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EXPERIMENT : Coupling Beam Transfer Function Measurement and Linear Coupling Compensation with the Skew Quadrupole.

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EXPERIMENTERS : J.P. Koutchouk and A. Poncet

1. Motivation

From ISR experience[1)], the measurement of the coupling beam transfer function provides a very sensitive tool for fine compensation of betatron linear coupling using skew quadrupoles. The idea was to apply this technique to the AA.

2. The coupling beam transfer function

A beam of protons injected via the loop was excited horizontally via the transverse feedback kicker with a swept frequency voltage from the ACR's HP 8505 A network analyzer, into which was fed back the beam response taken from the vertical Schottky PU. The $(11 + Q_V)f_r$ line was observed, as it proved to be naturally stable.

With the skew quadrupole set at 0 A, Fig. 1 shows the evidence of H-V coupling from a typical beam transfer function for a beam on the injection orbit and for the time's normal machine tune of $Q_H - Q_V \cong 0.005$ at $f_r = 1846$ kHz. As expected with coupling between two resonators, the response is relatively high at the edges' natural vertical and horizontal frequencies (these being relatively well separated with $\Delta Q = 0.005$), and the phase between excitation and response changes by 360°.

3. Amplitude dependence on $Q_H - Q_V$ and skew setting

It can be shown[1)] that the coupling BTF is proportional to the coupling vector C of the machine, in which the real part C_r represents the skew quadrupole field (localised or randomly distributed) existing in the machine. Thus, searching for the skew quadrupole current which minimizes the amplitude of the coupling BTF allows coupling compensation optimisation.

Furthermore, the coupling BTF depends on the distance of the working point from the diagonal of the tune diagram, and this on a more complicated way, but with a maximum amplitude response when sitting on the diagonal.

Fig. 2 shows a typical coupling BTF done at 1846 kHz with $Q_H \cong Q_V$. The ratio of beam response to excitation was about -30 dB (i.e. 3%), used as arbitrary reference and which was about the maximum found at all frequencies for 0 A in the skew quadrupole. When moving from the diagonal by $\Delta Q \cong 0.005$, the response fell by 10 dB (-40 dB, i.e. 1%). Subsequent fine optimisation of the skew quadrupole current allowed a further 20 to 25 dB reduction (-60 dB, i.e. 1 o/oo). The curve in Fig. 3 gives an example of the varying amplitude response with the skew quadrupole current.

The exercise of skew setting optimisation at various orbit frequencies using the coupling BTF was done and this resulted in the curve shown in Fig. 4 where it is seen that the modulus of the coupling varies almost linearly across the machine aperture.

4. Coupling BTF dependence on large coherent oscillation amplitude

Since the coupling BTF depends on $Q_H - Q_V$, the idea was to point at an eventual variation of Q with amplitude using the coupling BTF. A beam was then injected, kept on injection orbit, the initial coupling BTF measured, and subsequently kicked horizontally with a one-kicker module shot and the coupling BTF re-measured. This is shown in Fig. 5 where the amplitude response after the kick indicates some difference. A look at one horizontal Schottky band around 77 MHz on the spectrum analyser did show a slight change in Q_H (Fig. 5).

5. Conclusions

The coupling BTF does provide a very sensitive mean to optimise coupling in the AA. More than 90% of the natural linear coupling could be compensated via the skew quadrupole current optimisation.

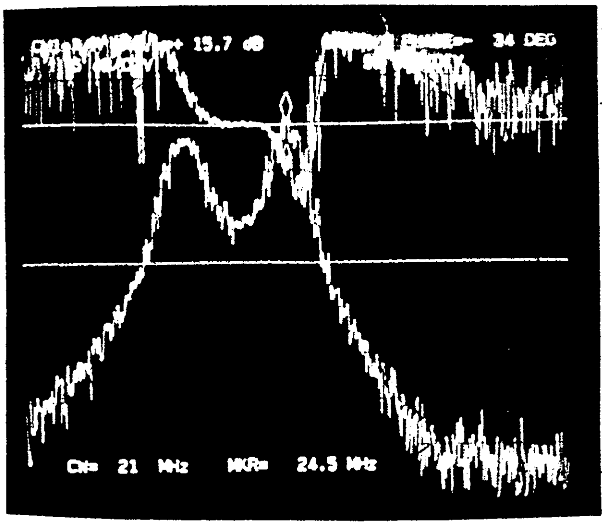
First attempts to use the coupling BTF strong dependence on $Q_H - Q_V$ to point at Q variations with amplitude were positive but more experiments are needed to assess on this subject.

Reported by A. Poncet

Reference

1. Linear betatron coupling measurement and compensation in the ISR, J.P. Koutchouk, XIth International Conference on High Energy Accelerators, CERN, 7-11 July 1980.

example:
$f_r = 1846$ kHz
$Q_H - Q_V \simeq .005$



— phase shows a 360° phase jump as one should expect

— amplitude response shows strong coupling: response is high for each resonator frequencies which are well separated.

FIGURE 1: ↑

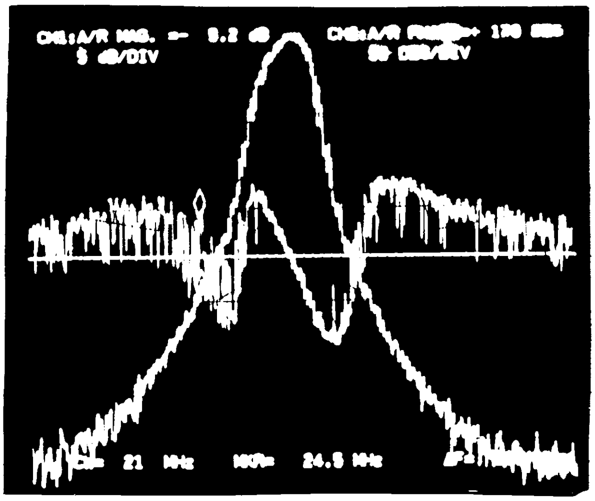
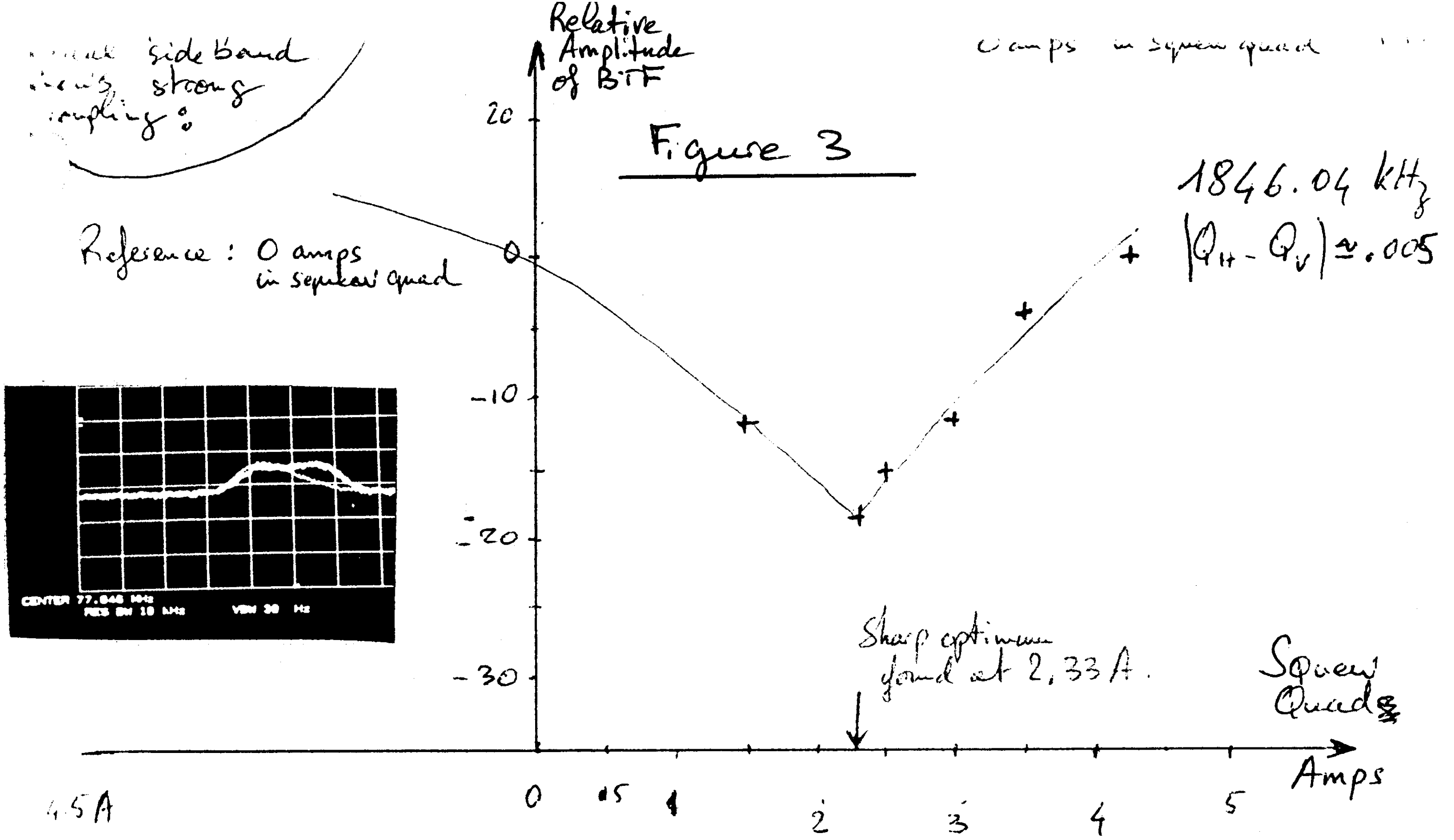
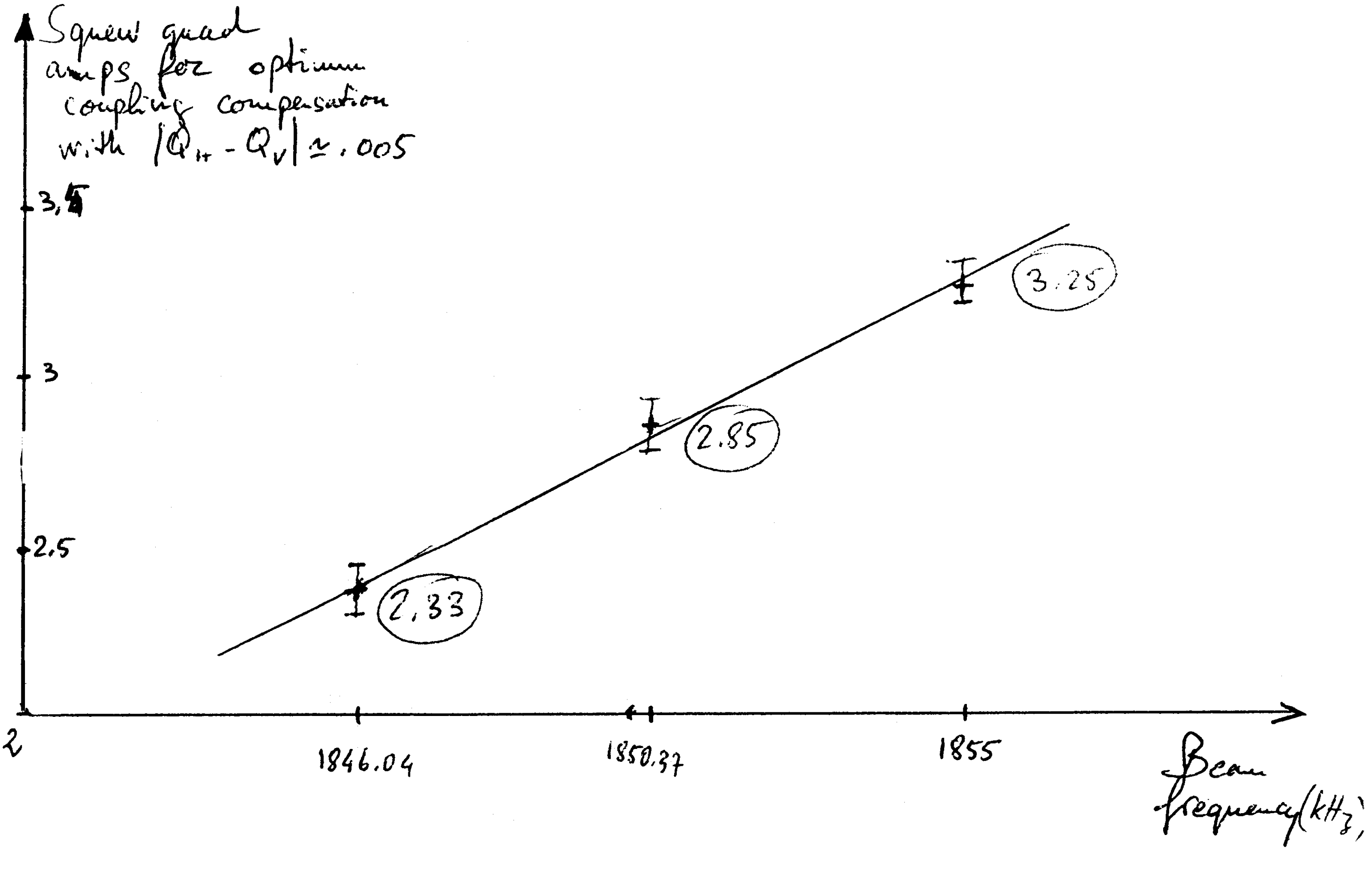


FIGURE 2: ←

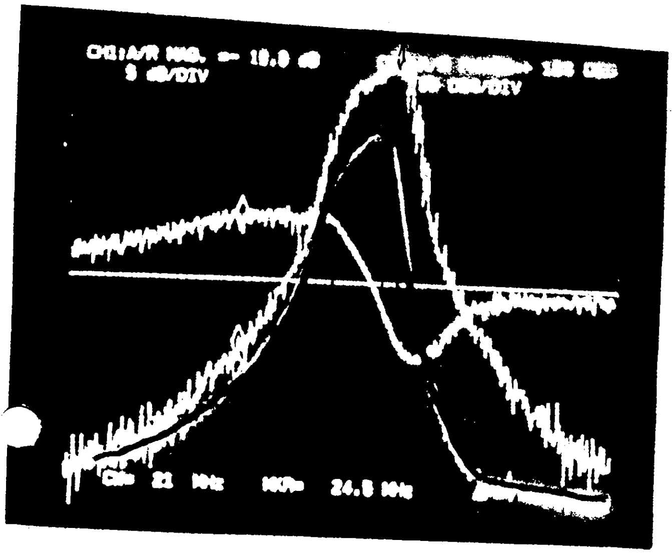
Typical Coupling BTF at 1846 kHz with $Q_H \sim Q_V$


side band
strong
coupling:
0 amps in squew quad
Relative Amplitude of BTF
Figure 3
1846.04 kHz
$|Q_H - Q_V| \simeq .005$
Reference: 0 amps in squew quad
20
0
-10
-20
-30
Sharp optimum found at 2,33 A.
Squew Quads
Amps
0
1
2
3
4
5


Squew quad amps for optimum coupling compensation with $|Q_H - Q_V| \simeq .005$
3,5
3
2,5
2
2,33
2,85
3,25
1846.04
1850.37
1855
Beam frequency (kHz)

- Figure 4 -

2) effect of horizontal large coherent amplitudes (filling the aperture with a one inj. kick module shot) on the coupled BTF, while sitting on the $Q_H = Q_V$ line at 1846 kHz:

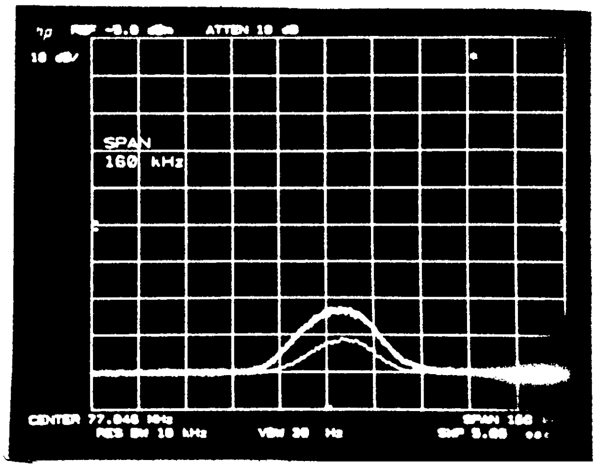


blue curve is after the kick:

1846 kHz
$Q_H = 2.2619$
$Q_V = 2.2629$

BUT:

the horizontal betatron side band shows a slight shift toward larger Q_H with large amplitude



from that ΔQ_H is calculated to be ν+.0016

Figure 5:

COUPLING BTF DEPENDANCE ON LARGE HORIZONTAL COHERENT OSCILLATIONS