

VIRTUAL ACCELERATOR AS AN OPERATION TOOL AT J-PARC 3 GEV RAPID CYCLING SYNCHROTRON (RCS)*

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Abstract

We have developed a virtual accelerator based on EPICS for 3 GeV Rapid Cycling Synchrotron (RCS) in J-PARC. It is important to have an on-line model of optics parameters, such as tunes, Twiss parameters and dispersion function at the commissioning stage in a high intensity proton machine. It gives a strong feedback for the RCS operation as a commissioning tool as well as for the studies of beam dynamics issues. Beam position monitors with finite resolutions, a transverse exciter to measure the betatron frequency, and a RF system with variable frequency to simulate off-momentum optics have been implemented into the system. The virtual accelerator system itself and results of beam dynamics studies are presented.

CONCEPT OF THE VIRTUAL ACCELERATOR

Development of the logical accelerator called “Virtual Accelerator”(VA) enables the revolutionary commissioning and operation of an accelerator. The VA has a mathematical model of the beam dynamics in order to simulate the behaviour of the beam. In the case of a control system based on EPICS [1] there is an elegant solution facilitating the VA. It is possible to create a model imitating real accelerator by using the EPICS portable channel access server (PCAS [2]) and the simulation program. This combination of PCAS and the simulation program has been termed the VA because it looks like real accelerator from the EPICS channel access view and produces a reasonable response generated by the simulation model. In order to provide the network communication between EPICS PCAS and the simulation model with the VA, we need an EPICS channel access client. The structure of the VA is shown in Fig.1.

Operation Interface (OPI) including Graphical User Interface (GUI) shown in Fig.1 is a program to operate a real machine and communicates only with the PCAS. It is possible to operate both a real machine and the VA through the PCAS, and gives a strong feedback for the real machine. An advantage of the VA is that the developers have as many VAs as they need. The many VAs should be created by various simulation codes, such as SAD, MAD, XAL, Trace3D and SIMPSONS, etc, through the Database storing values of various actual elements. This also allows to make a benchmark among simulation codes.

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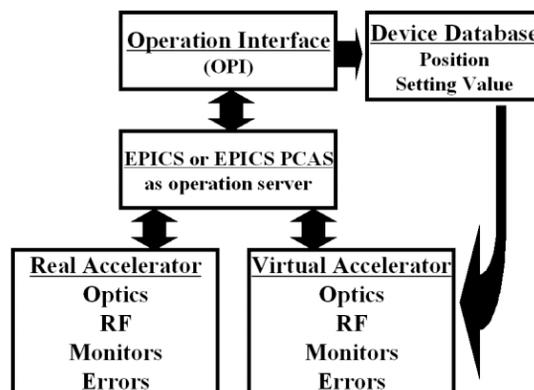


Figure 1: The structure of our Virtual Accelerator.

CONSTRUCTION OF THE VIRTUAL ACCELERATOR

We have constructed the control system for the VA based on EPICS PCAS (see Fig.1). The OPI and VA with CA Client created by SAD TkInter and SAD [3], respectively, transfer the information of the Input/Output via PCAS. The SAD is a simulation program of an accelerator developed at KEK and can communicate with EPICS. It is possible to operate the VA in the same way as a real machine.

The same Input/Output of the VA makes it possible to examine the measurement method of optics parameters and the communication of the OPI to EPICS channel without the real beam. During commissioning, the VA is directly compared with real machine by use of the same method and gives a strong feedback for the real machine. Beam position monitors (BPM), a transverse exciter, and a RF system have been implemented into the system for the operation of VA and measurement of these parameters in the same way as a real machine.

At 3 GeV RCS in J-PARC [4], the BPM detects the transverse beam position, and the resolution of the BPM depending on the beam current and noise is added to the VA. An element called exciter is used in order to excite the beam by the band-limited white noise. It consists of two electrode plates providing the band-limited white noise up to 1 kW. In addition, a RF system with various frequencies is added into the VA to simulate off-momentum optics.

THE VIRTUAL MEASUREMENT FOR BEAM DYNAMICS STUDIES

We virtually measured the betatron tune, chromaticity and the dispersion function by the VA for the storage mode in the commissioning phase at 3 GeV RCS. These parameters are the basic parameter in order to understand the synchrotron machine.

Betatron Tune

The betatron tune is one of basic parameter to clarify of the beam behaviour in the synchrotron machine. The strongly resonance of the betatron tune (Q_x, Q_y) causes the emittance growth of the beam, and consequently the beam loss.

A common method to measure the fractional part of betatron tune is to excite transverse beam motion and to detect the transverse beam position over a number of successive turns N [5]. The excitation consists of white noise or single kick. At 3 GeV RCS, the exciter with the band-limited white noise is used in order to excite the beam and the transverse beam position is detected by the BPM. A power density of the detected signal is computed via Fast Fourier Transform (FFT), and the betatron tunes are identified as the frequencies with the highest amplitude peak. However we may be not able to identify if noise level of power density is higher than the betatron tune peak.

The preliminary OPI for on-line measurement of the betatron tune is shown on Fig.2. This OPI have the abilities to plot the results of FFT, search the highest amplitude peak and turn on/off the exciter. In the plot, the power density is shown as $20\text{Log}_{10}\text{Sqrt}(A^2+B^2)$, where A and B are respectively a part of integer and complex of FFT.

We have examined the betatron tune measurement in case that the BPM's resolution are $\sigma=0.2, 0.5, 1.0$ and 3.0 mm, and these measurement accuracies have given the noise level of FFT power density that are respectively about $-66, -58, -50$ and -42 dB. These are shown Table 1. The betatron amplitude with the rated power of the exciter is about 0.3 mm in 10^4 turns and the power density is approximately -45 dB. As the result, if there is the BPM's resolution of 3.0 mm, we can't identify the peak of the betatron tune. So, we have made an average of several measurements. This suppresses a fluctuation of the noise level and consequently noise level has decreased about 10 dB.

Table 1: Noise level of FFT on BPM's resolution

BPM's resolution (in σ)	Noise level of FFT
0.2 mm	-66 dB
0.5 mm	-58 dB
1.0 mm	-50 dB
3.0 mm	-42 dB

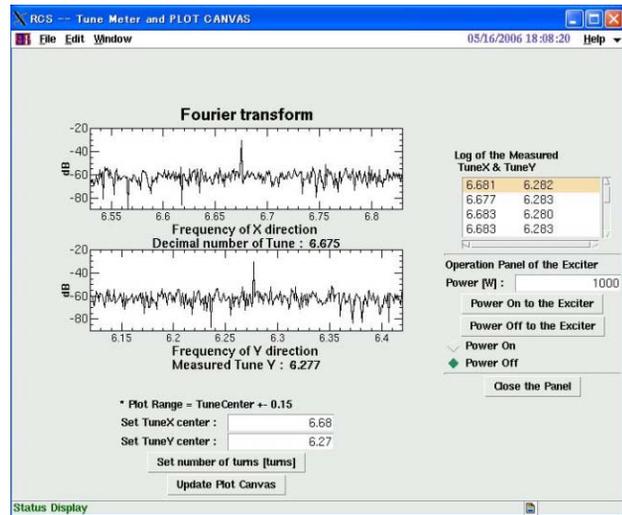


Figure 2: The preliminary OPI to measure the betatron tune.

We could have identified the betatron tune peak by an average of the several measurements in case that the BPM's resolution is less than 3.0 mm.

Chromaticity

The beam has the momentum-spread $\Delta p/p$ so that each particle having different momentum feels a different focusing by magnetic field and has the differing betatron tune. The chromaticity is the different betatron tune (dQ) from different momentum, which is $\xi = dQ / \Delta p/p$. It is important to correct the chromaticity in order to keep away from resonance of the betatron tune and suppress the betatron tune spread.

A common method to measure this parameter is to change the beam momentum or energy by a shift in the RF frequency and to measure the betatron tune [5]. A frequency shift Δf_{rf} changes the beam energy by an amount

$$\frac{\Delta p}{p} = - \frac{1}{\alpha - \gamma^{-2}} \frac{\Delta f_{rf}}{f_{rf}} \quad (1)$$

where α is momentum compaction factor, γ is Lorentz factor and f_{rf} is original RF frequency

We have virtually measured the betatron tune while changing $\Delta p/p$ from -0.5% to 0.5% within 0.1% step by RF and the result only for horizontal betatron tune is shown in Fig.3. The x and y axis in Fig.3 are respectively the momentum distortion $\Delta p/p$ (in percent) and the deviation of tune dQ_x. The measurement error for the betatron tune due to the discreteness of the frequency steps is equal to $1/N$, where N is a number of turns. We use respective data of 10^4 turns to measure the betatron tune of each $\Delta p/p$. Thus, we could obtain the betatron tune value with a resolution of 0.0001 and measure the chromaticity from the slope in Fig.3.

We have made sure of the method to measure the chromaticity at RCS.

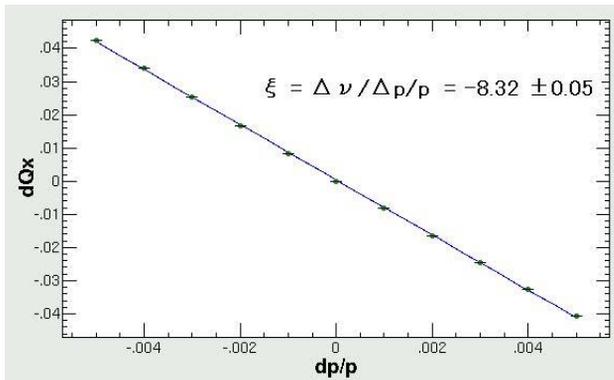


Figure 3: Deviation of horizontal betatron tune with different momentum and slop is the chromaticity value.

Dispersion Function

The beam has the momentum-spread $\Delta p/p$ so that each particle having difference momentum causes the orbit distortion. The dispersion function η is the ratio between momentum and orbit distortion Δx , which written as $\Delta x / \Delta p/p$. The dipole components existing around the ring make a contribution to the dispersion function and the dipole error field included in the various magnets causes the difference from the estimated or designed dispersion function. The orbit distortion from the dispersion function may cause the beam loss by hitting physical aperture.

A common method to measure this parameter is to change the beam momentum or energy by a shift in the RF frequency as well as the chromaticity measurement and to measure the beam position by the BPM located around the ring [5].

We have virtually measured the beam position by BPM while changing $\Delta p/p$ from -0.3% to 0.3% within 0.1% step by RF and the result is shown in Fig.4. The dispersion function has been measured from the slop of plot at each corresponding location. We have obtained the dispersion function by 54 BPMs located around the RCS ring and the result is shown in Fig.5. The x and y axis in Fig.5 are respectively the longitudinal position S (in meter) and the dispersion function (in meter) and the measured dispersion function at each BPM position (point) is plotted on the top of the designed dispersion function of RCS (line).

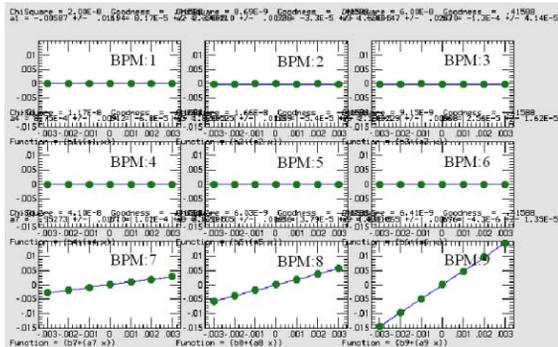


Figure 4: Orbit distortion caused by the $\Delta p/p$. Here only for first 9 BPM are shown.

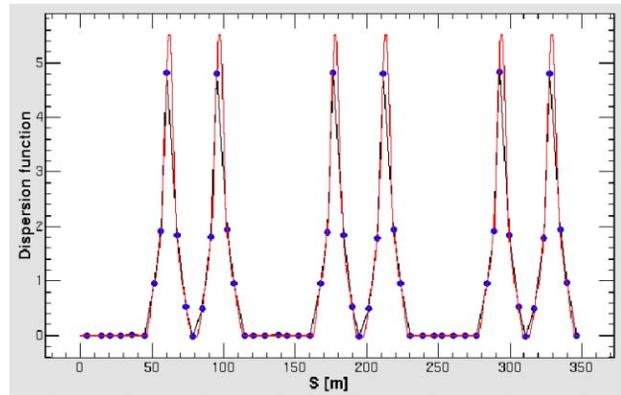


Figure 5: Dispersion function around the RCS ring.

We have made sure of the method to measure the dispersion function at RCS.

SUMMARY AND FUTURE PROSPECTS

We have developed a virtual accelerator based on EPICS for 3 GeV Rapid Cycling Synchrotron (RCS) in J-PARC. The combination of the portable channel access server (PCAS) and the accelerator simulation code with the channel access client is called “Virtual Accelerator”. It is shown that the VA has made it possible to virtually operate in the same way. We have created the preliminary Operation Interface (OPI) and have implemented the same Input/Output devices, such as a transverse exciter, beam position monitor and a RF system. We have made sure of the method to measure basic parameters in the synchrotron, such as the betatron tune, chromaticity and the dispersion function, from the virtual measurement without the real beam on Virtual Accelerator.

In the future, we will add individual variability of magnets with error, other monitors such as profile monitors and loss monitors, multipole components, the acceleration process, tracking errors, space charge effect and wake field into the VA using various simulation programs. In addition, we will make a development of OPI to operate the devices at the machine and to measure and correct the basic parameters.

This VAs will be widely used in application development for the RCS and will serve as a useful tool.

REFERENCES

- [1] EPICS, <http://www.aps.anl.gov/epics>
- [2] “The EPICS Based Virtual Accelerator – Concept and Implementation”, A.Shishlo, P. Shu, J. Galambos, T. Pelaia, Proceedings, PAC, 2003
- [3] SAD, <http://acc-physics.kek.jp/SAD/>
- [4] J-PARC, <http://jkj.tokai-sc.jaea.go.jp/index-e.html>
- [5] “Measurement and Correction of Accelerator Optics”, F. Zimmermann, SLAC-PUB-7844, SLAC, 1998