IRRADIATION STUDIES AT THE ADVANCED PHOTON SOURCE

TUP028

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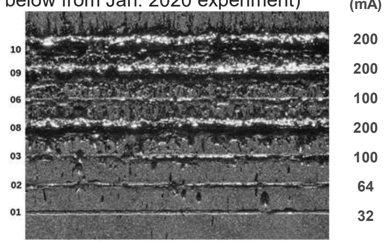
ABSTRACT

We present results from a recent collimator irradiation experiment conducted in the Advanced Photon Source (APS) storage ring. This experiment is the third in a series of studies to examine the effects of high-intensity electron beams on potential collimator material for the APS-Upgrade (APS-U). The intent here is to determine if a fan-out kicker can sufficiently reduce e-beam power density to protect horizontal collimators planned for installation in the APS-U storage-ring. The fan-out kicker (FOK) spreads the bunched-beam vertically allowing it to grow in transverse dimensions prior to striking the collimator. In the present experiment, one of the two collimator test pieces is fabricated from oxygen-free copper; the other from 6061-T6 aluminum. As in past studies, diagnostics include turn-by-turn BPMs, a diagnostic image system, fast beam loss monitors, a pin-hole camera, and a current monitor. Post-irradiation analyses employ microscopy and metallurgy. To avoid confusion from multiple strikes, only three beam aborts are carried out on each of the collimator pieces; two with the FOK on and the other with it off. Observed hydrodynamic behavior will be compared with coupled codes.

MOTIVATION

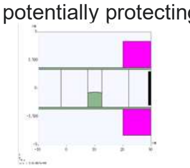
- Previous whole-beam-loss experiments carried out in 2019 and 2020 in the APS SR studied effects in aluminum and titanium collimator test pieces [1–3].
- No steps were taken to mitigate damage caused by the high intensity electron beam during these earlier studies.
- Significant damage was observed (in Al below from Jan. 2020 experiment)



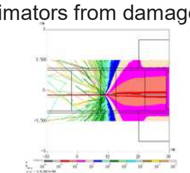
BACKGROUND

- Initial simulations with elegant[4,5] and MARS[6] indicated high temperatures and damage during unplanned beam loss
- Modeling with elegant suggested a vertically deflecting pulsed magnet could sweep the beam as well as increase its cross section potentially protecting horizontal collimators from damage

Simplified collimator geometry in MARS —x-z view

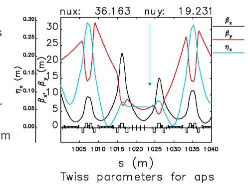


Electron/ positron flux contours, MARS —x-z view

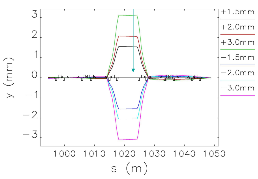


Lattice fns around S37 from elegant

Collimator located at s=1023.8 m

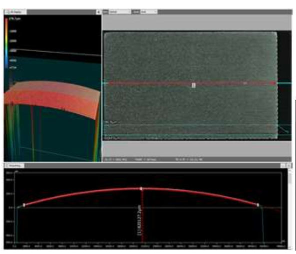


Vertical orbit bumps determined from elegant



MEASUREMENTS—PRE STUDY

Collimator surface analysis with Keyence VR 3200 microscope. 80-cm radius was machined onto both collimator test pieces in the horizontal plane



Copper collimator test piece showing 1-mm-spaced fiducial rulings.

Nominal ruling depth: 0.127 mm; every 5th: 0.254 mm

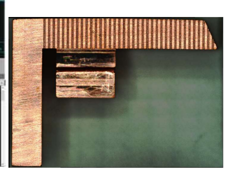
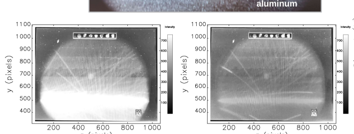


Table 1: Beam Abort Case List Parameters.

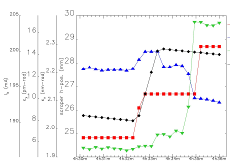
Case No.	Vertical Offset (mm)	Mat'l	FOK Voltage (kV)	Vert. defl. angle, y' (μrad)
0	+1.5	Cu	2	245.0
1	-1.5	Al	2	245.0
2	-2.0	Al	1	122.5
3	+3.0	Cu	0	0
4	-3.0	Al	0	0
5	+2.0	Cu	3	367.5

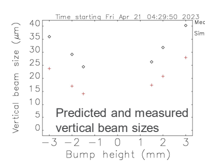
Sequential frames from smart phone recording of the diagnostic imaging system during Case 4.



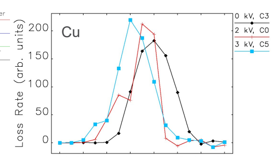
STUDY

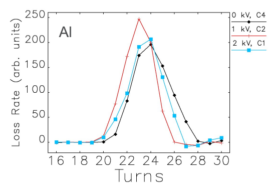
Pin-hole camera derived emittances, collimator position and beam current



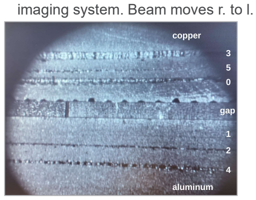


Turn-by-Turn (TBT) BPM data differentiated sum signals

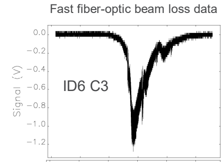


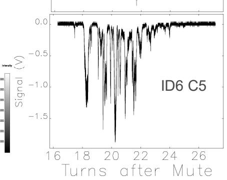


Final image from the diagnostic imaging system. Beam moves r. to l.



Fast fiber-optic beam loss data





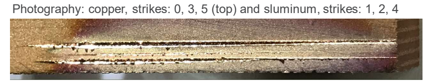
POST-STUDY

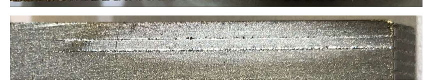
Table 2: Beam Parameters and Peak Dose during 200-mA Beam Aborts. At 6 GeV, S_{pc} = 2.153 MeV-cm^2/g for Al and 1.959 MeV-cm^2/g for Cu. β_x = 3.96 m/rad, β_y = 6.35 m/rad, η_x = 0.0584 m

C. N.	Kick kV	ϵ_x (nm-rad)	ϵ_y (pm-rad)	σ_x (μm)	σ_y (μm)	D_G (MGy)
0	2	2.102	17.13	108.3	10.43	20.28
1	2	2.245	14.15	110.9	9.48	23.90
2	1	2.166	22.69	109.5	12.00	19.19
3	0	1.844	50.88	103.5	17.97	12.32
4	0	2.086	40.33	108.0	16.00	14.58
5	3	2.029	27.50	107.0	13.22	16.22

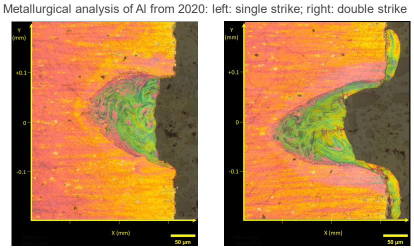
$$\sigma_{x,y} = \left(\beta_{x,y}\epsilon_{x,y} + \left[\eta_{x,y}\frac{\Delta p}{p}\right]^2\right)^{1/2} \quad \frac{\Delta p}{p} = .001 \quad D_G = S_{pc}\frac{N_e}{2\pi\sigma_x\sigma_y}$$

Photography: copper, strikes: 0, 3, 5 (top) and sluminum, strikes: 1, 2, 4



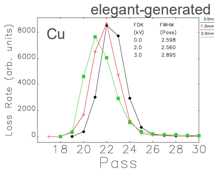


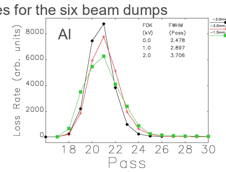
Metallurgical analysis of Al from 2020: left: single strike; right: double strike

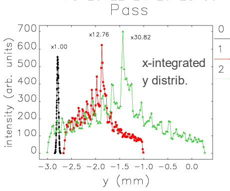


SIMULATIONS

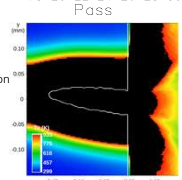
elegant-generated loss rates for the six beam dumps







FLASH apex simulation black begions: $T>T_m$ [7-11]



SUMMARY

- A third whole-beam-abort experiment was conducted
- A vertical FOK could be utilized to protect horizontal collimators planned for the APS-U SR.
- Tests carried out on both aluminum and copper targets.
- For aluminum, FOK voltage = 2 kV sufficient to protect
- For copper, a 3 kV kick not enough to prevent damage
- For both targets, damage was reduced as FOK voltage was increased.
- Data collected will provide useful information for benchmarking coupled-code simulation efforts to model the effects of whole-beam loss events

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