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STUDY OF YAG EXPOSURE TIME FOR LEREC RF DIAGNOSTIC BEAMLINE

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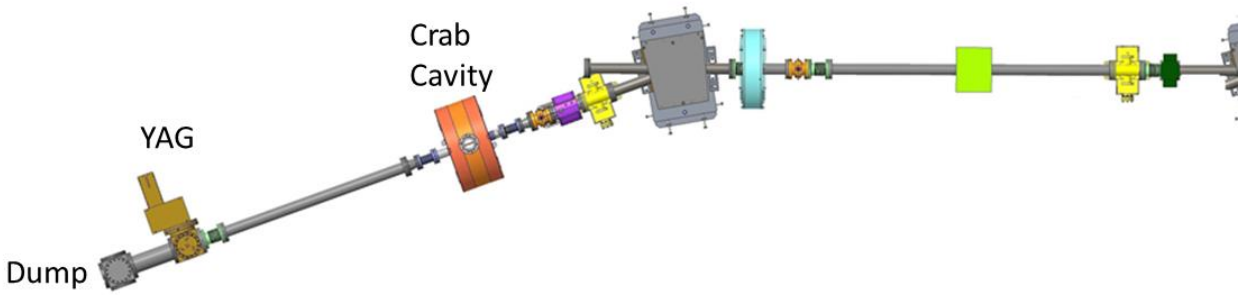

Figure 1: LEReC RF diagnostic beamline layout.

Abstract

The LEReC RF diagnostic beamline is supposed to accept 250 us long bunch trains of 1.6 MeV – 2.6 MeV (kinetic energy) electrons. This beamline is equipped with a YAG profile monitor. Since we are interested in observing only the last bunch in the train, one of the possibilities is to install a fast kicker and a dedicated dump upstream of the YAG screen and related diagnostic equipment. This approach is expensive and challenging from an engineering point of view. Another possibility is to send the whole bunch train to the YAG screen and to use a fast gated camera to observe the image from the last bunch only. In this paper we demonstrate the feasibility of the last approach, which significantly simplifies the overall design of the RF diagnostic beamline.

LEREC RF DIAGNOSTIC BEAMLINE

The LEReC accelerator [1, 2] includes a dedicated RF diagnostic beamline (Fig 1). This beamline will be utilized for fine-tuning of the RF required to produce electron bunches with energy spread better than $5{\cdot}10^{-4}$.

The beamline consists of a bending magnet creating dispersion at the location of the YAG screen and a deflecting cavity "crabbing" electron bunches in time domain. Thus, the beam image on the YAG screen represents the longitudinal phase space of the beam.

The temporal structure of the bunch train sent to the diagnostic beamline is as follows. There are N=30 (100 ps long) electron bunches, with nominal charge Q=130 pC, spaced by 1.4 ns and forming a single macro-bunch. The macro-bunches are separated by Δt=110 ns and form the train of any chosen length. The schematic of e-beam temporal structure is shown in Fig. 2.

The overall length of the bunch train required for RF diagnostic is determined by stabilization time of the RF system. It was determined [3] that bunch train of length t=250 us is sufficiently long to study the beam-loading effects in LEReC RF cavities.

We plan to send the whole bunch train to the YAG screen and to use a fast gated camera (such as Imperex B0610 with trigger jitter under 60ns [4]) to observe the image from the last macro-bunch only.

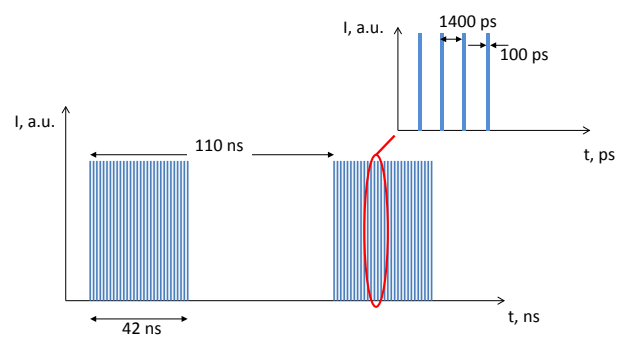

Figure 2: Temporal structure of electron beam.

In this paper we will consider two connected questions of YAG screen performance for the described bunch train.

First, we will study the instantaneous temperature jump in YAG crystal due to deposition of a single bunch train.

Second, we will find the steady-state temperature of YAG screen for various e-beam repetition rates.

YAG SCREEN PERFORMANCE

The best, known to us, test of YAG screen performance under temperature stress is the RHIC electron lens operation. In this test 5 keV, 97 mA DC beam "chunks" as long as 1.2 ms were deposited on the YAG screen.

The crystal response still was linear for such parameters and the Gaussian transverse distribution with σ=0.133 cm was still observed on the YAG screen.

We calculated that due to deposition of each shot YAG temperature had to jump by 194 K. Numerous shots with 3-5 s repetition rate were sent to YAG crystal without damaging it.

The test [5] of the dependence of YAG crystal performance on temperature corroborates that it is safe to heat the YAG screen up to 200 C.

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INSTANTANEOUS TEMPERATURE RISE FOR YAG SCREEN

YAG stopping power per electron with 2.1 MeV energy is p=1.46 MeV cm^2/g [6] (in our energy range it changes only slightly). Therefore, the energy loss per electron in YAG screen of width w=100 um is:

$$\Delta E = p \cdot w \cdot \rho = 0.066 \text{ MeV} \quad (1)$$

where $\rho = 4.55 \text{ g}/cm^3$ is YAG density.

The total number of electrons interacting with YAG screen is:

$$N_e = N \frac{Q}{e} \frac{t}{\Delta t} = 5.54 \cdot 10^{13} \quad (2)$$

where e is charge of electron.

Thus, from (1) and (2), the total energy deposited on YAG crystal by the bunch train is:

$$E_{tot} = N_e \Delta E = 0.59 \text{ J} \quad (3)$$

The typical beam profile on YAG screen is shown in Fig. 3. For the sake of energy density calculation we can substitute real beam profile with a homogenous ellipse with 0.11 cm and 1.79 cm semi-axes.

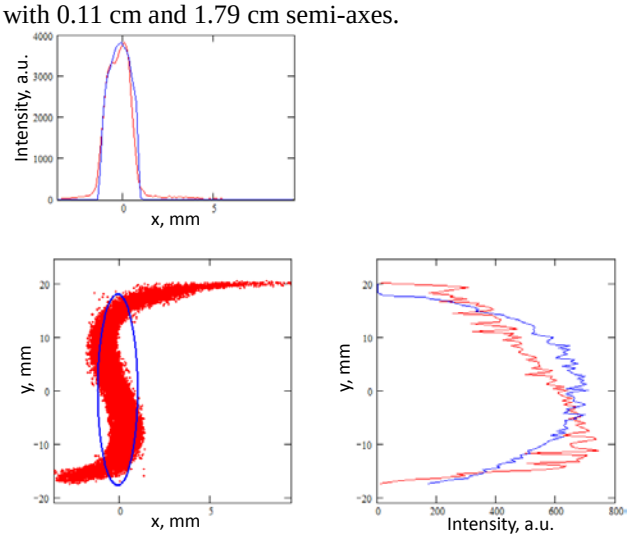

Figure 3: Typical beam profile on YAG screen (red) and equivalent ellipse (blue) homogeneously filled with the same number of particles. For the ellipse, only the outline is shown on the plot.

Since, the specific heat capacity of YAG is c_s=590 J/kg/K, the heat capacity of YAG heated by electron beam is C=0.017 J/K.

Finally, an instantaneous increase in YAG temperature due to deposition of a single bunch train is:

$$\Delta T = \frac{E_{tot}}{C} = 35.5 \text{ K} \quad (4)$$

Apparently, such small (as compared to electron lens experience) temperature jump will not degrade YAG performance.

STEADY STATE TEMPERATURE OF YAG SCREEN

Assuming that the main mechanism of YAG cooling is radiation we find from black-body radiation formula that the steady state temperature is given by:

$$T = \left(\frac{E_{tot} f}{A \sigma_{SB}}\right)^{\frac{1}{4}} \quad (5)$$

Here A is the area covered by the beam image; f is the repetition rate of the beam trains, and Stefan-Boltzmann constant $\sigma_{SB} = 5.67 \cdot 10^{-8} \text{ W/m}^2/\text{K}^4$. We assume 100% emissivity for the YAG crystal in (5).

The result of application of formula (5) to our case is shown in Fig. 4. It is obvious that the safe repetition rate can be at least one shot per 5 seconds.

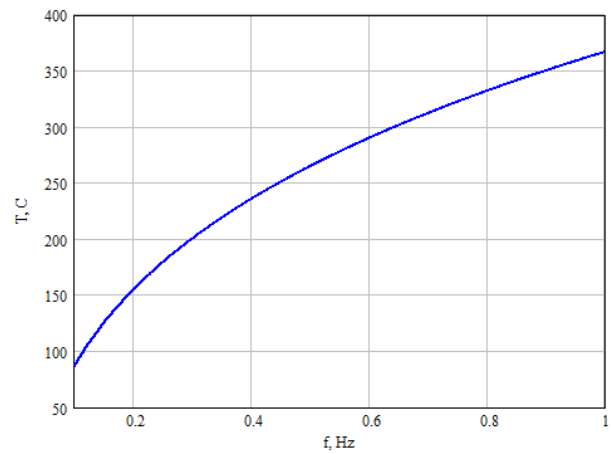

Figure 4: Steady state temperature of YAG crystal depending on e-beam repetition rate.

More precise simulations of YAG cooling take into account crystal emissivity ($\epsilon = 0.8$). To increase the YAG emissivity we plan to coat the back side of the crystal with a layer of carbon on top of the 100nm of aluminum.

In our simulations we assume that over time period dt the crystal is cooled by temperature:

$$dT = \frac{\sigma_{SB} \epsilon (T^4 - T_{room}{}^4) dt}{c_s \rho w} \quad (6)$$

where $T_{room} = 300$ K is room temperature.

Results of simulations for bunch train repetition rate of 0.2 Hz are shown in Fig. 5.

The average steady state temperature of YAG screen for bunch trains arriving with 5 s period is about 170 C and the maximum observed temperature is 186 C.

Notice that by not exceeding 194 C threshold for steady state temperature we create a rather large safety margin since average steady state temperature in electron lens test

had to be about 400 C (calculations for e-lens parameters were performed using (1)-(6)).

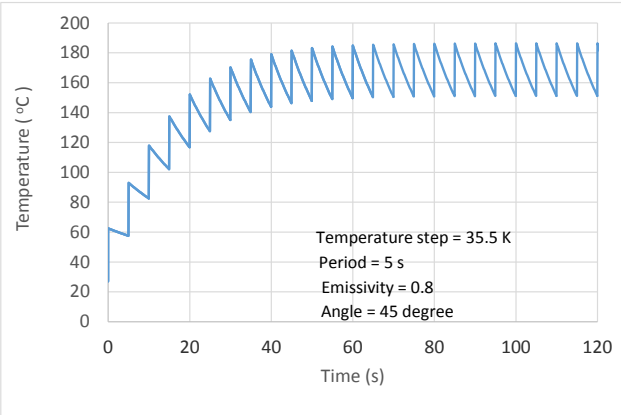

Figure 5: Simulations of steady state temperature.

Finally, one can measure longer than 250 us bunch trains by increasing the period between the trains. Figure 6 shows the period between the bunch trains of various length required to guarantee that YAG steady state temperature does not exceed 186 C (maximum temperature for nominal 250 us long bunch train arriving every 5 s).

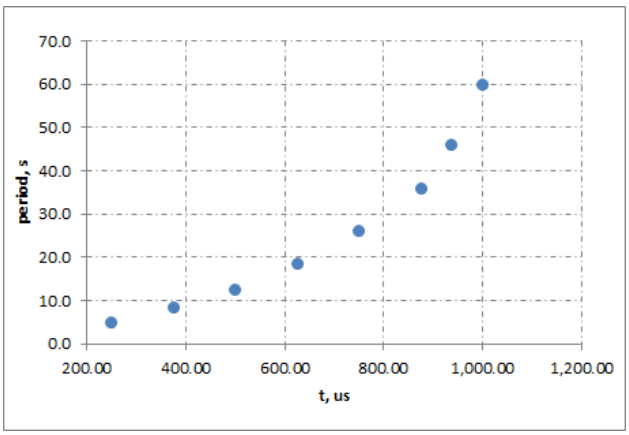

Figure 6: Period between bunch trains depending on train length. For each case YAG steady state temperature does not exceed 186 C.

CONCLUSION

We considered performance of the YAG screen in RF diagnostic beamline of the Low Energy RHIC Electron Cooler for the case of high power (250 us long) bunch trains directed to the YAG screen.

We determined that it is safe to operate such diagnostic with the bunch trains repetition rate of 0.2 Hz.

In case we need to measure the longer bunch trains, the trains' repetition rate can be farther decreased.

Our findings allow us to cut the cost and simplify the design of the RF diagnostic beamline by eliminating a necessity of a fast kicker and a dedicated dump at the beginning of the beamline.

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