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THE 50 MHZ TRANSVERSE FEEDBACK SYSTEM IN THE CERN ISR

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Summary

One of the intensity limits in the ISR is imposed by the transverse coherent instability. The intensity at which the instability occurs may be raised by Landau damping, i.e. increasing the tune spread of the stacked beam. However, due to non linear resonances, the maximum tune spread is limited. A vertical feedback system which detects and damps the first eight modes of the instability has succeeded in increasing the intensity limit by a factor of ∿1.6. Recently this factor has once again become insufficient due to the increase in intensity resulting from improvements in the longitudinal density and vacuum system. A new 50 MHz feedback system has now been installed which damps the first 166 modes of the instability. Hence at low chromaticity values the critical intensity is raised by around another factor of two. The electronic gain of this system decreases with frequency in order to limit the blow-up of vertical oscillations due to electronic noise and to reduce phase errors at high frequencies. The 50 MHz system has been used to explore the ISR vacuum limit to intensities of 39 A.

Introduction

In the ISR the high-intensity coasting beams are stabilized against transverse coherent instabilities partly by a feedback system[1] and partly by sextupolar fields. The continuous vacuum improvements have allowed even higher intensities which would require even stronger sextupolar fields for stack stability.

Experience with high-intensity stacks has shown that non-linear resonances of order lower than eight provoke unacceptable background rates for data taking. This condition limits the strength of the sextupolar fields (or the chromaticity) which may be applied. For a fixed maximum chromaticity the critical current is increased by increasing the frequency range of the feedback system. For this reason the range of the transverse feedback system has been increased to 50 MHz. Above 50 MHz a significant amount of Landau damping comes from the spread in frequency resulting from the stack momentum spread.

Experimental Results

The transverse stability criterion has been shown[2] to be

$$\frac{Z_L}{|n-Q|} \leq \frac{F}{G}\frac{E_o}{e}\frac{2Qb^2}{IR^2}\beta\gamma\frac{\Delta p}{p}\,|\,(n-Q)\eta - \xi Q\,| \quad ....(1)$$

where Z_L is the longitudinal impedance, F and G are form factors, I is the stack intensity, $\frac{\Delta p}{p}$ is the stack fractional momentum spread, Q is the tune value, $\eta = \frac{1}{\gamma^2} - \frac{1}{\gamma_t^2}$ and ξ is the chromaticity $\frac{Q'}{Q}$. Hence the theoretical intensity at which an instability will arise is given by

$$I_{critical} = \frac{1}{\frac{Z_L}{|n-Q|}}\cdot\frac{F}{G}\cdot\frac{E_o}{e}\cdot\frac{2Qb^2}{R^2}\beta\gamma\frac{\Delta p}{p}\,|\,(n-Q)\eta - \xi Q\,| \quad ....(2)$$

The values of F, G and b have been calculated for a typical ISR stack of $\frac{\Delta p}{p} = 3.2\%$, and the longitudinal impedance has been evaluated[3] from the shift of the phase oscillation frequency in a bunched beam. Using these figures ($F = 0.64$, $G = 1$, $b = 0.033$, $\frac{Z_L}{n} = 20\Omega$) for 26 GeV/c in the ISR gives, from equation (2),

$$I_{critical} = 2.645\, Q\,|\,(n-Q)\eta - Q'\,| \quad ......(3)$$

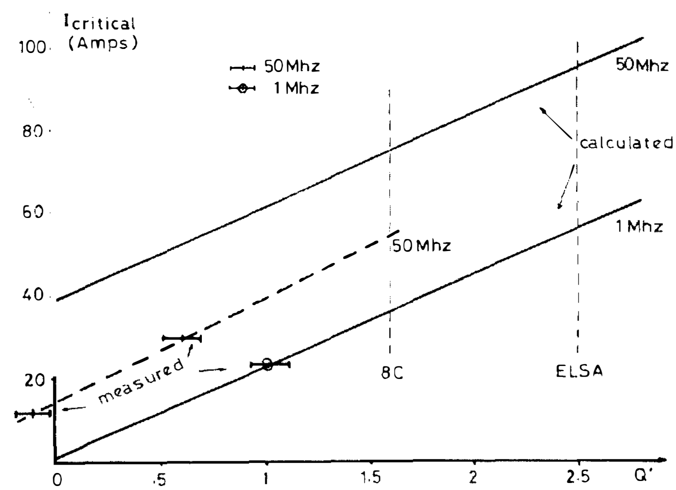

Fig 1 - Critical Currents as function of Q'

Fig. 1 shows a comparison of the critical current as a function of ξQ for the old feedback system (1 MHz, n = 13) and the new system (50 MHz, n = 166). It can be seen that if the longitudinal impedance (and hence transverse impedance also) remains substantially constant from 1 MHz to 50 MHz then the critical current should be increased by around 40 A by using the 50 MHz system.

In the ISR transverse stability tests have been performed as follows: Stacking is performed in such a way as to produce a full aperture $\left(\frac{\Delta p}{p} = 3.2\%\right)$ stack with an almost rectangular longitudinal density distribution. The ξQ of the stack (Q') is then reduced in small steps from its initially high value. After each reduction the stack is subjected to a transverse perturbation. When the Q' is made sufficiently small a coherent transverse instability arises and the stack is lost. The results of several such tests are also shown in Fig. 1. It can be seen that for the 1 MHz system the measured results are remarkably close to those calculated. However for the high-frequency feedback system the measured critical currents are significantly below those calculated. The discrepancy in the results could be explained by any combination of the following:

(i) an instability which arises within the stabilising frequency range of the transverse feedback system. In practice this could arise due to insufficient gain at higher frequencies or an undetected large phase error. From Fig. 2 it can be seen that the gain is reasonably constant up to around 25 MHz but decreases at higher frequencies.

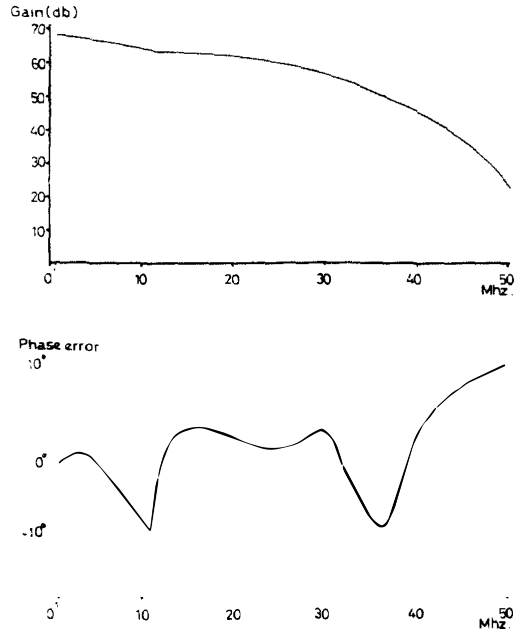

Fig 2

(ii) The impedance $\frac{Z_L}{(n-Q)}$ has been assumed to remain constant from 1 MHz to 50 MHz in order to obtain equation (3). If this impedance is larger at or above 50 MHz, then a reduction in critical current will result.

(iii) For the stability tests all possible precautions are taken to ensure that the chromaticity is constant across the aperture. However this is not always possible because of the difficulty in measuring very accurately the tune values in the presence of a high-intensity stack. This problem is aggravated in the presence of the 50 MHz transverse feedback system. A localised reduction in the chromaticity will cause the transverse instability to arise at a higher than calculated value of the chromaticity.

Nevertheless the measured results indicate that with a Q' of ~0.5 the higher frequency feedback system increases the critical current by a factor of two (14 A). This system has been used for testing the vacuum limit in the ISR. For these tests a maximum current of 38.93 A was reached on a working line with a ξQ of 1.6. Without the feedback system such high intensities may only be reached by increasing the Q' of the stack and hence crossing lower order non-linear resonances.

Hardware

Fig. 3 shows a simplified block diagram of the feedback system. The vertical pick-up (PU and the vertical correction kicker are separated by an odd number of quarter betatron wavelengths. The group delay is approximately equal to the time of flight of the particles between the pick-up and the kicker. The signals from the two vertical pick-up plates are impedance transformed and amplified in a special pick-up head amplifier with two discrete dynamic ranges (see Noise). The difference signal is taken with a 75Ω cable transformer and subsequently passed through a 40 dB HP 462A

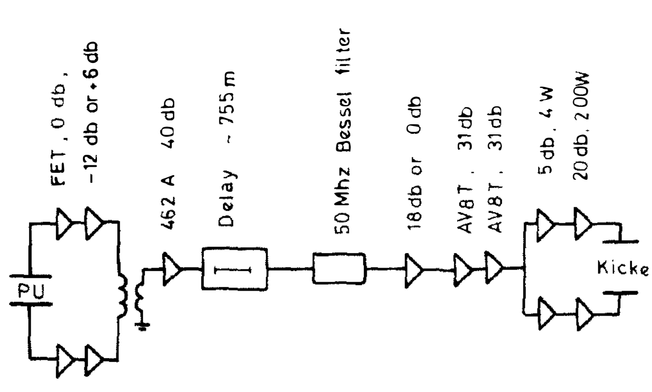

Fig. 3. Block diagram of electronics.

amplifier. A low pass Bessel type filter with constant group velocity limits the bandwidth of the system.[1] This filter attenuates almost linearly with frequency and at 50 MHz the gain is reduced by approximately 50 dB. The phase errors over this frequency range are less than 10° (see Fig. 2).

Another variable gain amplifier with two discrete gain values (18 dB or 0 dB) precedes an Avantek 8AV and two 4 W medium-power amplifiers driving the final 200 W power amplifiers. The two deflecting kicker plates are push-pull 50Ω transmission line structures of length 0.8 m.

The plates are powered by two distributed amplifiers, using six 4C × 600 Varian tetrodes each.

The overall gain and phase characteristic (Fig. 2) between pick-up and kicker has been measured with a network analyser, using in the reference channel a low loss transmission line with a delay equal to the particle time of flight between pick-up and kicker.

Noise

White noise from the preamplifiers will, via the loop and the kicker, give random kicks to the beam, causing an increase in the incoherent vertical betatron amplitude and a corresponding reduction in luminosity.

The pick-up head amplifiers can be used in two modes:

a) large dynamic range, low gain (-12 dB), higher noise figure,

b) low dynamic range, large gain (+6 dB), lower noise figure.

A large dynamic range for the feedback system is required during short stacking periods in order to avoid saturation of the head amplifier caused by large signals from injection errors and/or longitudinal bunch structure.

During long periods with coasting beams, however, the signals in the loop are $\sim$1000 times smaller and the dynamic range can be reduced without the risk of saturation.

For beam stability it is believed necessary to maintain the overall electronic gain (2400 from pick-up plate to kicker plate) constant when switching from one dynamic range to the other. For gain compensation an amplifier with variable gain is inserted after the Bessel filter. The amplifier gains are changed simultaneously in less than one revolution period.

At 26 GeV/c the rms voltage across the kicker plates due to white noise is, in the low-noise case, 100 mV, corresponding to a random kick (r) of 0.37×10^{-8} m expressed at an intersection point of the ISR. The mean square oscillation amplitude increases with nr^2 (n number of turns, $n = 3\times10^{10}$ for 30 hours). If the initial rms oscillation amplitude is 1 mm, then the beam height should increase by approximately 0.7% per hour due to the white noise. In practice the growth rate is significantly smaller, since the feedback system removes some of the oscillation caused by the white noise. Very low beam decay rates (1 part per million/min) have been obtained during long stable beam physics runs using this system.

Conclusions

One of the intensity limits in the ISR is imposed by the threshold of the transverse coherent instability. The level at which this instability arises has been significantly increased by the use of a high-frequency electronic feedback system. This has allowed the other ISR performance limits (the longitudinal phase plane density and the vacuum) to be explored and improved.

Acknowledgement

D. Cocq built the variable gain pick-up amplifier and A. Vaughan the variable gain amplifier inserted after the Bessel filters.

References

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