CONTROL OF A RAMPED 1.5 GeV ELECTRON STORAGE RING BY A MULTIPROCESSOR DSP NETWORK

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Abstract

The ramped storage ring BoDo is the full energy injector of the 1.5 GeV synchrotron light source DELTA. A novel distributed DSP (digital signal processor) multiprocessing system has been developed and installed in order to improve injector performance and storage ring filling times. The VMEbus-based DSP system handles all ramped magnet power supplies, RF power and beam diagnostics of BoDo, including beam position monitors (BPMs), betatron tune, beam loss and power supply current measurement. Beam diagnostics data, trigger and synchronization signals are distributed among VME DSP boards by a novel 160 MBaud real-time fiber optics network. The system allows to optimise beam parameters by implementing distributed real-time control loops up to some 10 kHz bandwidth. This paper describes the architecture and performance of the injector DSP system and beam diagnostics, as well as measurements and improvements of injector performance.

1 INTRODUCTION

DELTA consists of a 60 MeV linear accelerator, the full energy booster BoDo and the main storage ring with a length of 115.2 m. BoDo is 50.4 m long, with 5.95 MHz revolution frequency, and has a FODO lattice with 6 independent focussing magnet circuits. Beam can be stored at any energy between 30 and 1500 MeV, and ramp cycle frequencies range from 0.1 to 0.5 Hz.

In the past, beam charge transfer efficiency from booster to storage ring was typically 10-20% at 1.5 GeV. The bending and focussing magnet power supplies limit the ramp cycle period of a 60 to 1500 MeV ramp to 6-10 seconds, depending on the beam optics of the booster. Average booster beam currents of 3-6 mA injected every 7.3 seconds resulted in storage ring filling times of 30 to 80 minutes for 100 mA accumulated beam current. Thus, the long time required for refilling the storage ring after hardware failures with subsequent beam loss led to significant reduction of available beam time for synchrotron radiation users.

Therefore, it was necessary to monitor booster beam parameters and power supply currents with sufficient speed and precision to detect reasons for poor booster performance and low beam currents. Furthermore, the machine is not operated by accelerator physicists any more during user runs. This requires simplification or automation of ramp optimization, fault detection and beam parameter measurements.

To achieve this, a system of interconnected VMEbus DSP multiprocessor boards ("DeltaDSP") was developed [1] and installed, including DC-isolated ADCs and DACs with interfaces to the DSP boards. Furthermore, the booster was equipped with faster BPM electronics analog front-ends and ADCs, thus increasing the maximum orbit measurement frequency from 10 Hz to 10 kHz. Finally, a DSP-based swept frequency betatron tune measurement system was developed that will allow real-time betatron tune correction of booster energy ramps.

2 THE BOOSTER DSP NETWORK

Figure 2 shows the simplified schematic of a DeltaDSP VMEbus board. Each board contains 2 DSPs. DSP 1

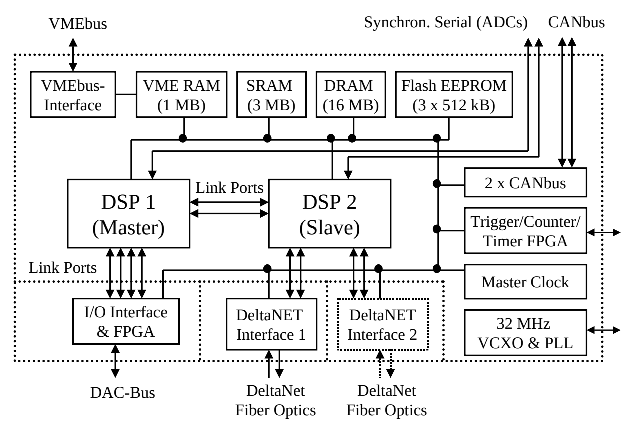

Figure 1: DeltaDSP VMEbus board

("master") is designated for local measurement data acquisition, data analysis, regulation algorithms or power supply control. External ADC boards can be connected to four differential synchronous serial busses (10 MBit/s each). Up to 8 16-bit DACs or similar devices can be connected to an I/O interface FPGA (field programmable gate array). Data (e.g. power supply set currents) can be transferred between master DSP memory and I/O FPGA by four so called link ports at 128 MByte/s and/or by the processor data bus.

The master DSP writes local measurement data to the internal memory of DSP 2 ("slave"), which broadcasts the data to the internal memory of all other slave DSPs via DeltaNet, a novel FPGA (field programmable gate array) based real-time network developed at DELTA [2] that transmits data, trigger and synchronisation signals over a single fiber optics cable. DeltaNet is a ring network that uses token passing for access arbitration. An FPGA handles power up, access arbitration, data transfer, 32-bit CRC checksum calculation and error detection. All DSP and FPGA clock signals of all VME boards connected to DeltaNet are synchronized using voltage controlled crystal oscillators with a timing recovery PLL (phase locked loop), with typically a few nanoseconds drift resp. jitter even on long timescales. Figure 2 shows the DSP boards and con-

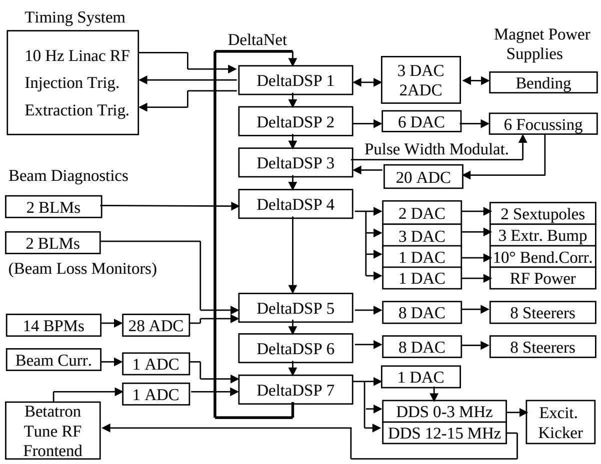

Figure 2: Booster DSP system overview

nected hardware of the booster. The Trigger/Counter/Timer FPGA of DSP board 1 counts the 10 Hz trigger pulses of the linac RF. Every p trigger pulses, the FPGA issues a DeltaNet trigger that starts a booster energy ramp on all DSP boards (e.g $p = 73$ for a 7.3 second ramp).

3 BETATRON TUNE MEASUREMENT

The DeltaDSP board is also used for betatron tune measurement (see figure 3). The system uses the swept frequency method and measures the fractional tunes by detecting the respective sideband of the 85th revolution harmonic frequency $F_h = 505.770$ MHz. Figure 3 shows the simplified schematic of the system. Most analog parts (resonators, signal amplifiers, bandpasses, mixers and rectifier) of the system were taken from the previous tune measurement system developed by K. Dunkel [3].

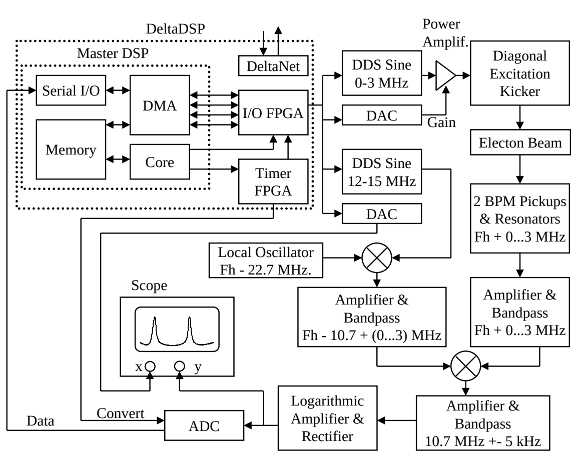

Figure 3: Betatron tune measurement scheme

The master DSP is connected to two DACs and two DDS (direct digital synthesis) sine function generators. One DDS generator and one DAC determine frequency and current amplitude of a slotted pipe diagonal excitation kicker magnet. The beam response is detected by two diagonal capacitive pickup electrodes that are directly connected to two resonators which amplify the desired frequency range. The resonator outputs are connected to a hybrid power combiner. Its difference signal is filtered and amplified before being mixed with the sum frequency $Fh - 10.7 + (0...3)$ MHz of the second DDS generator and a local oscillator. The resulting signal is filtered by a 10.7 MHz bandpass with 10 kHz bandwidth. Finally, its signal is amplified logarithmically, rectified and both sampled by an ADC and visualized on a scope in x-y-mode.

The DSP measures the tune by sweeping the kicker DDS generator within the desired frequency range while sweeping the second DDS generator at a frequency that is 12 MHz higher. The frequency difference can be adjusted to be different from 12 MHz to account for RF frequency changes without adjusting the master generator frequency, or to analyse higher harmonics of the kicker excitation signal. Horizontal and vertical tunes are distinguished by the tune shift that is caused by small changes of focussing magnet strengths. Figure 4 shows the ADC signal during a tune

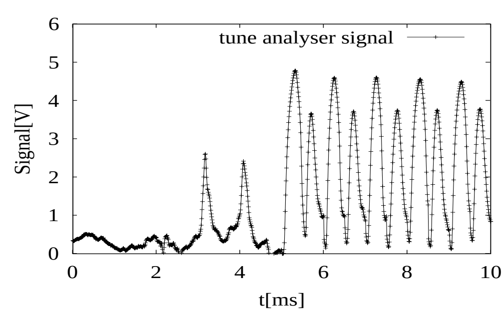

Figure 4: Betatron tune peak tracking

measurement after beam injection at 60 MeV. At first, the DSP sweeps once through a user-defined kicker frequency range (e.g. from 1 to 3 MHz) with a user-defined sweep rate (e.g. 400 kHz/ms). The DSP analyses the ADC data and finds both betatron tune peaks using a peak search algorithm. Then the DSP continuously sweeps in small frequency windows around each peak (here: 50 kHz width, 100 kHz/ms). Using this peak tracking method, the time required to measure both tunes was reduced to 1.35 ms, which will allow tune correction in real time.

Due to finite bandpass response times, the measured tune frequency has an error that increases with growing sweep rate. This error was measured for sweep rates between 5 kHz/ms and 400 kHz/ms. The DSP corrects the tune frequency and the peak tracking windows (for bidirectional sweeps) respectively. The correction can be approximated by the fit function

$f_{shift}[kHz] = 1.06 \times v_{sweep}[kHz/ms]^{0.555}$.

Futhermore, averaging between up and down sweeps can also be used to eliminate this error. The correction formula improves relative resp. absolute frequency resolution to typ. ± 1 kHz resp. ± 2 kHz at sweep rates < 100 kHz/ms.

Figure 5 shows the integrated count rate of a "Wittenburg" PIN diode beam loss detector (BLM) [4] in a vertically focussing booster quadrupole magnet at 69 MeV, measured by a DeltaDSP board. Tune peaks were tracked in 200 kHz windows for each peak and with 20 kHz/ms sweep speed. Tune peak and maximum beam loss should coincide, but the tune peak occurs ≈ 0.25 ms later, which corresponds to 5 kHz tune peak shift. The result of the tune shift correction formula for 20 kHz/ms is $f_{shift} = 5.6$ kHz. This indicates that the formula is correct and that betatron tunes can also be measured using BLMs instead of BPMs, with approximately 1 kHz precision at 20 kHz/ms.

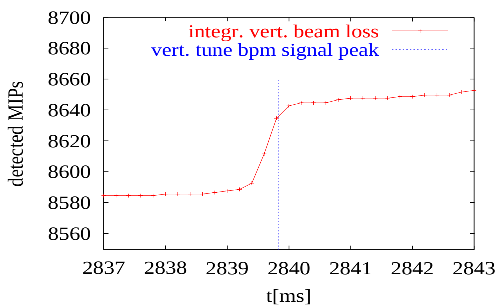

Figure 5: Beam loss in a vertically focussing quadrupole magnet, caused by the tune excitation kicker

4 IMPROVEMENT OF STORAGE RING FILLING TIME

Booster to storage ring charge transfer efficiencies of up to 100% at 750 MeV indicated that a decrease of booster emittance might improve injection at 1.5 GeV significantly. Optics calculations showed that the vertical plane was not critical, but that only 2.5 sigma of the horizontal transverse booster beam charge distribution can be accumulated in the storage ring even under ideal conditions. Due to various transfer channel hardware imperfections and reduced storage ring dynamic aperture the actual phase space might be significantly smaller, resulting in bad injection efficiency.

Therefore, new booster beam optics with smaller emittance were developed and tested [1]. Booster emittance can be reduced by a factor of 3.5 (see table 1, optics no. 3) compared to the actual optics (table 1, no. 1), reducing the transverse beam size by 50%. Since this optics exceeds the maximum available focussing power supply currents at 1.5 GeV, optics no. 2 was developed, with only 50% emittance reduction, but feasible power supply currents.

After orbit correction at 60 MeV beam currents of 3-6 mA were reached with optics no. 2. When ramping to 1.5 GeV, the beam was lost due to large orbit drift. Orbit measurements showed that the kick of each of the four 10 degree dipoles at 1.5 GeV was 4 mrad too weak compared to the sixteen 20 degree dipoles, due to different saturation behaviour. The value of 4 mrad was confirmed by magnet field measurements [5]. The kicks result in 14 mm max. orbit deviation for optics no. 1, but 30 mm for optics no. 2. After correcting the kicks by installing additional coils on the 10 degree magnets, 3 to 6 mA could be ramped up to 1500 MeV, with storage ring charge transfer efficiencies of 50 to 65 %. Precise correction of betatron tunes (see fig. 6) finally resulted in reproduceable average booster beam currents of 8-9 mA for optics no. 2, and storage ring filling times of 10 minutes for 100 mA were achieved.

Table 1: Booster Optics

Parameter	opt. 1	opt. 2	opt. 3
Emitt./nm rad, 1GeV	212	101	61
horizontal tune	2.811	3.623	4.863
vertical tune	2.277	2.562	2.702

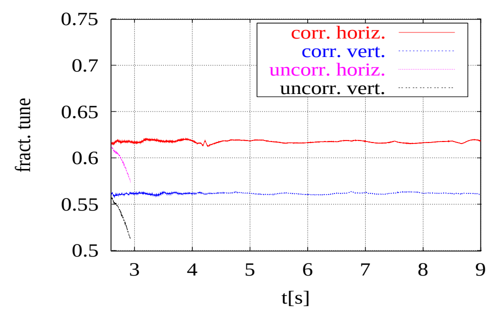

Figure 6: Fractional tunes, 60-1500 MeV ramp, optics no.2 with and without focussing magnet correction. Beam is injected at t = 2.6 s. Without correction, it is lost at t=3 s.

5 CONCLUSIONS

The architecture of a newly developed distributed DSP multiprocessing system and improvements of booster beam diagnostics were presented. The system was successfully used to commission a new booster optics, leading to increased beam current and considerable reduction of storage ring filling time.

6 ACKNOWLEDGEMENTS

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7 REFERENCES

[1] B. Keil, Ph.D. thesis, to be published

[2] B. Keil et al., The Evolution of the DELTA Control System, Proceedings of the 8th ICALEPCS'2001. San Jose, CA, USA

[3] K. Dunkel, Entwicklung und Test einer Meßelektronik zur Arbeitspunktbestimmung am Synchrotron BoDo, diploma thesis, University of Dortmund, July 1996, unpublished

[4] K. Wittenburg; DESY; Beam Loss Monitors for the HERA Proton Ring; EPAC 1990, Nice, France

[5] G. Schmidt, DELTA, private communications