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SIMPLE Q-MEASUREMENT OF KEK PROTON SYNCHROTRON

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Summary

A simple, and rich in information, method for Q-measurement is developed. The method is essentially Fourier analysis, using a transient recorder and mini-computers. The word "simple" is for electronic circuit, though the program of computer is not so complicated. We use the revolution frequency of bunched protons as a "clock", so our method is free from recalibration or elimination of revolution frequency. We were able to measure Q-value even in the case that betatron oscillation was very rapidly damped.

Introduction

Q-value, or the frequency of betatron oscillation, is fundamental for the operation of circulating accelerators. Several methods for Q-measurement have been developed at laboratories in the world[1]. Most of them consist of analog circuits including clock and complicated filters. They need at least several hundreds beam revolutions with betatron oscillation for measurement. At Fermilab they developed a new method using fast Fourier transform (FFT)[2]. Our method is similar to it.

KEK PS is now under construction. The betatron oscillation decays rather rapidly for filter methods. It continues for only a few tens beam revolutions in the worst case. To get the Q-value in such a case, we made a system aided with a transient recorder and mini-computers, hoping that Fourier analysis would find Q-value even if its amplitude is very small and damps rapidly. The result is satisfactory.

Principle

The principle of this method is FFT with the beam itself as a clock. The block diagram of system is shown in Fig.1. The proton beam, deflected by a kicker magnet etc., passes through the pick-up electrodes of a position monitor. The integrator integrates the output signal of the position monitor for one beam bunch and feeds to a transient recorder, the voltage linear to the total charge induced at the single side plate of pick-up electrodes. Simultaneously the timing pulse generator feeds a clock pulse to the transient recorder. Then it digitizes integrator output and stores into a 8-bits memory word. After that the clock pulse generator resets the integrator and the system waits for next turn. The transient recorder has stored 2048 digital data after 2048 beam revolutions. Then they are transferred to center computer (CC). CC computes FFT of them, regarding the data as sampled with unit time interval, that is, the time interval of one beam revolution is one unit time. In other words, we apply "tracking time base".

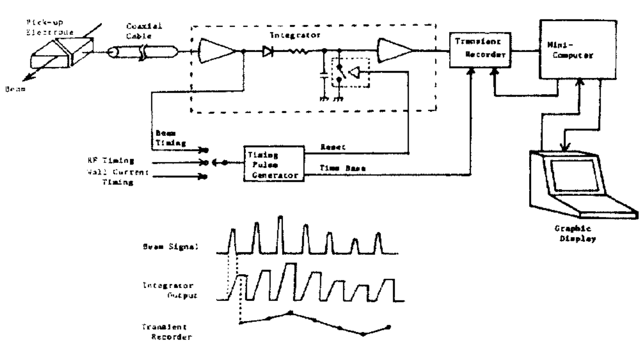

Fig.1 Block diagram of Q-measurement system.

So, in FFT of N data,

$$\Delta t \equiv \frac{1}{2f_{max}} = 1 \text{ (revolution)}$$

$$\Delta f \equiv \frac{1}{T} = \frac{1}{N} \text{ (rev)}^{-1}$$

$$N_f = \frac{f_{max}}{\Delta f} = \frac{N}{2}$$

where
Δt: sampling interval
f_{max}: maximum frequency of FFT
Δf: frequency interval of FFT
T: time window interval
N: number of sampled data
N_f: number of Fourier coefficients.

Then we get a series of N_f Fourier coefficients which are ranged from $f_{min} = 1/N$ to $f_{max} = 1/2$, equally spaced of Δf (we neglect the DC component). For example, if N = 1024,

$$\Delta f = f_{min} = \frac{1}{1024} \simeq 0.001$$

$$N_f = \frac{1024}{2} = 512$$

$$f_{max} = \frac{1}{2} = 0.5$$

For we get the data from one position monitor, the result is fractional part of Q-value ($0.0 \leq q \leq 0.5$). With the result of one turn fast position monitor, we can know its integer part (N)[3]. Then $Q = N \pm q$.

Details of apparatus

1) Integrator and timing circuits: The four-diode-gate consists of matched quad diodes (HP5082-2970). With input range of 0.01 - 0.1 V (50 ohm term.) and repetition rate of 10 MHz, the lineality of output is less than 1 %. The timing pulse from beam signal itself is most recommended. But there are some cases in which the beam signal is very noisy. Then the timing pulses become unstable, and FFT, based on the principle mentioned above, loses its validity. For the measurement in such a case, timing signal from a wall current monitor or RF is preferable.

2) Transient recorder: Biomation Model 8100 is used. Maximum sample rate of 50 MHz (external time base) is fast enough for our accelerator with maximum beam revolution frequency of 6.03 MHz (booster ring). Memory length is 8 bits × 2048 words. So if we calculate with full data, the accuracy of FFT is 1/2048 ≈ 0.0005. It is computer controllable via digital interface, so Q-measurement is very easy for a operator.

3) Mini-computer: We use two MELCOM-70 (Mitsubishi Electric Co.) mini-computers in the computer network for accelerator control. One with 8K words is for data acquisition, and the other (CC) with 64K words for FFT calculation and general control.[4] As they are installed mainly for machine control, we can use only 12K words of CC as background job on time sharing mode. FFT calculation takes a fairly long time, say, 6 seconds for 256 points.

4) Graphic display: Tektronix 4010-1 with keyboard is used. The data transfer rate with CC is 2400 bits/sec. It takes 70 seconds to plot 1024 points. It is a little slow for a short-tempered operator. For example, it takes about 18 seconds to display 128 data points and 128 Fourier coefficients.

Computer program

The flow chart of program is shown in Fig.2. In the mode set routine, we can set the operation mode from the graphic display keyboard as the conversation with the computer. Parameters set from the keyboard are:

N_{DA}: Number of data from transient recorder (16, 32, 64,$\cdots$, 2048)

N_{DD}: Number of data for dispaly (16,$\cdots$, N_{DA})

N_{FT}: Number of data for FFT (16,$\cdots$, N_{DA})

F_{start}, F_{end}: Range of Fourier coefficients for display ($0.0 \leqq F_{start} \leqq F_{end} \leqq 0.5$)

F_{start} and F_{end} can be preset up to 5 pairs. Furthermore, each routine (data acquisition, data display, FFT, and Fourier coefficient display) can be skipped independently by preset commands. This is convenient for quick getting of desired result only.

After the display of Fourier coefficients, the operator can set F_{start} and F_{end} on the screen of graphic display with cross-hair cursor. The computer finds the maximum coefficient within the range between F_{start} and F_{end}, and shows its amplitude and frequency

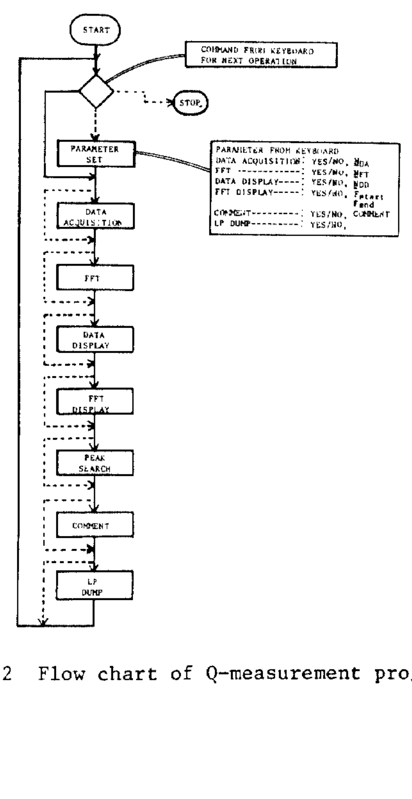

Fig.2 Flow chart of Q-measurement program.

on graphic display. This can be done repeatedly. If there is no need of mode change, pushing "Return" key makes the next measurement on the same mode of previous run.

Discussions

The Q-values obtaiend by this method were checked on booster and main ring. On booster, they were in good agreement with the values obtained by RF knockout methods.[5] On main ring, they were compared with Q-values calculated from oscilloscope photos of beam bunch signal of position monitor (Fig.3). The result was satisfactory.

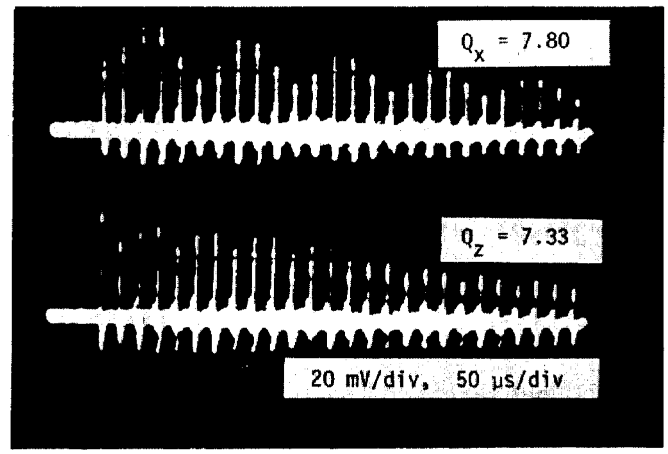

Fig.3 Main ring beam bunch signals of pick-up electrodes at the injection. Upper and lower traces are of horizontal and vertical monitors respectively.

The system is basically a Fourier analyzer. So we can find not only betatron oscillation, but also the coupling of Q_x and Q_z, synchrotron oscillation, and damping behaviour of these oscillations. These are demonstrated in Figs.4-7. Furthermore, any signal can be analyzed according to the time base of beam revolution frequency. For example, Fig.8 shows the result of a scintillation loss monitor near the main ring magnet. It shows that the beam loss machanism is strongly coupled with Q_x and Q_z.

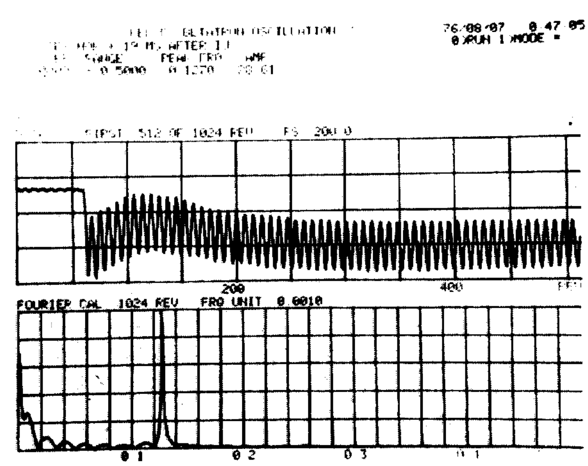

Fig.4 Booster horizontal Q-measurement. Oscillation is excited by a kicker magnet at 19 ms after the injection. Upper graph shows the envelope of signal from pick-up electrode (512 turns). Lower shows the result of 1024 data FFT (q_x=0.1270).

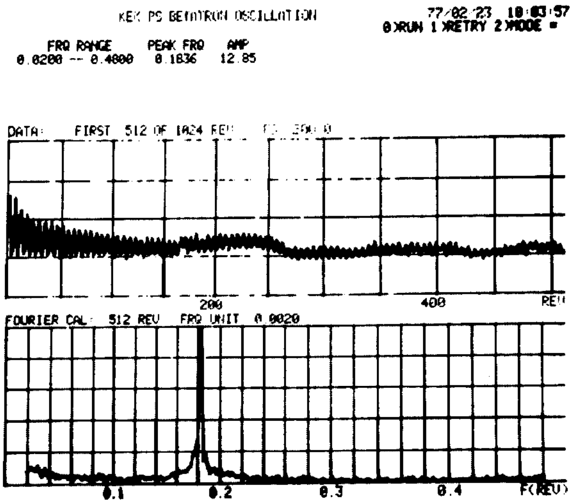

Fig.5 Main ring vertical Q-measurement. Oscillation continues fairly long of the thin beam of high quality.

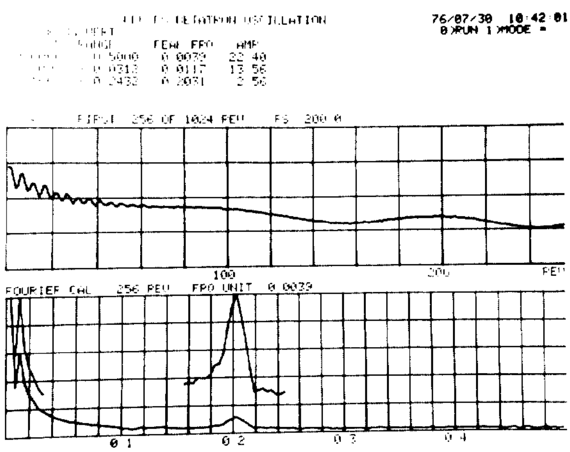

Fig.6 Main ring vertical Q-measurement at the injection. Large component of low frequency is for intensity loss. Two pairs of hair-cursor operations are shown, one for synchrotron frequency (0.0117) and the other for betatron frequency (q_z = 0.2031).

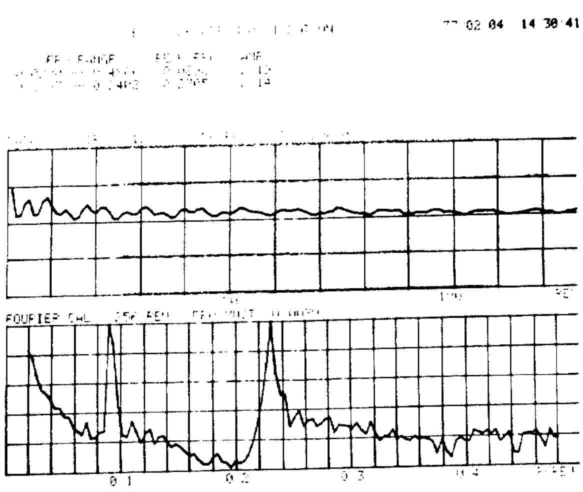

Fig.7 Main ring vertical Q-measurement. Oscillation is excited by horizontal pinger. Note the coupling of q_x (= 0.0898) and q_z (= 0.2305).

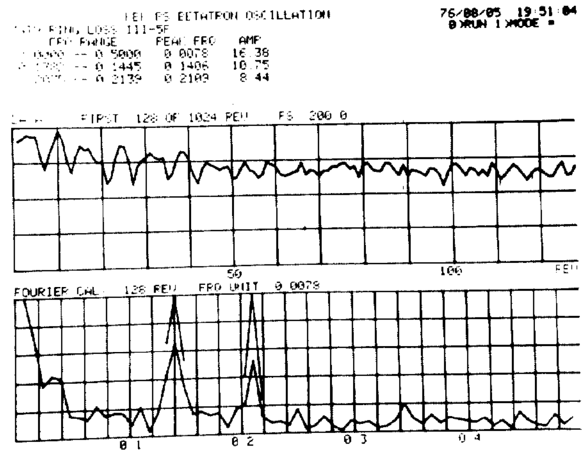

Fig.8 Main ring loss monitor. Two peaks correspond to q_x and q_z.

The response time of the system will be improved by faster data transfer rate between CC and graphic display and by shorter FFT calculation time. FFT program is now written in Fortran. If it is rewritten in machine code, the calculation time will become shorter than now to some extent. But the linkage of a hardware FFT processor may be the best answer. In this case, the calculation time will be negligible.

We have measured the Q-value of the booster (harmonic number = 1), and the main ring (harmonic number = 9) with single pulse injection. For the normal operation of 9 pulse injection to main ring, a ring counter with suitable trigger should be inserted in the timing circuit to pick up one from nine pulses.

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