

BEAM IMPACT STUDIES FOR ILC COLLIMATORS

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Abstract

Spoilers in the ILC Beam Delivery System are required to survive without failure a minimum of 1-2 direct impacts of 250 GeV-500 GeV bunches of electrons or positrons, in addition to maintaining low geometric and resistive wall wake fields. The likelihood of spoiler survival was determined using finite element models of thermal and mechanical properties of the spoilers, with realistic patterns of energy deposition as input. The second phase of an experiment to calibrate the finite element models using electron beam data will be performed in the ATF2 extraction line, by subjecting a small sample of Ti-6Al-4V to bunches of electrons. The displacement of the surface will be measured with a Velocity Interferometer System of Any Reflector (VISAR). This paper shows the project plan as well as results of the simulations and expected readout from the VISAR.

INTRODUCTION

The International Linear Collider requires a collimation system in order to remove halo particles which would cause unacceptable background readings in the detectors. We have been investigating traditional collimators which are a two part system comprising of a near beam spoiler which protects the downstream absorber which is further away from the beam line by reducing the energy density of the beam via multiple Coulomb scattering in case of accident. Occasionally due to a magnet failure or other problem the beam could be miss-steered into one of the spoilers. The spoiler will have to absorb 1 bunch, at 1 TeV centre of mass energy, or 2 bunches, at 500 GeV centre of mass energy, without being damaged before the machine protection system can react and steer the beam into the beam dump. The bunches are made up of high energy particles, 250 or 500 GeV electrons and positrons, as they interact with the spoilers they deposit energy as heat. The heat is deposited rapidly within a small volume of material. This causes this heated volume to expand, although it is constrained by the unheated mass of material. This causes a build up of compressive pressure which is released as a wave through the material. This pressure wave can damage the spoilers; it is of special concern when the compressive wave reaches a free surface and returns as a tensile wave because the tensile strength of the candidate material is lower than the compressive strength [1].

In order to design spoilers that can survive 1-2 beam impacts we performed a series of simulations using FLUKA [2] to calculate the amount of energy absorbed

by the spoilers. This energy figure was then used in ANSYS [3] and AUTODYN Finite Element Analysis (FEA) software [4] to calculate the resulting pressure wave. To validate these simulations we are performing several beam tests at the Accelerator Test Facility (ATF) [5] at KEK in Japan.

The first phase of testing was carried out in February 2008. This test was designed to allow familiarisation with ATF operations, commission equipment and to test alignment of a sample with the beam line [6].

EXPERIMENTAL SET UP

The second phase of testing is an instrumented test which aims to characterise the pressure wave caused by an electron beam hitting a sample. This will be carried out at ATF2. It is not straight forward to measure the pressure within the sample. However it is possible to measure the surface velocity of the sample after it has been hit by the electron beam using a VISAR. This can then be compared to FEA predictions and if in agreement can validate the FEA solution.

The experiment set up is shown in figure 1. A sample of Ti-6Al-4V alloy is mounted on a VG Scienta 3 axis vacuum manipulator. The manipulator is stepper motor driven and can repeatedly place the sample within 5 μ m of its intended position. The sample is 4mm in diameter and 4mm in length and will be highly polished to give a smooth surface finish. The sample will then be aligned with the electron beam in a similar method to the first phase of testing [6]. The VISAR is mounted on a Physik Instruments DC motor driven stage which has similar resolution to the vacuum manipulator. The VISAR stage will be positioned next to the vacuum chamber allowing the VISAR beam to shine through a window and on to the sample. The VISAR beam will be aligned with the sample in the similar way to that used to align the electron beam to the sample. It is critical that the VISAR, the electron beam and the sample are aligned within approximately 5 μ m, so that the read out from the VISAR matches the predicted result from the FEA simulations.

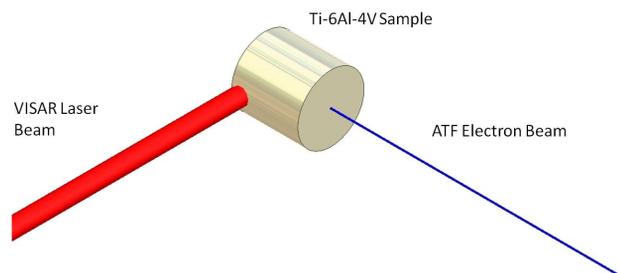


Figure 1: Schematic showing test Set Up.

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PREDICTIONS

Using the ATF2 it should be possible to create a beam with a circular spot size that is $50\mu\text{m}$ in diameter. Radiation safety at ATF2 allows the sample to absorb 0.3% of the beam energy. This would deposit 0.006J within a volume $7.85\text{e-}006\text{ cm}^3$. Analytical calculations show that this would lead to a temperature rise of 335°C and the stress within the heated volume would rise to 370MPa .

FEA Simulations

A model of the sample was created in AUTODYN. AUTODYN is a non-linear FEA code that has a material model for Ti-6Al-4V. Due to the small size of the model the units were converted to microns for the solution and then converted back to metres for the post processing analysis following standard ANSYS procedure. A 2D axial-symmetric model was constructed to reduce the computation time. The energy was deposited within a central volume that measured $50\mu\text{m}$ diameter by 4mm in length. It was assumed that the energy was deposited equally along the length of the sample. At a point on the surface the surface velocity was measured at each time step. This is shown in figure 2. As a cross check the

temperature of the heated zone was also recorded, this was found to be 335°C and agreed with the analytical calculation.

VISAR

The VISAR is a laser velocity interferometer that can be used to measure the surface vibrations of a material. Briefly it comprises of a lens that focuses a laser onto a surface, the light that is reflected from the surface is also collected by this lens. The collected light is split into two signals, half of the light is sent down a delay leg whilst the other half is sent straight to a detector. At the detector the two light sources are recombined and interference patterns are produced. The signal from the VISAR is affected by the length of the delay leg used. Figures 3 and 4 show the expected VISAR returns from using delay legs of lengths 1m , 10m , 30m and 100m [7].

In order to validate the FEA models the data of interest is the time taken from the beam striking the target to the target starting to move and the maximum velocity. From the figures the optimum delay leg would appear to be 10m as shown in figure 3. However the expected return from the VISAR, specifically the signal to background readings is predicted to be low and could cause problems in analysing the data.

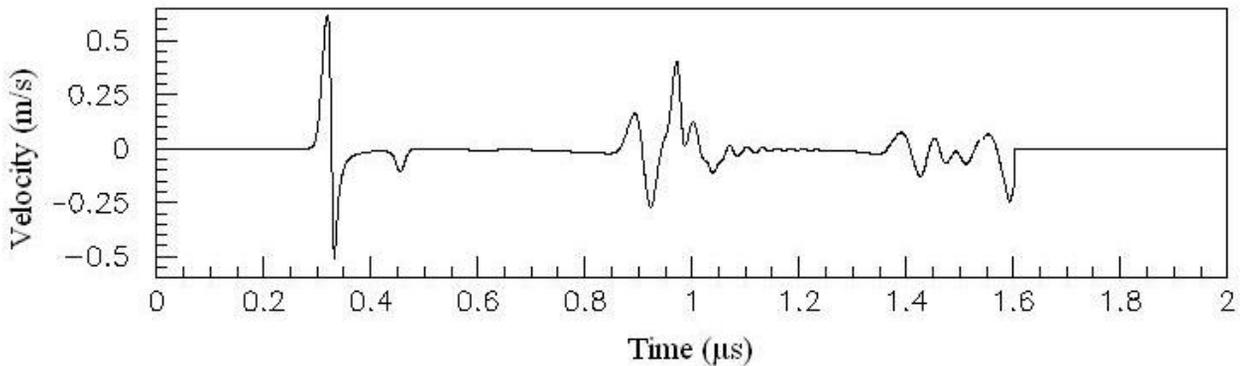


Figure 2: Predicted Surface Velocity vs. Time from AUTODYN Simulation.

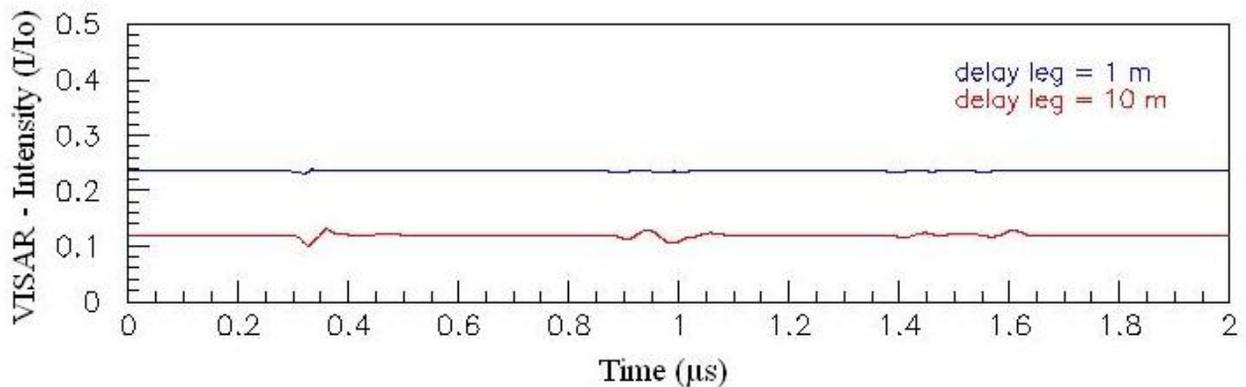


Figure 3: Predicted VISAR Signal from the surface velocity shown in figure 2 using a 1m and a 10m delay leg.

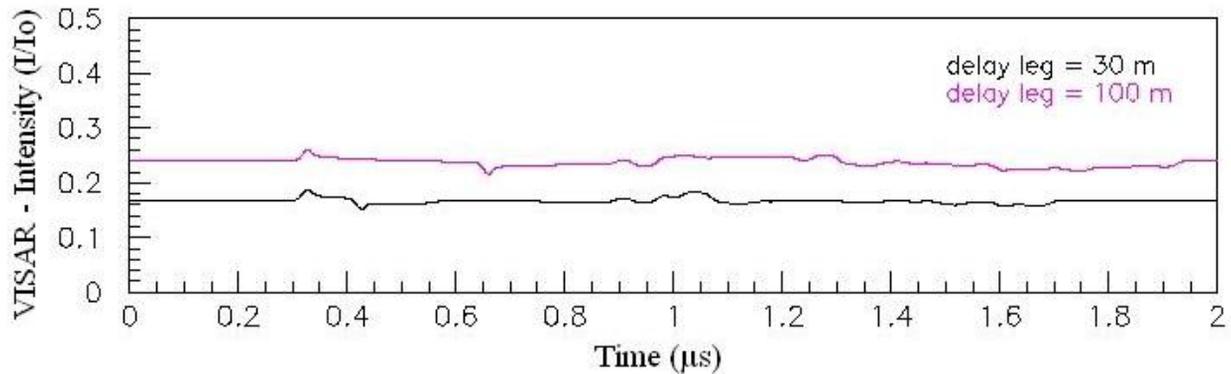


Figure 4: Predicted VISAR Signal from the surface velocity shown in figure 2 using a 30m and a 100m delay leg.

CONCLUSIONS

The planned experiment at ATF2 should be a good way to characterise materials that could be used for ILC Collimator Spoilers. The planned second phase of testing builds on the success of the first phase of testing which demonstrated a method of aligning a sample with the ATF electron beam and operation at ATF. The second phase uses similar principles to align a laser beam with the sample and the electron beam. This will allow a VISAR to measure the surface velocity of a sample after it has been struck by an electron beam.

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