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COMPENSATION OF THE RESISTIVE AND REACTIVE TRANSVERSE WALL IMPEDANCE IN THE ISR WITH A FEEDBACK SYSTEM

by

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ABSTRACT

The transverse coupling impedance has been measured in the ISR in the vertical plane and found to be mostly inductive with a phase angle of about 50° for the lowest mode. The resistive part of this impedance is compensated below 1 MHz by a transverse feedback system. However, by applying to the kicker the signals from two pick-ups giving respectively a resistive and an inductive compensation, the phase angle of the feedback can be varied. The signal levels from the two pick-ups are individually adjusted with the correct settings obtained from the information given by the beam transfer function. In this way the stability margin is increased without changing the electronic gain of the feedback. A special set-up has been developed for the measurement of beam transfer functions at low frequencies (10 kHz to 1 MHz).

INTRODUCTION

In the ISR high density proton beams are stabilized against transverse instabilities by a feedback system$^{1)}$ which in the frequency range from 10 kHz to 1 MHz compensates for the resistive part of the transverse coupling impedance.

Nevertheless, beam losses still occur because of a transverse instability in the vertical plane. Transverse signals from a pick-up have shown that most often the instability occurs within the lowest transverse Schottky band which with the presently used working line for high intensity stacks is situated in the frequency band from 25 to 50 kHz.

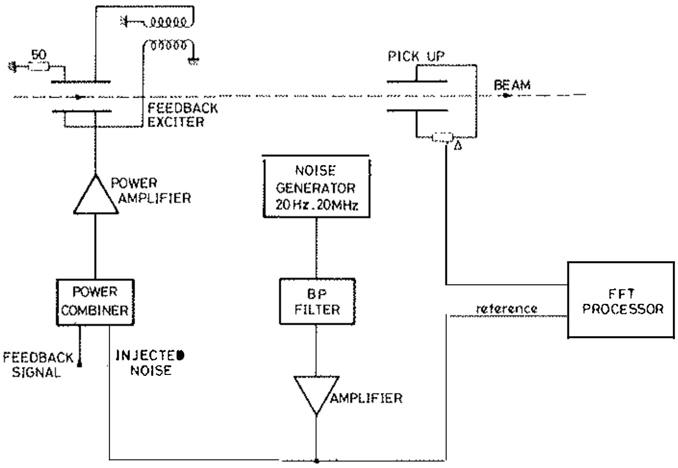

Fig. 1 Block diagram of the set-up for low frequency beam transfer function measurements.

The stability margin cannot be increased by an increase in the chromaticity as this would mean crossing lower order resonances which give unacceptable background conditions for data taking. The gain of the feedback system cannot be increased. In spite of the large dynamic range of the system, a further gain increase can cause saturation during stacking where large signals from injection errors and the bunch structure are present.

The feedback system was then investigated with the aid of beam transfer functions

(BTF's). With the equipment for BTF measurements[2] it is not possible to work at frequencies below ~ 2 MHz. For measurements in the frequency range of the feedback system and especially in the lowest and least stable Schottky band a set-up in which white noise was injected into the power amplifier for the transverse feedback system was used (Fig. 1).

THE "IMPEDANCE" OF A FEEDBACK SYSTEM

With the method described above BTF's of low density stacks which were stable without transverse feedback have been measured. The normalized stability diagrams were computed and the transverse impedance calculated from the formula[3,4] :

$$\frac{G_0}{x} = j\,\frac{1}{r'} + Z_{TN} \qquad (1)$$

which is valid for the (n-Q) term (the 'slow-wave'). 1/r' is the inverse of the normalized dispersion integral, G_0/x the inverse BTF and Z_{TN} the normalized transverse impedance given by[4] :

$$Z_{TN} = \frac{ecI}{4\pi\, Q_0\, S\, \gamma\, m_0\, c^2}\, Z_T \qquad (2)$$

I is the beam current, Q_0 the betatron wave number, S the half width half max. frequency spread (rad/s) and Z_T the transverse coupling impedance.

From several measurements around 40 kHz it was found :

$$Z_T \simeq (7.4 + j\,9.2)\ \mathrm{M\Omega/m} \qquad (3)$$

With transverse feedback a vector Z_{FN} is added to the normalized transverse impedance. This vector is given by :

$$Z_{FN} = je^{j\mu} \cdot A_{PU} \cdot A_e \cdot G_{KN} \qquad (4)$$

where μ is the betatron phase between the pick-up and kicker counted from the pick-up, A_{PU} is the pick-up sensitivity, A_e the electronic gain and G_{KN} the normalized acceleration caused by the exciter.

With a PU gain of 79·I V/m, an electronic gain of 2600 and an acceleration in the kicker of $1.9.10^5$ m/Vs^2 (at 26.6 GeV/c), one obtains with a Q-value of 8.88 :

$$Z_{FN} = -\,1.1\ .\ 10^3\ .\ \frac{I}{S}\ .\ je^{j\mu} \qquad (5)$$

The normalized transverse resistance is :

$$\mathrm{re}\,(Z_{TN}) = 7.5.10^2\ .\ \frac{I}{S} \qquad (6)$$

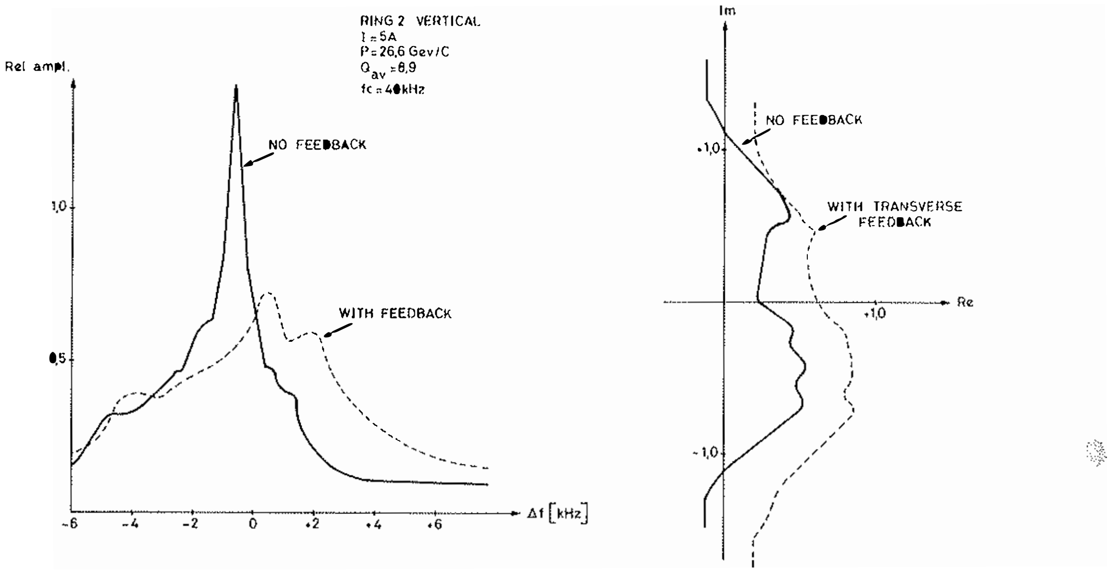

Fig. 2 Beam transfer function and stability diagram of a 5 A stack with and without transverse feedback.

For compensation of the resistive part of the wall impedance the distance between pick-up and kicker is chosen to be an odd number of betatron wavelengths. Fig. 2 shows a stability diagram without and with transverse feedback. As foreseen from Z_{FN} and Re (Z_{TN}) the feedback system overcompensates the transverse resistance. However, the stability margin can be further increased by compensating for not only the resistive part but also for the inductive part of the wall impedance. As seen from equation (4) the phase angle of the compensation can be changed by changing the distance between the pick-up and the kicker of the feedback system. In the ISR $\mathrm{Im}(Z_T)/\mathrm{Re}(Z_T) = 1.24$ for the lowest mode. The optimum value of μ is then

$$\mu_{opt} = (0.871 + n/2)\,2\pi \qquad (7)$$

where n is an even integer for positive A_e and an odd integer for negative A_e.

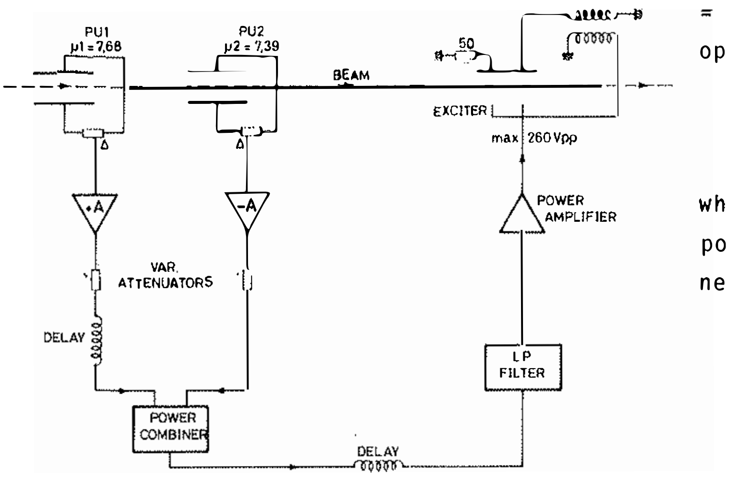

Fig. 3 Simplified block diagram of the transverse feedback system with adjustable inductive compensation.

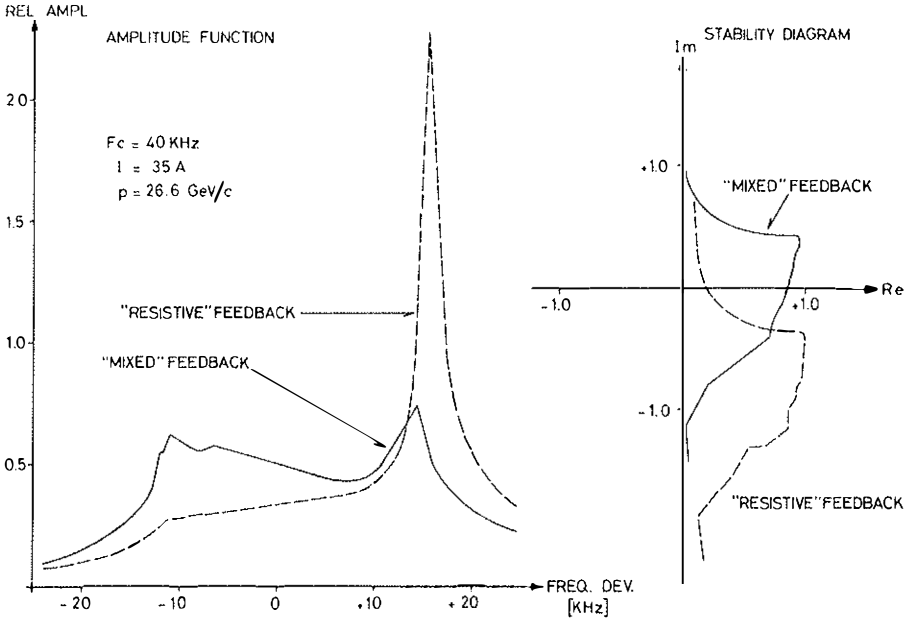

Fig. 4 Beam transfer function and stability diagram of a 35 A stack with 'resistive' compensation and combined 'resistive' and 'inductive' compensation.

EXPERIMENTAL RESULTS

In practice it is hardly possible to obtain the correct value of μ with a single pick-up as the angle of the feedback will change with the average tune value. Therefore another approach has been taken in the ISR (see Fig. 3). Two pick-ups are used, PU 1 with μ_1 = 7.676 and PU 2 with μ_2 = 7.388 (for an average tune value of 8.882). The signals from the two pick-ups are added in a power combiner. By adjusting the attenuators (the total gain is kept constant) the phase of the feedback is then adjustable from + 27° to - 50°.

The system has been tested on a high density stack of 35 A (Fig. 4) with BTF's measured at the lowest transverse sideband. With the present feedback system the stack is very close to the stability limit (the average Q-value of this stack was rather low (Q_{AV} = 8.865) so the system increased slightly the inductive impedance). The feedback system was then adjusted until the beam transfer junction was symmetrical. The electronic gain was kept constant. From the stability diagram it is seen that the stability margin has been increased by a factor of 3.

At higher frequencies the transverse impedance becomes more inductive but the total impedance decreases as the skin effect falls off5). Therefore, a total compensation of the transverse coupling impedance at the lowest sideband will cause overcompensation at higher frequencies and the stability margin kept large all over the frequency range of the feedback system.

An inductive compensation of the (n-Q) term will give a similar compensation of the (n+Q) term provided that the electronic delay of the feedback system equals the time of flight of the particles between pick-up and kicker6).

ACKNOWLEDGEMENT

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REFERENCES

1) L. Thorndahl, A. Vaughan, Transverse Feedback for the ISR, IEEE Trans. Nucl. Sci. NS-20, No. 3, pp. 807-808

2) J. Borer et al., ISR Beam Monitoring System using 'Schottky Noise' and Transfer Function, Contribution to this Conference

3) L. Vos, J.-Y. Hemery, Procedure for Obtaining Transverse Wall Impedance and Working Line from Transverse Beam Transfer Function Measurements, Contribution to this Conference.

4) J. Borer et al., Information from Beam Response to Longitudinal and Transverse Excitation, IEEE Trans. Nucl. Sci. NS-26, No. 3, pp. 3405-3408.

5) A. Hofmann, B. Zotter, Measurement of Beam Stability and Coupling Impedance by RF Excitation, IEEE Trans. Nucl. Sci., NS-24, No. 3, pp. 1487-1489.

6) D. Möhl, G. Petrucci, L. Thorndahl and S. van der Meer, Physics and Technique of Stochastic Cooling, CERN-PS-AA/79-23, 23rd July 1979.