Analysis of Discharging Noise of Line-Type Pulse Modulator

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Abstract There is high electromagnetic noise radiation in Hefei Light Source (HLS) klystron gallery, which is from pulse discharging of thyratron modulator. This paper expounds the components of discharging circuit of HLS modulator. On the basis of it, the paper analyses the generating of discharging noise of klystron modulator and puts forward the method about reducing discharging noise of klystron modulator.

Key words klystron, modulator, thyratron, electromagnetic noise

1 Introduction

HLS is composed of 200MeV LINAC and 800MeV electron storage-ring. 200MeV LINAC is offered microwave energy by five D-4009 type 20MW klystrons with five cavities, which work at pulse modulating mode[1]. The high power modulating pulse of klystron gather electrode is fed-in through high voltage pulse modulator. High voltage pulse modulator is the pulse power source of high power klystron. The HLS line-type pulse modulator is composed of three tanks. The first is power supply tank. The second is charge tank, in which there are transformer and accessory system. The third is discharge tank, in which PFN (pulse forming network) and hydrogen thyratron are installed. The interference noise mainly comes from the discharge tank.

2 Discharging Circuit Analysis of Modulator

Discharging circuit is the output circuit of modulator. The basic components are PFN, switch tube and load, pulse transformer and pulse transmission cable[2]. Fig.1 shows the discharging circuit of modulator.

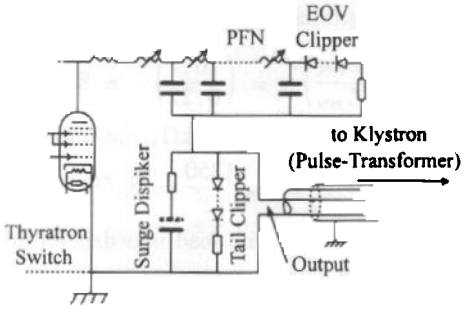

Fig.1. The discharging circuit of high-voltage pulse modulator.

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2.1 PFN

Storing energy and forming pulse waveform are the twofold effects of PFN. PFN acts as load in charging process and power supply in discharging process. PFN, which is also called artificial line and composed of divers L-C net-nodes, takes the place of factual transmission line in line-type modulator. The number of L-C net-nodes of HLS modulator PFN is ten, and every node inductance and capacity is $L_0 = 1.67\mu H$, $H_0 = 0.022\mu F$.

However, the perfect homo-capacity and homo-inductance can not meet the requirement of small top-down and flat-top quiver of output pulse waveform. In order to improve the pulse top-down, the practical capacity ranges from the small to the big, and inductance from the big to the small.

2.2 The switch element

The switch element is used for controlling pulsed discharging frequency, and is composed of the main trigger and hydrogen-thyratron. The effect of trigger controlling ducting and cut-off is exporting timing pulse signal. The endurable voltage of HLS modulator switch tube is 70kV, using 4050-model hydrogen thyratron.

2.3 Klystron load

HLS microwave power source is KMF-1017 type S-band high power klystron with five cavities. It works at the state of spikepulse, using water cooling method, coaxial input, wave-guide output and electromagnetic focusing. Its major technical parameters are:

Operating Frequency 2856.04MHz; Filament Current 10.5 ± 0.3A; Pulse Working Voltage -250kV; Output Pulse Power >15MW; Pulse Width 2.5μs; Efficiency $>30\%$.

2.4 Pulse transformer and pulse transmission cable

High power pulse transformer is used as offering charging and discharging pathway, raising pulse voltage, building matching relationship between klystron and artificial line. The parameters of HLS pulse transformer are:

Pulse Power 60MW; Pulse Voltage 20.8kV/250kV; Pulse Current 2.88kA/240A; Turn Ratio 1:12.

The characteristic impedance of HLS artificial line is

$$Z_0 = \left(\frac{L_{PFN}}{C_{PFN}}\right)^{\frac{1}{2}} = \left(\frac{16.7}{0.22}\right)^{\frac{1}{2}} = 8.71\Omega.$$

Because the impedance of HLS klystron is 1.25kΩ, the impedance reflected to primary is

$$Z' = \frac{1250}{n^2} = \frac{1250}{12^2} = 8.68\Omega.$$

The characteristic impedance can match with load impedance through impedance change of the transformer, which can attain maximum output power.

The output pulse is transported to the transformer primary through pulse transmission cable. The uniformity of the cable is an important parameter. The destruction of uniformity will cause wave reflecting, bring about much tangly waviness, and lead to signal distortion.

3 Generating of Discharging Noise of Modulator

The unstability of plasma, which is formed when hydrogen thyratron discharges, generates noise. Meanwhile the pulse current of discharging loop and the common ground wire of modulator radiates HF electromagnetic noise.

3.1 Electromagnetic noise coming from the unstability of plasma of hydrogen thyratron

Because the hydrogen thyratron is gas-discharge tube, gaseous discharge forms plasma, in which space charge fluctuation generates electromagnetic noise with the random motion of electron and ion. There are three reasons about the hydrogen thyratron discharging noise.

(1) Heat disturbance in plasma region

The random motion of electron and ion in thyratron surely generates electromagnetic noise. But the noise is weak, it is not the main noise source of modulator.

(2) Enlarging of elastic noise coming from position fluctuation of ion layer

The emitted Electron fluctuation of the hot cathode of thyratron generates elastic noise. The fluctuation and disturbance of ion layer leads to the enlarging of the cathode emitting electron fluctuation.

(3) Space charge fluctuation enlarges ion current

According to the central limit theorem: the sum of unindependent infinite random variables tends to normal distribution, the probability distribution of thyratron noise is normal distribution. The power spectrum of thyratron noise is relating to the following factors.

The magnitude of noise power is relating to the ionization current (i.e. anode current);

The frequency spectrum is relating to the transit time of electron and ion.

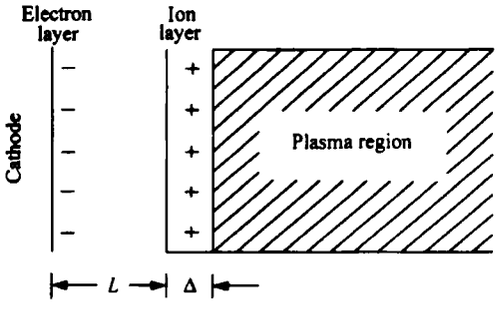

Fig.2. The charge disturbance region.

Fig.2 shows the charge disturbance region. The ion transit time from ion layer to electron layer is

$$\tau_i = \frac{L}{v_i} = \frac{L}{v_e}\sqrt{\frac{m_i}{m_e}},$$

where L is the interval between ion layer and electron cloud near cathode, m_i, m_e are respectively mass of ion and electron, v_i, v_e are respectively motion speed of ion and electron.

Because the mass of electron is less, the transit time of electron can be ignored. According to $f_{max} \propto \frac{1}{\tau_i}$, the less the ion mass m_i, the less the ion transit time τ_i, and so the wider the frequency spectrum.

3.2 Electromagnetic noise coming from pulse current of modulator

The electromagnetic interference is generated at discharging pulse front-porch of hydrogen thyratron, when the high current passes through discharging circuit in short time and radiate outwards electromagnetic noise. Fig.3 shows the discharging current of klystron load, which can reach

200A, during 3.6μs pulse duration. Fig.4 shows the space noise voltage waveform in time-domain. We can see that the noise duration is very short and it attenuates at rapid speed.

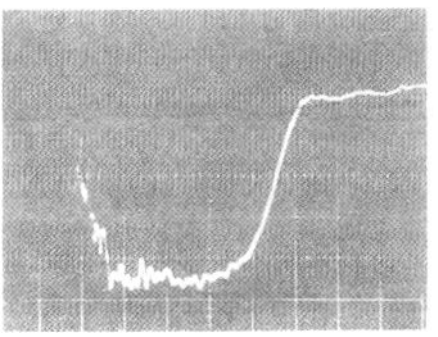

Fig.3. The discharging waveform of modulator.

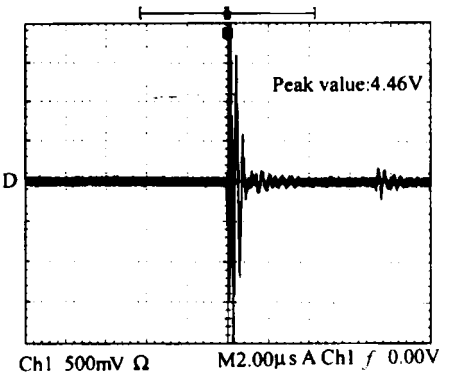

Fig.4. The space noise voltage waveform.

3.3 Electromagnetic noise coming from the common ground Wire of Modulator

As the reference electric potential of modulator common point is affected by pulse discharging, it is undulatory. Therefore the common ground wire of modulator radiates high frequency electromagnetic noise. In particular, when the ground wire length is odd numbers fold of wave-length, the high impedance ground wire corresponds a antenna and radiates electromagnetic noise.

4 Methods about Reducing Discharging Noise of Modulator

The electromagnetic interference of klystron modulator comes from the pulse discharge of hydrogen thyratron. In order to reduce the rather high interference-level, we set about reducing space radiation and circuit coupling[3].

4.1 Shielding

Shielding radiation noise source is very valid measure to reduce space radiation interference. That the discharging circuit is shielded and grounded in principle of Faraday-cup, can reduce effectively radiation electromagnetic interference.

The modulator discharging circuit is enveloped in shield tank. The secondary discharging circuit, which is composed of pulse transformer and klystron load, is enveloped in working cylinder. The coaxial transmission cable, connecting PFN with pulse transformer, is strictly disposed with ferromagnetic material. Though HLS adopts shield-tank, the imperfection of shield (such as aperture, venthole, and so on) leads to electromagnetic radiation outwards.

4.2 Grounding

Because the modulator discharging process is pulsed operating mode, and the rate of change di/dt is very big, the minimal rate of change will cause big voltage-drop. Avoiding the discharging current passing through the ground-wire and avoiding ground-wire loop are necessary about the modulator grounding. Let's account for the ground methods of modulator in example of discharging circuit.

(1) Two-points grounding

Fig. 5 shows that the point A and B are grounding points, which the main discharging circuit passes through. As there is some impedance and sudden-change current in ground-wire between A and B, the ground-wire corresponds antenna, which radiates electromagnetic noise. At the same time, the high-voltage between A and B may cause firing between the ground and other devices. Obviously, the ground-wire participates in the discharging circuit, for the sake of device asfe or anti-interference, the grounding method is inadvisable.

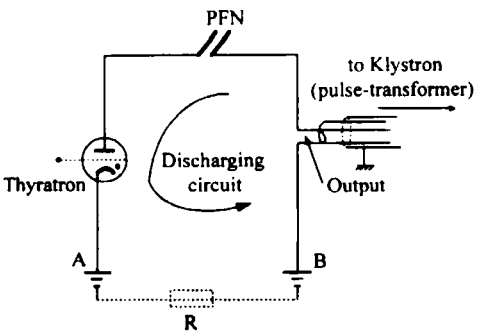

Fig. 5. Two-point grounding.

(2) Parallel two-points grounding

Fig. 6 shows the point A and B are separately two grounding points. There is an electric line between the point A and B, which is parallel with ground. in the case, the electric potential distribution is not uniform along the ground and the line. The non-uniformity may cause firing between the line and ground. At the same time, the ground-wire participates in the discharging circuit, and has antenna effect. As the line can cause strong electromagnetic radiation, the grounding method is inadvisable too.

(3) One-point grounding

Fig. 7 shows the main discharging circuit is insulated with the ground. In order to fix zero potential of the discharging circuit, there is a good grounding point between A and B. The pulse discharging current does't pass through the ground wire, and the ground interference is less. But there is still pulse current at the ground-wire, and it has antenna effect owing to the ground-wire impedance. So in order reduce radiation noise, it is necessary to ground reasonably and shield the ground-wire.

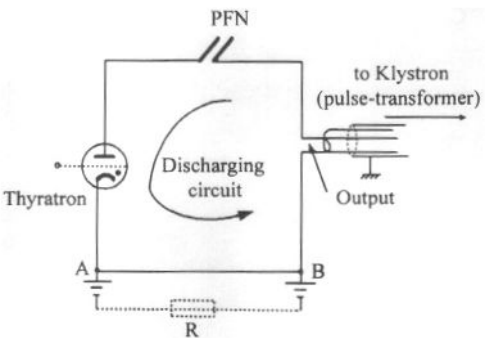

Fig. 6. Parallel two-point grounding.

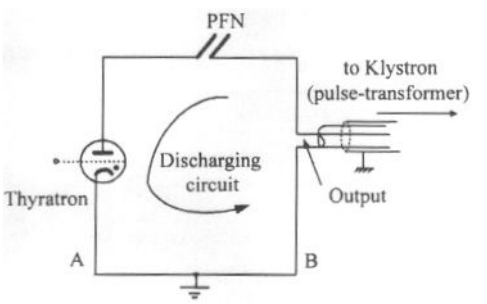

Fig. 7. One-point grounding.

5 Conclusion

In order to reduce electromagnetic noise, the anti-interference measure of shielding and grounding should be adopted. Though the HLS modulator has a grounding system in klystron gallery, the shield-tank is not isolated electrically with the discharging circuit. So the modulator circuit must be improved for the goal of shielding and grounding. Referring KEK anti-interference experience,

we intend to design a low inductance (or impedance) current returncircuit connecting PFN, hydrogen thyratron, pulse transformer and klystron[4,5].

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线型脉冲调制器放电噪声的分析

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摘要 合肥光源速调管走廊内存在着强电磁辐射噪声,这些噪声来源于氢闸流管的脉冲放电. 本文阐述了合肥光源高压脉冲调制器放电电路的组成结构,在此基础上,对速调管调制器的放电噪声的产生进行了分析,并提出了抑制调制器放电噪声的方法.

关键词 速调管 调制器 闸流管 电磁噪声

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