DEVELOPMENT OF A SIGNAL PROCESSING BOARD FOR SPILL DIGITAL SERVO SYSTEM FOR PROTON SYNCHROTRON *

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Abstract

A prototype data processing board for a digital spill control system has been made. The system is considered to be used to control proton beams in 50-GeV synchrotron rings of J-PARC. The prototype circuit board consists of four ADCs, two FPGAs, a DSP, memories, and four DACs. The four inputs of the processing board are assumed to be an intensity signal of the proton beam in the accelerator rings, a digital gate signal that indicates the duration of beam extraction, a spill signal that shows the intensity of the extracted proton beam and a reserved signal. The resolution and maximum sampling speed of the ADC are 16-bit and 2.5 Msps, respectively. The one of the FPGAs is Vartex-2 1000-4C and a real-time power spectrum analyzer will be implemented. It analyses the spill signal every 1ms or shorter period. The analyzed result reflects optimum parameters used in spill control by servo. The DSP takes charge of these digital servo processing. The DACs with 16-bit resolution drive control signals for magnet currents. The system has another FPGA for communication between the processing board and network. MicroBlase CPU core is implemented and uCLinux is installed to use EPICS.

INTRODUCTION

J-PARC MR which is an accelerator under construction at present has two kinds of beams extraction line of fast extraction line for the neutrino experiment and slow extraction line for the hadron experiment. The feedback equipment using DSP is installed as the equipment which flattens the structure of the spill of slow extraction. The basic research[1] was carried out using KEK-PS that the shutdown was done in March, 2006. However, the difference is in the approach of extraction of the beam between J-PARC and KEK-PS. And, the technology utilized in J-PARC is different from the thing of reference literature of 1, since the electronics advances.

In KEK-PS, slow extraction was done using 1/2 resonance. In JPARC, 1/3 resonance is utilized. The evaluation test on the spill control is being carried out by HIMAC of NIRS(National Institute of Radiological Sciences) in order to evaluate the effect by the difference between the resonance. The result of initial experiment is reported.

At the R&D[1] with KEK-PS, VME computer which used MAP(IEEE-802.4) for the network was used for the control. Then, the board for the feedback control was made at the VME-bus standard. In J-PARC which carries out the equipment control in EPICS, Ethernet is used for the connection between equipment and control computer.

Then, the feedback equipment should be also perfectly remade. The high processing speed in the old feedback equipment using the fixed point DSP has been realized. Since the performance of the floating point DSP is recently improved, in J-PARC, the floating point DSP is used for the operation of the feedback. It has also been confirmed that the contamination of the noise to the signal transmission line induces the noise in the spill. In J-PARC, the attention has also been paid to noise contamination prevention in the signal transmission line. These aspects are reported.
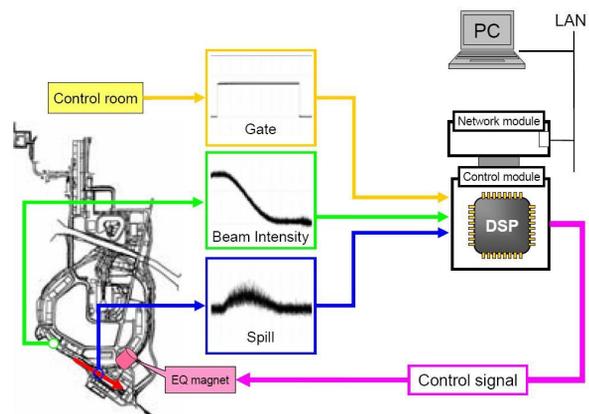

Figure 1: Flow of the signal of the feedback system of slow extraction

SPILL CONTROL AND EXTRACTION QUADRUPOLE MAGNET

The work of feedback equipment for the spill control is to control the current of the extraction quadrupole magnet in order to flatten the spill. Though two patterns of method for fixing the strength per unit time and method for fixing extraction time are considered, in J-PARC, extraction time is fixed. The feedback equipment

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measures the beam quantity in the ring, and it divides in the time for extract, and the spill height is decided. The feedback equipment adjusts the current of the extraction quadrupole magnet so that the calculation result and measured value of the spill may become identical. The flow of the signal on slow extraction in J-PARC is shown in Fig. 1.

There is a restriction of the frequency which depends on the structure on the extraction quadrupole magnet which manipulates the resonance. The following two kinds of extraction quadrupole magnets are used : EQ(Extraction Quadrupoles magnet) which does the spill trapezoidal and RQ(Ripple Quadrupoles magnet) which removes the fluctuation over about 100Hz . Sharing of roles of EQ and RQ are explained in Fig. 2.
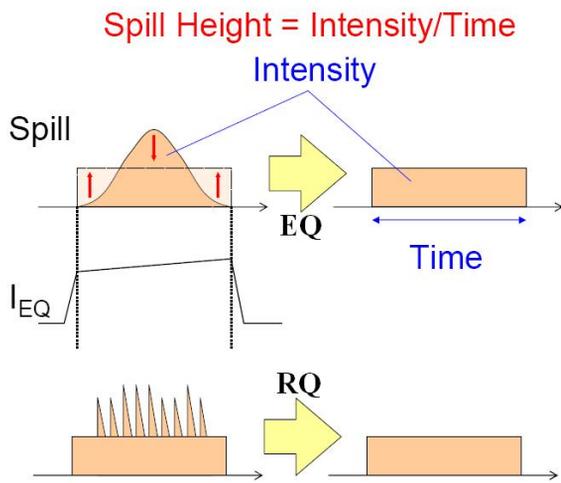

Figure 2: Sharing of roles of EQ and RQ

EQ is made in the material which made the steel sheet of the 0.1mm thickness to be the layered structure, and the EQ specification is shown in Table 1.

Table 1: EQ Specification

Field Gradient at Center	2.60 T/m
N	22 Turn/pole
I	301 A
Magnetic Length	0.7 m
Inductance	8.8 mH
Coil Resistance	97 mΩ
Alternate Voltage	1.1 V/A @20 Hz 54 V/A @1000Hz

FEEDBACK CONTROL SYSTEM

From the research of extract in KEK-PS, it has been confirmed that there is a term which depends on the distribution of the beam in the loop of the feedback.

Though the characteristic is fixed when the analog feedback is used, the characteristic change is also possible on coming out under work when the digital feedback is

used. The compensation of the beam distribution is easy, when the digital feedback is used. Therefore, it has been confirmed that the flatness of the spill can be greatly improved.[2] The optimum feedback is always maintained by the compensation of the gain changing with the beam distribution, by using the digital feedback. The concept is shown in Fig. 3.
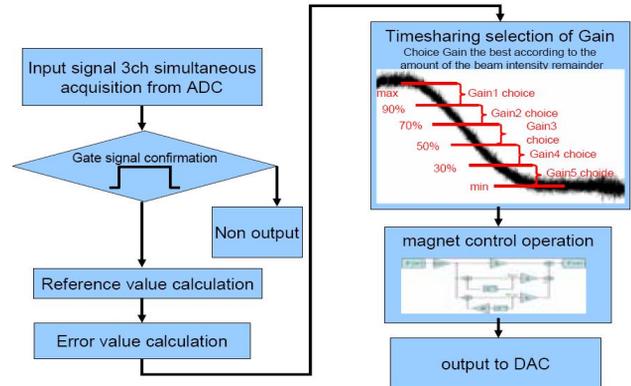

Figure 3: Approach of the gain change

The prototype consists of one DSP and four ADCs and four DACs and two FPGAs. The spill feedback is carried out using DSP(TMS320C6713). FPGA(Vartex-2 1000-4C) is spent in order to control ADCs and DACs, and in this element, the frequency analysis in real time[3] is also carried out. Resolution of ADCs and DACs is the 16 bits. It communicates using other FPGA(XC3S1200-4FG320C) with this system and other equipment. Micro Blasé CPU core is formed on the FPGA used for the communication, and EPICS is moved by the installation of uCLinux. The configuration of the test equipment is shown in Fig. 4.

AD/DA is included in the development as a input-output unit. However, AD/DA conversion part is separated in the practical use. The signal is converted into the numerical value in the near place in head end circuit of signal processing. The value is transmitted, after it converts into the optical signal, and it prevents the contamination of the noise to the signal.
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BEAM STUDY

In KEK-PS, slow extraction was done using 1/2 resonance. Whether it could use the equal method in slow extraction using 1/3 resonance had to be verified. Then, the experiment is being carried out by getting cooperation of NIRS which does slow extraction using 1/3 resonance. The beam distribution was measured, and current pattern in which the spill took the constant value was calculated. Then, calculated pattern current was applied to the extraction quadrupole magnet, and the spill was measured. In the other, the current of the extraction quadrupole magnet was controlled in DSP, and the spill

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① DSP board **TMS320C6713 DSK (TI)**
   DSP C6713(TI)   starter kit

② AD/DA board **ORS-112**
   input   4ch : ADC 16bit x 4
   output 4ch : DAC 16bit x 4
   FPGA Vartex II 1000-4C

③ Network I/O board **SZ130-SIL**
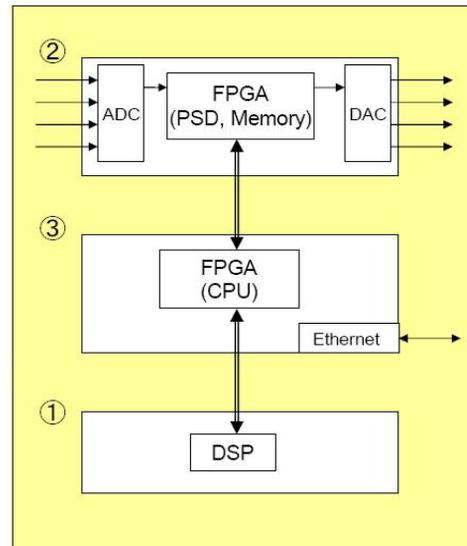   SUZAKU-S starter kit
   Ethernet I/O

Remarks
   Sampling rate : 225MHz
   PSD(Power Spectrum Density) in FPGA
   Magnet control operation in DSP
   Change the parameter from the outside

Figure 4: Configuration of the prototype

was measured. The comparison of these two spills is Fig. 5.

However, the synchrotron oscillation is seen, because it is applying on high-frequency electric field in order to measure betatron oscillation. By doing the smoothing of the data, the main component of the spill was also confirmed. Extraction by 1/3 resonance was able to control the spill as well as 1/2 resonance.
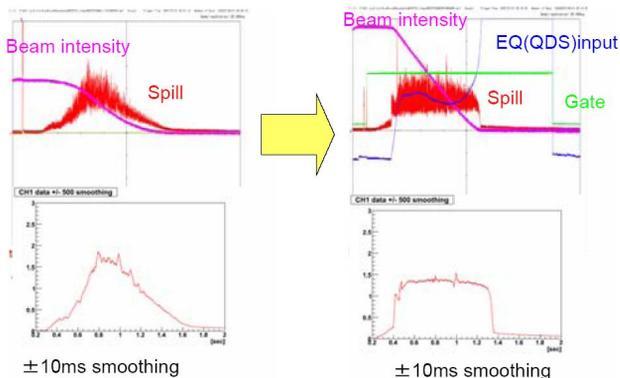

Figure 5: Example of experimental result in NIRS

FUTURE SCHEDULE

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SUMMARY

It was verified that the approach developed in 1/2 resonance extraction could apply for 1/3 resonance extraction. In until now test, it is seen, as the approach is available. And, DSP of the floating point type is also sufficiently available. Then, we manufacture the practical machine of the feedback used in present policy at J-PARC.

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