Influence of Grid Gated Pulse Edge on Streak Tube′s Characters

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Abstract: Based on a 5.0 ps time resolved streak tube with length of 189.472 mm, the influence of grid gated impulse on the characters of the streak tube was discussed. It is found that the rising edge and falling edge of the gated impulse would deteriorate both temporal and spatial resolution capabilities of the streak tube. The spatial resolution may fall sharply to half when the voltage on grid has a fluctuation of 10%. The main cause for the destructive influence is that optimal imaging position shifts when the voltage on grid changes. Influence on temporal and spatial resolution would reinforce as the deviation of voltage on grid increases. In conclusion, the rising and falling edge of gated impulse on grid gated impulse should be controlled strictly in narrow to reduce the impairment on the streak tube.

Key words: Gated impulse; Streak tube; Temporal resolution; Spatial resolution

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0 Introduction

Streak camera plays a significant role in ultra-fast diagnosis study areas such as laser ICF technology, detonics, arc discharge, biochemistry, and so on. Streak tubes have been improved a lot on its characters and capabilities since they are invented in 20th century. The temporal resolution of streak tube has developed to picoseconds and subpicosends. Simultaneously, wide response spectrum range and dynamic range become development trends to keep up with requirements and demands. Besides, streak camera is able to detect 3-dimensional space and intensity information based on multiple-slit imaging system[1-3]. The multiple-slit streak tube imaging system optimally meets the requirements of some military imaging scenarios such as missile tracking and navy mine detection which demand 3D lidar imaging capabilities. Moreover, multiple-slit streak camera renews imaging technologies such as 3D multi-spectral fluorescence imaging, 3D imaging polarimetry, and flash lidar imaging systems.

In this paper, we gave an introduction to the basic idea of 3 dimensional imaging lidar system based on streak tube. Then we designed a streak tube with specific analysis on theory and simulation results. Finally we considered potential problems of gated electrical pulse imposed on the grid, and discussed the influence of rising and falling edge of grid gated impulse on streak tube′s temporal and spatial resolution and analyzed the possible causes for the affect.

1 Introduction to 3D imaging principle based on streak tube

Based on multiple-slit streak tube imaging system, streak tube should work under sweep mode[4-5] in order to measure the third dimensional information. As is shown in Fig. 1, assume the point P_1 and P_2 has a distance of δ, a laser beam starts from the target object and the reflected signals from point P_1 and P_2 has a distance delay of 2δ. The two signal pulses spread on screen in sweep direction and the distance between them is $2\delta c/v$, where v represents the sweep velocity of deflector. The distance δ between point P_1 and P_2 can be calculated reversely by measuring the distance on screen. Practically, in order to record the signal pulse independently, a gated rectangular impulse voltage is applied to the grid of streak tube. The gated impulse is generated synchronously when the signal impulse is detected by PIN set in near front of the streak tube. The gated impulse ensures the electron can pass through the grid only when the signal impulse arrives. The gated impulse on grid can restrain the

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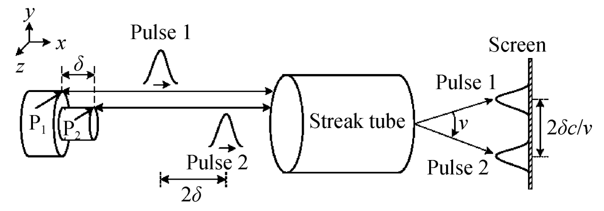

Fig. 1　Mechanism of 3-dimensional imaging system based on multiple-slit streak tube

background noise signals and enhance signal to noise radio as well.

2　Theoretical character of designed streak tube

The discussed streak tube is an electrostatic streak tube with the length of 189.5 mm. The structure figure of the tube is shown as Fig. 2. The tube is composed of cathode, grid, focus electrode, anode, and the deflector. We have simulated[6-8] the statistic distribution of electrons' initial energy, position and emitting angle, and then traced the trajectories of 3000 electrons in the tube. The transmit time as well as the final position on screen of each electron are recorded individually. According to the statistic simulation results, we can figure out the significant character parameters of the streak tube such as temporal and spatial resolution.

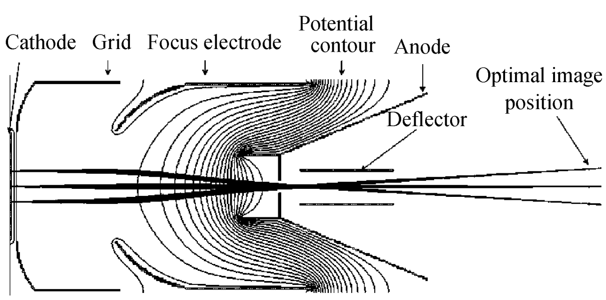

Fig. 2　Architecture structure of designed streak tube

Modulation transfer function (MTF) is usually used for evaluating the imaging quality of a optical system. Electrons emitting from the same point on cathode, which have different initial emitting angles and energies, would spread into a spot on screen rather than focusing into a point after imaging through an electron optical system. The function to describe this spatial spread spot calls point spread function (PSF). It is defined as the two dimensional distribution function of electrons on screen, which emit from the same point on cathode. Line spread function (LSF) is the calculus of PSF in one dimension. It is divided into LSF in sweep direction (on meridian plane) and LSF in slit direction (on sagittal plane). The calculation expression is given by[6-7]

$$\mathrm{MTF}=\sqrt{A_1^2+A_2^2} \tag{1}$$

$$A_1=\frac{\int_{-\infty}^{+\infty}\mathrm{LSF}\cos(2\pi f\cdot\xi)\,\mathrm{d}\xi}{\int_{-\infty}^{+\infty}\mathrm{LSF}\,\mathrm{d}\xi},$$

$$A_2=\frac{\int_{-\infty}^{+\infty}\mathrm{LSF}\sin(2\pi f\cdot\xi)\,\mathrm{d}\xi}{\int_{-\infty}^{+\infty}\mathrm{LSF}\,\mathrm{d}\xi} \tag{2}$$

Where f represents spatial frequency and ξ is the coordinate in sweep or slit direction. When it comes to calculation of Temporal MTF (TMTF) by the expression above, f represents the temporal frequency and ξ represents time. For a time resolved imaging system, spatial MTF and temporal MTF should be both take into account to evaluate the system's characters. Moreover, Dynamic spatial MTF (DSMTF) and Dynamic temporal MTF (DTMTF) should be figured out if imaging quality under sweep mode is evaluated. The calculation of DSMTF is also given by the expressions (1) and (2).

The sweep velocity is decided by the characteristic of deflector and the ramp of voltage applied on deflector. The sweep velocity is given by: $v=KP$, where K represents the ramp of voltage on deflector and P is the deflection sensitivity which means the deflection distance of electron on screen under unit sweep voltage. The deflection sensitivity P of the designed tube is 17.1×10^{-2} m/KV. The sweep velocity should be fixed suitably, which can neither be too high to affect the temporal resolution nor too low the affect the spatial resolution of the tube. The temporal resolution is a weak demand when streak tube works under multiple-slit mode, therefore the sweep velocity can be fixed at a relative low value to make sure the tube has a high spatial resolution and large effective cathode area. In this paper, the ramp of voltage on deflector is set as 1 V/ps, and the sweep velocity is 17.1×10^{-2} m/ps

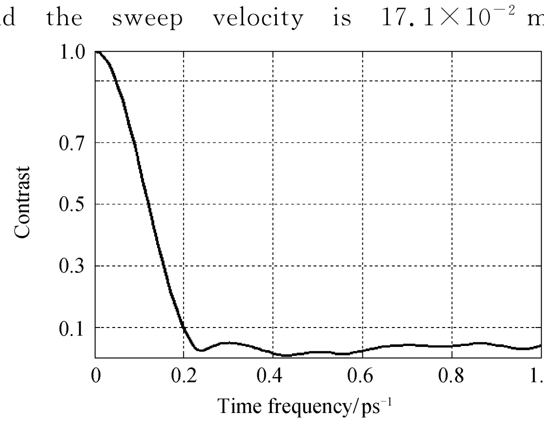

Fig. 3　Dynamic time modulation transfer function curve

Table 1 Spatial resolution of the streak tube when electrons emit from an off-axis cathode point of *R* distance

R distance/mm	1	2	4	6	8	9	10
Static resolution /(lp · mm^{-1})	>200	>200	>200	60	26	15	9
Dynamic resolution in sweep derection /(lp · mm^{-1})	120	112	49	24	14	10	7

correspondingly. Fig. 3 shows dynamic temporal MTF curve from which we can estimate the temporal resolution of the streak tube. The temporal resolution is defined as the reciprocal of time frequency when the temporal MTF contrast decreases to 0.1, thus the dynamic temporal resolution of the tube is 1/0.2=5 ps. In addition, the spatial resolution (in sweep direction) of point on cathode with different distance away from the center is given in Table 1. From the data shown in Table 1, we can see that the tube has an effective cathode area of 18 mm diameter in sweep direction when the minimum spatial resolution is 10 lp/mm.

3 Influence of grid gated impulse on streak tube

The grid gated impulse is generated synchronously when the signal pulse is detected. As is shown in Fig. 4, the rising edge of the gated impulse is about 10 ns, and the duration time of high level voltage is about 50 ns. Theoretically, *A* represents the low level voltage stopping the signal pulse going through the grid, and *B* represents high level voltage which release the signal pulse passing through the grid. However, the signal pulse may probably pass through the grid during the rising edge time before the voltage reaching high level *B*. In such a case, the signal pulse may pass through the grid under any voltage in range of [*A*,*B*]. We have compared the TMTF and SMTF under several different grid voltages with the normal situation in Fig. 5. The temporal resolution and spatial resolution both decrease when the voltage deviate from the normal high level (−7.0 kV). As is shown in Fig. 5 (a), the temporal resolution deteriorates from 5 ps to 10～20 ps. While the spatial resolution deteriorates more sharply, the spatial resolution drops half from 120 lp/mm to 65 lp/mm when the voltage deviates no more than 10% (−7.05 kV) from the normal high level. There are two causes for the influence as follows: one is that the reduction of voltage between cathode and grid increases the electron dispersion nearby the cathode. The other

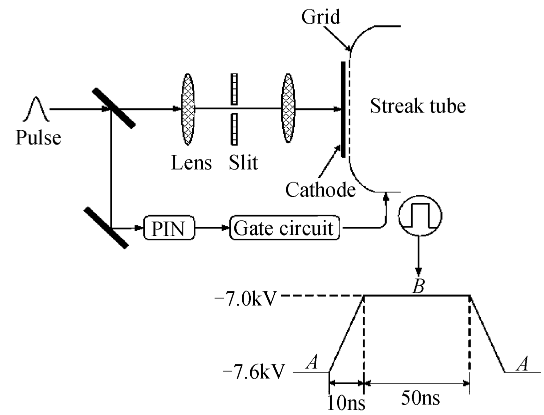

Fig. 4 Synchronous gated impulse on grid

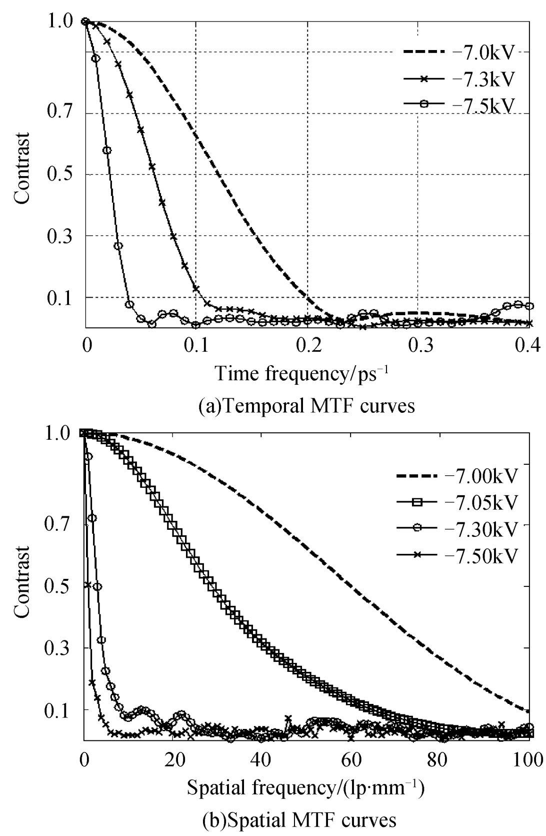

Fig. 5 Temporal and spatial MTF curves under different voltages on grid

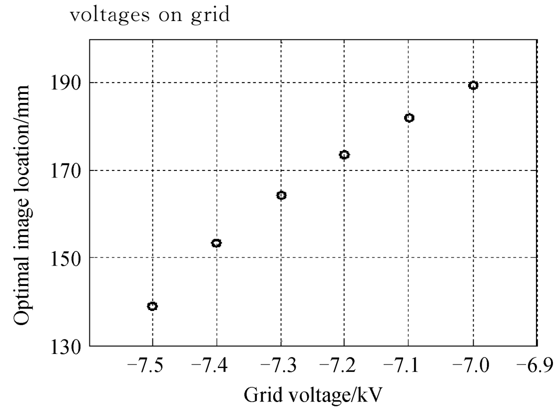

Fig. 6 Optimal imaging location shifts when voltage on grid changes

is that the change of voltage on grid makes optimal image position shift . We present the trend that how the optimal image position shifts according to the change of grid voltage in Fig. 6. And this reason is regarded as the main cause for influence on streak tube imaging. Therefore, the rising and falling duration time of the gated impulse should be controlled strictly in narrow to reduce their influence on the streak tube.

4 Conclusion

We discussed the influence of grid gated impulse on a designed streak tube with the length of 189.5 mm. The rising edge and falling edge of the gated impulse deteriorate both temporal and spatial resolution capabilities of the streak tube. The main cause for the influence is that optimal imaging position shifts when the voltage on grid changes. This paper provides the theoretical analysis and proof for reducing the influence of grid gated impulse on streak tube's characters. The rising and falling duration time should be controlled strictly in narrow and make sure the signal pulse pass through the grid under the stable normal high level voltage. In addition, the detected signals at the edge of screen which are far away from the center point can be discarded for they may probably be affected remarkably by the rising edge or falling edge of the gated impulse.

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栅极选通脉冲前沿对变像管性能的影响

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摘　要：讨论了管长为 189.5 mm，时间分辨率为 5 ps 的条纹变像管工作在多狭缝情况下对目标物体进行探测时栅极开关脉冲对其成像性能的影响. 开关脉冲的上升或者下降前沿都会降低条纹管的时间分辨和空间分辨性能，特别是空间分辨能力下降得很明显，当栅极电压波动 10%，条纹管空间分辨能力将下降为原来的一半. 产生影响的主要原因是栅极电压的变化使得条纹变像管的最佳成像面位置也发生了变化而偏离了原来位置，偏离得越多对条纹像管性能参量影响就越大. 所以在栅极开关脉冲发生电路中应该严格控制产生脉冲的前沿和后沿宽度，降低其对条纹变像管成像性能的影响.

关键词：开关脉冲；条纹变像管；时间分辨率；空间分辨率

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