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ANOMALOUS HIGH RADIATION BEAM ABORTS IN THE PEP-II B-FACTORY*

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Abstract

The PEP-II B-Factory at SLAC has recently experienced unexpected beam losses due to anomalously high radiation levels seen in the BaBar detector. The problem was traced to the occurrence of very high (>100 nTorr) pressure spikes that had a very short duration (a few seconds). We describe the events, show analysis predicting where in the vacuum system the events originated, and show what we eventually found to be the source of these vacuum events.

1 INTRODUCTION

In October 2005, just before shutting down for a month, PEP-II achieved a peak luminosity of 1×10^{34} /cm^{-2}/sec^{-1} with beam currents of 2.94 A in the low-energy ring (LER) and 1.74 A in the high-energy ring (HER) [1]. In early December, we discovered we were unable to sustain LER currents much above 2 A without an abort occurring due to either beam instabilities or high radiation levels in the detector. In January, we uncovered two problems. One was an RF seal for a flange pair in the LER that had not been properly installed and was generating arcs that produced beam instabilities;[2] the other was the occurrence of very fast, very high pressure spikes in the vacuum chamber just upstream of the detector. The radiation levels in the detector caused by these gas events were too high and the beam had to be aborted. Fig. 1 shows a layout of the Interaction Region (IR) with typical pressures from local gauges.

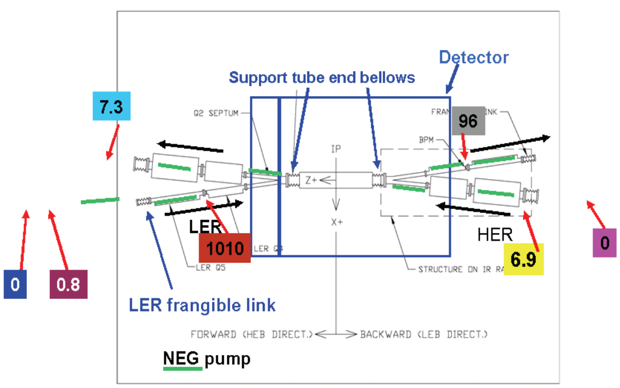

Figure 1. Layout of the Interaction Region. The numbers are typical peak pressure readings in nTorr for one of these fast pressure spike events. The green bars indicate the location of NEG pumps in this area. The layout is pictorial. The total z length of this region is about ±10 m.

Fig. 2 shows a time plot of a typical event. The fast rise and fall in pressure was also seen in events in which the beam did not abort.

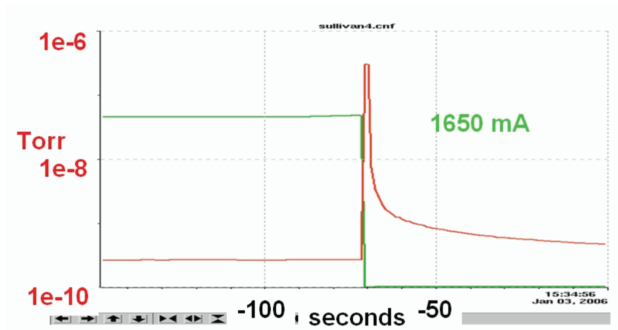

Figure 2. Time plot of a fast pressure spike and radiation abort event. The green curve is the LER beam current. The current was about 1.6 A when the spike occurred. No activity is seen before the spike. The red curve is the pressure seen from the vacuum gauge with the highest signal--about 5 m from the IP in the upstream LER beam pipe. The peak pressure for this event was about 300 nTorr. The pressure at this gauge returned to below 1 nTorr in less than 20 sec.

2 EVENT FEATURES

A great deal of effort went into trying to find out what kind of events these pressure spikes were.

Essentially all of the beam aborts were accompanied by transverse beam instabilities in either one or both of the beams. This prompted the suggestion that perhaps the instability of the beam was *causing* the pressure spike and high detector backgrounds and hence the abort. We tested this idea by making the beams go unstable and looking for pressure spikes in the IR. Pressure spikes were seen but the magnitude of these spikes is 100-300 times smaller than the peaks of the fast spikes.

The colliding beam currents at which these aborts happened was remarkably stable at about 1.6 A for the LER and 1.2 A for the HER. The single ring threshold for the LER was closer to 2.2 A. Once the beams were above the threshold an abort would occur within 30 min. Attempts to “burn through” the problem by rapidly raising beam currents were unsuccessful. No difference was found between colliding and non-colliding beams. Bunch charge dependence was studied, but with no clear outcome.

We studied the gas characteristics of these events in several ways. We have a residual gas analyzer (RGA) head on either side of the detector and we were able to capture some of the fast spike events on the RGA recorders. The primary mass peaks seen were 14 and 28, with the peak heights in a ratio consistent with nitrogen gas signal. In addition, lower than expected argon and oxygen peaks were observed. Taken altogether, the data

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tended to rule out an air leak. However, we checked this conclusion by flowing He outside all of the vacuum joints in this area, no He peak appeared on the RGA. We also added a gas injection mechanism to the vacuum system that allowed us to inject a controlled amount of either N_2 or dry air into the vacuum. The He test and the gas injection test had to be done when the beams were present and both tests confirmed that the unknown gas spikes must be coming from somewhere inside the vacuum system. The location was somewhere along the incoming LER beam line less than 8 m from the IP. We could not completely rule out the possibility of something happening in the outgoing HER beam line since the two beam lines join 2.3 m from the interaction point (IP).

Throughout the months of January, February and March the IR part of the vacuum system was vented a total of 4 times. Each time, the area was scanned with a bore scope. We looked for missing or damaged RF seals, discoloration indicative of arcing, anything that looked unusual. Nothing was found in these scans.

3 NEG PUMP HEATING

Most of the vacuum components in this area are either copper or stainless steel. Materials of a more exotic nature in this region are the NEG pumps and the high loss-tangent tiles used to absorb higher-order mode (HOM) power. Initially, the NEG pumps fell under suspicion because we knew that HOM power was penetrating the screens that shield these pumps. We monitor the temperature of the NEG heater rods and see an increase in temperature as the beam current increases. In fact, we knew that some of the local NEG pumps were getting hot enough to start outgassing hydrogen. We had never seen any sort of fast outgassing behavior from the NEGs but perhaps something was wrong with one of them.

We have the ability to remotely heat up any of the NEG pumps in the IR. While beam was present in the machine we systematically heated up all eight of the NEG pumps shown in Fig. 1. We learned several things from this exercise. First, heating up the pumps should change the characteristics of the fast vacuum spikes if the heated NEG is the source. The beam current threshold or trip rate should change. We saw no change in the nature of the fast events when any of the NEG pumps were being heated.

Second, when any one of the pumps is heated to a high enough temperature the pump starts to outgas hydrogen. The pump then becomes a source of gas, which can be seen on the gauges in the vacuum system. This allowed us to create at least six gas sources at various locations in the vacuum system. We then compared the various pressure values from the NEG heating to the pressure values seen during a fast spike. Only one NEG pump produced peaks similar to the gas spike events. That pump is the one located near the junction of the incoming LER beam and the outgoing HER beam about 2.3 m from the IP.

When we heated the NEG pump located in the upstream LER beam pipe we monitored the background levels in the detector and discovered that we needed about 15-30 times more vacuum pressure in order to get the same level of background during a fast vacuum spike. This agreed with the RGA assessment that the gas in a fast event was nitrogen, which is 15-30 times heavier than hydrogen.

We also found that if we generated a pressure bump in the outgoing HER beam line by heating the NEG in that area, we could create a fairly high pressure that did not produce backgrounds in the detector. We were able to generate a vertical beam blowup and then, when the pressure increased further, a vertical beam instability by raising the local pressure to 50-100 nTorr. This has now become a signal (vertical size increase followed by vertical instability) for some kind of vacuum problem in the HER and has helped us find a vacuum burst seen now in the HER distributed ion pumps in the arc bends.

The data from the heating up the local NEGs in the IR has been a great help in producing a more accurate vacuum model for the IR. One of the biggest difficulties in generating a good model of this area has been the correct estimate of the pumping speed of the NEG pumps and this data has been very helpful.

4 LOCALIZATION ATTEMPTS

Aside from the NEG pump heating, there were many other attempts to localize the source of the fast gas spikes. Some of these attempts are listed below.

- Acoustic sensors were attached to the beam pipe in order to try to detect any noise from something like an arc. Nothing found.
- An antenna was hooked up to try to detect any electromagnetic pulse from a possible arc. Nothing seen.
- An analysis of the gas pulse shape as seen at the local gauges and the observation of pulse widening for gauges that are farther away from the source.
- A careful analysis of the timing of the background pulses seen by the detector led to a projected z location.
- Data from the BaBar detector was collected with a trigger that accepted a wider z distribution in the hope of finding a vertex cluster near the source.
- The arrival time of the gas pulse to the various gauges was used to project a z location.

This brief summary does not do justice to the tremendous amount of work that went into the effort of trying to track down the location of these fast gas spikes. The BaBar collaboration alone generated at least half a dozen efforts. The net result was that all of the analyses that had a signal (many attempts did not) converged on a z location about 2.3±0.3 m from the IP on the +Z (incoming LER) side of the detector. This is almost precisely in the middle of the bellows section at the end of the support tube where we have placed 96 HOM tiles.

5 HOM TILES AND RF SEALS

The HOM tiles located in this bellows section had always been considered suspect, but we could not understand how they could cause the events. The tiles do absorb RF power-over 10kW. A possibility we considered was that one of the tiles got hot and became unbrazed thereby getting *very* hot and perhaps outgassing in some strange way. It would have to be a bottom tile. We checked this by opening up the vacuum chamber about 1 m away and using probes to see if one of the tiles was loose and if so to simply remove it. No loose tiles were found. We were very reluctant to disassemble the bellows section directly because it is close to the detector and several days of effort would be required to just get to the vacuum chamber, with an equal amount of time to reassemble everything. We also did not yet know what we had to fix.

At about this time it became clear that there was a design flaw in how the RF seal works near the HOM tiles. The seal is supposed to electrically connect two vacuum pieces at flange joints so that the image current can easily flow along the inside surface of the chamber. The RF seals for the bellows section, however, were touching the HOM tiles instead of metal. The HOM tiles are essentially insulators, consisting of 60-40 composites of AlN and SiC. A damaged tile might be able to emit nitrogen gas. After designing and building a new set of RF seals we were ready to remove the bellows section.

6 THE ANSWER AND THE SOLUTION

The pictures tell the story. Fig. 3 is a picture of the bellows section. A close look shows a small discoloration on the edge of the top row of tiles. Fig. 4 is a close-up of the damaged tile. The breakdown appears to start at the corner of the tile and then travel along the surface of the tile to the copper underneath the tile. Fig 5 is the RF seal that was next to the tile and figure 6 shows the new RF seal.

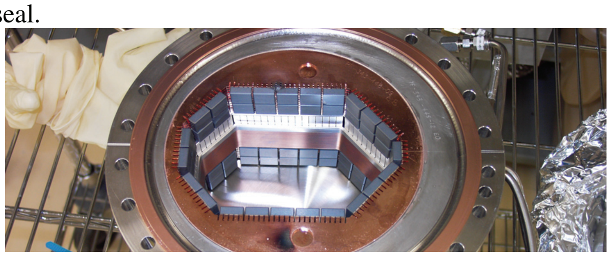

Figure 3. The entire bellows section. The LER beam is on the left side and the HER beam is on the right side. The damaged tile is a little closer to the LER than to the HER.

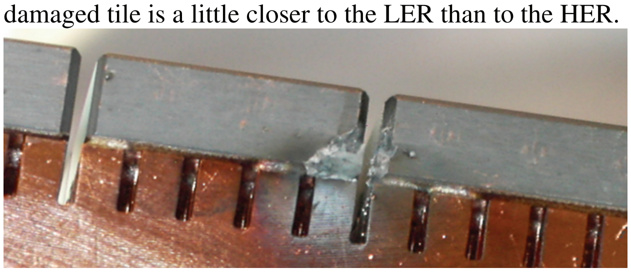

Figure 4. A close-up of the damaged tile.

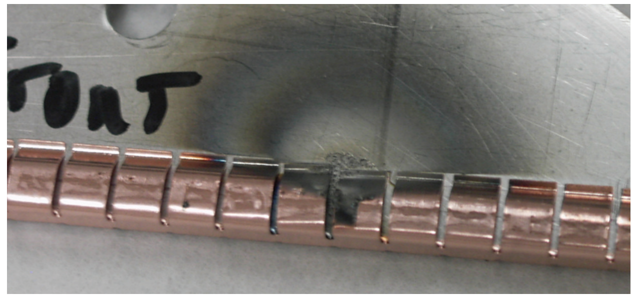

Figure 5. The RF seal that mated with the damaged tile. All of the discoloration was hidden behind the RF seal. We do not completely understand why the breakdown occurred at this location. There is a small dark spot on the third RF finger to the left of the discoloration that matches a small pit on the tile in Figure 4.

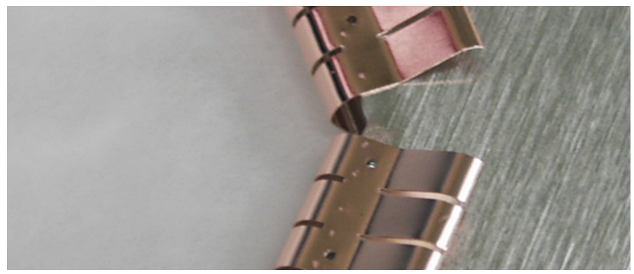

Figure 6. Picture of the replacement seal. Note how the contact point is much lower and will engage the copper underneath the tiles.

7 SUMMARY

PEP-II started Run 5b last November and as soon as the LER beam current got high enough (>2.3 A) experienced a reduction in deliverable luminosity due to beam aborts from high radiation events near the detector. After a great deal of detective work from a very large pool of people these events were eventually identified as coming from a surface arc on the side of a HOM absorber tile located 2.18 m from the IP on the incoming LER side of the detector. The hardware was fixed at the end of March and the beams current have been as high as 2.7A LER and 1.7 A HER with no gas occurring from this location.

8 ACKNOWLEDGEMENTS

We wish to thank everyone who worked so hard to help solve this mystery. We want to especially thank the BaBar collaborators, in particular H. Nicholson and B. Petersen, who helped with background measurements and with location analyses. We also want to thank the vacuum and support technicians, who were always ready for hardware installations and removals throughout this period.

9 REFERENCES

[1] J. Seeman, *et al.*, “Achieving a Luminosity of 10^{34} cm^{-2} sec^{-1} in the PEP-II B-factory”, these proceedings

[2] U. Wienands, *et al.*, “Tracking Down a Fast Instability in the PEP-II LER”, these proceedings.