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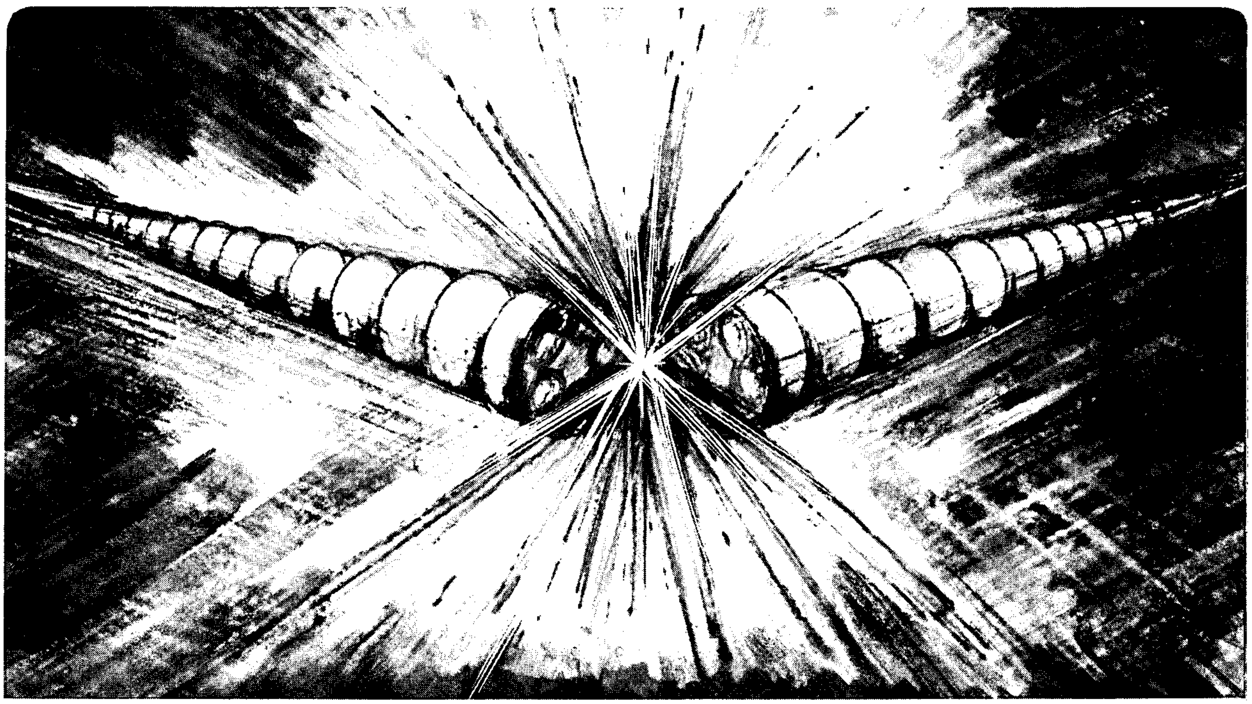

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Longitudinal and Transverse Feedback Kickers for the ALS

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Abstract

We describe the development of electromagnetic kickers for coupled-bunch feedback systems at the ALS. Transverse kickers are of a stripline design with one kicker per plane, operating in the baseband, 10 kHz to 250 MHz. Longitudinal kickers are of a coaxial design with electrodes paired in series operating over the band 1.00 to 1.25 GHz. Operating-band measurements and parasitic impedance measurements are presented. Power levels from beam induced signals are presented. Fabrication techniques are discussed.

1. INTRODUCTION

Broadband coupled bunch feedback systems using a bunch-by-bunch technique are being commissioned at the ALS [1,2]. In order to provide a corrective kick for each coupled-bunch mode a bandwidth appropriate to the bunch spacing is required, both in the feedback system electronics components, the pickups, and the kickers. All coupled bunch modes appear as sidebands around orbit harmonic frequencies in the beam spectrum within the frequency range pf_b to $(p+1/2)f_b$, where f_b is the bunch frequency and p is an integer. For the ALS, with a 500 MHz RF system and every bucket filled, this bandwidth requirement is 250 MHz. The response of the kicker structure must be such that the feedback signals applied do not persist significantly from bunch to bunch.

The nominal feedback system voltage kick requirements of 1.5 kV per turn in the longitudinal direction and 1.6 kV per turn in the transverse directions are determined from the beam impedances of the storage ring and estimated injection conditions [3]. The kickers should provide a large shunt impedance in their operating band in order to minimize the expenditure on costly broadband high power amplifiers.

Parasitic beam impedance in the kickers may result in heating of components, and possible excitation of beam instabilities, and should be as small as possible. The periodic nature of the structure acting as a pickup also gives rise to considerable power coupled from the beam, with a spectrum extending to tens of gigahertz for the nominal rms bunch length of 12 ps. This power is dissipated partly in absorptive loads on the upstream terminals, and part is incident upon the power amplifier connected to the downstream terminals.

Two transverse kickers are installed in the ALS, one for each plane. Four longitudinal kickers are installed.

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2. TRANSVERSE KICKERS

The transverse kickers are of a stripline pair design, with one kicker per transverse plane to improve efficiency over a kicker combining both planes in a single structure. The curved electrodes of a kicker can be seen in Figure 1.

Figure 1. Transverse kicker detail showing electrodes

Each electrode appears as a 50 Ω transmission line when the pair is driven differentially (opposite polarity on electrodes), which provides a transverse deflection of the beam passing through the structure. Each electrode is individually powered by a broadband power amplifier, the phase shift between the electrodes being introduced in a low power 180° power splitter feeding both amplifiers per plane. The transverse shunt impedance of the kicker is given by [4]

$$R'_{shunt} = 2Z_l\left(\frac{g_{trans}}{kh}\right)^2 \sin^2\theta$$

where Z_l is the electrode line impedance (50Ω), g_{trans} the geometric coverage factor, k the wavenumber, h the electrode separation, and θ=kl where l is the length of the electrodes. The angle subtended by the electrodes is 120°, giving g_{trans} approximately 1.2, and the separation between electrodes is determined by the beam stay-clear aperture to be 70 mm.

Longer electrodes give a greater maximum shunt impedance, however the maximum length of the electrodes is determined by the need for each bunch to be driven independently of the previous bunch - the filling time plus the bunch passage time through the kicker (both determined by the electrode length) must be less than or equal to the bunch separation time. This gives a maximum length of half the bunch spacing, 30 cm for the ALS case. The kickers were chosen to operate in the baseband, 10 kHz to 250 MHz. The kicker transverse shunt impedance then peaks at the low frequencies of the coupled bunch modes driven by the strong resistive wall impedance, maximizing the efficiency of the device for these modes.

Measurements of the kickers involved operating-band and parasitic mode measurements. In the operating band, 10 kHz to 250 MHz, the insertion loss when driven in odd mode is less than 0.3 dB, return loss better than 15 dB. The transverse shunt impedance was measured by use of a network analyzer measuring transmission from a twin wire line, mounted along the kicker axis, to the upstream kicker terminals. The twin wire driven in odd mode by use of a 180° hybrid power splitter induces differential signals in the electrodes. Upstream electrode terminals were connected via a 180° hybrid, and S_{21} measured from the twin wire to the combined signals from the electrodes. The transfer impedance (pickup impedance) is determined using the relation:

$$\left| Z'_{transfer} \right| = \frac{\sqrt{R_0 R_{wire}}}{\Delta x} \left| \frac{S_{21}^{pickup}}{S_{21}^{reference}} \right|$$

where Δx is the separation of the wires (with correction for center of current distribution), R_0 the terminating impedance (50 Ω), R_{wire} the impedance of the twin wire transmission line (100Ω), and $S_{21}{}^{reference}$ is the transmission measured through the twin wires in a smooth reference vessel and corrects for the effects of the 180° hybrids and impedance mismatches in the apparatus. From this the kicker shunt impedance is determined [4]:

$$R'_{shunt} = \frac{\left(2c \left| Z'_{transfer} \right|\right)^2}{R_0 \omega^2}$$

The measured transverse shunt impedance is shown in Fig. 2.

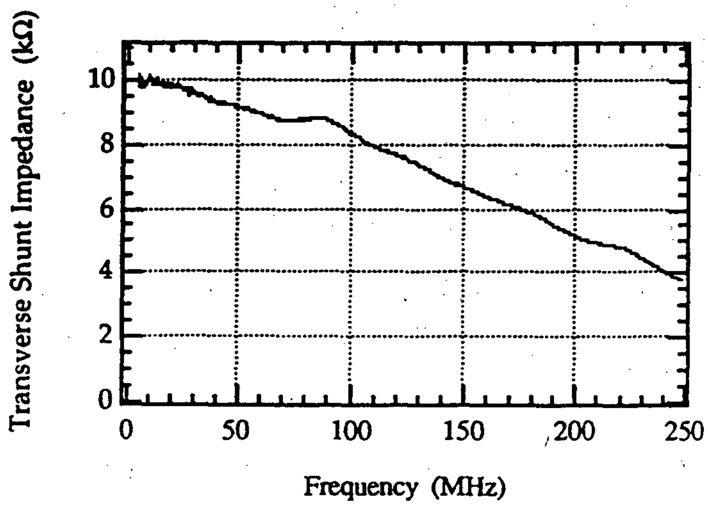

Figure 2. Transverse shunt impedance

The kickers may also be driven with a single electrode connected, in which case the shunt impedance follows the form of figure 2 but with approximately half the magnitude, and the input impedance is changed to 60 Ω. This configuration has been used in preliminary tests of the ALS transverse feedback system [1].

Each electrode will also couple to the beam as a longitudinal pickup. For a multibunch beam (all buckets filled) there is very little signal from the electrodes since the beam spectrum coincides with the zeroes of the pickup spectrum for the device. For a given current per bunch, the worst case is with alternating buckets filled, when the kicker spectrum maxima coincide with the beam harmonics. We do not anticipate the ALS operating under such conditions. For a single bunch of 10 mA a total of approximately 5 W is produced at the kicker terminals. Since the directivity of the electrodes decreases with increasing frequency, and the beam spectrum extends into the 10's of GHz range, the downstream port experiences an appreciable part of this power. A limit of 20 mA has been placed on single-bunch operation in order to protect the feedback system amplifiers from the voltage pulses of hundreds of volts in amplitude induced by the single bunch.

The shunt impedance of the kicker driven as a longitudinal device (in even mode, with both electrodes at the same polarity) peaks at 33 Ω. This configuration has been used with the prototype longitudinal feedback system to provide longitudinal kicks in the ALS while awaiting the installation of the longitudinal kickers [2].

Measurements of the longitudinal beam impedance of the kicker were made using a coaxial wire technique. The beam impedance is shown in figure 3. For a Q=1 resonator centered at the beam pipe cut-off frequency (3 GHz) we calculate the corresponding Z/n to be 53 mΩ. Weighting the measured impedance by the single-bunch spectrum we determine the effective loss parameter, which for a 12 ps bunch is 0.66 V/pC (35 mΩ effective z/n).

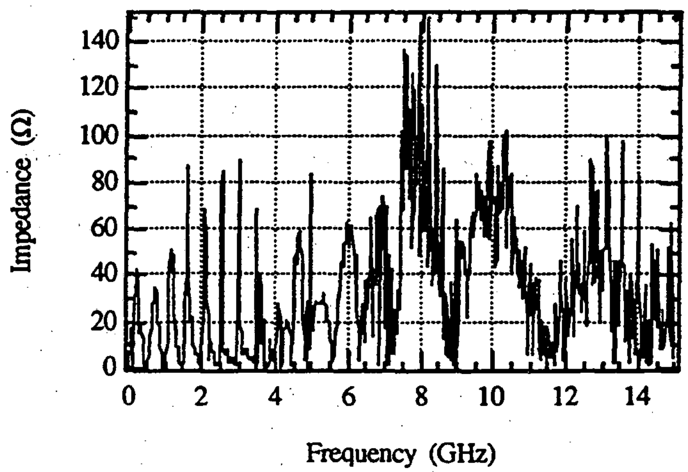

Figure 3. Transverse kicker beam impedance

3. LONGITUDINAL KICKERS

In order to improve efficiency, the longitudinal feedback kickers are of a two-in-series design. A pair of coaxial electrodes connected by a half-wavelength delay provide increased efficiency with an acceptable bandwidth, reducing the burden of costly broadband high power amplifiers [5]. Figure 4 shows a photograph of an electrode pair, machined from a single piece of aluminum. The longitudinal shunt impedance is given by [6]:

$$R_{shunt} = 4Z_l(n\,T)^2$$

where

$$T = \frac{\sin 2n\theta}{2n\cos\theta}\, e^{j\left(\frac{\pi}{2} - (2n-1)\theta\right)}$$

Z_l is the coaxial line impedance (25 Ω) and n is the number of electrodes connected in series.

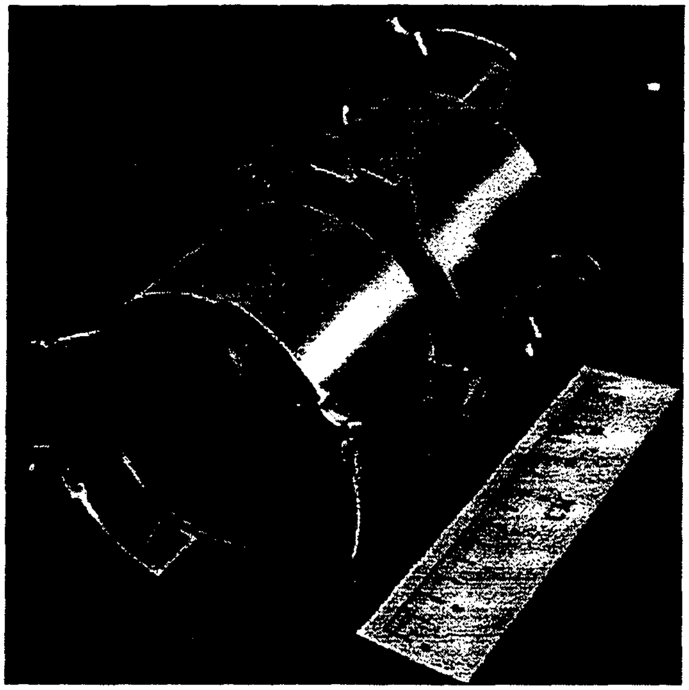

Figure 4. Longitudinal kicker electrode pair

Four such kickers are installed, powered in parallel, with appropriate delay between each kicker. Measurements were made by exciting a single coaxial wire on the kicker axis and detecting the sum signal of the upstream terminals. The longitudinal transfer (pickup) impedance is determined from

$$|Z_{transfer}| = \sqrt{R_0 R_{wire}} \left| \frac{S_{21}^{pickup}}{S_{21}^{thru}} \right|$$

Where S^{thru}_{21} is transmission measured through the coaxial line. The shunt impedance is then determined from [4]

$$R_{shunt} = \frac{(2\,|\,Z_{transfer}\,|)^2}{R_0}$$

Figure 5 shows the shunt impedance in the operating-band 1.00 - 1.25 GHz. A parasitic mode is present at 1.2 GHz due to the effects of the fringe reactances between the electrodes, this is not expected to cause operational problems. Insertion loss is less than 0.6 dB, return loss better than 10 dB.

Beam impedance measurements using the coaxial wire technique show resonances due to trapped modes in the coaxial structure. In order to reduce the power dissipated in these parasitic modes, a damping probe has been used to couple to the strongest modes and dissipate their power externally.

Heat dissipation within the electrodes is expected to be of the order of ten watts, and in order to improve the radiative heat dissipation, the surfaces of the electrodes and the vacuum chamber bore have been blackened by a plasma deposition of copper oxide, increasing the emissivity of the surfaces[7].

The effective loss parameter for an electrode pair is 0.44 V/pC, and using a simple broad band resonator the Z/n is 25 mΩ (20 mΩ effective).

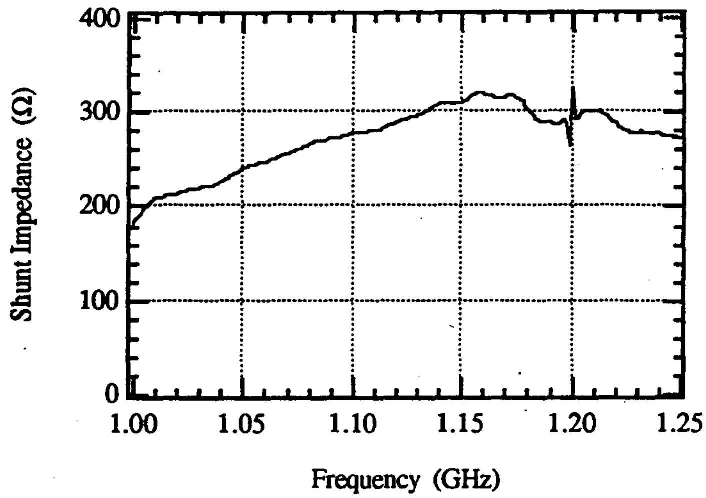

Figure 5. Longitudinal kicker shunt impedance

Acting as a pickup, the resulting power from a 400 mA multibunch beam is 365 W per electrode pair. A low pass filter may be used to reject out of band power toward the drive amplifier.

4. CONCLUSIONS

Kickers for the coupled bunch feedback systems of the ALS have been measured and installed. Transverse kickers have been used in preliminary tests of the feedback systems and have performed as expected. Tests of the longitudinal kicker are in progress.

5. ACKNOWLEDGMENTS

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