X-RAY STREAK CAMERA OF 10 FS RESOLUTION FOR XFEL

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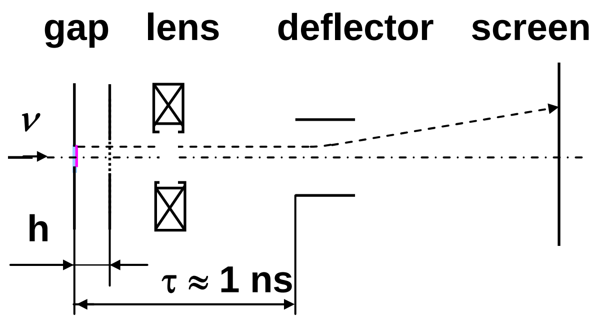
X-ray streak camera, based on new principle operation, with resolution of 10 fs for the XFEL project is considered. Main its characteristics and construction features are presented and discussed.

Typical scheme of conventional streak camera



- *h* = 1 mm - accelerating planar gap length
- $U_0 \leq$ 10 kV – gap voltage

Temporal resolution is manly restricted by longitudinal chromatic aberration of the gap due to initial energy spread and space charge effect

The best resolutions Δt, reached at present

- Table 1: Longitudinal chromatic aberration of planar gap for initial energy spread 0-0.1eV and 0-4 eV.

U_0 = 10 kV, h = 1 mm		
ΔW_0 (eV)	0.1	4
Δt_{ch} (ps)	0.1	0.7

Table 2: The best resolutions Δt, reached at present.

Streak camera	Δt (ps)	$\leq Q(e)$
FESCA 200 (S-1, S-20)	**0.2** [1]	**20** [2]
X-ray camera (Au)	**0.9** [3]	**50** [4]

[1] Hamamatsu Photonics K.K., Hamamatsu, City, Japan, http://www.hamamatsu.com

[2] M.Ya. Schelev. Physics - Uspekhi **43** (2000) 931.

[3] R. Shepherd et al., Rev. Sci. Instrum. **66** (1995) 719.

[4] M.M. Murnane, H.C. Kapteyn, R.W. Falcone, Appl.Phys.Lett. 56 (1990) 1948.

Comments on some papers, issued last time

- It is stated of creating x-ray streak camera with resolution of much less than 0.9 ps, reached in work [3] earlier, and operating also with gold photocathode.
- In the work of LBNL [6], for example, the camera has been calibrated with UV pulses, obtaining the initial energy spread of 0.5 eV instead of 4 eV for x-ray illumination and, consequently, the camera resolution was obtained of 230 fs. The chromatic aberration is proportional to square root from the initial energy spread, so that at the spread 4 eV the resolution will be not less than 0.7 ps at using gold photocathode, that is mentioned in the paper [6], and at the same parameters, listed in Table 1. We note that **these works [5, 6] have not been directed on decreasing the chromatic aberration and increasing the bunch population that can be reached on the base of new principle of camera operation.**

- [5] Z. Chang et al., Proc. of SPIE **2869** (1998) 971.
- [6] J. Feng, et al., Appl. Phys. Lett. **91**, (2007) 134102.

Conventional streak camera for attosecond pulses ?

- There are statements concerning possibility of creating streak camera with attosecond resolution, but the authors do not explain how they intend to overcome the quantum limit on finite sizes of an electron wave package in time Δt_q and in energy ΔE_q that defines the electron energy uncertainty ΔE_q or energy spread from the well-known relation [7]:
- $\Delta E_q \cdot \Delta t_q \geq \hbar$, where $\hbar$ = 0.6582 eV·fs.

- [7] I.E. Tamm, L.I. Mandel'shtam. J.Phys. **9** (1945) 249

Main requirements to the x-ray camera for European XFEL

– Temporal resolution has to be **at least of 20 fs** at single hoot regime of the camera operation and at recording temporal distributions of x-ray pulses, going with frequency up to **5 MHz**, without superimposing.
– Taking into account time-jitter effect of 1 ps, the number of recording channels has to be not less **10^2**.
– **Hence, we need the measuring x-ray technique, exceeding the reached temporal resolution nearly by a factor of 10^2 along with increasing the photoelectron bunch population by an order.**

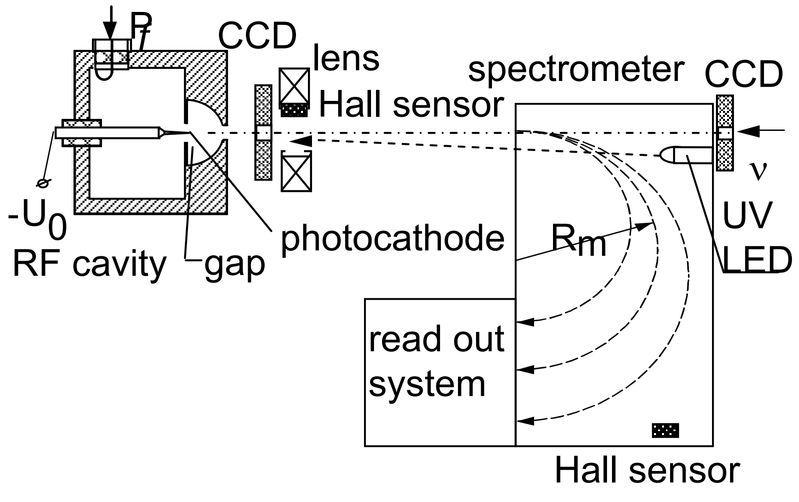
New principles in photochonography

- New principles [8] consist in transformation of the time of photoelectrons escapement from photocathode into one of their dynamic variable that must be performed at the moment of the escapement and for the shortest time, i.e. the transformation has to be performed at the photocathoode surface, and this transformation must be identical for all photoelectrons, starting from different points of emitter, i.e. fields in the gap must have appropriate symmetry, for example, spherical or cylindrical in volume, occupied by photoelectrons.
- [8] A.M. Tron, Proc. of SPIE **4948** (2003) 141.

New principles realization

- By means of combining the electrostatic accelerating field and RF- field, modulating electron on its longitudinal momentum, in a coaxial resonator with internal conductor as a photocathode and taking the radius of the photocathode surface rather small (20-100 μm) one can enhance and localize the field near the surface of emitter so that the time of effective interaction between photoelectron and these fields will be about 1 ps. In the case many effects, mentioned in the case of a conventional camera, can not develop for short time, and resolution can reach 10 fs and much less.
- Then temporal resolution will be defined by quantum limit [8] and escaping time dispersion that will be much less than 10 fs in our case.

Camera scheme



- Photoelectrons, modulated in energy in the gap, are analysed with the spectrometer. The RF-gap is a capacity gap of a quarter wave coaxial resonator with its internal conductor ending by needle with a tip in the form semi sphere, covered by a photocathode material.
- X-ray CCD matrixes are required for aligning the camera and estimating x-ray flux. The UV LED illuminates photocathode in the regime of the camera tuning. The read out system as a chip with 256 channels has pixels size in plane of temporal resolution of 16 μm.

Temporal resolution

- Table 3: Parameters of the camera gaps.

N	R_0/R µm/mm	f GHz	U_0/U kV	Δt_g fs	E_0/E kV/mm	W keV
1	100/10	3.9	0/20	11	0/202	17.7
2	100/10	3.9	8/20	8	82/202	24.8
3	100/10	3.9	6/15	10	61/152	18.3

- R_0 **(in µm),** R **(mm)** – radius of cathode and anode, U_0**,** U – static accelerating voltage and amplitude of modulating voltage on **3.9 GHz** in the gap, E_0**,** E – maximal static and alternative fields at the cathode surface in kV/mm, Δt_g – the best resolution and W – electron energy at the exit gap, corresponding Δt_g.
- The resolutions were obtained, taking into account of initial cosine-cube angular distribution of photoelectrons and initial energy distribution from paper [9, 10].

- [9] B.L. Henke, J.A. Smith, J.Appl.Phys. **48** (1977) 1852.

Temporal resolution

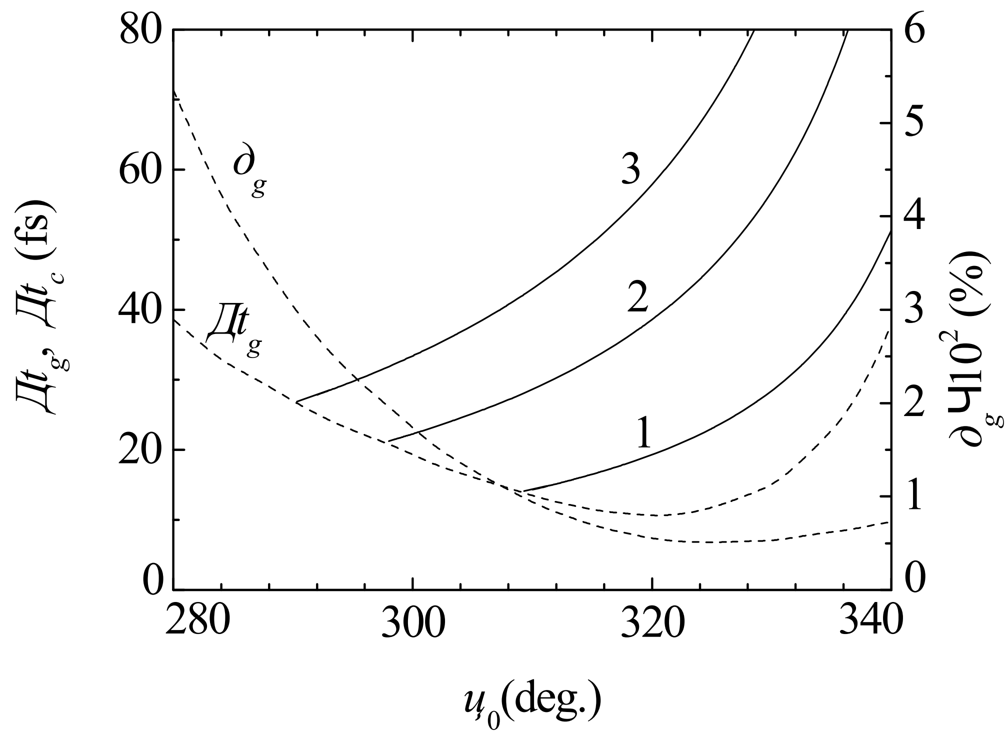


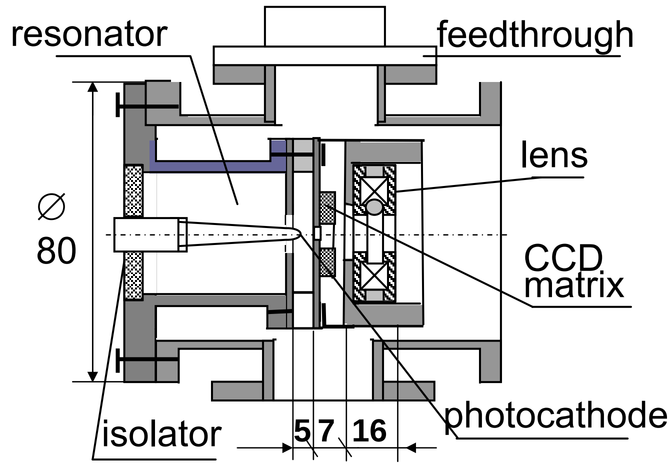
Figure 3: Dependences of camera gap resolution Δt_g,(with parameters in the Table 3, marked as 3,) camera Δt_c (with spectrometer resolutions, marked in hundredth percent) and relative momentum spread δ_g at the exit gap vs. photoelectron phase start. Camera resolution is represented by solid line and at the left from minimum it is as a dash line, coinciding with gap resolution.

Temporal resolution

- The resolutions will be of 15 fs at bunch population of 500 electrons due to space charge effect [11].
- Photocathode surface roughness has an impact on the camera resolution [12], and, for example, for getting temporal resolution not worse 20 fs the rms height of the roughness must not exceed 10 nm.
- Time window of the camera, within which the resolution changes not more than on 10%, is 7 ps. It means that the window allows realize up to 500- 300 channels in the read out system.

- [11] A.M. Tron, I.G. Merinov, T. Gorlov. Proc. of EPAC 2006, Edinburgh, June 2006, p. 1175.
- [12] A.M. Tron, T. Gorlov, Proc. of EPAC 2006, Edinburgh, June 2006, p. 121.

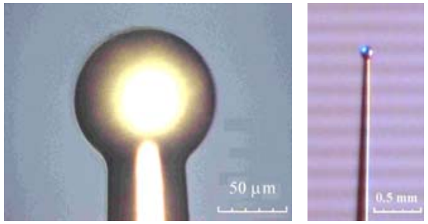
Camera construction



- Figure 4: Photogun of the camera
- At the left from the isolator there are another part of the cavity where coupling loops for microwave feeding and detection are placed, being under atmosphere pressure. The vacuum part is sealed off, but for getting and maintaining vacuum on the level of $1 \cdot 10^{-8}$ Torr there is a pump VacIon Plus 20, mounted on the bottom flange.

Principal new photocathode

- Novelty of proposed photocathode consists both in spherical configuration and in new material - thoriated tungsten with work function 2.6 eV and up to 2 eV, taking into account Schottky effect in our case.
- The new photocathode will allow to carry out the camera calibration on laser bench, operating with 20-10 fs pulses on 2-d harmonic of a Ti:Sa generator.
- Gold-plated phorocathode, technology which has been developed already [17], will be also used. Its quantum efficiency in the x-ray energy rage 0.1-12 keV is not worse 5% [9].
- **[17] A.M. Tron, T. Gorlov. Proc. of DIPAC 2007, Venice, http://felino.elettra.trieste.it/papers/TUPC18.pdf**
- **Figure 5: Gold-plated photocathode**
- **with the 50-μm radius before polishing (left)**
- **and conical steely holder of the spherical**
- **photocathode before its gold plating**.



CONCLUSION

- For investigating ultra fast phenomena, based on recording x-ray flux in femtosecond time scale, there was proposed a principal new streak camera of 10 fs resolution that is developing for the XFEL project at present, some results which were outlined in the paper.
- The camera system, offered for XFEL, consists from 3 parts, including mainframe, unit of the camera feeding and laptop.
- The mainframe sizes are not more than: 160 mm – in width, 250 mm – in height, 320 mm – in depth. The camera weight is about 15-20 kg.

Consortium

- Consortium for creating the x-ray streak camera for XFEL includes the following organizations:
- Lebedev Physical Institute of RAS,
- Moscow Engineering Physics Institute (State University),
- Federal State Unitary Enterprise “Istok”
- Federal State Unitary Enterprise “Experimental Factory of Scientific Engineering”.