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HIGH-CURRENT EFFECTS IN THE PEP-II STORAGE RINGS*

U. Wienands, M.K. Sullivan, R. Akre, W. Cheng, W. Colocho, S. DeBarger, F.-J. Decker,
S. Ecklund, A. Fisher, D. Kharakh, A. Krasnykh, A. Novokhatski
Stanford Linear Accelerator Center, Stanford, CA 94025, USA

Abstract

High beam currents in PEP-II have been a challenge for vacuum system and ring components. For the $\approx$ 1 cm long bunches peak currents exceed 100 A and modest impedance can give rise to voltage spikes and discharges. During the last two runs, difficulties arose from rf seals at the "flex flanges" in the HER. High temperatures were seen and the seals turned out to be severely damaged by discharges. In the LER, the horizontal stripline kickers of the bunch-by-bunch feedback system experiences breakdown at high bunch current—Macor pins installed for mechanical stability turned out to be a weak spot causing discharges. Finally, in the HER an experiment to shorten the ion-clearing gap in the beam revealed signs of ion-induced instability indicating that the HER has been operating quite close to the stability limit.

The effects shown here are relevant to future high-intensity electron and positron rings like Super*B*[1] and PEP-X[2].

INTRODUCTION

Towards the end of its experimental program, PEP-II achieved record beam currents of 2.07 A in the High Energy Ring (HER) and 3.21 A in the Low Energy Ring (LER), at bunch lengths of about 12 mm. These high beam currents lead to a number of challenges to the vacuum system of both rings, some of which have been reported on earlier[3].

FLEXIBLE JOINTS

The high synchrotron radiation heat load on the HER dipole chambers[5] causes their extending by several mm as the stored beam current increases during a filling cycle and also a small but noticeable bowing due to the one-sided heat load. In order to reduce stress in the vacuum system, "flex flanges"—i.e. very short bellows—are integrated in the flange connection to the next chamber, thus allowing a certain movement of the chamber. The gap between the chamber is bridged by a flexible, "Ω"-type rf seal which was originally made of GlidCop for stability under heat. As the beam current in the HER approached 2 A, more and more discharges in the vacuum system were observed. Thermal monitoring deployed during Run 6 (after having observed some failures of these rf seals) indicated widespread thermal spikes at these flex flanges, at increasing frequency as the beam current was raised. Fig. 1 shows an example.

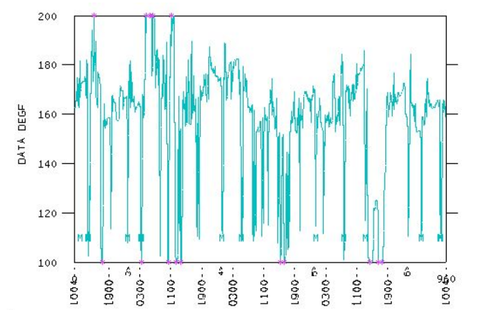

Figure 1: Measured temperature of flange with a damaged rf seal.

Based on these measurements, it was decided to replace the seals at *all* of the 192 flex flanges in the ring. The final tally showed that all but 10 of the seals were damaged to at least some degree. Fig. 2 shows an example of a damaged GlidCop rf seal. The damage stems most likely from the

Figure 2: Rf seal damaged by beam-induced heating.

flexing of the two chambers against each other across the seal, which appears to not have sufficient spring-back to avoid lift-off of some fingers. When that occurs, rf power can couple into the cavity behind the seal, causing significant voltage to build up across the narrow gap which in turn can lead to discharge. In addition, rf power is dissipated on the steel plate of the seal causing it to heat up, this may explain some of the observed damage to the mounting screws[4].

In order to avoid repeat of these failures, the replacement seals used spring fingers made of Inconel 718, with silver plating to maintain conductivity. Inconel (a high-resistivity

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stainless steel) has a melting point near 1330°C, compared to 1080°C for GlidCop, in addition, Inconel maintains better springiness. Fig 3 shows the same flange temperature as above, after replacing the seal. One of the Inconel seals was removed after a couple of months of high-current running, to be found in good, undamaged condition.

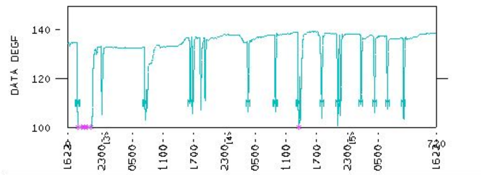

Figure 3: Measured temperature of flange after rf seal replacement.

FEEDBACK KICKER

The PEP-II transverse bunch-by-bunch feedbacks stabilizing the beams against multibunch instabilities use stripline kickers to act on the beam. The LER kickers use molybdenum electrodes for heat tolerance and were expected to easily support the highest possible beam currents[6]. However, on inspection it was found that the electrode of the horizontal kicker had sagged down by a few mm, due to the increased weight of the Mo electrode compared to the original Al electrode and the cantilevered support of the electrodes by the feedthroughs. The remedy of this sagging effect was to add Macor pins to the “paddle”structure holding the electrode; these pins engage into openings in the end caps of the kicker housing. Careful rounding of the holes was done to avoid local field emission and discharge. This modification was done to the horizontal kicker only.

Initially, the modified kicker performed well with measurements confirming that the match at the ends had not deteriorated in any measurable way. However, as beam currents were increased, and during a period of relatively high bunch current, vacuum spikes were observed in the pumps near the kicker and the bunch current became limited to close to 1.1 mA before a clear discharge phenomenon near the kicker set in. Eventually the vacuum system was opened up and one of the pins was observed to be badly damaged with signs of melting and discharge, see Fig. 5.

Reanalysis of the kicker structure revealed the most likely scenario of failure. The impedance spectrum of the kicker is shown in Fig. 6. When evaluated at low frequencies using the average beam current, the expected voltage to ground in the region of the mounting paddles is on the order of 100 V and no danger of arcing exists. However, with bunch length of about 12 mm the peak beam current in fact approaches 100 A (for 3 A average beam current) and in addition the impedance spectrum shows impedance peaks of near 250 Ω at frequencies ranging from 1.5 to 2 GHz, where the beam current still has significant spectral power.

Figure 4: Borescope of the kicker end showing damaged pin.

Figure 5: The molten and the intact Macor pins removed from the kicker.

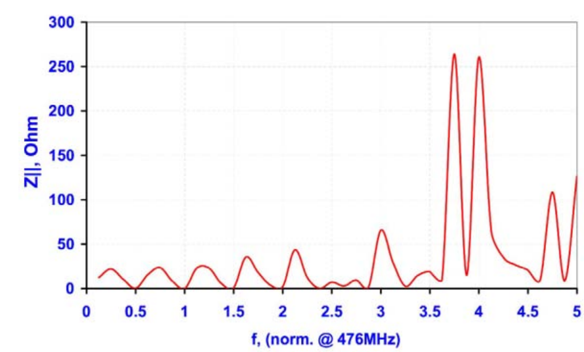

Figure 6: Impedance spectrum of the feedback kicker.

This can then give rise to voltage drops of many kV of potential, and arcing—esp. along the pins—becomes a distinct possibility. The situation may have been aggravated by a possible deterioration of the electrical properties of Macor at high temperature.

The immediate repair for this problem was to reinstall the old kicker without the Macor pins. For any future redesign of this kicker concept, one would have to consider carefully how to increase the withholding strength against electric fields, possibly by introducing rings around the surface, thus increasing the pathlength any discharge would have to span.

EFFECT OF IONS IN THE HER

While initially a concern, ion effects in the HER have not been a significant limitation to operation of PEP-II. In fact, the machine had been run with the abort-kicker gap reduced to about 1.4% (18 buckets or about 100 ns), down from the originally envisaged 10%. Since the gap in the beam leads to significant phase transients—which cause difficulties for the rf system—an experiment was conducted to explore reducing the gap to its minimum size and, potentially, omitting the gap completely. The experiment had the surprising outcome that in fact we could not reduce the gap by any significant amount without causing trouble. By the time the gap was reduced to near 1% clear signs of beam motion were observed and luminosity had in fact not increased. Further reduction in the gap lead to outright beam instability and reduction of luminosity. The motion occurred in both planes and the vertical motion exhibited enhanced spectral content around 2. . . 4 MHz, see Fig. 7. This signature is characteristic of ion effects in the HER, in fact, it has been seen with the normal gap when bad vacuum conditions exist. Note that the observed frequency bump does not correspond to the frequency of the prevalent ion species (CO and CO_2) presumably as it is shifted due to the combined action of the transverse bunch-by-bunch feedback and the Landau damping from the beam-beam interaction. There is some indication in the time-domain data that the phenomenon is likely a fast-ion type of instability[7]: After the gap near the left side of Fig. 8 the motion is small, it then grows along the bunch train, however, later in the train the amplitude appears to be reduced again. Also, there is strong motion in the horizontal plane which is not fully explained although it does appear that with the reduced gap the beam tended to lock onto the half-integer resonance (with a mode 6 or 7 oscillation) but not get lost.

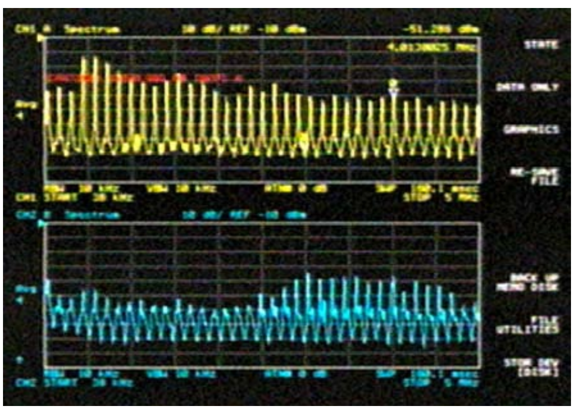

Figure 7: Transverse spectra of the HER with 16-bucket gap (34 ns). Top trace (yellow) is horizontal; bottom trace (blue), vertical motion. The frequency range is from 20 kHz to 5 MHz and the vertical scale is 10 dB/div in both spectra.

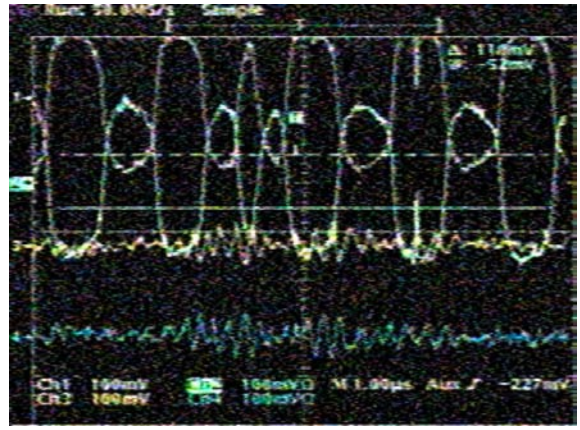

Figure 8: Transverse motion of the HER with 16-bucket gap (34 ns). Traces 1 and 2 with the large mode-6 oscillation are horizontal, traces 3 and 4 with the much smaller amplitude, the vertical plane. Horizontal time scale is 1 μs/div (10 μs total), the vertical scale is 100 mV/div for all traces.

CONCLUSION

Operating at high beam currents and short bunch lengths has been a constant challenge for PEP-II. The effects reported on here have been only the last issues uncovered.

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