DESIGN AND TEST OF A FAST FEEDBACK SYSTEM FOR ORBIT CORRECTION AT TTF AND THE TESLA LINEAR COLLIDER.

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Abstract

To achieve high luminosity in the TESLA Linear Collider feedback systems will be needed to provide orbit corrections within the bunch train. A prototype of the complete vertical feedback system has been installed in the TESLA Test Facility at DESY. The use of digital signal processing techniques led to a fast and highly flexible solution for the controller function. Additional features such as data logging and analysis allow easy adjustment of the feedback parameters to achieve the optimum performance of the system. An overview of the system will be presented as well as the results of first measurements.

1 INTRODUCTION

The luminosity of a collider is proportional to the interaction rate, that next to the center of mass energy, is the most important parameter. TESLA aims for a luminosity of \(6 \cdot 10^{33} \text{cm}^{-2} \text{s}^{-1}\). Reaching this goal requires small transverse spot sizes [2] with a dynamically calm beam at the interaction point (IP)

Unpreventable disturbances perturb the beam on its way to the IP: e.g. misalignments and mechanical vibrations of the focusing magnets scatter the bunch centroids and can result in separations of the beam centers. Consequently, control systems correcting the beam trajectory are required in order to insure high beam stability and thus high luminosity. [1]

The first prototype of a complete bunch-to-bunch orbit correction feedback system has been built, installed and tested at the TESLA Test Facility (TTF) at DESY. TTF offers the possibility to study the behavior of real beam motion and testing the performance of different feedback strategies.

2 FUNCTIONAL DESCRIPTION

Deviations in angle and position of a certain bunch can be corrected by applying two consecutive kicks. Similarly two beam position monitors can be used to measure the same deviations from the ideal trajectory. Fig. 1 shows the principle configuration of a feedback system including monitors and kickers at the collider. Since the bunches are ultra relativistic the kicks to correct the trajectory of bunch no. \(N\) can only be determined using the orbit information of the previous bunches \(n < N\). Thus the feedback is only effective if the orbit information of successive bunches are correlated. The correction procedure consists of a feed forward and a feedback part. If the orbit deviation of bunches have a similar pattern which changes slightly from shot to shot a feed forward controller can compensate these offsets. The update rate of this controller depends on the repetition rate of the collider and is therefore relatively slow. In the case that the displacements of bunches within a bunch train differ from shot to shot a feedback controller is applied. It is described in section 4 in detail. The spectrum of the orbit deviations extends from

\[ f_m = 0 \text{ to } f_m = 1/2 (t_b = \text{bunch spacing}) \]

In order to damp these frequencies the controller must generate a correction that acts on the successor of already passed bunches as a result of their motion. This implies that the propagation delay of the feedback loop must be shorter than the time interval between bunches e.g. 1\(\mu\)s at TTF conditions. The typical propagation delay time of such a feedback system, which is determined by cable delays and signal processing, cannot be less than about 600ns. Therefore, if the bunch spacing of a certain collider will be less, it may also be possible to act within a time interval of two times the bunch spacing. This will decrease the system bandwidth with the result that the cut off frequency of the damping performance is shifted down. Fig.2 shows the theoretical reduction of orbit deviations by a feedback loop that is able to act from bunch to bunch.

![Fig 2](image-url)

A common offset of all bunches from the design orbit should not be treated by the feedback kickers. Trying to do this would easily drive the system into saturation.
Therefore applying an offset correction algorithm must eliminate such an offset. The required correction may be directed to the steerer magnets to compensate these offsets.

Due to the fact that the system has to be compatible to various collider configurations i.e. TTF, TTF phase II, TESLA [2], it must be programmable with respect to different clock frequencies and algorithms.

3 BUNCH POSITION DETECTION

3.1 Re-entrant Cavity BPM

A broadband re-entrant coaxial cavity BPM serves as a high-resolution beam position detector. It consists of a tube surrounding the beam-pipe thus forming a piece of coaxial transmission-line. The coaxial cylinder is excited at the upstream end by the EM-fields of the bunched beam passing a concentric gap, which is shortened at the downstream end. Position sensitive signals are sensed by 4 symmetrical arranged antennas at the upstream end of the coaxial structure. Instead of operating the re-entrant cavity at the narrow-band cavity dipole mode, we monitor the evanescent fields of the beam excited fundamental TE_{11} wave-guide dipole mode. The frequency of this mode is much lower (approximately half) and it offers a very large bandwidth (about 100 MHz), thus gives high signal levels. Details on the theory of the re-entrant coaxial cavity are found in [3]

3.2 RF Detector Electronics

The RF electronics consists of a calibration box located close to the BPM inside the tunnel and a synchronous detection part, which is outside the tunnel. 180° hybrid couplers are used to generate the beam position signals (\(\Delta X, \Delta Y\)). The bunch current signal serves to scale the \(\Delta\) signals. Fig 3 shows a principle sketch of this device.

Figure 3: BPM with RF Detection Electronics

Constant amplitude bursts are obtained using limiter amplifiers, to get the phase dependent position signals converted to the base band. [4] After filtering they can be sampled by fast high-resolution analog to digital converters.

4 DIGITAL SIGNAL PROCESSING

4.1 Printed circuit board layout

Compared to feedback systems for circular accelerators, in a linear collider the calculated correction information is needed after a time equal to the bunch spacing rather than a full machine revolution. Therefore the required processing rate is much higher, so that techniques like piping can only be used very limited. Use of devices like cable drivers and signal buffers must be minimized. To achieve the optimum processing rate, a field programmable gate array (FPGA) is used. It reaches operation frequencies up to 100 MHz. FPGA chips may have over 200 I/O pins, so that all peripheral devices can be directly connected making it much faster than using a data bus. Contrary to microcomputers signal processing is executed in parallel and is thus extremely fast. Complex FPGA's have sufficient capacity to hold the entire functionality of the feedback signal processing. Since FPGA's are software-programmable high flexibility is achieved. Later modifications of the controller algorithm may be easily down loaded. Taking all these considerations into account leads to a single printed circuit board design, one for each transverse direction. The principle block diagram is shown in Fig. 4. The main processing components are the FPGA with its direct connected data converters. This establishes the feedback loop operation and has a total throughput time of about 200 ns. A sequencer is used to manage system set-up, program download and real-time data logging into the RAM. The CPU, connected to a CAN fieldbus or VME bus, performs host communication. For feedback parameter set-up it is also connected to the sequencer. Configuration settings are stored in an EEPROM enabling stand-alone power-up.

Figure 4: Block diagram of the DSP board
4.2 Controller function

As shown in Fig. 5, to gain a beam current independent deviation signal at first the bunch position information is scaled by the current information delivered by the BPM electronics. The offset corrected orbit deviation signal is processed by the feedback path realized as a PI controller and an integrating feed forward path to generate the output signal. The controller output signals are combined according to beam optical requirements with the help of a decoupling matrix and then fed into the high power amplifiers.

Figure 5. Signal flow of the feedback controller.

5 KICKER

The kicker prototype consists of a V2A sputtered ceramic tube surrounded by two semi shell conductors and four ferrite plates. This construction allows all kicker parts to be outside the vacuum, thus avoiding high voltage feedthroughs and preventing vacuum contamination.

V2A seems to be the best compromise between minimum kick-field shielding and sufficient heat conductance. The ceramic tube is sputtered from the inner side with a coating thickness of 1µm. This leads to an effective field attenuation of about 5%. The electrical characteristics are specified as a 50-Ohm system with a bandwidth of 30 MHz. The tube type class-A driver amplifier has an output power of 1 kW and 60dB gain. [5,6]

6 FIRST EXPERIENCES AND RESULTS

Up to now the system is operating under TTF test conditions.

<table>
<thead>
<tr>
<th>Bunch spacing</th>
<th># Bunches</th>
<th>Charge</th>
<th>Energy</th>
</tr>
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<tbody>
<tr>
<td>1µs</td>
<td>10-20</td>
<td>2.4 nC</td>
<td>200 MeV</td>
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In order to measure the response of various components a test pattern is fed into the stimulus input of the feedback electronics. For example by using a synchronized 500kHz signal one is able to produce an alternating bunch displacement along the bunch train that can easily be distinguished from other beam movements. This method is used to adjust the feedback parameters and will aid to measure the whole frequency response of the closed loop. As a first experiment a one dimensional feedback loop was closed over kicker #2 and BPM 2 while kicker #1 was used for the test pattern stimulus. Fig. 5 illustrates the mode of operation. The first trace of the background picture shows 16 consecutive bunch trains with 10 bunches. Seen is a certain offset, a fluctuating slope over the bunch train and the stimulus ripple of 500kHz detected by BPM#2.

Fig. 5 Open and closed loop operation.

The foreground picture shows 8 LINAC cycles when the feedback loop was closed. Now the slope and the ripple are compensated. (trace #1) The second trace shows the kicker output signal. The feed-forward part of the output signal is displayed by trace #3 and the Integrator output by trace #4.

7 REFERENCES


