The SPEAR 3 Vacuum System

An Analysis of the First Two Years of Operation (2004 and 2005)

Rebecca Armenta

Office of Science, SULI Program

University of California at Los Angeles

Stanford Linear Accelerator Center

Menlo Park, California

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under the direction of Mr. Harold A. Morales and Mr. Benjamin D. Scott in the
Engineering and Technical Services Division of the Stanford Synchrotron Radiation
Laboratory (SSRL) at the Stanford Linear Accelerator Center.

Participant: _____
Signature

Research Advisors: _____
Signature

Signature

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Abstract

SPEAR 3, a synchrotron radiation source at the Stanford Linear Accelerator Center, has been in operation for the past two years. SPEAR 3 was designed to achieve high beam lifetimes while operating at a higher current level than previously achieved with SPEAR 2. Maintaining high electron beam lifetimes within the ring allows users to perform their experiments with a consistent supply of high current synchrotron radiation. The purpose of this analysis is to evaluate the SPEAR 3 vacuum system's performance during the 2004 and 2005 runs while considering methods to optimize and improve vacuum system conditioning, especially within the pumping system, so that a recommended plan of action can be created for the FY 2006 run. Monitoring the dynamics of the electron beam within the ring can be a difficult task. Pressure data obtained from the gages attached to pumps, temperature data obtained from thermocouples located at various locations around the ring, and beam lifetime projections help to provide some indication of the health of the electron beam, but the true conditions within the beam chamber can only be extrapolated. Data collected from sensors (gauges, thermocouples, etc.) located around the ring can be viewed and extracted from a program created at the Stanford Synchrotron Radiation Laboratory (SSRL) called *Historyplot*. Manipulation and analysis of data was performed with the commercially available programs *Matlab* and *Excel*. The data showed that the beam lifetimes in 2005 were much greater than they were in 2004, but it did not provide a clear indication as to why this occurred. One variable of major importance between the 2004 and 2005 runs is the Titanium Sublimation Pump (TSP) flash frequency (flashing is the process in which Titanium from filaments within the pump is sublimated onto the wall surfaces of the

pump, where it removes gas molecules from the system by chemisorption). The data indicated that pressures in 2005 could have been lower, based on a comparison between 2004 pressures, if the TSPs were flashed more frequently than they were in 2005. However, the data from 2004 and 2005 does not provide enough information to accurately determine an optimal conditioning frequency, though it does provide enough information to formulate a recommended plan of action for the next run. It appears that flashing at a high rate during the beginning of a run and at a lower rate as the run progresses may be the most effective pumping approach to further improve the vacuum level of the ring. It is recommended that the SPEAR 3 vacuum system should be operated in this way next year.

Introduction

The Stanford Positron Electron Asymmetric Ring (SPEAR) is currently a third generation synchrotron radiation source. SPEAR 3 replaced SPEAR 2 during the period of April to October, 2003, and has been operating for two years. It was designed to run at 500mA, a much higher current level than the SPEAR 2 maximum current level of 100mA. The 2004 and 2005 runs were primarily 100mA runs, but tests at 200mA and 500mA during the 2005 run have proven that SPEAR 3 is ready for 500mA in 2006.

In addition to 500mA design objective, SPEAR 3 was designed to have an increased beam lifetime and much lower beam emittance than the SPEAR 2 ring produced (lower beam emittance is equivalent to a more focused electron beam). A new vacuum system, along with a new magnet lattice system and several new insertion devices were designed to achieve these performance goals and operational efficiency. As a result, scientists can perform “the next generation of experiments” with fewer obstacles than in the past.

Maintaining consistent beam life for users (increasing beam lifetime) is one of the main performance goals of the system. The vacuum system has much to do with maintaining the beam life. The objective of this project is twofold: one, to analyze the vacuum system and either confirm or refute that the vacuum system is operating as expected according to its design and two, to determine if it is performing optimally.

Optimal performance of the vacuum system is highly dependent upon its vacuum pumping capabilities. Maintaining a very low pressure within the beam chamber helps to

prevent beam current losses that would occur when electrons composing the beam collide with the molecules of the residual gases remaining in the chamber. Less collisions and, subsequently, less losses corresponds directly to high beam lifetime, or high vacuum quality. The SPEAR 3 ring utilizes both sputter ion pumping (using noble diode pumps) and titanium sublimation pumping to achieve ultra high vacuum (UHV) levels (pressures $< 10^{-10}$ Torr). SPEAR 3 uses 74 Titanium Sublimation Pumps (TSPs) and 129 Noble Diode Ion Pumps (IPs) to create the UHV environment for the electron beam.

The two types of pumps are used in combination because each is more effective at pumping different gas molecules from the vacuum chamber. TSP pumps are capable of operating at high pumping speeds for “getterable” gases (chemically active gases such as N_2 , O_2 , H_2 , CO , CO_2 , H_2O), but do not efficiently remove noble gas molecules (Ar, He, CH_4 , C_2H_6) from the chamber. Noble ion pumps are much more effective at pumping the noble gas molecules from the vacuum chamber than the TSPs are (noble gas molecules are present during leaks).

The “batch deposition method” is the procedure used for operating the TSP pumps in the SPEAR 3 ring. In this method, the sublimation of Titanium onto the pumping surface (in this case, the pumping surface is extruded aluminum fins) is induced periodically, and the film deposited on the surface will trap gas molecules and eventually saturate (resulting in a reduction of pumping capacity) with those trapped gas molecules between sublimations [1]. The optimum SPEAR 3 TSP flash frequency for maximum vacuum pressure improvement has not yet been determined. It is the common belief that frequent flashing results in favorable performance characteristics. However, this assumption overlooks disadvantages that may be presented by this practice. Flashing too

often may increase the titanium film thickness on the walls of the chamber to a point where it may begin to flake off (or to peel away from the surface), thus producing additional surfaces that may introduce more gas molecules (and possibly particulates) into the chamber. In addition, the flashing process is quite time consuming—flashing the 74 TSP pumps can take up to 8 hours. This time spent on flashing the TSPs takes away from the time that could be dedicated to accelerator physics applications or to the extension of the user run.

A major component of this project will be the determination of an optimal flash frequency for the TSPs. It is appealing to determine this optimal flash rate because when implementing it, it will not be necessary to perform any extra physical work on the apparatus. Scientists and engineers have direct control over how the TSPs are utilized in the system, so an optimized flashing scheme can be achieved quite simply by just a change in procedure.

The SPEAR 3 vacuum system consists of a series of copper chambers (which incorporate an antechamber design) with discrete absorbers, masks, and pumps. All of these are supported, along with the magnets, on girder sections around the 234.126 meter circumference ring. A benefit of the SPEAR 3 copper chamber with antechamber design is that high gas loads produced from photon stimulated desorption (PSD) at the masks and absorbers are located close to the high speed TSP pumps; the TSPs should be able to pump these gas molecules out of the chamber with ease. A disadvantage of this antechamber design is that the chamber has more surface area, and thus the thermal gas load (from desorption) is increased. The copper chambers and various interior devices are connected with bellows, which are designed to aid installation and assembly, and to allow

a smooth transition for the electron beam to and from different devices in the ring that may require different aperture configuration. Because the bellows are part of the beam aperture transition devices, they are also often locations of higher order mode (HOM) heating and can contribute to losses in beam lifetime. During the analysis, the temperatures at these locations will be reviewed.

Methods and Materials

In order to achieve the objectives of this project, it is pertinent to first determine if, as predicted by design, optimal performance is being achieved by the vacuum system. Performance predictions can be found in the Conceptual Design Report [2] and in released documents on the vacuum group network. However, not all aspects of the vacuum system can be easily measured for comparison. For example, a test chamber was used to determine much of the preliminary data on the TSPs used in the system. The test chamber was equipped with gages not present on all TSPs within the ring. Uncertainty about what occurs within the chamber during periods of normal operation is part of the motivation for this project. The next step toward completing the objectives of this project is analyzing the relationship between the vacuum system components and losses in beam lifetime. This analysis will determine if the vacuum system itself contributes to beam lifetime losses. A somewhat comprehensive grasp on the vacuum system is necessary to make such an assessment. If a relationship exists, further work can be undertaken to determine methods of prevention or modification. It would also be helpful to be able to develop a relationship between measurable vacuum system parameters and overall system performance parameters, the most obvious one being beam lifetime. It is convenient and reasonable to assume that the vacuum pressure has a direct effect on the beam lifetime, however, this is not always the case. The relationship between these two parameters is much more complicated to assess because many other parameters have an effect on beam lifetime.

The majority of the system analysis requires run data obtained in the last two years of operation. Data from SPEAR 3's database will be extracted using a program

called Historyplot and imported into other graphing programs such as Excel and Matlab. The data will be explored and relationships between pertinent parameters may be drawn.

Preliminary data procured from the database has been organized into graphs. There are no experimental findings, as no experiment was actually performed, but many helpful observations have been made as a result of the rearrangement of the raw data into graphs revealing salient information. The data procurement process is a tedious one. Extracting information from the SPEAR 3 database proved to be the most time consuming activity of the whole analysis process. Several methods of extracting the data from the current system were pursued (methods in Matlab), but none provided a significant advantage over the system's default program (Historyplot) for viewing and extracting data. Although inconvenient, Historyplot did provide the information needed to assess the subject at hand.

Discussion

SPEAR 2 maintained lifetimes of about 40 hours while operating at 3GeV and 100mA. SPEAR 3 currently maintains lifetimes of over 40 hours, even at the beginning of a run, when beam scrubbing has not yet rid the chamber of residual gas molecules within the chamber. {Beam scrubbing is a phenomenon that highly affects the performance of the system, but it is not easily measured as a parameter. Beam scrubbing is the phenomena described as reductions in dynamic pressure rise (due to photon stimulated desorption) with increasing integrated photon dose (Amp-hours) [2]}. It is obvious that the performance of SPEAR 3 surpasses that of SPEAR 2. What is not obvious, however, is whether or not SPEAR 3 can perform even better. If it can operate more efficiently, it would be helpful to know before the machine begins its 500mA run. Hopefully, this can be determined from the data that is available from the past two years.

Figure 5 shows the lifetimes achieved in 2004 and 2005 as functions of integrated run current. Integrated run current is a better parameter than time to consider when analyzing the development of the system because it represents events in terms of how much current had run through the chamber at that point of time, and therefore gives an indication of how much beam scrubbing may have occurred in comparison to other events plotted against integrated run current. The figure clearly shows that higher lifetimes were achieved more quickly in 2005 than in 2004. Additionally, the 2004 data shows a much smoother curve than the 2005 data. There are many reasons/combinations of reasons why this may have occurred. The first is that the ring chambers had already been exposed to a whole year of beam scrubbing by the beginning of the 2005 run, and, therefore, could have experienced lower desorption rates during the 2005 run than during

the 2004 run. Another factor that may have contributed to the large differences in lifetimes is the TSP flash sequence for 2005. The flash frequency for the 2005 run and the 2004 run are very different. In 2004, the TSPs were flashed as many as 20 times, while the TSPs were only flashed a maximum of 5 times in 2005. The flash frequency, however, could not have contributed to such large differences in lifetimes all on its own. Figure 1 shows that the pressure for the TSP settles to about the same final pressure level after a certain integrated run current level is reached. If the lifetimes were solely affected by the vacuum pressures, they would have settled at similar values towards the end of the runs. HOM heating doesn't explain this jump in lifetime either; the temperatures measured at aperture transition areas (especially at BL11 upstream bellows) indicate that the temperatures were actually lower at these locations in 2004 than they were in 2005. Therefore, high occurrences of HOM heating could not have been the only reason for the lower lifetimes in 2004. Information about the nature of the dominant gas molecules within the chamber during the different runs might provide an explanation for the lifetime differences. However, only two Residual Gas Analyzers (RGAs) have been attached to the ring of which one is non-operational and the other is attached to the back end of a TSP (so it cannot accurately analyze the gas composition within the beam chamber). Clearly more information is needed to explain the differences shown in Figure 5.

Other information that can be drawn from Figure 1 is that the multiple flashings of 2004 created a smooth pumpdown curve for the whole year. The sparse flashings of 2005 created large steps in the pressure profile for 14G-TSP1. These pressures are at times higher than pressures at the same integrated run current levels in 2004. The profile of 03G-TSP1 is less dramatic. This may have to do with the fact that its pressure was

significantly lower before and after each flash. Its pressure reading was initially lower than the pressure at 14G-TSP1 because it was actually flashed an extra time before the 2005 run started. It is difficult to say whether or not the 2005 run would have benefited significantly from multiple flashings, but it is definitely an issue that needs to be looked into more closely.

Figure 2 shows the 2004 and 2005 pressure profiles of the girder 14 ion pumps. It is interesting to note that although the 2004 and 2005 pressures for ion pumps 2 and 3 end up with approximately the same final pressures at the end of each respective run, while the final pressures for ion pump 1 do not.

Figure 3 and Figure 4 show the relationship between certain TSP pressures and beam lifetime. Flashes are indicated on the graphs by vertical red lines. These figures help to map out a relationship between the flash pattern and the pressure profiles of these pumps. The flash patterns in 2004 and 2005 are obviously quite different. The TSPs were flashed 20 times in 2004 (14 times during beam current operation) and 5 times in 2005 (3 times during beam current operation). The contrast between these two figures strongly suggests that multiple flashings in 2004 contributed significantly to the smooth pumpdown curve shown in the figure. However, it is not evident that flashing multiple times throughout the *whole* run is entirely necessary. The sizable amount of time spent flashing the TSPs during the middle and tail end of the run (6-8 hours per flash), during the time when beam time is needed to run and complete experiments, may have been wasted since it may not have been necessary to flash so often in order to maintain the shape of the curve. The data from 2004 and 2005 is not sufficient enough to determine

whether or not this is so. More data from future runs will have to be scrutinized in the same way to determine a definitive solution to this flash pattern puzzle.

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Conclusion

As of yet, the only definitive conclusions that can be made are that the vacuum system is performing quite well at 100mA and that it is capable of safely handling 500mA current levels since no dramatic beam losses occurred during tests. However, much more work on the subject is currently in progress, and data from future runs will aid in determining the optimal performance conditions of the system. From the data that is available, it appears that the TSPs may not have been utilized at their maximum efficiency in either 2004 or 2005. The most effective approach may be to flash often during the initial pumpdown and during the beginning of the run in order to develop the “smooth curve” trend, and to flash less often once the run progresses. Vacuum pressure, lifetime, and RGA data from the next few runs will be analyzed to determine whether or not this is the best TSP flashing method.

Tables and Figures

Figure 1: TSP pressures for certain pumps in 2004 and 2005

Figure 2: Ion pump pressures for certain pumps in 2004 and 2005

Figure 3: Relationship between the pressure profile of certain TSPs in 2004 (14G-TSP1 and 03G-TSP1) and beam Lifetime. Red vertical lines are locations of TSP flashes.

Figure 4: Relationship between the pressure profile of certain TSPs in 2005 (14G-TSP1 and 03G-TSP1) and beam Lifetime. Red vertical lines are locations of TSP flashes.

Figure 5: Electron Beam Lifetimes in 2004 and 2005 as Functions of Integrated Run Current

Literature Cited

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