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TRANSVERSE FEEDBACK FOR THE ISR

by

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Summary

A feedback system designed to assist Landau damping against resistive wall instabilities in the vertical and horizontal planes is described. The purpose of the feedback system is to make it possible to run the ISR with reduced Q-spread, so that low-order resonances can be avoided at high intensities. An important problem in the system is the electronic noise of the amplifiers which can cause excessive long-term vertical beam blow-up if the bandwidth is too large. Only four transverse modes are included in the loop.

General Principle

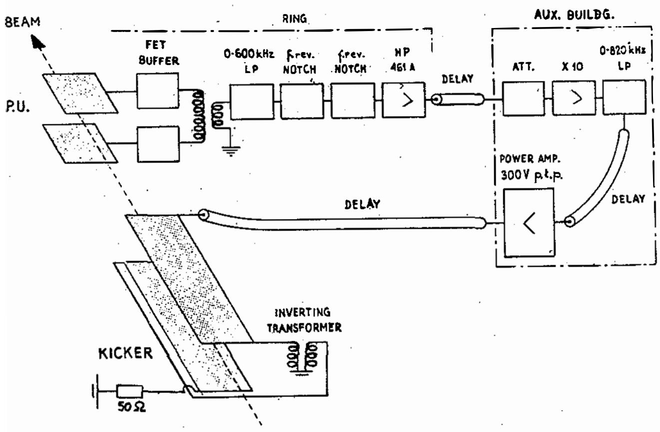
Dipolar beam oscillation can occur in many modes, each mode being characterized by a mode number N and having the frequency $f_\beta = (N-Q_{V,H})f_{rev}$ at fixed azimuth. The oscillation in a given mode depends on the coupling constants U and V between beam and chamber;[1] $(U + V)/2\pi$ being the real and $V/2\pi$ the imaginary part of the Q-shift in the fictitious zero Q-spread case. Furthermore, V is proportional to $f_\beta^{-\frac{1}{2}}$ (skin effect). It has been shown theoretically[1] that for the ISR parameters, U << V, at least for the modes 9, 8, 10 and 7 which have the lowest frequencies, and that therefore the necessary Q-spread to suppress dipolar instabilities should be proportional to V. A significant reduction in necessary Q-spread should be gained by stabilizing, say the above-mentioned four modes, with active feedback. The necessary Q-spread with feedback should theoretically be $[(9-Q/(11-Q)]^{\frac{1}{2}} = F$ times the Q-spread in the no-feedback case. When Q = 8.65, F = 0.386.

To estimate the loop gain of the system we use the information from ref. 1 that the typical zero Q-spread growth time of the 9th mode instability is around 100 turns for a 10 amp stack. Consequently a reasonable average gain $\delta/2$ per turn should be between 1/200 and 1/50. Alternatively, using ref. [2], p.2, and assuming a typical r.m.s. Q-spread of 0.006, as used during our experiments to suppress the instabilities, one calculates the coherence time to be around 38 turns. This last consideration indicates that a higher average gain $\delta/2$ of say between 1/80 and 1/20 is necessary.

Hardware

The hardware consists of the pick-ups and deflection structures separated by 8.75 betatron wavelengths, the amplifier chain, filters to restrict the bandwidth, and a delay network to make the phase of the feedback negative at the frequencies of interest (see Figure). The group delay of the whole system should equal the time of flight of the proton between pick-up and kicker (3.2 μs).

BLOCK DIAGRAM OF VERTICAL FEEDBACK SYSTEM



The signals from both plates of the pick-up are buffered by two FET-source followers, then feed a 600 Ω differential transformer. At this point we have three filters, one a low pass cutting at 600 KHz and the other two notch filters for revolution frequency components. After these is a Hewlett-Packard 461 A Amplifier modified for 600 Ω input impedance and two remotely controlled attenuators. One is a commercial step attenuator and the other has five preset infinitely variable positions. In normal use 6 dB loss is held in the step attenuator and the overall gain is set on the other.

Following the attenuators is a small amplifier with a gain of 10 driving a 820 kHz low pass filter and a length of coaxial cable to give the required delay and then the final amplifier. This is a solid state, class A B amplifier capable of 150 V peak output on 50 Ω, with a power bandwidth of 1 MHz.

For the output stage we use a transformer coupled system with four units in parallel with a common driver. For reasons of reliability the amplifiers have very large heat sinks. Some redundancy is inherent in the design due to the parallel output stage. The deflecting kickers are push-pull 50 Ω transmission line structures of 0.8 metres length for the vertical plane and 2 m for the horizontal. One plate is driven directly and then the signal is inverted in a transformer to drive the other. The line is terminated in a 50 Ω load. The low-level apparatus is situated underneath the pick-up station and the high-level gear is in two auxiliary buildings. Controls are in the main control room and at some later date will be connected to the ISR computer.

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Noise

Reductions in ISR luminosity due to noise will mainly come from vertical beam blow-up. White noise in the first amplifiers of the chain causes at each passage of a proton through the kicker r.m.s. random kicks of value ν.[3] We first neglect the fact that the coherent oscillations caused by the kicks are partly removed by the feedback system itself, before they become incoherent due to the Q-spread. We assume therefore that the loop is open. Random kicks add quadratically.

Unrestricted aperture

The initial mean square amplitude a_o^2 of the protons is increased after n revolutions by $n\nu^2$.[3] Assuming $a_o = 1$ mm, $n = 3 \cdot 10^{10}$ (30 h) and $\nu = 0.37 \cdot 10^{-8}$ m (this is approximately the noise when the loop gain g = 0.1 and at 10 A circulating current), we obtain an increase in r.m.s. amplitude of $\sim$20%.

Restricted aperture

We consider the blow-up as a diffusion process.[4,5] The vertical aperture limitation is at $\pm R$. The dominant mode of this process in the normalized two-dimensional phase plane is

$$J_o(2.405\rho/R)\exp(-n/m)$$

where $\rho = (z^2 + (z'\beta_v)^2)^{\frac{1}{2}}$, $m = 0.69 \frac{R^2}{\nu^2}$ and J_o is the zero order Bessel function. The loss rate for R = 6 mm (intersection region) and the parameters already used is $0.92 \cdot 10^{-5}$/min.

In ref. 4 we see that the fact that the loop is closed should theoretically reduce the above-mentioned loss rate by a factor 2 for $\delta/\Delta Q = 5$, where ΔQ is the r.m.s. Q-spread.

Experiments

Experiments with provisional set-ups and with the definitive equipment recently installed have so far yielded a gain of a factor $\sim$1.67 in the Q-spread required to stabilize a beam of 7 A (F = 0.6). Noise experiments with a restricted aperture have shown loss rates agreeing with calculations within a factor 2.

The optimum gain δ has turned out to be between 0.1 and 0.2. This is 5 to 10 times higher than expected. The reasons are not understood yet.

Acknowledgement

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References

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