OPERATION OF CESR DISTRIBUTED ION PUMPS AT REDUCED VOLTAGE

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*Abstract**

A transverse single-beam instability is observed in CESR which has been found to arise from the DC static electric field leaking into the beam chamber from distributed ion pumps (DIPs). Further, a very large photoelectron current is measured in the DIPs which may impose a potential problem in future CESR upgrades. The purpose of this study was to investigate the possibility of lowering the DIP operating voltage without sacrifice of DIP pumping speed. A relatively constant DIP pumping speed was measured with the anode voltage ranging from the 'normal' operating voltage of 7.6 kV to as low as 1.8 kV, when there is beam stored in CESR. On the other hand, a higher (5 kV) minimum DIP anode voltage is needed to sustain effective pumping speed without beam present. A simple model is proposed to describe the operation of DIPs under the influence of the stored beam. As the result of this study, the majority of CESR DIP controllers have been modified to enable remote switching of the DIP anode voltage between 2.2 kV (for normal beam operation) and 6.6 kV for start-up or for long periods without stored beam.

1. INTRODUCTION

Ultrahigh vacuum is a necessity for a storage ring system to provide required good beam lifetime. Both lumped noble diode ion pumps (LPs) and distributed ion pumps (DIPs) are employed in the arc regions of CESR to keep the beam chambers at typically $2\sim3\text{x}10^{-9}$ torr with total stored electron and positron beam currents more than 300 mA. The detailed description of the DIPs can be found in references [1]. All the DIP anodes had been operating at 7.6 kV for more than 15 years prior to this study. It has become desirable to reduce the operating DIP anode voltage for the following two considerations. First, a transverse single-beam instability was observed in CESR. Studies[2] indicated that this transverse instability has been caused by the interaction between the stored bunched particles and photoelectrons trapped by the DC static electric field leaking into the beam chamber from DIPs. The growth-rate of the instability is observed to peak at some intermediate beam current, which imposes a difficulty during beam injection. It is also found that the growth-rate decreases with lower DIP anode voltage. Secondly, we have measured very high DIP pump current with beams stored in CESR. For some DIPs, the pump current are as high as 5 mA per 100 mA of stored beams, which may extrapolate to a power dissipation of more than 370 W in those DIPs at planned CESR Phase III upgraded operation at total stored beam current of 1A. This is very likely to impose a potential operation problem in future CESR upgrades. As will be discussed in the paper, this high DIP pump current is due to scattered photoelectrons and does not reflect pressure in the pump chamber. It is observed that the DIP current may be reduced at lower DIP anode voltage.

The practical purpose of this study is to explore the possibility of reduction of DIP anode voltage without degradation of pumping performance. Thus we measured the relative DIP pumping speed as a function of anode voltage, with and without stored beams. The DIP current is also studied to understand the pumping behavior of the DIPs under the influence of stored beams in CESR.

2. DIP PUMPING SPEED

Most of the measurements were carried out in a special sector of CESR, which consists of one long straight chamber and four bending chambers, which is densely instrumented for pressure readout. The schematic layout of the instrumentation section is given in Figure 1. The power supplies for the four DIPs in the section were modified to enable remote control of DIP anode voltage from 0 to 7.6 kV. Nine cold cathode gauges (CCGs) and one residual gas analyzer (RGA) are installed in the

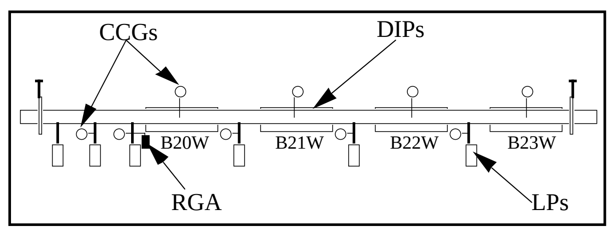

Figure 1. Vacuum Instrumentation Sector Layout

section to measure pressure and gas composition in the beam chamber. Prior to the study, the vacuum chambers in the test section had been subjected to more than 250 Amp•Hours total beam dose so that the variation of vacuum conditions due to beam-conditioning in the section during this study can be ignored. Most of the data shown below were taken during CESR high energy physics (HEP) runs, in very stable conditions.

Measuring absolute DIP pumping speed is no easy task, as detailed information is required of the pressure, pumping speed and gas-load distributions along the beam chambers, as well as the gas conductance of the beam chambers. However, for the practical purpose of this study, we were interested only in the relative DIP pumping speed as we vary the DIP anode voltage. One can calculate the relative DIP pumping speed from measured pressure at the center of the bending chamber[3]. The relative DIP pumping speed is defined

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as S^{i}_{DIP}/S^{H}_{DIP}, where S^{i}_{DIP} and S^{H}_{DIP} are the DIP pumping speed at anode voltages of V_i and at the 'nominal' higher setting 7.6 kV, respectively. In Figure 2, the measured relative DIP pumping speed for the four DIPs in the section is shown as a function of DIP anode voltage.

The relative DIP pumping speed was also measured without stored beam in CESR, and the result is shown in Figure 3. One can see that the behavior of the DIPs without stored beam is very different from that with stored beam. With stored beam in CESR, the DIP pumping speed is rather insensitive to the anode voltage from 1.8 kV to the 'normal' operating voltage of 7.6 kV. In fact, we can gain about 20% higher pumping speed by operating the DIPs between 2 to 6 kV. However, without stored beam in CESR, the DIP pumping speed drops rapidly when the anode voltage is reduced below 5 kV. These measurements clearly indicate that stored beam in CESR has a significant effect on the DIPs.

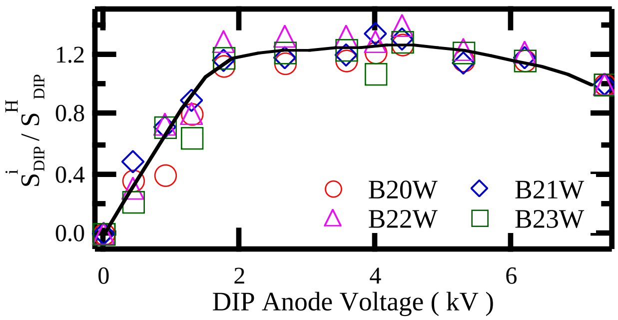

Figure 2. Relative DIP pumping speed vs. DIP anode voltage, with 300 mA total stored beam in CESR.

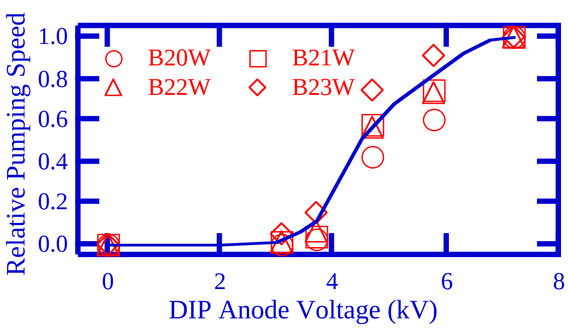

Figure 3. Relative DIP pumping speed Vs. DIP anode voltage, without stored beam in CESR.

The measured chamber pressures changed from 0.4 to 1.1 ntorr with no stored beam and from 1.0 to 3.0 ntorr with stored beam, as the DIP anode voltages were decreased over the full range. No significant change in the residual gas composition was observed at all tested anode voltages, with and without stored beam.

3. DISCUSSION

We have measured very large pump current (milli-amperes) in the DIPs when there is stored beam in CESR, and have found the pump currents have no correlation with the pressures in the pumps. In figure 4, the measured DIP current is plotted as a function of anode voltage with total stored beam of 320 mA in CESR, for a typical DIP, B20W. As can be seen in figure 4, the DIP current increases with increasing anode voltage approximately linearly with stored beam in CESR. In contrast, the DIP current is small (microamps) and is found to depend on the anode voltage exponentially when there is no stored beam in CESR. It is clear that the rather large DIP current is induced by a coupling between the stored beam and the DIP. One measure of the coupling at any given beam current is the slope of the pump current vs the anode voltage, as in Fig. 4, or the DIP 'conductance'. As shown in Figure 5, this coupling is proportional to the total stored beam current.

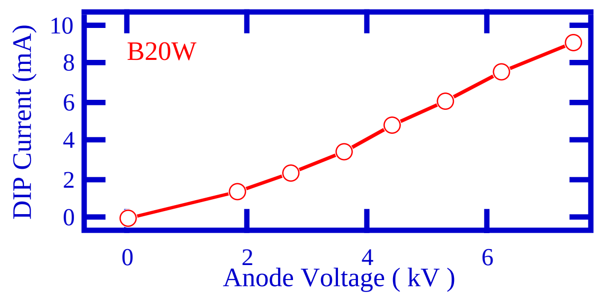

Figure 4. Measured DIP current as a function of the anode voltage with 320 mA total stored beam in CESR.

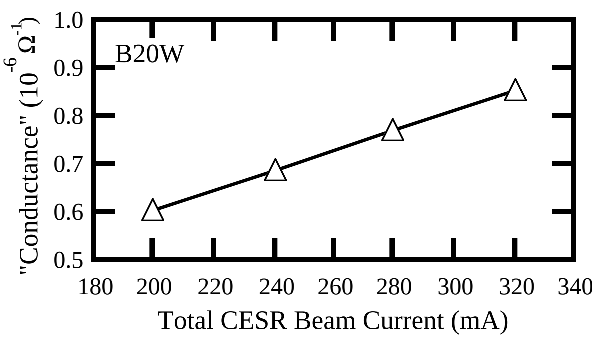

Figure 5. DIP 'conductance' vs. total stored beam current.

There may be two possible coupling mechanisms: (a) higher-order-mode (HOM) RF coupling which is sensitive to bunch structure and orbit of the stored beam; (b) photoelectrons produced in the DIPs by scattered synchrotron radiation (SR) photons. The photoelectron current depends on the total stored beam current and is insensitive to the beam bunch structure. To differentiate between the two mechanisms, we measured the DIP current with two different beam bunch structures, namely, 9-trains of one bunch (or 9x1), and 9-trains of two bunches (or 9x2). The results, as shown in Figure 6, indicate that DIP current is insensitive to the beam bunch structure. Considering the linear dependence of the coupling on the total beam current (see Figure 4),we can conclude that the large DIP current with stored beam is dominated by the photoelectron current induced by scattered SR photons.

Among many factors which affect the pumping speed of an ion pump, there are two fundamental

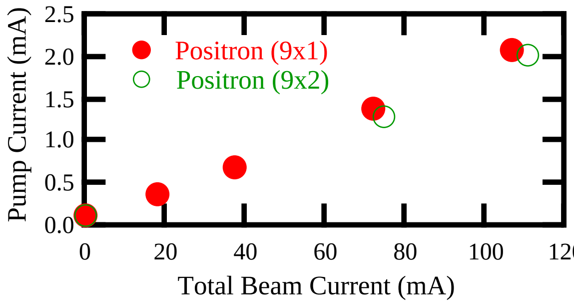

Figure 6. DIP current vs. stored beam current with different bunch structures of the stored beam (see text).

parameters for a given sputter-ion pump: electron cloud density in the pump cell and the sputtering yield of energetic ions on the pump cathode. At low pressures, the pumping speed can be expected to be proportional to electron density and sputtering yield. As is shown above, a sufficient high electron cloud density is always maintained in the DIP due to the photoelectrons when there is stored beam in CESR. In this case, the pumping speed is limited by the sputtering yield of ions on the pump cathode. As a matter of fact, the dependence of relative DIP pumping speed on the anode voltage (Fig. 2) almost resembles the ion-energy-dependence of sputtering yield[4] of typical residual gas ions on a titanium cathode (as in CESR). On the other hand, without stored beam in CESR, the DIP current, proportional to the electron cloud density in the pump cells, is observed to decrease exponentially when the anode voltage is reduced. As a result of the decrease of the electron density in pump cells, the pumping speed of DIPs drops rapidly at lower DIP anode voltage.

4. DIP CONTROLLER MODIFICATION AND OPERATIONAL EXPERIENCE AT REDUCED ANODE VOLTAGE

To summarize the above results: we have observed very different pumping behavior of the DIPs with and without stored beam in CESR. With stored beam, the DIP pumping speed is insensitive to the DIP anode voltage from 1.8 kV to 7.6 kV. On the other hand, with no stored beam in CESR, lower DIP pumping speed always results if the anode voltage reduced, and the DIPs virtually stop pumping when the anode voltage is decreased below 4 kV. Based on the results of this study, we have modified DIP controllers for over 80 DIPs in CESR. The CESR DIPs are grouped in twenty stations, and DIPs in each station may be remotely switched between a 'HIGH' state at 6.6 kV and a 'LOW' state at 2.2 kV. During normal CESR operation with stored beam, all the DIPs may be switched to the 'LOW' state to suppress the transverse beam instability, without sacrifice of DIP pumping speed. However, the DIPs will be set to the 'HIGH' state for long periods without stored beam or during start-up after any maintenance or upgrade shutdown, to provide effective pumping.

This modified DIP operation mode has been in place for more than a year in CESR. Both vacuum data and beam lifetime data have shown no degradation in DIP pumping speed and vacuum condition in the CESR arc regions. Meanwhile, the transverse instability has been greatly reduced from operating the DIPs at the reduced anode voltage.

However, we have observed pressure bursts in some DIPs which have operated at the reduced anode voltage over long periods. This has raised some concerns about metal-deposition from ion-sputtering, or so-called 'whisker' growth in the DIPs when operating at reduced anode voltage. At higher anode voltage filamentary metallic growth on the cathode is inhibited due to the higher discharge density and higher kinetic energy of sputtered ions in the DIP pumping elements.

Two proposals are currently under investigation to condition the DIPs in CESR after operating at lower anode voltage and to prevent possible 'whisker-growth' in the DIPs. One is to operate DIPs one to two stations at a time at higher voltage with stored beam over certain time periods, and cycle through all DIPs stations on a regular schedule. As the beam instability induced by DIPs in a few stations is usually relative small, this way of DIP-conditioning will have minor impact on the CESR HEP operation. But the effectiveness of this conditioning has yet to be evaluated. The other proposed conditioning method is to operate DIPs periodically at higher anode voltage under a relative high pressure (typically in 10^{-5} torr range) of N_2 or Ar gases. Though this method is reportedly[5] effective, it poses a much greater impact on CESR operation. The high-pressure conditioning can only be carried out during an accelerator shutdown period, and it usually conflicts with other shutdown activities.

5. CONCLUSION

We have measured DIP pumping speed at various anode voltages with and without stored beam in CESR. As a result of this study, most of the CESR DIPs are routinely operated at a much lower anode voltage. This has greatly suppressed a transverse beam instability induced by the DIPs and has also reduced photoelectron current in the DIPs. Long term DIP operation at the reduced anode voltage shows no degradation of vacuum condition and beam lifetime.

6. REFERENCES

1. N.B.Mistry, "Ultrahigh Vacuum Systems for Storage Rings and Accelerators",AIP Conference proceedings No.153, Physics of Particle Accelerators, American Institute of Physics, New York, 1987
2. J.T.Rogers and T.Holmquist, CEIBA Workshop, Tsukuba, 1995
3. Y. Li, R. Kersevan and N.B. Mistry, CESR Notes, 1997, CBN 97-11, Cornell University, Ithaca, NY
4. H.H.Anderson and H.L.Bay, in *Sputtering by Particle Bombardment I*, ed. (Springer-Verlag, 1981) by R.Behrisch, compiled sputtering yield data for Titanium, p.170;
5. Y. Suetsugu, *Vacuum*, **45**, 133 (1994)