Researches on the trigger pulse width’s compression of high power thyristor

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Abstract. The width compression phenomenon of the trigger signal in triggering high power thyristor was first observed in the experiments. The trigger pulse was measured by the oscilloscope in the experiments. The experiments showed that with the increase of the voltage supplied to the thyristor from 1kV to 7kV, the width of the trigger pulse was compressed gradually from 70us (the width with no compression) to 45us. Then with the increase of work voltage from 7kV to 10kV the width of the trigger pulse was not compressed further. This research is very valuable for the design of the thyristor trigger signals.

1. Introduction
The Electromagnetic launching (EML) technology is very active research area in many countries such as America, China, Russian, France and Germany etc [1-13] for its ultrafast velocity and huge kinetic energy of the projectile. And high power switches are one of the most important components in pulsed power system (PPS) which supply the power for the EML. There were many high power switch devices such as flash-gap switch, high power Trigger Vacuum Switch(TVS), Reversely Switched Dynistor (RSD) and high power thyristor switch were applied to the PPS these years [1-6]. The existing flash-gap switches suffer from limited lifetime and levels of jitter [13]. The high power TVS switch has more than 150kA current transfer ability with very low forward current and can be controlled precisely, however it is very sensitive to libration which limits its practical application [6]. RSD switch has great through-current ability (more than 250kA), but it needs complicated triggering circuits and is still on the research [12]. With the fast technology development of the high power semiconductor devices, the operational capability of the high power thyristor’s enhanced greatly. The through-current ability of the thyristor increased from several kA to several hundred kA with smaller bulk and higher di/dt. And it has long life time and can be controlled easily and precisely. It prevailed in the application to PPS recent years such as the 200MJ pulsed power in United States Naval Research Center [5-7], the 1.2MJ [1], 100kJ [2], 450kJ [3], 30MJ [6] and 4MJ [7] pulsed power system for railgun experiments.

The efficient and reliable trigger of the thyristor is one of the key factors for the PPS’s operation. So the design of the trigger circuit for the thyristor is very important for the system. The trigger pulse width is one of the important parameters of the trigger circuit, if the width of the trigger pulse is too short, the thyristor cannot be triggered sufficiently which will cause damage to the device and if the
width is too long it will demand higher characteristics for the trigger device. The design of the trigger pulse width much more depends on the traditional practical experiments than theory analysis and lack of experiment data support.

By measuring the input trigger signal to the pulsed transfer in the trigger process of the thyristor, trigger pulse width’s compression phenomenon was found the first time in the PPS system. The result of the experiments is valuable for it gives the important experimental support for the thyristor trigger design.

2. Principle

The structure of the high power thyristor was shown in figure 1 with three ports anode A, cathode K and gate G. Its equivalent circuit was shown in figure 2 in order to accelerate the opening of the thyristor the thyristor was designed as the two structures consisting of two thyristors which was the main thyristor T and the assistant thyristor T’. The cathode of the assistant thyristor is the gate of the main thyristor T, which was called amplified gate G’.

The opening process of the thyristor was shown in figure 3; $i_{GT}$ was the current of the trigger pulse; $i_{AG’}$ was the current of the assistant thyristor; $i_{AK}$ was the current of the main thyristor; $V_{AK}$ was the voltage of the main thyristor.

![Figure 1](image1.png)

**Figure 1.** The principle and structure of the thyristor.

![Figure 2](image2.png)

**Figure 2.** The equivalent circuit of the thyristor.

The opening process of the thyristor has five steps:

1. Trigger: The trigger current pulse was input to G-G’-K. At the beginning of the rise of the trigger current, the thyristor T’ and T were both in the state of high resistance and the current is 0, and the voltage between the anode and cathode is VAK.

2. T’ startup: With the increase of the trigger current, the resistance thyristor begins to conduct and the state of high resistance changes to low resistance. With the increase of the current in thyristor T’,
the VAK decreases synchronously. However, the main thyristor T is not conducting yet and was in the state of high resistance.

T’ is open and T begins to startup. The conduct current of T’ rises quickly and the port voltage was only the saturation voltage. The conduct current trigger the main thyristor T directly and make it begins to startup. At this time the current transfering through the main thyristor begins to rise gradually.

T is open. When the main thyristor begins to conduct, the on-state current increase quickly and the port voltage decrease to saturation voltage quickly. At this time, the port voltage of the T’ is very low and the current through it decreases quickly because of the load’s influence until turn off completely.

The trigger evacuation. When the current of the main thyristor was expended completely it can maintain open by itself. Then the trigger current can be evacuated.

![Figure 3](image)

**Figure 3.** the current and voltage in the process of thyristor’s triggering.

Typically, VAK is the voltage between the Anode and the Cathode of SCR, and it is from 0.5kV to 10kV in most applications; iAK is the conducting current of the SCR, its value is up to the parameters in the circuit; iAG is the trigger current and is about the 10 times of the iGT; iGT is about 1A, tG is the width of the trigger pulse and it is more than 50μs.

3. Experiments

The trigger signal was input to the pulsed isolator transfer, and the output of the transfer is connected with the gate G and cathode K of the thyristor. The voltage V2 between the gate G and cathode K of the thyristor as shown in figure 4.
V2 was measured by the oscilloscope. When the work voltage is 1kV, the width of the V2 is 70us as same as the input trigger signal’s width. And when the work voltage increased to 7kV, we found the width of the V2 was compressed to 45us, shown in figure 5.

From figure 5 we can see that when the work voltage of the thyristor is 1kV, the width of the trigger pulse is 70us with no compression, and when the work voltage of the thyristor is 7kV, the width of the trigger pulse was compressed to 45us.

In EML system, the transferring current $i_{SCR}$ of SCR can be calculated by the formula:

$$i_{SCR} = \frac{U_0}{\omega L} \times e^{-\frac{R}{\pi L}t} \times \sin(\omega t)$$  \hspace{1cm} (1)

$$\omega = \frac{1}{\sqrt{LC}}$$ \hspace{1cm} (2)

In the formula, $U_0$ is the work voltage; $C$ and $L$ are the values of capacity and inductance of the system, and $C$=1000 μ F, $L$=40 μ H; $t$ is the charge time; $R$ is the resistance of the EML system, and $R$=8mΩ.

According to the four-layer PNPN structure of the thyristor, when the thyristor begins to conduct, the current flows through the base N1 from anode P1, then flows through the gate P2 at last reaches the cathode N2. In the several ten microseconds before the thyristor’s triggering, the main current’s flowing route mainly concentrated in the partial region of the gate. When the rise rate of the main current is big enough, the voltage $V_{gk}$ between the gate P2 and cathode N2 will increase accordingly. With the increase of the main current in the process of the thyristor’s triggering, the $V_{gk}$ increased too. When this $V_{gk}$ is bigger than the gate triggering voltage V2, then the trigger signal from the outside
can’t input trigger current into the gate G and cathode K. Finally it results in the compression of the width of the trigger signal.

\[ V_{gk} = i_{scr} \times R_{gk} \]  

(3)

Rgk is the equivalent resistance between the gate P2 and cathode N2 of SCR, which is about 6.4mΩ in our system.

The voltage of the trigger pulse is 30V.

The Vgk is increasing as the figure 6 shows when the work voltage is 1000V and 7000V respectively.

![Figure 6](image)

**Figure 6.** the Vgk in the inducting progress of SCR by the trigger pulse.

The figure 6 explains the congress of the trigger pulse’s width well. When the work voltage is small, such as 1000V, the Vgk increases slowly, which is much less than the voltage of trigger pulse, so the trigger pulse is not compressed; when the work voltage is 7000V, the Vgk increases fast. When t is about 28μs, Vgk is about 30.1V, which is equal to the trigger pulse’s voltage, so the V2 is about 0V, like the width of the trigger pulse is compressed. And when Vgk increases continually, V2 will be minus, as the signal showed in the oscilloscope in figure 5.

4. Result

By measurement of the trigger pulse width of thyristor in operation, we found that with the increasing of the voltage between the thyristor, the width of the trigger signal was compressed. That means even the width of the trigger signal is more than 50us, when the work voltage is more than 7kV, the voltage of the trigger signal can’t be input into the gate G and the cathode K of the thyristor, the voltage of the signal was reduced to zero or even the minus value compulsively. So the width of the trigger pulse of thyristor is designed as 50us-70us which is appropriate because a wider width of the trigger pulse does not work so long in the practical triggering process of the thyristor. This results supply the valuable experiment support for the trigger design of the thyristor.

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