SLAC–PUB–6134
May 1993
(A)

Requirements for Linear Collider Instrumentation

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I. Abstract

Instrumentation performs a critical role in the operation of a linear collider. New acquisition and data processing techniques are required for feedback, tuning procedures and performance monitoring. For example, many collider systems are initially tuned using complex bootstrap procedures whose convergence rate will depend on the speed and performance of several instrumentation systems. Furthermore, mechanical and electrical tolerances are computed assuming the success of this process. In this paper we review the performance of specific instrumentation systems, wire scanners and beam position monitor based feedback, at the SLAC Linear Collider (SLC). Particular attention is paid to the application the lessons learned at SLC will have for future Linear Colliders.

II. Introduction

The next leap in electron - positron accelerator performance will result in part from improvements in instrumentation technology. The latest generation of accelerators, from high current synchrotron light machines to B-factories and linear colliders require feedback control loops that are both greater in number and complexity than they were at more conventional machines. As a result, the instrument is no longer a diagnostic tool, intended for use only in cases of sub-standard performance, but a truly integrated accelerator component. This has obvious implications for the instrumentation system designer, among which are that the system must have the integrity required of other accelerator systems, such as power converter and vacuum systems.

Linear colliders represent the most extreme application of this philosophy. The lack of closed, equilibrium conditions that maintain stability in the machine force the use of several layers of sophisticated feedback loops. The underlying reason for this requirement are the tolerances that must be applied for the correct transport of low emittance beams[1]. In some extreme cases, initial bootstrap procedures are required before any beam can be transported through the system[2]. Tight mechanical and RF system tolerances will not only require special systems to address them directly, but will also demand beam based feedback and tuning procedures.

Perhaps the most important improvements in instrumentation technology will not come from the harnessing of fundamentally new physical processes to better the performance of beam position or size monitors. Instead, they will come from the integration of existing instrument beam sensors with more powerful controls. This paper addresses the latter issue. As will be discussed below, very strong integration with the control system is needed to provide the robust, high data processing bandwidth needed for higher level control.

An important aspect of the shift in the role of instrumentation will be its use in general optimization systems that will ultimately change the character of the control room operator's task. Traditional applications of instrumentation systems in colliding beam accelerators have required heavy involvement of the operator. In storage rings, for example, operator technique in optimizing injection and luminosity has proven to be a

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*Work supported by Department of Energy contract DE–AC03–76SF00515.

Contributed talk presented at the 1st European Workshop on Beam Instrumentation and Diagnostics for Particle Accelerators, Montreux, Switzerland, May 3-5, 1993

key factor in long term performance[3]. In a heavily feedback and optimization control laden system, the operator's task becomes the more complex one of controlling and monitoring the performance of these automated tasks.

III. A Practical Model for Control and Optimization

Application of Feedback

Given beam diagnostic system specifications derived from clearly defined tuning and feedback applications, it is straightforward to develop the system requirements. Since these applications are critical, the reverse will also be an important consideration and the performance of other accelerator subsystems will be specified assuming the performance level of the instrumentation system[4].

Inherent in the need for such systems is the expectation that there will be sources of instability. Instabilities in colliders can be classified according to their time scales and the response they evoke. Table 1 lists typical instabilities and examples.

Classification	Sources	Examples	Diagnostic
Pulse to pulse Not amenable to beam based feedback - truly random process	Pulsed Devices (e.g. thyratron driven) Beam dynamics Vibration	Kicker Girder vibration Source	Synchronous acquisition
Fast Quickly detected and corrected with no interference	Power Converters Thermal Operator	Power line phase synchronous	Fast feedback Optimized tuning procedure
Slow Complex analysis requiring expert	Ground settling Thermal Power Converters	Optics tuning RF phases	Dither control Synchronous acquisition
Rate Beam power limiting machine protection system	Beam Dynamics Pulsed device breakdown	Klystron Fault	Trip driven snapshot Data acquisition traps

Table 1. Table of linear collider instabilities and examples. Instability classifications are determined in part by the rate with which the problem can be cured.

The goal of this model is to describe tools that can be used to address most of these instabilities. Short of directly fixing the instabilities, the approach should be one of placing as many as possible into the table 1 category labeled 'Fast'. In order to do this effectively there must be a sensor and corrector that can be used for the feedback, a high level programming environment that can be used to generate the software based loop and a clear understanding of the transfer function between the corrector and the sensor. For the latter, understanding of probable faults and diagnostics for handling them are also required.

Narrow Band Techniques

The most accurate way to detect and correct complex, non-centroid, beam errors is to use narrow band techniques. Narrow band techniques are a mainstay of storage ring diagnostics where a spectrum analyzer is coupled to an excitation system. In a linear collider many pulses must be used to provide the integration time needed to cleanly separate the signal from noise. Using sub-tolerance excitation and synchronous detection techniques, as used in communication and radar systems[5], colliding beam operation can continue while critical measurements are in progress. A related technique will be used at the BPM system[6] of the multi-pass linac of the Continuous Electron Beam Accelerator Facility.

This tightens the tolerances placed on the excitation device and the instruments used to detect the signal since both must be able to control and detect changes below those specified as adequate for nominal beam operation. Furthermore, both of these systems must be able to respond rapidly enough to provide a large number of transitions in a time short compared to typical stability time scales. For linear colliders, the transitions must occur with a one or several pulse time scale. The detector or instrument data bandwidth must be able to provide corrected measurements on an externally synchronized pulse to pulse basis.

As an alternative to direct generation of an excitation, several types of devices provide their own instability and correlations can be developed between instrumentation on that device and beam monitors. Examples of this technique are the thyratron pulse monitors on high power kickers and klystrons and low level RF system monitors.

Both the beam stability and the detector resolution determine the limits of the technique. The accuracy depends on the product of the number of transitions and the size of the step with respect to the noise.

Parameter Controlled	F/O	Detection Instrument	Bandwidth max120Hz	Features
Position and angle	F	BPM	20Hz	provides diagnostic data
Energy	F	BPM	120Hz	
2 beam energy difference	F	signals from energy loop	10Hz	
Collision	F	IP BPM's (deflections)	120Hz	
Time slot	F	BPM's	1min	
Compressor optics	O	Wire scanners at linac launch	hours	Uses asymmetric gaussian fits
IP spot	O	Deflections and luminosity mon	minutes	Can use dither
Linac emittance	F	Wire scanners in linac	minutes	Uses asymmetric fits and skew moment propagation
Beam phase (linac energy spread)	F	BPM's using dither phase synchronous excitation	minutes	All pulses must be dithered to achieve needed accuracy
Positron capture phase	F	Beam power integrator	120Hz	uses estimated temperature
Kicker timing	O	Linac BPM's	minutes	Correlates beam with kicker thyratron timing

Table 2. Feedback and Optimization in use or planned at SLC. The second column of the table indicates feedback, or restoration to a specific setpoint (F) or optimization, 'best' value tuning (O).

Data acquisition requirements

A useful instrumentation control feature that facilitates the optimization of the instrumentation system itself is the de-coupling of the instrument's control settings on a per-user basis through the control system. Thus, for example, each user may set their own attenuation settings or trigger timing and carry out system performance tests while feedback is in operation and others are doing unrelated tests using the same instrument on different beam pulses.

The data acquisition must be able to acquire and compress data on all time scales. At SLC four examples are: A) finest time scale possible with 500 pulses maximum guaranteed taken in succession, B) is the next finest scale taken from the feedback ring buffer over the last 50 seconds, C) is data taken from the correlation plot utility with up to 500 points taken over 100 seconds and D) a longer term history of data taken at 6 minute intervals. All data except for D) is from single pulses. A and C may be directly correlated throughout the SLC using synchronized data acquisition.

IV. Performance of SLC Systems

Table 2 describes some SLC feedback and optimization systems.

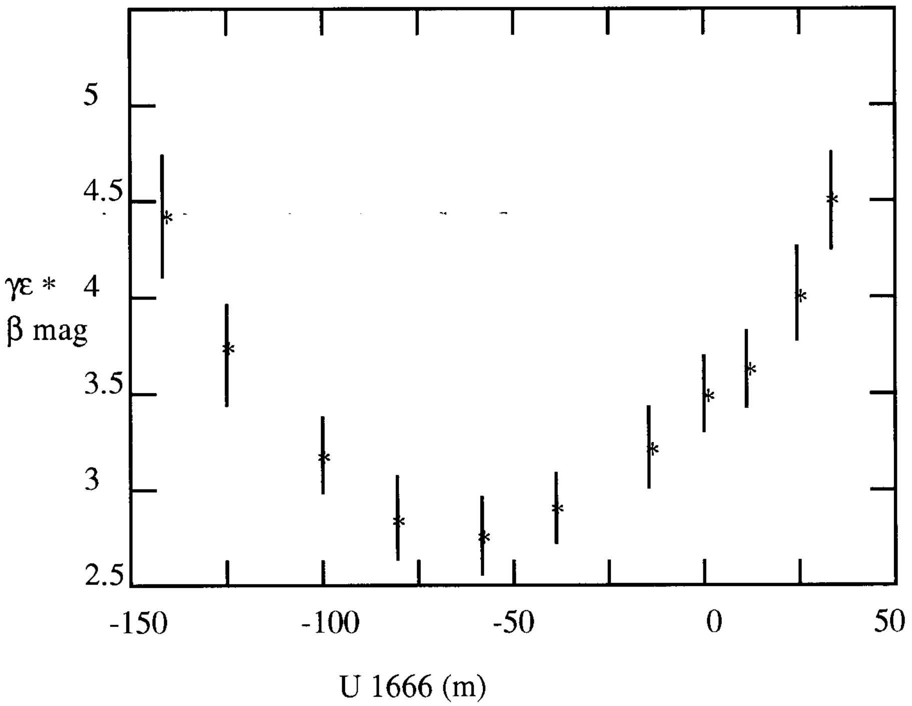

Figure 1. Typical results from an optimization scan[7]. In this plot the product of the emittance and beta function mismatch parameter are shown as a function of an octupole strength (third order TRANSPORT[8] notation) in the electron bunch compressor ring extraction transport line. This scan can be checked using centroid based techniques and the comparison used to determine systematic errors[9].

The steering loops at SLC provide 1) Operability (through rapid recovery from simple faults), 2) Orthogonalization of beam parameters through calibrated fit of BPM data, 3) improvements over the single instrument resolution through constrained fits of many

BPM's, 5) immunity from thermo-mechanical effects and 6) decoupling of upstream and downstream systems. The final item in the list is perhaps the most significant since it allows fine optical optimization to proceed continuously without complications due to downstream centroid displacements.

Figure 1 shows typical results from an optical optimization procedure. In this case the beam size is scanned as a function of the strength of an octupole magnet in the bunch compressor. It is important to understand the systematics of the beam profile monitoring device thoroughly enough to cleanly detect the small changes in the beam size generated by these adjustments. Optimization procedures to be tested in 1993 include the use of the dither technique to scan the optical corrections.

IX. Conclusion

Recent reviews of control system effort have focused on the extent to which software development has become the dominant cost[10]. Linear collider controls will require high level, software driven feedback and optimization with excellent error handling and diagnostic capability[11]. The engineering resources required to implement this will be a larger fraction of the total effort than it was for more conventional accelerators.

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