Q MEASUREMENT WITH SWEPT RC FILTER FOR AUTOMATIC DATA ACQUISITION AND DISPLAY

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Summary

This paper describes an automatic Q measurement system ($Q = f_{betatron}/f_{revolution}$) which was developed and installed at the 28 GeV Proton Synchrotron of CERN. At the desired moment the beam is excited to 1mm betatron oscillations by means of a programmed full aperture air kicker. The frequency spectrum which appears at a beam position pick-up station contains the non integer part of the Q value as the lowest frequency. A voltage controlled RC filter scans the pick-up signal spectrum. When the lowest frequency of the spectrum is attained, a feedback loop switches the filter to a constant frequency. The ratio measurement (normalization to the revolution frequency) is performed by counting the doubled acceleration frequency during 10 periods of the filter output frequency. The counter output is fed to a computer which displays after data handling the Q value on an alphanumeric cathode ray tube. The measurement time for the acquisition of the horizontal or vertical Q value is less than 1ms. The resolution of the measurement is $\Delta Q = 0.001$.

Introduction

The automatic Q measurement system described in the following is based on the semi automatic one[1], which has been used during several years. The manual tuning of an LC filter to the desired betatron frequency required several machine cycles (1 cycle ≈ 2sec). With the new system which needs less than 1ms for the acquisition of the Q value, many measurements per cycle are possible.

Principle of the Q Measurement with Swept RC Filter

Fig. 1 shows the block diagram of the measurement system. The proton beam (on the left hand side) passes through a magnetic kicker[2] which is excited by a half sine wave current after triggering the discharge circuit. Behind the kicker, the beam performs betatron oscillations with 1mm amplitude independent of the beam energy. This is accomplished by the programmed power supply.

A pick-up station senses the position modulation. The observed signal spectrum contains the frequencies

$$f = (m \pm q) \cdot f_{rev} \qquad (1)$$

m = 0, 1, 2, ...
q = non integer part of the Q value
f_{rev} = revolution frequency of the beam.

As the revolution frequency increases during acceleration, all spectrum lines shift with the same ratio. This signal arrives, after amplification, at a prefilter which eliminates the low frequency noise and frequencies higher or equal to the revolution frequency f_{rev}. The linear gate is open only during the measurement time (≈ 0,8ms). This gate was introduced to be sure that no energy is stored in the swept filter before the measurement starts.

The swept filter is an active RC filter where the resonance frequency can be controlled by an external voltage which modulates the drain source resistances of a FET pair.

At the trigger moment, the function generator produces a ramp voltage which moves the filter frequency from

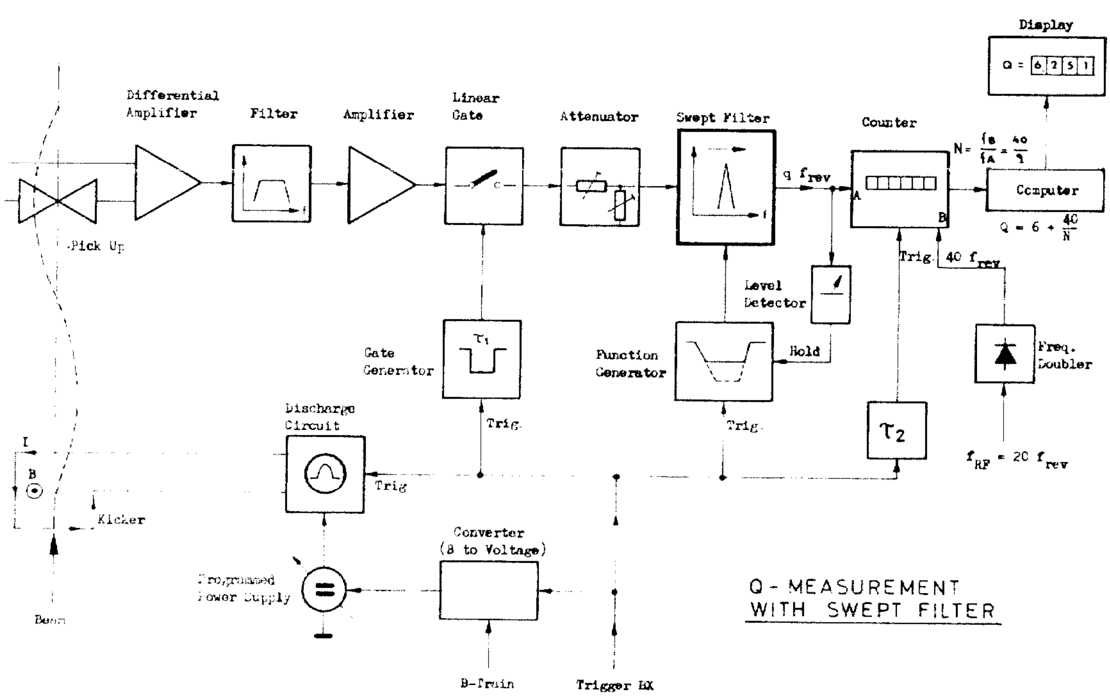


Figure 1.

$$f_{0\,min} = 10\text{KHz}$$

to

$$f_{0\,max} = 250\text{KHz}$$

within 100μs. When the increasing filter frequency f_0 equals the lowest frequency of the pick-up signal spectrum

$$f_b = q\, f_{rev}, (m = 0) \tag{2}$$

a resonance signal appears at the filter output which contains the desired betatron frequency f_b and the excited filter frequency f_0. When the amplitude of this signal has reached a certain value, the level detector switches the filter via the function generator to the detected frequency f_b = const. After disappearance (delay τ_2 ~ 100μs) of the filter frequency f_0[3], the counter is triggered and measures the frequency ratio between the doubled acceleration frequency f_{RF} and the betatron frequency f_b

$$N = \frac{2\, f_{RF}}{f_b} = \frac{2 \cdot h \cdot f_{rev}}{q \cdot f_{rev}} = \frac{40}{q} \tag{3}$$

($h \mp 20$, harmonic number). This result is fed to a computer which calculates the Q value

$$Q = 6 + \frac{40}{N} \tag{4}$$

(6 = integer part of the Q value) and displays it on an alpha numeric CRT on request.

In the case of $q > 0.5$, the first frequency discovered by the swept filter is

$$\bar{f}_b = (1 - q) f_{rev}, \quad (m = 1) \tag{5}$$

Hence,

$$N = \frac{40}{1 - q}, \tag{6}$$

$$q = 1 - \frac{40}{N} \tag{7}$$

and

$$Q = 7 - \frac{40}{N} \tag{8}$$

The discrimination ($q > 0.5$ or < 0.5) is made by two measurements where one is done with a superposed known alteration of the q value.

The Swept RC Filter

The most important element of the system is the swept filter whose principle is shown in Fig. 2.

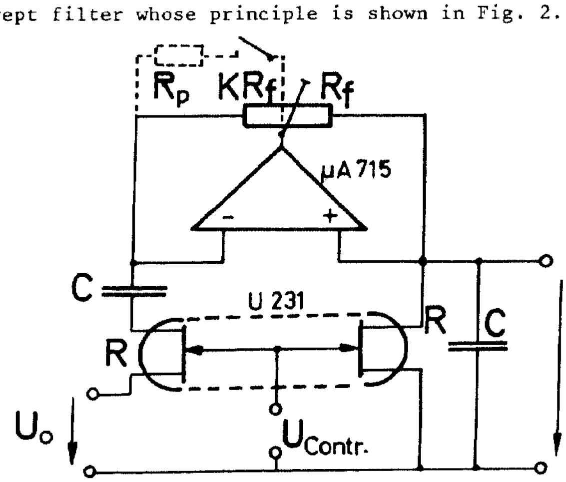


Figure 2.

The operational amplifier works with positive and negative feedback in a bridge circuit. The circuit analysis gives the transfer function[4]:

$$\frac{U_1}{U_0} = \frac{-K\, p\, \omega_0}{p^2 + p\omega_0\,(2 - K) + \omega_0^2} \tag{9}$$

with

$$\omega_0 = \frac{1}{RC} \tag{10}$$

($p = j\omega = j\,2\pi f$; K = divider ratio of the feedback resistors). Compared with a parallel LC resonance filter, one finds the differences shown in table 1.

	Filter Type	
	LC	RC
quality factor	$Q^*_f = R\sqrt{\frac{C}{L}}$	$Q_f = \frac{1}{2 - K}$
resonance frequ.	$\omega^*_0 = \frac{1}{\sqrt{LC}}$	$\omega_0 = \frac{1}{RC}$
resonance gain	$G^*(\omega_0) = G(R_L R_1 C_1 L)$ (R_L = Losses of L)	$G(\omega_0) = \frac{-K}{2 - K}$

TABLE 1

For wide range filter sweeping with constant quality factor Q_f and constant gain G, the RC filter type is much more advantageous.

The quality factor of the RC filter can be varied between ½ and theoretically infinite by means of potentiometer adjustment (parameter K, s. Fig. 3). The region for $K > 2$ is unstable and must be avoided.

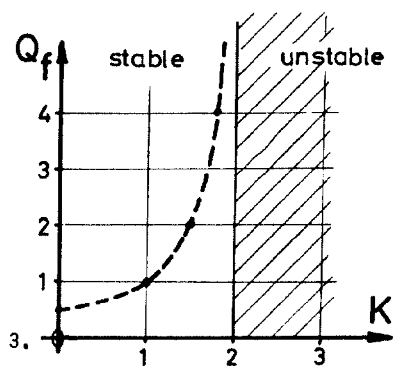


Figure 3.

The electronic circuit was realized on the basis shown in Fig. 2. The output voltage U_1, which should be smaller than 50 mV for linearity reasons, is amplified by a further operational amplifier with high input impedance.

One problem with this filter is to maintain it in the stable region when its power supply is switched on, or later, when input overload occurs (caused by biasing unsymmetry or the non-linear characteristic of the FETs). This was overcome by introducing a feedback branch which, in these cases switches the quality factor Q_f automatically to a lower stable value. This was accomplished by decreasing the feedback resistance KF_f ($R_p || KR_f$) with a relay contact during such periods (s. Fig. 2).

Results

Photo 1 shows the control chassis with the block diagram on the front panel which is similar to the one of Fig. 1. All important functions:
- selection of horizontal or vertical kick
- selection of horizontal or vertical pick-up
- filter input attenuation
- trigger gate

can be adjusted manually or by computer remote control. (Further details in ref. [4])

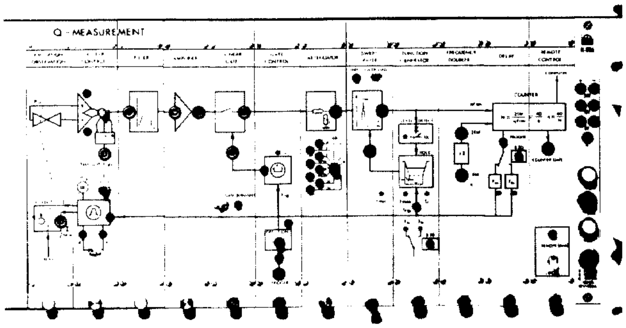
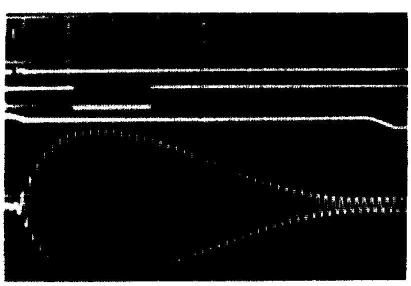


PHOTO 1

Photo 2 shows how the system works. It was taken on 4 test points of the control panel. The first trace shows the kicker current pulse, the fourth trace the resonance signal behind the swept filter. The voltage program of the function generator is displayed on the third trace and the counter gate signal on the second.

The voltage of the function generator (and hence the filter frequency) remains constant during about 380µs after having selected the betatron frequency. The frequency ratio measurement is done during 10 periods (tg = 85µs) of this signal (where the counter gate signal is low).

The photo was taken at a proton momentum of 24 GeV/c where the amplitude of the betatron oscillations is small and the damping relatively high.



50 µs/div.

Kicker current 2V/div.
Counter gate 2V/div.

Voltage program 2V/div.

Filter output signal 0,5V/div.

Trigger B1119 (24 GeV/c)

PHOTO 2

The counted frequency ratio was

$$N = \frac{2\ f_{RF}}{f_b} = 2\ f_{RF} \cdot \frac{tg}{10} = 162.1 \qquad (11)$$

with f_{RF} = 9.54 MHz and tg = 85µs.

The resolution of the measurement (from equ. 3 and 4)

$$\Delta q = q\ \frac{\Delta N}{N} = \frac{\Delta N}{40}\ q^2 \qquad (12)$$

depends on the q value and the error of the counter ratio measurement ΔN.

For the worst case q = 0.5 and the obtained uncertainty ΔN = 0.2

$$\Delta q = \Delta Q = \frac{0.2}{40} \cdot 0.5^2 \simeq \underline{0.001}$$

(For the case 0.5 < q < 1 equ. (12) is no more valid, but

$$\Delta q = \frac{\Delta N}{40}\ q\ (1 - q) \text{ see equ. 6 and 7} \qquad (13)$$

Equ. (13) has its maximum at q = 0.5.)

The acquisition of the counter result N, the computation (equ. 4) and the mentioned controls of the Q meter are performed by a data transmission system[5] handled by the CPS IBM 1800 computer.

The use of a syntax[6] allows the operatior to know the horizontal or vertical Q values and the other parameters which can affect it, such as the mean radial position of the beam or the settings of the focalization elements. These informations are displayed simultaneously on a CRT, driven by a satellite computer PDS 1, specially devoted to the man computer interface.

Modifications of the apparatus settings can be accomplished by orders typed on an alpha numeric key board linked to the PDS 1.

References

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6. B.E. Carpenter - Experience with Interactive Control Software at the CERN Proton-Synchrotron. IEE Conference, July 1973.