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Streak Tubes for Diagnostics of Lasers and Plasmas

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Abstract. Designing a facility for laser fusion research requires sufficient advancement in diagnostics techniques for lasers and plasmas, including those involving streak camera imaging. Maximum specifications of streak cameras depend on the parameters of streak tubes. The paper illustrates how these devices function, and which of their parameters are limiting. The paper presents a novel technological platform designed at VNIIA, which was used to develop a new generation of streak tubes. Using these streak tubes in streak cameras, the efficiency of streak camera imaging techniques can be improved by several orders of magnitude, and new techniques can be designed.

1. Introduction

Work at laser fusion research facilities, such as NIF, OMEGA, LMJ, ISKRA-5, involves a wide range of complex scientific problems, one of them being the measurement of the laser and plasma pulses parameters lasting ~ 10^{-12} ... 10^{-9} s [1–10]. Streak cameras with streak tubes as the key components are used to address these issues. Information capacity of a streak camera image depends on its dynamic range and spatial resolution, which are limited by the similar parameters of streak tube. Improving these characteristics in new designs of streak tubes is one of the main objectives of VNIIA Research & Production Center for Pulsed Technique, which has over 30 years of experience in developing and producing streak tubes, successfully used by VNIIEF in their methods [1, 3].

2. Effect of streak tube parameters on the effectiveness of diagnostics methods

A typical streak camera image, which provides power measurement over time for ten different channels of igniting laser radiation, is shown in Figure 1. The number of channels in a single streak camera image depends on two parameters: the number of resolution elements and dynamic range of streak camera, and the dynamic range and resolution of streak tube, respectively. Increase of the number of channels will allow to reduce the necessary amount of streak cameras used in the detection methods of the laser time structure [3, 5, 8] and to avoid non-simultaneous arrival of laser beams to the thermonuclear target from different channels [4].

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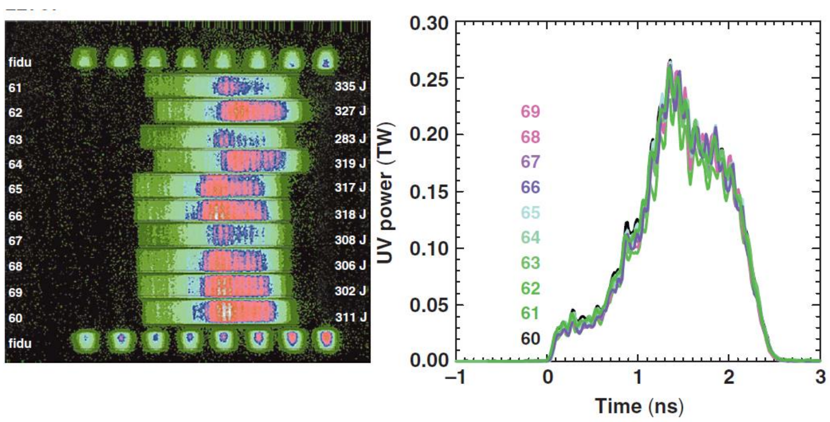

Figure 1. Ten-channel streak cameras provide pulse shape and power measurements at OMEGA [8].

Dynamic range is also the key parameter in the measurement method of contrast and profile of the laser pulse front, which define the fusion target implosion [2, 3]. At up-to-date facilities, the ratio of the maximum value of emission power vs. the value at the beginning of a pulse is of seven orders of magnitude or larger [2, 3], which forces to use ranging principle for such measurements (see Figure 2). The number of ranges is defined by the dynamic range of streak tube.

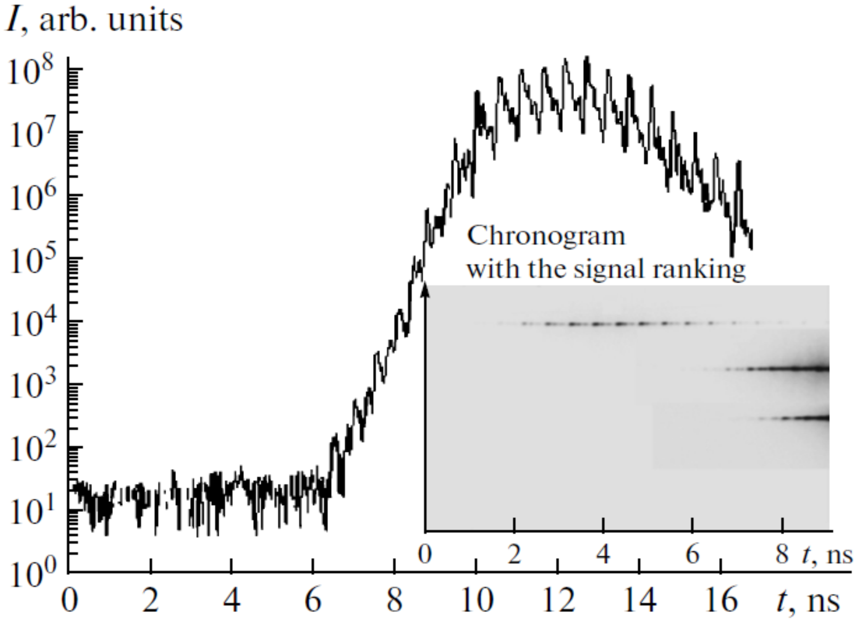

Figure 2. Result of the laser pulse deep front reconstruction [3].

The spatial resolution is the key characteristic for methods involving variation analysis over time of the laser spectral intensity scattered from the hohlraum plasma [6, 9]. The streak camera resolution determines the spectral resolution of such methods and measurement precision of the major plasma parameters (composition, temperature, and density).

3. Factors affecting the performance of streak tubes

As it was demonstrated above, the main streak tube parameters affecting the efficiency of diagnostic methods are the dynamic range and the limiting spatial resolution.

The streak tube dynamic range depends on the maximum photocurrent, which can be removed from the photocathode without image distortion on the screen, as well as on the signal-to-noise ratio of a streak tube [10]. Theoretically, the maximum current is limited by Child-Langmuir law, so its value is directly proportional to the electric field strength that accelerates and focuses photoelectrons in streak tube. Actually, streak tube with semitransparent photocathode rarely operates in the Child-Langmuir space-charge-limited current mode because image distortion on the streak tube screen appears much earlier due to electron trajectory disturbance as a result of the space-charge repulsion in crossover or violation of the electric field equipotentiality close to photocathode. The higher the resistance of the photocathode, the smaller the maximum photocurrent, which can be removed from it without violating the equipotentiality.

The signal-to-noise ratio is determined by the streak tube photocathode sensitivity and its dark current noise, which depends on the number of parasitic electrons sources in the streak tube envelope: free cesium, parasitic photocathodes on the electrodes of the cathode chamber, field emission points, etc.

Regardless of the streak tube maximum spatial resolution being mainly determined by its electron-optical system [11, 12], the calculated values are rarely achievable in practice due to significant deterioration introduced by the device assembly error (apart from considering the influence of other technological factors). Inaccuracy of the assembly in the previous generation devices produced by VNIIA Research & Production Center for Pulsed Technique up to 2015 was due to the quality of metal-glass body and specific limitation of tubulation technology of photocathode production.

4. New generation streak tubes

In 2015, VNIIA Research & Production Center for Pulsed Technique implemented a new technological platform for manufacturing of vacuum electronic devices that enabled producing streak tubes with improved key parameters. The platform is based on the finish processing of tubes using transfer technology, which involves producing a photocathode within an individual vacuum volume followed by its transfer to the case and sealing. This technology has significantly increased the photocathode sensitivity and reduced the dark current noise thanks to the absence of parasitic photocathodes on the electrodes of the streak tube cathode chamber and reduction of the alkali metal residual vapor in the volume of the device.

Using the transfer technology allowed to avoid direct contact of alkali metals with the streak tube internal parts during photocathode formation, which in turn, together with the introduction of ceramic-and-metal envelope, allowed significantly increasing the dielectric strength of insulators. As a result, the new generation of streak tubes operates at high electric field strength modes and allows to obtain the maximum time resolution up to 0.7 ps. Transition to ceramic-and-metal envelope increased the accuracy and reproducibility of its dimension. High-precision assembly of streak tubes has become possible using a special equipment.

Thanks to introduction of a number of special technologies for photocathode substrate preparation, its effective resistance was reduced and its sensitivity was increased manyfold.

Based on the previous developments [3, 11, 12], the introduction of technological improvements mentioned above allowed to create a new generation of streak tubes (see Figure 3) with improved capabilities. High-precision assembly and increase of the field strength made it possible to increase the streak tube resolution from 20 lines/mm to 30 lines/mm. Increase of the field strength, reduction of the dark current noise, lower photocathode resistance, and increase of its sensitivity led to an increase of the dynamic range of a streak tube by an order of magnitude from 1300 to 10000 (measurement method is described in [3]). The new generation streak tubes have smaller weight and dimensions and outperform their predecessors in almost all features, including time resolution and life time.

Figure 3. New generation streak tubes: TPO29 series (left) and TPO30 series (right).

5. Conclusion

According to our estimates, using streak cameras based on the new generation of streak tubes will increase the effectiveness of the methods described above in the following way: using one streak camera image it will be possible to record more than 1.5 times the number of laser channels at the same time, 2 times as low number of ranges will have to be introduced in the pulse shape measurements, while the spectral resolution of the stimulated Raman scattering recording method will increase by a factor of 1.5. The developed new generation of streak tubes will no longer limit the parameters of the existing streak cameras [3]: other components of these systems will require improvement.

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