CONTROLLING THE RESISTIVE WALL INSTABILITY IN THE FERMILAB MAIN RING

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Abstract

The Fermilab Main Ring has a strong transverse instability identified as a resistive wall[1] . Previous methods of dealing with this problem have primarily been to find settings of tune, chromaticity, and octupole that result in stable operation. Controlling this instability in this manner has had limited success and reduces beam lifetime. A new damper system has been installed in the Main Ring to control this instability. This damper effectively provides a negative impedance to the accelerator to cancel the effects of the resistive wall. With this damper in operation we have been able to adjust the tune, chromaticity, and octupole settings to improve beam efficiency without becoming unstable due to the resistive wall of the accelerator.

INTRODUCTION

The transverse modes commonly referred to as the resistive wall, instability have previously been observed and measured in the Main Ring1. When running intensities above about 1 E13 in the machine it becomes necessary to make adjustments in the chromaticity and octupole circuits away from nominal settings to stabilize the beam. If adjustments are not made, the resistive wall will became strong enough to cause growth in the betatron oscillations until the beam hits the accelerator wall and is lost (fig 1 and 2). Notice that the growth rate in the vertical plane is significantly greater than that in the horizontal. This difference is due to the geometry of the rectangular beam pipe. In the Main Ring, on average, the horizontal aperture is about 2.7 times that of the vertical. Since the magnetic field produced from the wall currents changes as 1/r2, where r is the distance from the beam to the beam pipe, it is clear that the kick the beam receives will be much stronger in the vertical plane than it is in the horizontal. In the past there were two different damper systems built for the Main Ring. These systems are referred to as the Slow dampers and the Super damper. The Slow dampers operate in both planes and have bandwidth to damp first 40 modes. The super damper operates in the vertical plane only and can damp all 1113 modes. The main reason the slow dampers do not damp the resistive wall is that they are saturated by the revolution frequency of the beam. These dampers do not have any cancellation of the revolution frequency, or harmonics, and as a result are sensitive to the position of the beam through the beam position detector. The Super damper was built for the vertical plane because the resistive wall is so much stronger. This damper has the same problem with the revolution frequency as the Slow dampers but has more bandwidth to work on a bunch by bunch basis. This Super damper does provide some damping for the resistive wall but it turns out that the overall gain of the system may not be high enough and the result is that this damper is not sufficient for the resistive wall at high intensities. The horizontal plane was not addressed because it was thought that the resistive wall would not be an issue. As improvements to the upstream machines occurred, the beam emittance in all planes improved and the intensity threshold of the instability became lower. Consequently, the horizontal plane became the limiting factor on the intensity before the new dampers were implemented.

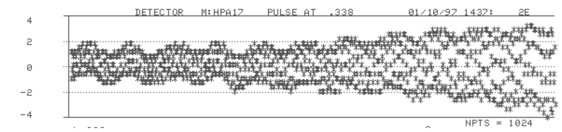

Fig 1. Turn by turn data from a BPM showing growth in horizontal betatron amplitude due to resistive wall. 1024 turns are displayed.

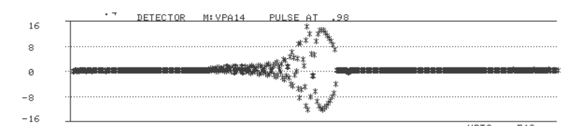

Fig 2. Turn by turn data from a BPM showing growth in vertical betatron amplitude due to resistive wall. 512 turns are displayed.

NEW DAMPER SYSTEM

The damper system consists of 4 beam position detectors, two for each plane, two kickers, low level electronics, and high level electronics. The beam position signals are detected at the RF frequency and down converted by mixing with the low level RF signal (LLRF). This process creates a phase synchronization problem between the LLRF and the beam due to the locations of the LLRF and the damper systems[3]. These two systems are separated by about 2 Km and the frequency shift during acceleration is about 291 khz.

The number of wavelengths that occur across this 2 Km distance changes as the LLRF frequency sweeps. This effect needs to be compensated in order for the damper to remain in phase with the beam. This compensation is accomplished with a phase unwinder and a phase locked loop. The phase unwinder monitors the LLRF frequency and makes course adjustments to the LLRF phase. The phase locked loop compares the phase of the beam and the phase of the LLRF signal and makes fine adjustments to the phase of the LLRF signal. Together these two phase corrections provide a stable, beam synchronous, LLRF signal for the damper

* Operated by Universities research Association Under contract with the U.S. department of energy.

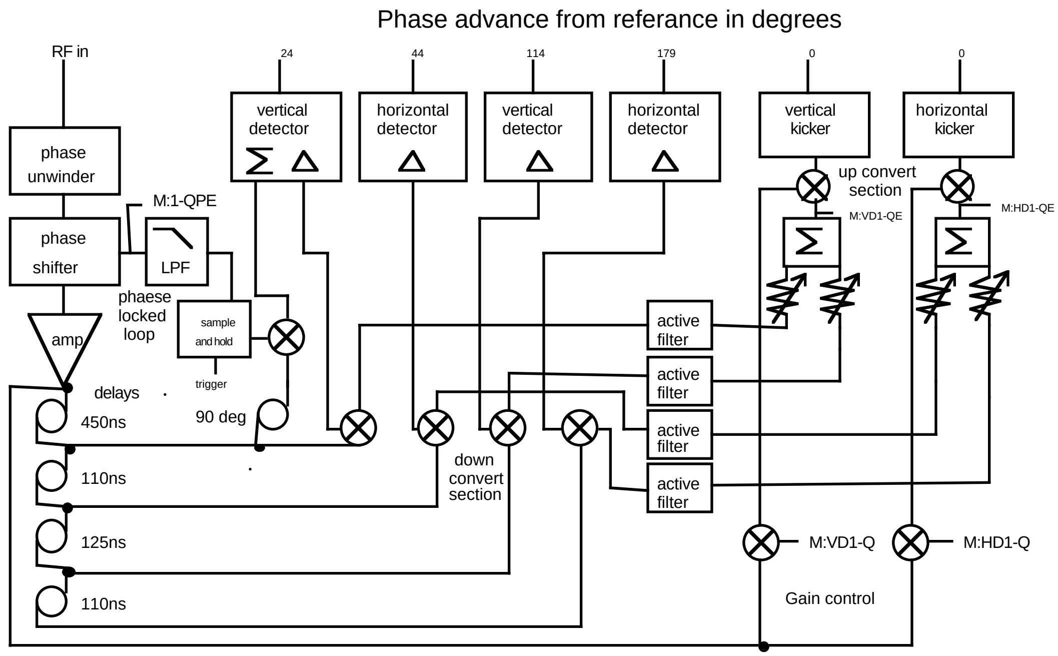

Fig 3. Block diagram of the damper system. M:1-QPE is the phase correction of the phase locked loop. M:HD1-QE and M:VD1-QE are horizontal and vertical corrections applied to the kickers. M:HD1-Q and M:VD1-Q are ramp generators which control the gain of the damper during the machine cycle.

system. This LLRF signal is sent through a series of delay elements which correct for cable length differences between detectors. The next stage of the damper is the down conversion section. In this section the difference signals from the beam detectors are mixed with the phase corrected LLRF signals. The reason this conversion is necessary is because the response of the beam detector is much greater at the RF frequency. The down converted beam signal is then sent through a series of filters to isolate the component due to the resistive wall instability. The frequency components induced on the beam from the resistive wall below the first revolution frequency are $\omega[1-f(\sqrt{})]$ and $\omega[f(\sqrt{})]$ .Where ω is the revolution frequency and $f(\sqrt{})$ is the fractional tune[2]. In the Main Ring the revolution frequency is 47 khz and the induced frequencies from the resistive wall are about 19 and 28 khz. There are actually three sections to these active filters: a high pass filter to eliminate the low frequency signals such as the synchrotron frequency, a low pass filter to eliminate the higher order modes and a sharp notch filter at the revolution frequency. These filters are tuned such that the phase shift is 0° at F_{rev} / 2. The filters are set in this manner is to provide an integer revolution period delay. Together these filters select the signal necessary to correct the instability from the resistive wall. In an ideal situation one would have one beam pickup with 90° of phase advance between the pickup and the kicker. A position error at the pickup would then be an angle correction at the kicker. Since ideal situations rarely exist in practice, two pickups are used with the signals summed to give the kick correction. The filtered signals are sent through variable attenuators and then summed together. This type of system is sensitive to the tune of the machine and these attenuators need to be adjusted if a different operating point is desired. After these signals are summed, they are up converted to the RF frequency of the accelerator. The gain of the damper is controlled by changing the level of the RF signal. The fundamental RF frequency is suppressed from this modulated signal leaving the two sidebands to be passed to the high level for final amplification. The high level final is a broad band solid state amplifier. This amplifier has a bandpass from 22 to 94 mhz and a power output of 1.6 Kw. There are two of these amplifiers for each plane, one for each plate. They are driven 180° out of phase with each other to provide the voltage at the kicker plates to deflect the beam. Diagnostics to aid in tuning the gain for optimal performance are also provided by this damper. The summed signals from the damper are fed into the accelerator control system and provide information as to the amplitude of the beam oscillations induced by the resistive wall.

MEASUREMENTS AND PERFORMANCE

Since the damper system provides a measurement of the strength of the resistive wall instability, it is a convenient way to measure the growth rate. By turning off all the dampers in the Main Ring and setting the chromaticity more positive at 8 Gev, it is easy to induce this instability. Figure 4 is an example of this situation.

Repeating this measurement for the horizontal plane and fitting to an exponential function will give a rough idea of the growth rates of the instabilities. In this case the growth rates came out to be 130/sec vertically and 23/sec horizontally[4]. The response of the damper's

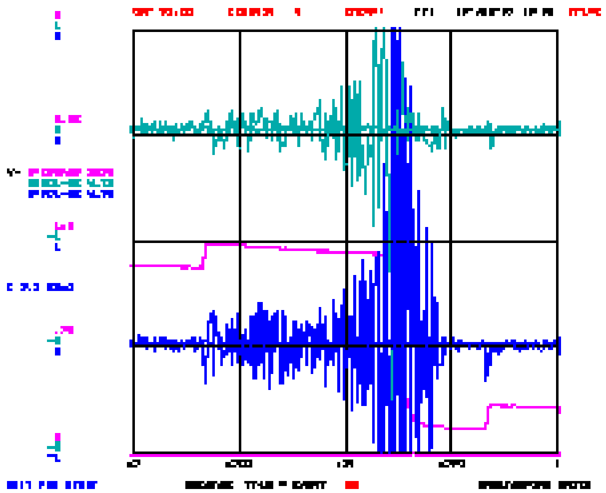

Fig. 4 Shows the growth rate of the instability in the vertical plane. Displayed is the beam current and the error signals from both damper planes. bottom trace is vertical error, center trace is beam current, top trace is horz error.

filters could effect this measurement. When analyzing the turn by turn data from fig. 2, the actual growth rate appears to be larger. Measurements of the damping rate can be found by measuring the open loop gain of the damper system and measuring the frequency spread of the betatron signal. This measurement gives a damping rate of about 10 turns and depends on the chromaticity. Another way to look at the damping rate is to look at the injection oscillations on the BPM turn by turn fig. 5.

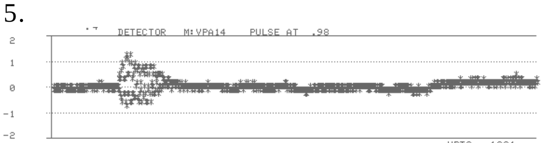

Fig. 5 injection oscillations and damping. 1024 points.

With this type of measurement it is difficult to obtain a valid number for the damping rate because the damper system saturates with vary small oscillations. This saturation causes linear damping until the oscillations become small enough for the damper to get out of saturation.

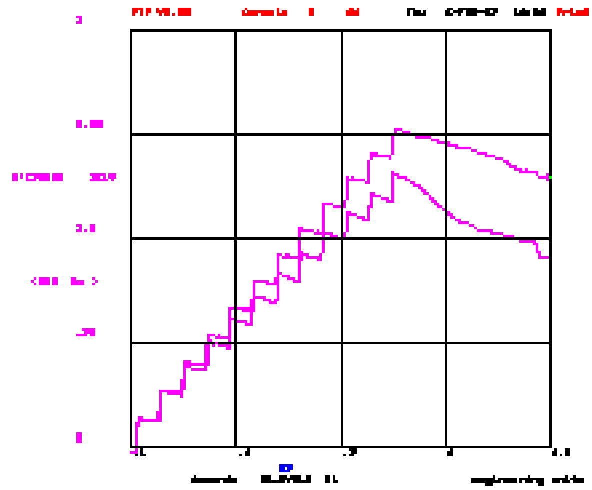

Fig.6 Multibatch injected beam. The two traces show the efficiency difference with the damper on and off. In both cases the accelerator was adjusted for maximum efficiency while avoiding the resistive wall instability.

CONCLUSION

The overall effectiveness of this damper system can be seen from fig. 6. Without the damper system it is necessary to introduce large chromaticities into the beam in order to avoid the resistive wall. This process causes the beam lifetime to suffer which results in poor efficiency. When this damper is in use, the impedance from the accelerator wall is effectively canceled. With this instability under control, adjustments to tune, chromaticity, and octupole can be made to optimize the efficiency of the accelerator.

With this damper in operation we have been able to obtain an intensity of 2.81 E13 ppp. Without this damper it would have been difficult to reach 2 E13ppp. In the era of the Main Injector, the damper system will be modified to operate over many modes. For this modification to work effectively, electronics will have to effectively cancel the revolution frequency.

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