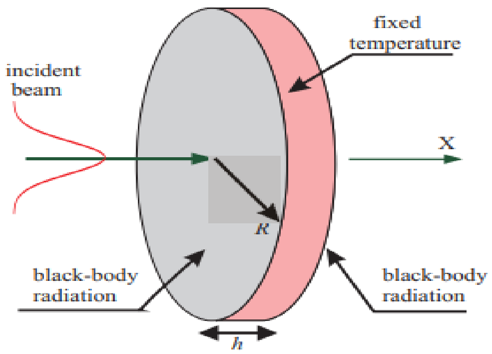
Some comments on the article : « Thermal damage at short electron bunches passage through a thin target » by A.A.Babaev and A.S.Gogolev

Using the XFEL beam parameters the thermal effects concerning the target heating are analysed and the conclusion underlines an overheating of the target. Moreover, mechanical stresses are evoked due to the high bunch charge in small central area of the target.

I shall concentrate my comments on the thermal and mechanical stresses provoked by the energy deposited by high charge bunches in a small volume of the target.

1- *Hypothesis (recall)*



Target : radius : 5.6 mm ; thickness : 10 µm
Bunch : length : 25 µm RMS ; transverse dimension : σ= 10 µm ; time between two successive bunches : 100 ns ; bunch population : 2.5×10^{10} e- (4 nC)
Energy deposited by bunch : 19.04 µJ
This energy is deposited in the target in a small volume which can be described as a cylinder with a radius of two σ=10 µm and a length of 10 µm ; that leads to a volume of $4\pi.10^{-9}$ cm^3. That corresponds, in some approximation, to the *total volume for a gaussian distribution- (see Hereward)* The « core » of the deposition volume is a cylinder of 10µm length and 10 µm radius (σ) ; it corresponds to a volume of $\pi\times10^{-9}$ cm^3 . The PEDD will be calculated in this core where the energy deposition density is the largest.

2- Peak Energy Deposition Density (PEDD)

The stresses in the target are related to a high value of the energy deposition density . The maximum of this density (peak) has to be determined in order to foresee if any damage could occur. The SLC target

breakdown led to an analysis and some tests which conclude that for this W target the PEDD must be lower than 35J/g.
So, what is the situation with the target described in the article?
If we calculate the PEDD we have 19.04 μ Joule deposited by one bunch ; for a gaussian beam almost half of this value is contained in a cylinder having a length h and a transverse section with σ as a radius (which can be considered as the *core* for the deposited energy volume) ; for such a volume of $\pi.10^{-9}$ cm^3 that gives, with a density of 3.5 g/cm^3 a PEDD of almost 900 J/g which is high enough!

3- *One or more bunches ?*

For the SLC target analysis it turns out that the relaxation time between two succesive stresses was about one μs . I dont know what would be the case for the diamond but I guess that we are in the same order of magnitude. Remembering that the interval between two bunches is only 100 ns, so, it would benecessary when calculating the PEDD to consider more than one bunch ! And the PEDD value to consider would be even more than for one bunch.

4- *Target resistance*

The ultimate tensile strength for the W is about 1500 MPa, whereas for the diamond it is about 2800 MPa (referred in some tables as the *minimum value*) ; that represents almost a factor 2 w.r.t. the tungsten. The limit on the stress would be higher than for the W case.
It is necessary to evaluate the stress in the diamond target ; longitudinally the target can expand, though radially it is constrained by a support. The expression of the radial stress is :

$$\sigma_r = E\alpha\Delta T/2(1-\upsilon)$$

where E is the Young modulus, α, the thermal expansion , υ, the Poisson ratio and ΔT the temperature rise. We have for the Diamond : E= 1220 GPa ; $\alpha = 1.1\times10^{-6}$ $°K^{-1}$; ΔT= 1724 °K.
That gives a stress of : 1.45 GPa for **the *first bunch*** As noticed before, the following bunches are contributing also to the stresses : the breakdown can be foreseen.
If we consider a realistic limit, we should put this limit around half of the Ultimate tensile strength, i.e. 1.4 GPa. The radial stress due to the first bunch is very close to this value. If we consider only this bunch we are in a limit case.

We note that a PEDD of 900 J/g is provoking a radial stress of 1.45 GPa . The reduction needed on that stress corresponds to an equivalent reduction on the temperature rise and, hence, on the PEDD.
But we have to take into account the contribution of the following bunches in order to get a complete solution. A simulation with programs as ANSYS could help.

5-*Bunch duration and stress propagation velocity*

The temperature rise in the diamond provokes an expansion as in other solids. That gives rise to pressure waves crossing the target. These waves are crossing the diamond target with the sound velocity. In diamond crystal this speed is about 12 km/second for a <100> orientation. We shall consider this value to calculate the time needed for the wave to travel from the target disk edge to the center. With the target dimensions that gives :
τ = 0.46 µs.
We have to compare this value to the bunch passage time when it crosses the target, i;e. (σ= 0.53 ps). In this duration the 19.04 µJoule are deposited in a stroke. Moreover, during the wave travel time from the target edge to its axis many bunches are depositing their energy. This situation is particularly harmful and breakdown of the target can be foreseen. That is a similar situation as for SLC target where

$$\tau_{bunch} << \tau_{wave}$$

6 -Preliminary conclusion

- If we consider, for the energy deposition, the effects of the first bunch we have a radial stress close to half of the ultimate tensile strength ; if we had only this bunch the PEDD must be reduced of some amount to be below this limit (1.4 GPa)
- The stress wave provoked by the first bunch did not arrive at the target center that the following bunch is provoking another stress which arrives after that of the first one. There is a cumulative effect during a time very probably smaller than the relaxation time of one stress. We have to consider many numbers of bunches to evaluate the actual effects.
- In this note only an approach is given on the stresses. A realistic description needs the use of a specialized program of simulation ,

like ANSYS, to evaluate correctly the stresses and the possibility for the target to avoid the breakdown.

- As what concerns the use of this diamond disk for diagnostics, may be a non-invasive method,- in order to avoid the target destruction- as the diffraction radiation may be interesting .

Robert Chehab, February 13th, 2023