ADVANCED COLLIMATOR ENGINEERING FOR THE NLC*

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*Abstract**

The high beam intensities in the next linear collider can damage the collimation system jaws if a failure of the electronic machine protection system allows the acceleration of a mis-launched pulse. We are developing a prototype collimator that will allow a new jaw surface to be moved into place after beam damage. We are also developing a prototype collimator based on continuously reforming the collimator jaws out of liquid metal. This second system would allow the use of smaller beam sizes, and thereby shorter beam line lengths in the collimation system. Status of both prototypes is presented.

1 NLC COLLIMATION HARDWARE

1.1 Requirements

The NLC requires collimation both before and after the main linacs. In the post linac collimators, on a miss-steered pulse the beam densities are sufficient to damage any solid material. Designs that avoid damage by increasing the beam size in the collimation section result in a very long system length and a very sensitive optical design. The collimators must also be designed to minimize wakefields.

Table 1: NLC Parameters in the Collimation section

Parameter	Value
Beam Energy	500GeV
Bunch Charge	1×10^{10}
Beam Emittance (normalized)	$500 \times 8\ 10^{-8}$m
Spot Size	60×10 µm
Bunch Length	120 µm
Number of Bunches	95
Peak Current	~1200A
Required Edge Stability	~5 µm
Required surface roughness	<1 µm RMS
Collimator Gap (half gap)	~100 µm

1.2 Overall Collimator Mechanical Design

The NLC collimator design uses a combination of a thin (<1R$_l$) spoiler and thick (~20R$_l$) absorber. Only the thin spoiler is located close to the beam where damage and wakefield issues are significant (Fig. 1).

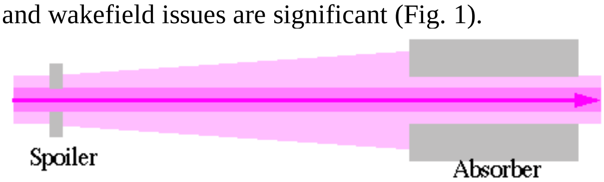

Figure 1: Spoiler / Absorber Combination

1.3 Consumable Spoiler

A pair of wheels is used to form the spoiler jaws. After damage is detected, the wheels are rotated to present a new surface. After a full rotation of the wheel (approximately 1000 damage locations), the wheels must be replaced (Fig. 2). This is the baseline design for the NLC.

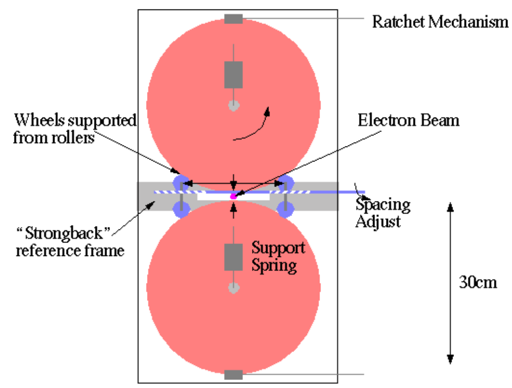

Figure 2: Rotating "wheel" spoiler

1.4 Repairable Spoiler

A spoiler design, which can operate even if beam damage occurs on every pulse, is being developed. It this system, liquid tin is frozen onto a continuously rotating drum to form the spoiler surface. After damage, the surface is replaced with new metal (fig. 3). While development of a repairable spoiler is not required for the NLC, it might allow a reduction in the size and cost.

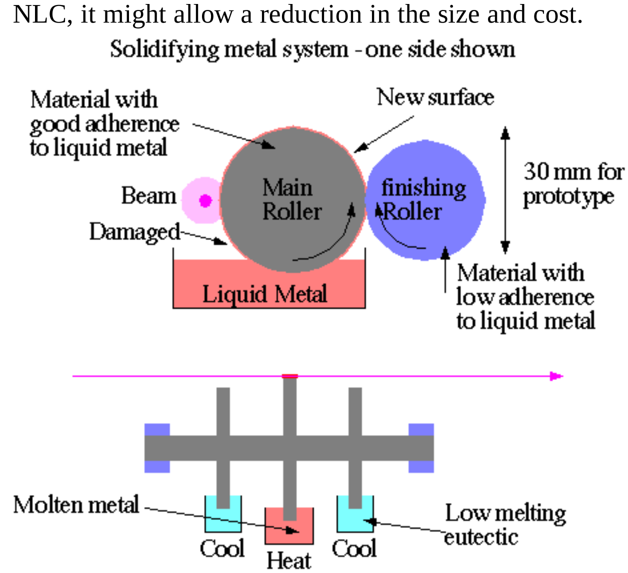

Figure 3: Solidifying metal spoiler

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2 DAMAGE MECHANISMS

2.1 Materials Damage

Beam damage in materials results from melting and vaporization due to energy deposition. In addition, if the thermal stress caused by the temperature rise exceeds the yield strength (or fatigue strength for multiple shots) of the material, damage can also occur.

2.2 Electromagnetic Shower Damage

For each incident particle that intercepts the collimator surface, an electromagnetic cascade of particles is created over a depth of several radiation lengths. For the NLC beam parameters, peak materials temperatures of $>10^5$ °C would be created at the peak of such a shower. We will avoid this damage mechanism by using the “spoiler” and “absorber” collimation scheme as shown in figure 1

2.2 Direct Lionization Damage

Even without showering, the direct lionization loss of high-energy particles is sufficient to damage the spoiler jaws at nominal beam size and intensity. However, under normal operating conditions, only the beam halo will be intercepted, and the spoiler should not be damaged.

2.3 Collective Damage

The high peak currents in the NLC can produce damage from collective beam effects without beam interception. Image current heating and collective electric field lionization can both be significant damage sources when the spoiler gaps are <100µm full gap [1]. Collective damage does not appear to be significant for the present NLC collimation optics design [2].

3 CONSUMABLE SPOILER R+D

3.1 Wheel Spoiler Mechanical Design

We have designed a system where two main rollers, which provide the spoiling surface, are sprung onto two pairs of smaller guide rollers (Figs. 2 and 4). The guide rollers act as a position reference and reduce misalignment from expansion of the main rollers. Changing the gap between the guide rollers controls the separation between the main rollers.

The main rollers are mounted on simply constrained flexure supports. A ball screw is used to change the gap between the guide rollers. BPMS (not shown in the figure) are mounted to the support frame to allow measurement of the position of the beam centroid relative to the spoiler center.

The main rollers are 30cm in diameter and constructed from aluminum. Note that during the lifetime of the system, the main wheels make only one revolution, so bearing lifetime is not expected be a problem.

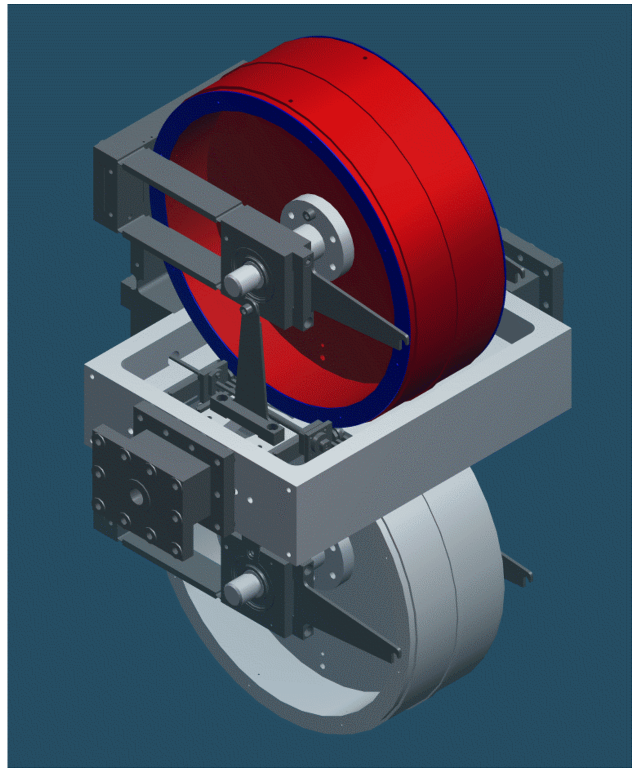

Figure 4: 3-D drawing of the consumable spoiler.

3.2 Consumable Spoiler Prototype

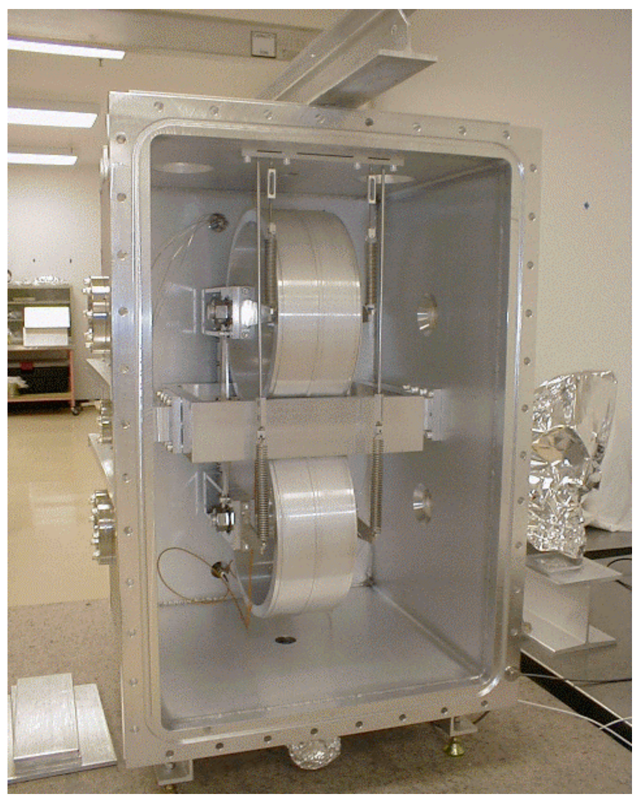

Figure 5: Consumable spoiler prototype

A prototype consumable collimator has been constructed. The system uses Aluminum rather than beryllium / copper composite main rollers, but is otherwise similar to the final device.

3.3 Prototype Test Results

The prototype system has been operated at ~3x10^{-7} Torr for approximately 1 month. Beam heating, estimated at ~1 Watt average, was simulated with electrical heaters installed near the collimator surface. The gap was measured with capacitive sensors.

Table 2: System performance

Parameter	Value
Full gap range	0-700 microns
Variation with atmospheric pressure	5 micron / Bar
Temperature rise for 1 Watt heat	6°C
Gap variation with temperature	0.5 micron /°C
Gap stability over 24 hours	<0.5 micron
Variation with rotation of spoilers	7 microns
Gap control accuracy	35 microns
Gap control hysterisis	13 microns
Gap unidirectional repeatability	7 microns

4 R+D ON REPAIRABLE SPOILERS

4.1 Concept Demonstration System

We have constructed a prototype repairable collimator based on solidifying metal (Fig 3). Tin was chosen for the liquid metal and niobium as the substrate material [4]. The finishing roller was molybdenum. The Niobium roller was initially coated in high temperature liquid tin at 850C for 24 hours as described in [4]. A 10°C melting point eutectic (gallium / indium / tin) was used for cooling.

Both the main and finishing rollers were 30mm in diameter. The main roller was driven at 6 RPM with a high torque (10 N-M) vacuum feed through. Needle bearings running directly on the molybdenum or niobium rollers were used to handle the transverse load (~500N). The gap between the main and smoothing rollers was adjustable, with an adjustable release pressure.

Heat was provided by "halogen" light bulbs heating a molybdenum block that contained the liquid tin. The normal operating temperature was approximately 290C.

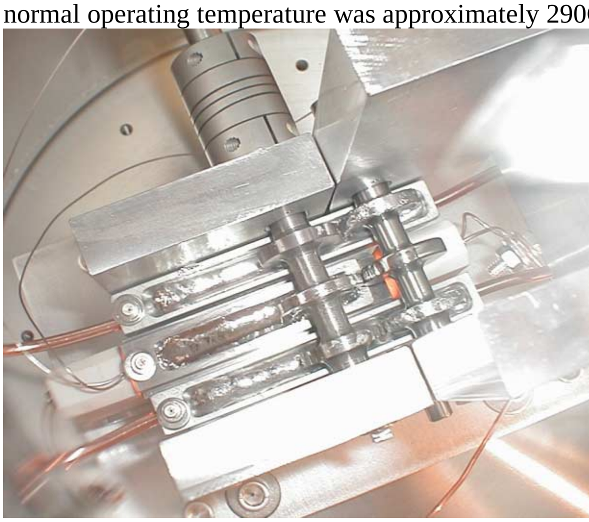

Figure 6: Liquid metal spoiler test system in operation

4.2 System performance

The system was operated for approximately 48 hours at a pressure of ~5x10^{-8} Torr with a liquid tin temperature of 280 – 300C. Operation was terminated due to a failure of one of the needle bearings on the niobium roller. On disassembly, the niobium surface was found to have been galled by the needle bearing. The needle bearings are being replaced with stainless ball bearings lubricated with tungsten disulphide: similar to those used on the consumable collimator system.

At relatively high tin temperatures (>290C) a thin (visually estimated at 100 microns) coating of tin was produced on the roller. The finishing roller produced a surface that appeared smooth to the eye (<10 micron estimated roughness). Operation was stable (until bearing failure).

At lower temperatures (270-280C) a thick (1-3mm) coating of tin was produced. The finishing roller smoothed this coating to a similar roughness to that of the thin coating. Operation in this mode was unstable: the coating thickness would continue to increase until all of the tin was frozen onto the niobium roller. For the next experiment we are adding an additional heater to prevent this run-away effect and allow continuous operation with thick tin coats.

5 SUMMARY

The high beam energy density in the NLC requires the use of advanced collimator technology. A prototype consumable collimator, which can survive on the order of a thousand events of beam damage from errant pulses, is being tested. A demonstration system for a repairable collimator based on a continuously formed solidifying metal surface is also being tested

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