one correspondence with the 32 thyristor trigger circuits and are linked by optical fibers. This digital counter system is stable to temperature changes and any fluctuation of the power supply.

C. High voltage trigger circuit

An outline of the high-voltage trigger circuit is shown in Fig. 5 This unit circuit is linked with the allocated thyristor in one-to-one correspondence. Optical pulses are transmitted from the timing control module through optical fibers to the input of the high voltage trigger circuit. The power of the trigger circuit is supplied by an insulated high-voltage transformer in order to isolate the trigger circuit from the earth potential. The photo-transistor and switching transistor Tr1 are exited by an optical signal and deliver the pulse current from the charged capacitor C1 (220μF) to the gate of thyristor. The rise time of the trigger current is shorter than 10A/μsec, well satisfying the specification 1A/μsec for simultaneous firing of a fast-rise thyristor.

When the trigger current is delivered to the gate circuit of the thyristor, the switching transistor Tr2 is exited and generates an optical pulse for the confirmation of triggering, which is transmitted to the inerlock unit through optical fibers.

D. Interlock system

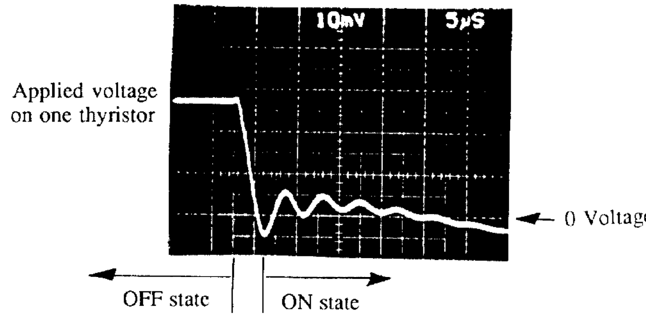
If one or small number of thyristors should be mistriggered by some problem in the control circuit or due to an electrical breakdown of some device, the applied PFN charging voltage may be concentrated to one or a small number of thyristors over the rated value. As a result, it may cause the electrical breakdown of a thyristor.

To prevent this situation, an interlock unit always used to observe the condition of the simultaneous firing of all thyristors. In the case of an emergency, the operation of circuit is halted immediately by the gate control unit.

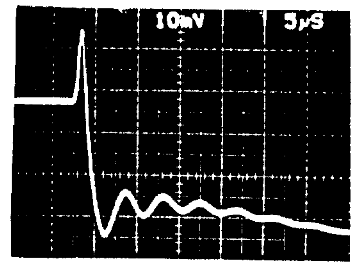
Adjustment of turn-on timing

Each time of firing is adjusted independently by regulating the preset counter while observing the voltage between the anode and the cathode of a thyristor. The voltage waveform at the turn-on time is shown in Figs. 6a ~ c. Fig. 6a indicates the case of a well-adjusted simultaneous firing. Fig.6b shows the case of a 0.2 μsec delay. The surge voltage shown in Fig. 6b is generated by the concentration of an applied PFN voltage. This condition is dangerous. Fig. 6 c is the case of a 0.2 μsec advance. An early fall of the applied voltage is observed. This condition is not so serious since only 1/32 PFN voltages are added to other thyristors.

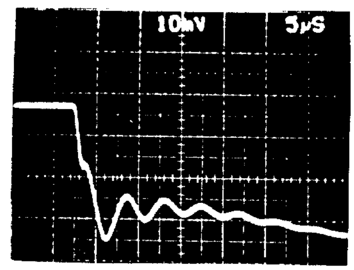
The preset counter of the timing control modules are regulated so as to cause the turn-on waveform of all thyristors to become as shown in Fig. 6a. This procedure is easily performed and makes precice adjustments possible.



a. Well adjusted simultaneous firing



b. 0.2 μsec delay



c. 0.2 μsec advance

Fig. 6 The voltage waveform of the thyristor at turn-on time. X: 5μs/div, Y: arbitraly unit

Conclusion

A new system using an optical method to trigger a series array of fast-rise thyristors has been operating successfully from April 1988. With this method, the simultaneous turning on of all thyristors in series is made possible, in spite of the fast rise time of the current and the scattering of the characteristic delayed turn-on times. This system can also be useful with other kinds of device, which require both high voltage and fast-rise current switching.

Aknnowlegement

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Reference

(1) T. Kawakubo, I. Sakai, H. Saaki and M. Suetake, 13th Int. Conf.on High Energy Accelerators (1986).