THERMAL DESIGN OF THE FETS CHOPPER BEAM DUMP

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Abstract

The Front End Test Stand Project (FETS) at RAL is being built to demonstrate fast beam chopping. This is required to create precisely defined gaps in the bunched H- beam which is essential in order to minimise beam losses in a synchrotron during injection. The gaps are created in the Medium Energy Beam Transport (MEBT) section of the FETS beam-line using a 'fast-slow' chopping scheme. This scheme uses two choppers, one fast and one slow, each kicks a portion of beam into its corresponding downstream beam dump. The challenge for the beam dump design is that it must occupy a limited longitudinal space to ensure that the beam transport is preserved and must absorb a beam power that is close to the sustainable stress limit of common engineering materials. This paper will describe the simulations made to study the cooling scheme required to absorb the power deposited in the dump plates for the fast and slow choppers.

INTRODUCTION

The FETS project requires two chopper beam dumps to withstand and safely dissipate power from the incident beam. The beam parameters, listed in Table 1, thus form the design criteria for these dumps [1].

Table 1: Parameters for the FETS Beam

Parameter	Value
Particle	H-
Beam Energy	3 MeV
Beam Current	60 mA
Pulse Length	20 ms
Duty Cycle	0.1
Maximum Power	180 kW
Average Power	18 kW

The beam is on for a 2 ms pulse in each 20 ms period. During this time, it is broken by choppers into a repeated cycle of ON/OFF states. The two choppers in the FETS project are denoted 'fast' and 'slow', based on their respective response times. During each ON stage of a chopper, it deflects beam particles to its corresponding downstream dump. The chopper timings have been designed in accordance with the ISIS synchrotron frequency of 1.5 MHz. The FETS beam has a frequency of 324 MHz, resulting in 216 periods of ON/OFF cycles, or beam bunches for each ISIS period [2]. Table 2 describes how these 216 beam bunches are broken by the fast and slow choppers.

Table 2: Sequenced Timing for the Fast / Slow Choppers

Number of bunches	Fast Chopper State	Slow Chopper State
4	ON	OFF
57	OFF	ON
4	ON	OFF
151	OFF	OFF

During an ON period of a chopper, its corresponding dump sees the full 180 kW of incident power. However, each chopper deflects only a certain proportion of the total 216 bunches, and the dump is required to dissipate power according to this proportion, as presented in Table 2. The sequence of states can be expressed in terms of the average power seen by the two dumps, shown in Table 3.

Table 3: Summary of Power Incident on Chopper Dumps

Number of bunches	Fast Chopper Dump	Slow Chopper Dump	Main FETS Dump
Percentage of total power dissipated	3.70%	26.39%	69.91%
Average power over 2 ms beam pulse	6.67 kW	47.50 kW	125.83 kW
Average power over 20 ms period	0.667 kW	4.750 kW	12.583 kW

PRELIMINARY DESIGN

This section describes the initial design decisions that have been taken for the chopper dumps. A rectangular plate-geometry was selected, with dimensions incorporating space constraints imposed by the FETS set-up. In this configuration, the deflected beam hits the plates at a shallow incident angle, with the power effectively distributed over a larger area, minimising the surface heat flux. Heat dissipates through the plate material, and is absorbed in water-cooled channels along the length of the plates.

The beam power must be safely dissipated by the plate and water cooling, and the material selection must be carried out accordingly. In order to select the material, existing beam dumps of similar specifications were first identified, and the materials used for these beam dumps were considered. Copper was then selected for the initial thermal analysis, with the possibility of using Nickel-coated copper in future simulations, should the radiation study deem this necessary. The subsequent analyses have all been carried out on a copper plate.

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THERMAL ANALYSIS

Thermal analysis has been performed using General Particle Tracer (GPT), MATLAB and ANSYS software to support the design for the chopper dump plates, and identify points for refinement of the preliminary design [3-5].

Particle Distribution

The beam is characterised by a Gaussian-like energy spread. In order to determine the power distribution on the chopper dump plates, GPT simulations were carried out to determine the distribution of particles hitting the plates. Each simulation was conducted using 95,200 macro-particles, with each particle carrying an equal proportion of the total beam power. For each dump plate, the output of the simulation was the co-ordinate location of the beam particles, in the plane of the plate. The particle distribution is shown in Figure 1.

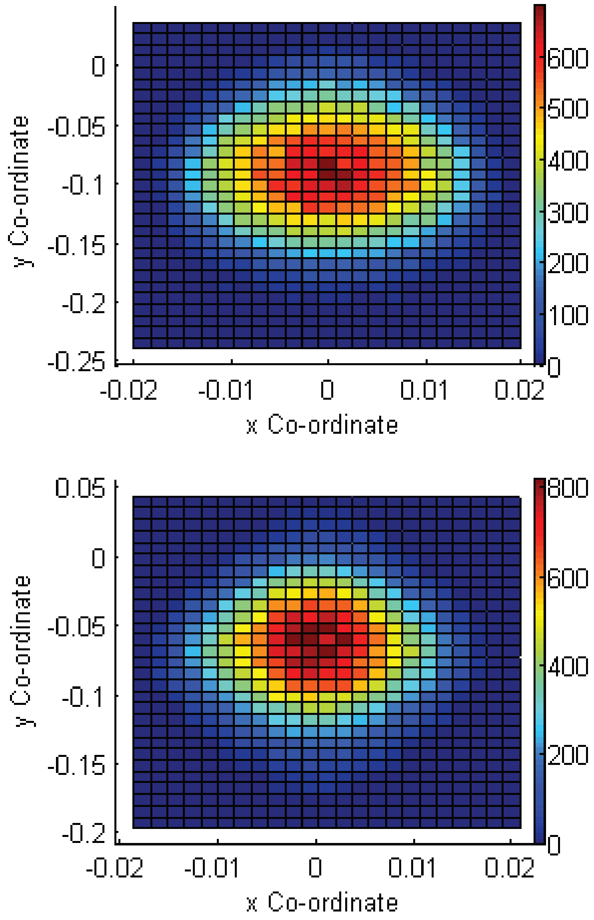

Figure 1: Particle distribution on the fast (top) and slow (bottom) chopper dump plates.

Finite Element Analysis Set Up

Finite element analysis (FEA) was conducted on the beam dump plate using the geometry described in the previous section. The boundary condition was a heat transfer from the beam on one surface, as obtained from the GPT simulations. For the transient and steady state analyses, the total power was distributed in proportion to the particle distribution described in Figure 1 for the fast and slow chopper dumps. The water-cooled channels were modelled using a convective heat transfer coefficient, with scope to extend to a full CFD analysis in future studies. The remaining plate surfaces were represented by a conservative zero heat flux model.

Steady State Analysis

The steady state temperature distribution for the two water-cooled plates under the influence of the time-averaged beam power of 0.666 kW and 4.75 kW to the fast and slow chopper dump plates respectively is presented in Figure 2.

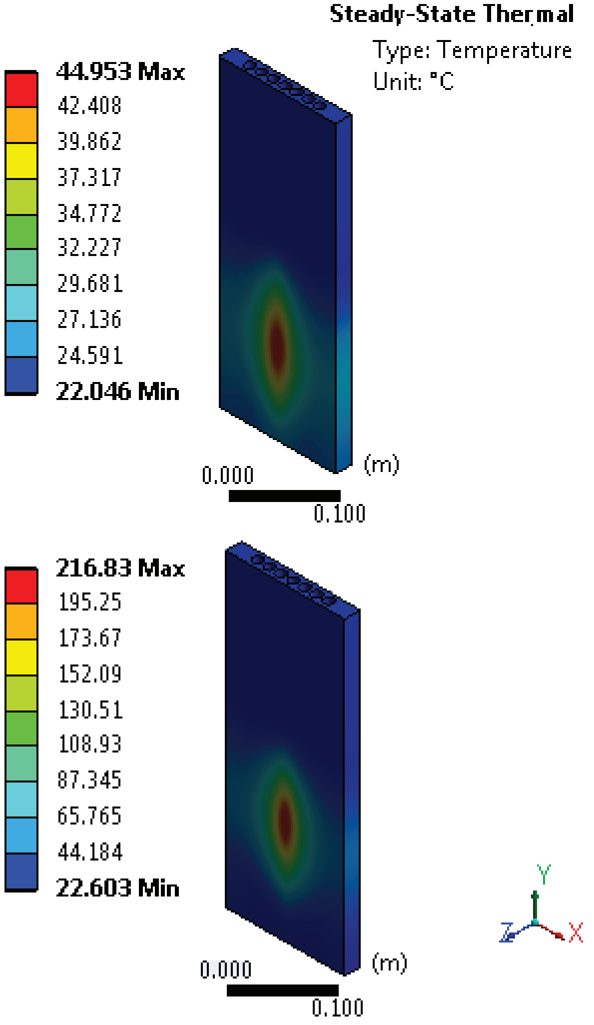

Figure 2: Steady state temperature distributions for the fast (top) and slow (bottom) chopper dump plates.

The maximum temperature obtained for the fast chopper dump, 45.0 °C is well below the creep temperature of copper, and the option of radiative cooling will be explored in future designs. The slow chopper dump has a maximum steady state temperature of 217 °C under active cooling by water. It is unlikely that radiative cooling alone will keep the maximum temperature below the creep temperature of copper.

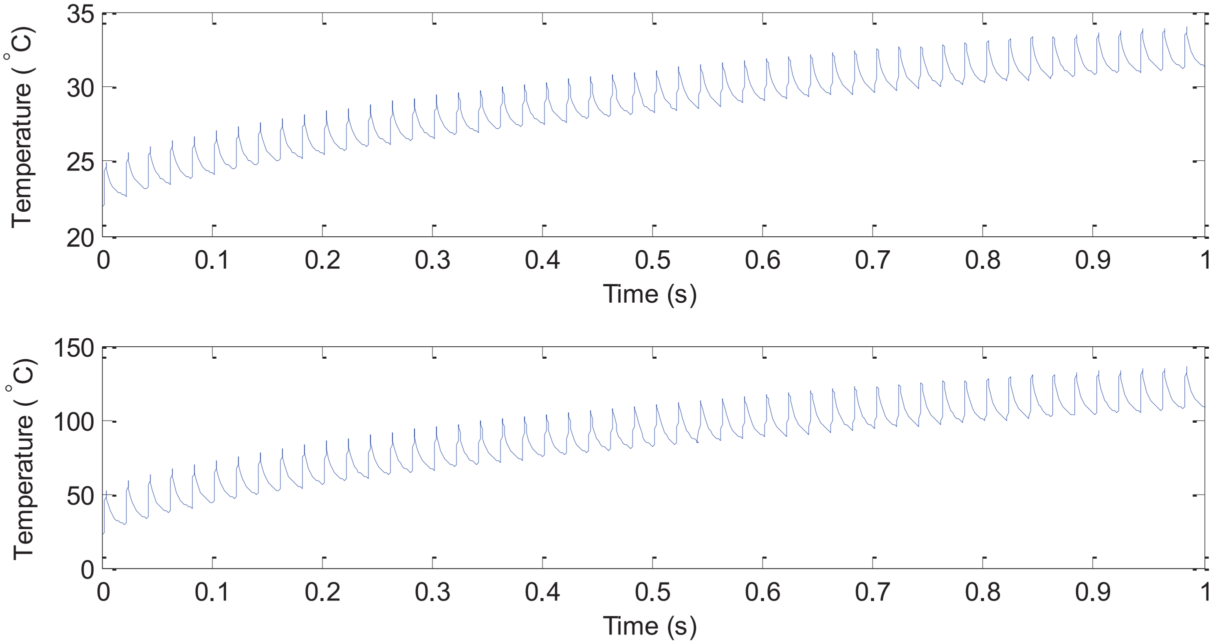

Figure 3: Graph of the maximum temperature as a function of time for the fast (top) and slow (bottom) chopper dump plates.

Transient Analysis

In the transient analysis, the beam power was applied for a period of 2 ms and then turned off for the next 18 ms, over consecutive cycles, in accordance with the data presented in Table 3. Time-averaged power over the 2 ms ON period of 6.67 kW and 47.5 kW were used for the fast and slow chopper dumps respectively, using the power distribution indicated in Figure 1.

Figure 3 illustrates the time history of maximum global temperatures of the two chopper dumps for the first 500 periods of these ON-OFF cycles. The difference in the vertical scale between the fast and slow chopper dumps should be noted; the slow chopper dump has a much larger ripple within each cycle. This represents the difference in heat flux applied to these dumps. Between subsequent cycles, it is seen that the temperature approaches the maximum steady state temperature for each dump, closely approximating an exponentially decaying trend. Within each cycle, the increase in temperature during the 2 ms period, followed by the decrease during the next 18 ms also follows similar kinetics.

CONCLUSION

The transient and steady state thermal effects of the incident beam on the two chopper dumps proposed for the FETS project have been investigated. The fast chopper dump has a maximum steady state temperature of 44.9 °C, and the slow chopper dump has a maximum steady state temperature of 217 °C. These results show that for the two chopper dumps, the material selected and geometry proposed are both thermally feasible.

The simulations done so far thus provide necessary groundwork for future analyses required in refining the design for the chopper dumps. Where approximations have been made to simplify the simulations, they have been conservative. There remains scope to incorporate a full computational fluid dynamics analysis to determine the variations in convective heat transfer coefficient along the water channels.

Additionally, it is necessary to translate the thermal analysis to determine the stress distribution, based on the plate mounting method. During the transient phase, temperatures vary by up to 30 °C in each pulse. This could lead to fatigue life problems if the stress levels are high. Subsequent work should also incorporate the effect of radiation on the material, to determine whether copper is feasible, or the copper bulk requires coating to enable the dumps to withstand the full beam power.

REFERENCES

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