SLAC-PUB-12742
August 2007

MATERIAL DAMAGE TEST FOR ILC COLLIMATORS *

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Abstract

Simulations were completed to determine the energy deposition of an ILC bunch using FLUKA, Geant4 and EGS4 to a set of different spoiler designs. These shower simulations were used as inputs to thermal and mechanical studies using ANSYS. This paper presents a proposal to optimise the material choice and mechanical design of ILC spoilers jaws using ATF and benchmark the energy deposition simulations and the ANSYS studies giving the researchers valuable data which will help achieve a definitive ILC spoiler design.

INTRODUCTION

At the ILC, the removal of halo particles having large amplitudes relative to the ideal orbit is mandatory to both minimise damage to beam line elements and particle detectors and to achieve tolerable background levels in the latter. In the high energy, high intensity environment of the linear collider the low background levels will largely be ensured by placing a set of mechanical spoilers/absorbers very close to the beam. This presents two significant problems: (i) short-range transverse wakefields excited by these collimators may perturb beam motion and lead to both emittance dilution and amplification of position jitter at the IP, and (ii) impact of even a small number of bunches at the expected energy densities can damage the spoilers.

The required spoiler design must have a surface resistivity and geometry which reduces wakefield effects to an acceptable level, and must achieve this using materials and construction which resists damage due to rapid shock heating where such damage would degrade the operation of the spoilers, see e.g. [1]. The wakefield aspects of the design are being addressed by both experimental work centered around the T480 project [2] at SLAC ESA and modeling with GdfidL and ECHO, for details see [3,4].

This test beam will provide direct experimental data to test extensive simulations carried out recently [5,6,7]. It is complementary to earlier related work [8], and is an integral part of the work proposed by the UK LC-ABD Collaboration and the EUROTeV Consortium [9]. The second phase of this work leads into the development of a damage detection system for ILC spoilers.

PURPOSE AND DESCRIPTION OF TESTS

The purpose of the first test run at ATF is to:

1. Make simple measurements of the size of the damage region after individual beam impacts on the collimator test piece. This will permit a direct validation of FLUKA/ANSYS simulations of properties of the materials under test.
2. Allow us to commission the proposed test system of vacuum vessel, multi-axis mover, beam position and size monitoring.
3. Validate the mode of operation required for ATF in these tests.
4. Ensure that the radiation protection requirements can be satisfied before proceeding with a second phase proposal.

Assuming a successful first phase test, the test would be to measure the shock waves within the sample by studying the surface motion with a laser-based system, such as VISAR (or LDV), for single bunch and multiple bunches at approximate ILC bunch spacing.

Description of tests

The experiment will initially study the effect of single beam impacts on a small sample of material, with dimensions transverse to the beam direction of ~10mm, as shown in Fig. 1.

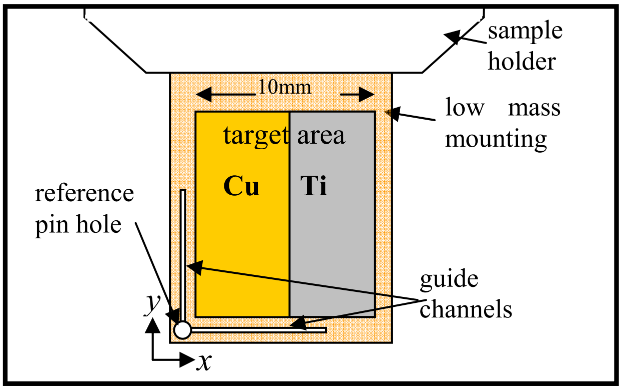

Figure 1: Spoiler target test sample

The sample will be manipulated in vertical (y) and horizontal (x) directions using a VG multi-axis vacuum mover [10], allowing the sample to be driven into the beam and stepped to different impact sites in (x,y) between each single pulse striking the sample at full charge. In operation, we envisage using ATF with low bunch charge to locate the horizontal and vertical guide

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* This work is supported by the Commission of the European Communities under the 6th Framework Programme “Structuring the European Research Area”, contract number RIDS-011899
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Contributed to Particle Accelerator Conference (PAC 07), 06/25/2007--6/29/2007, Albuquerque, New Mexico

Work supported in part by US Department of Energy contract DE-AC02-76SF00515

channels (beam through), and subsequently the reference pin hole in one corner of the sample. Having located the pin hole at the lower *y* edge of the sample with the beam, the beam is in a known position in the local coordinate system of the sample and motion of the test proceeds with successive cycles of beam off; (*x*,*y*) translation of sample to next impact site; beam on for single bunch at full charge. We anticipate approximately 200 separate impact points on sample, and estimate a rate of operation of 10—20 points per hour.

Repeated beam impacts would be performed for each transverse bunch size at a several different (*x*, *y*) grid locations on the sample to estimate the uncertainty in the area damaged under nominally identical conditions. Variations of bunch charge would also be made to test the predicted behaviour with energy density. The sample itself would consist of two materials in different regions of (*x*,*y*), and be homogeneous in z. Ti4Al6V and OFE Cu will be used, the former being a good candidate for spoiler construction from a damage resilience perspective, the latter being a material where previous data exists [8] which is expected to be damaged by ATF beam and will therefore serve as a control of the simulations and experimental methods.

The sample would be of varying thickness in *z* to allow different amounts of material to be presented to the beam, in the range of 0.3-0.6 radiation lengths of either material.

The extent of damage in this test would be assessed by SEM at KEK after the end of the running period, and compared to SEM made prior to the tests. Careful preparation of the surface prior to testing would be carried out to ensure small average roughness (<0.06μm) for both materials compared to the feature size expected to result from melting. Fractures may be produced below the melting temperature, and the surface would be examined for evidence of these.

Description of Test Apparatus

We propose the construction of a vacuum vessel similar to the one illustrated in Fig. 2. The suggested location is where the ODR is at present (midway between the SLAC-Livermore BPM triplet and the KEK triplet), where there are wire scanners within a metre upstream. Accurate knowledge of the transverse beam size is critical to a reliable prediction of the damage caused. The choice of transverse beam size is determined by available locations in ATF and is a balance between having a spot size sufficiently small that damage can be caused (and the onset of damage observed in the range of bunch charge/size variation possible), but sufficiently large to allow it to be measured with acceptable precision. We assume a transverse profile $\sigma_x \times \sigma_y = 20\times2\mu m^2$ can be achieved, similar to that used for the Laser Wire IP, and that this will be measured with e.g. 10μm round tungsten filament.

One BPM immediately upstream of the vessel is required to allow positioning of beam onto the sample, and an additional BPM downstream to allow measurement of angle.

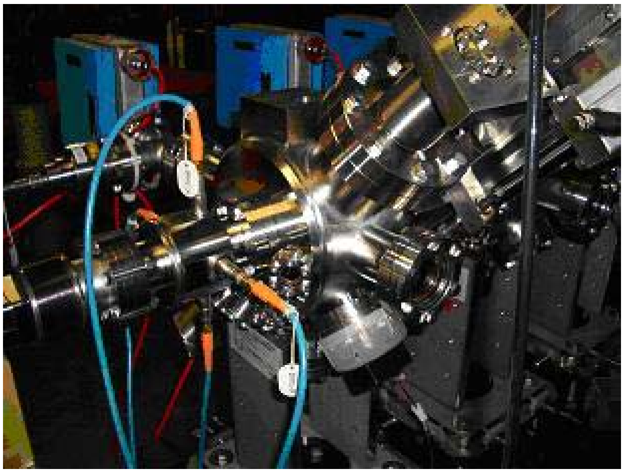

Figure 2: Vacuum vessel proposed for test

SUMMARY OF TEST PREDICTIONS

Results of FLUKA simulations for the size of the melted region when one or two bunches of ATF nominal bunch charge and energy are shown in Table 1. For the case of two bunches this size represents a minimum as it is assumed that both are incident at exactly the same position on the sample. The preferred bunch size is $\sigma_x \times \sigma_y = 20\times2\mu m^2$, as explained above.

Table 1: Predicted size of region damaged by melting from single bunch impacts. The corresponding minimum size for two consecutive bunches incident on exactly the same location is shown in parenthesis.

Bunch $\sigma_x \times \sigma_y$ (μm^2), material	**Estimated damage region, x**	**Estimated damage region, y**	**Estimated damage region, z**
1.9×0.5, Ti alloy	11 (14) μm	4 (5.6) μm	5 (8) mm
20×2, Ti alloy	45 (90) μm	5 (9) μm	2 (7) mm
20×2, Cu	65 (100) μm	7 (10) μm	3 (7) mm

SENSITIVITY TO SURFACE MOTION IN STAGE 2 OF THE TEST

It is essential that the surface motion resulting from the beam impact is within a measurable range using existing techniques [5]. Although a full proposal for the second stage of this test is not included in this document, we summarise below a justification of our choice of this system based on its resolution capability in comparison with the expected motion for shock waves produced by ATF bunches.

Out initial studies show that with a 20 μm beam, the heating effects are spread over about 100 μm. Heating in a region of this size will cause a shock wave of the same size to propagate towards the edge of the sample, travelling at the speed of sound, *v*, for the material. The interaction period at the sample edge is given simply by $\tau = \lambda / v$, where λ and v are the wavelength and phase velocity of the wave, respectively.

For a λ=100 µm and v=5000 ms^{-1} (typical of Ti alloy) the interaction period is thus approximately 20ns. As shown in Fig. 3, FEA studies predict that the interaction period is in fact somewhat longer than the simple formula would suggest. An effect having such a period will be just resolvable with VISAR, which is capable of resolution down to about 50 ps. Increasing the beam size will directly affect the interaction period and so a larger beam would give a more readily resolved effect. The consequence of varying the relative horizontal and vertical beam size on these measurements is under study.

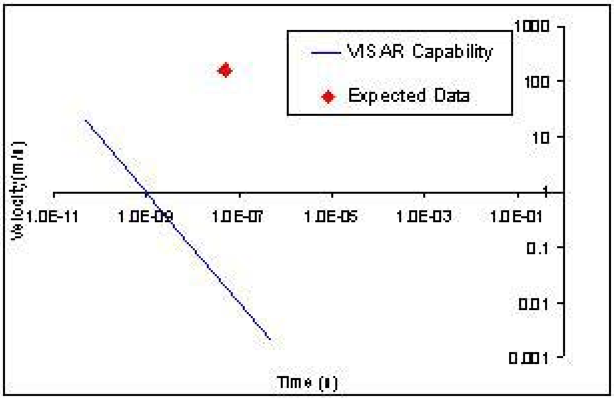

Figure 3: Comparison of VISAR measurement technique capability [11] with expected surface motion parameters determined from FEA simulations, for second stage of ATF damage test. (The data in the figure is from the same manufacturer as the VISAR owned by STFC).

CONCLUSIONS

A proposal for a two stage radiation damage test beam in ATF is presented in this paper. Several considerations have to be taken into account as per: the definitive positions the different targets will occupy in the EXT ATF line, the optics and different beam sizes that can be achieved, and the area radiation estimates that the beam will generate when colliding with the target material.

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