Study of Distributed Ion-Pumps in CESR[1]

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Abstract

It is desirable to reduce anode voltage of distributed ion pumps (DIPs) in CESR in order to suppress a beam instability caused by the leakage electric field from the DIPs and to extend the lifetime of the DIPs and DIP power supplies. The DIP pumping speed is measured as a function of anode voltage with and without stored beam. It is found that the DIP pumping speed remains relative unchanged with the anode voltage changing from 'normal' operation voltage 7.6 kV to as low as 1.8 kV , when there is stored beam in CESR. On the other hand, the pumping speed drops rapidly as the anode voltage is decreased below 5 kV with no stored beam in CESR. A simple model is used to explain the operation of DIPs under the influence of the stored beam.

1. Introduction

In the arc regions of CESR, the beam chamber is maintained at ultrahigh vacuum condition, typically 2~3x10^{-9} torr with 300 mA stored electron and positron beams by lumped ion pumps and distributed ion pumps. Within the length of each normal dipole magnet, CESR vacuum chamber contains two DIPs. With stored beam in CESR, synchrotron radiation photons impinging upon the beam chamber wall desorb gas molecules. A series of pumping slots allows gas to flow from the beam chamber to the pump chamber. The bending beam chamber cross-section and the pumping slot pattern are depicted in Figure 1.

The DIP anodes were operated at 7.6 kV prior this study. It is desirable to reduce the DIP anode voltage for the following two considerations. First, an anomalous transverse coupled bunch instability ("anomalous anti-damping") is observed in CESR. It is believed [1] that this instability is caused by the electrostatic leakage field of the DIPs through the pumping slots. It is also found that the growth rate of the anomalous antidamping decreases with lower DIP anode voltage. Secondly, we have observed that the DIPs draw very high pump current with beams stored in CESR. The pump currents for some DIPs are as high as 5 mA per 100 mA total stored

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beams, which may extrapolate to a power dissipation of more than 370 W in some DIPs at planned CESR Phase III operation at total stored beam current of 1 A. This may be a potential serious problem for the current DIPs and DIP controllers in the future operation. As it will be discussed in this paper, this high DIP current is due to a coupling between the stored beam and the DIPs and does not reflect pressure in the pump chamber.

In the paper, we measured DIP pumping speed as a function anode voltage with and without stored beams, in order to define an 'optimum' CESR DIP operation mode. The coupling between the stored beam and the DIP current is also studied to understand the pumping behavior of the DIPs under the influences of stored beam in CESR.

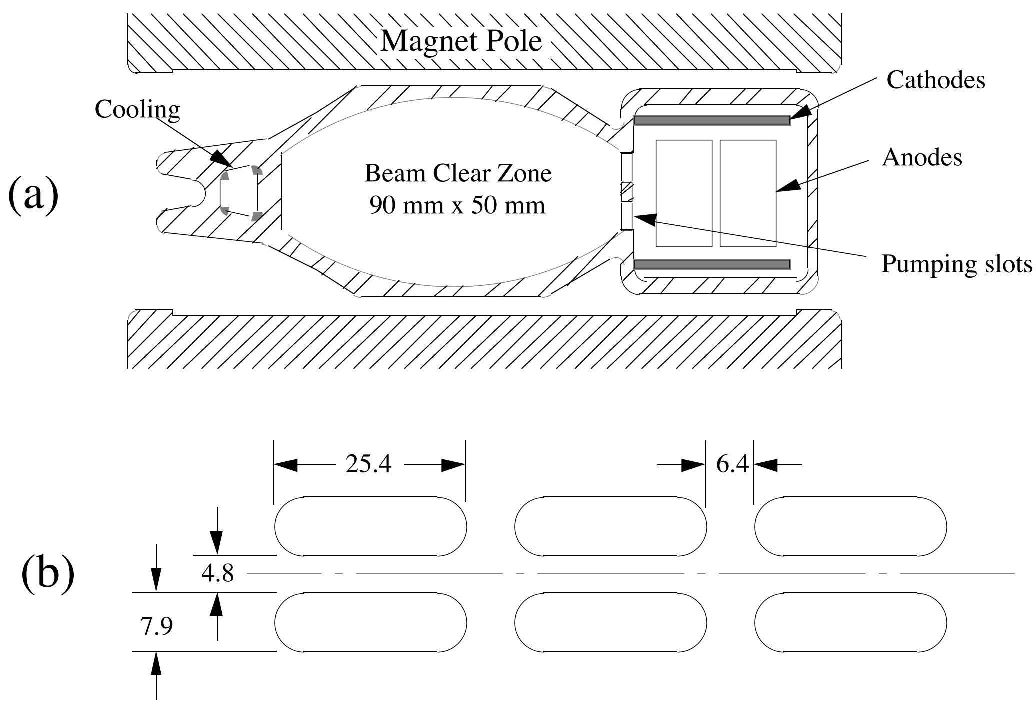


Figure 1. Cross-section of CESR vacuum chamber inside the bending magnet(a), and the pattern of pump slots between the beam chamber and pump chamber (b)

2. Experimental

Most of the measurements were carried out in a special vacuum instrumentation section, as shown in Figure 2. The instrumentation section consists of one long straight chamber and four bending chambers. In the center of each bending chamber between the two DIPs, a cold cathode ion gauge (CCG) is installed on a port through the DIP chamber, with a tube insert connecting to the beam chamber so that the gauge measures the total pressure in the beam chamber. All nine CCGs in the section were calibrated against a spinning-rotor gauge before installation. There is also a residual gas analyzer installed in the section for partial pressure measurement.

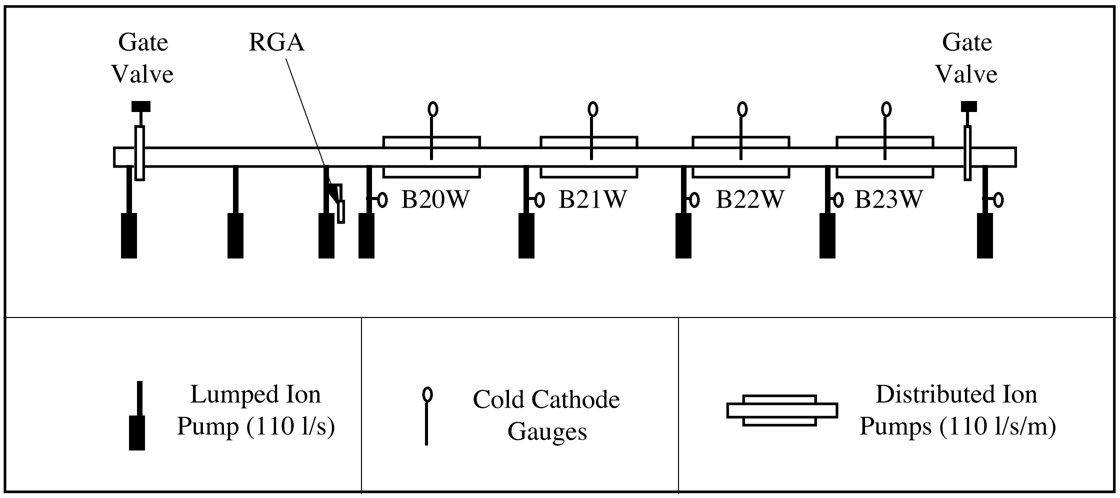


Figure 2. Schematic of CESR Vacuum Instrumentation Section

Modified DIP controllers were used in the study to power the DIPs in the section so that their anode voltages may be varied remotely from 0 to 7.6 kV. All the pump current and CCG pressure data are recorded by CESR control system every minute. Prior to the study, the vacuum chambers in the test section had been subjected to more than 250 Amp•Hour total beam dose. The variation of vacuum conditions in the section during this study can be ignored. Most of the data shown below were taken during so-called CESR high energy physics (HEP) runs for a number of considerations. First, the HEP runs are usually at very stable conditions. Second, it is important to measure the DIP pump currents and the beam chamber pressures over a long duration for any anode voltage as the DIP anode and cathode condition may take a very long time to stabilize. Since the measurements had little effect on the HEP runs, this arrangement saved a large amount of valuable machine time. Lastly and most importantly, the optimum DIP operation mode must be tested at the normal HEP condition.

3. Pumping Speed Measurement

The pressure distribution, P(x), along the beam chamber can be solved from the following equation

$$C\frac{d^2P}{dx^2}+S(x)\cdot P(x)=q(x) \tag{1}$$

where S(x) is the pumping speed function, and q(x) is gas-load function, respectively. C is the gas conductance of the beam chamber, and has a value of 32 meter•liter/sec. Not only lumped ion pumps and DIPs contribute to S(x). It is also a known fact that the well conditioned vacuum chamber wall acts like a dynamic getter pump by trapping-and-sticking of gaseous molecules.

Since it is practically impossible to measure pressure distribution in the beam chamber, we cannot directly calculate DIP pumping speed by solving eq.(1). However, it can be proven, to a very good approximation, that both the pumping speed distribution S(x) and gas-load distribution q(x) are symmetric functions about the center of the bending chamber at HEP condition. It is easy to show that with symmetric gas-load and pumping speed distributions at the center of a bending chamber

$$d^2P\big/dx^2\approx 0 \tag{2}$$

As the pumping at the center from the lumped ion pump is negligible, we can consider only the local conditions at the center. Thus we have

$$S_{total}\equiv S_{DIP}+S_{wall}=q_o/P_o \tag{3}$$

where P_o is the pressure at the center of the bending chamber which can be measured by the CCG, and q_o is the gas load per unit length. S_{DIP} and S_{wall} are the pumping speeds per unit length from DIPs and from the beam chamber wall, respectively. In this study, we are only interested in the relative pumping speed of the DIPs at a reduced anode voltage of V_i, as compared to the pumping speed at nominal high anode voltage of 7.6 kV.

$$\frac{S^i_{DIP}}{S^H_{DIP}}=(1+R)\frac{P_H}{P_i}-R \tag{4}$$

and

$$R\equiv\frac{S_{wall}}{S^H_{DIP}}=\frac{1}{P_{off}/P_H-1} \tag{5}$$

where P_H is the bending chamber center pressure when the DIP anode voltage is 7.6 kV, P_i is the pressure when the DIP anode operates at a reduced voltage V_i, and P_{off} is the pressure when the DIP is turned off. Assuming that S_{DIP} is uniform along the pump length, one can calculate the relative pumping speed as a function of DIP anode voltage from pressure measured at the center port of the bending chamber.

We found that the beam chamber pressure increase of the synchrotron radiation induced desorption is proportional to the total stored beam current, up to as high as 350 mA, at all tested DIP anode voltages. This indicates that the DIP pumping speed is independent of the stored beam current. In Figure 3, the pressures measured at the centers of the four bending chambers at 300 mA total stored current are shown as a function of DIP anode voltage. Using eqs. (4) and (5), the relative DIP pumping speeds are calculated. The results are plotted in Figure 4.

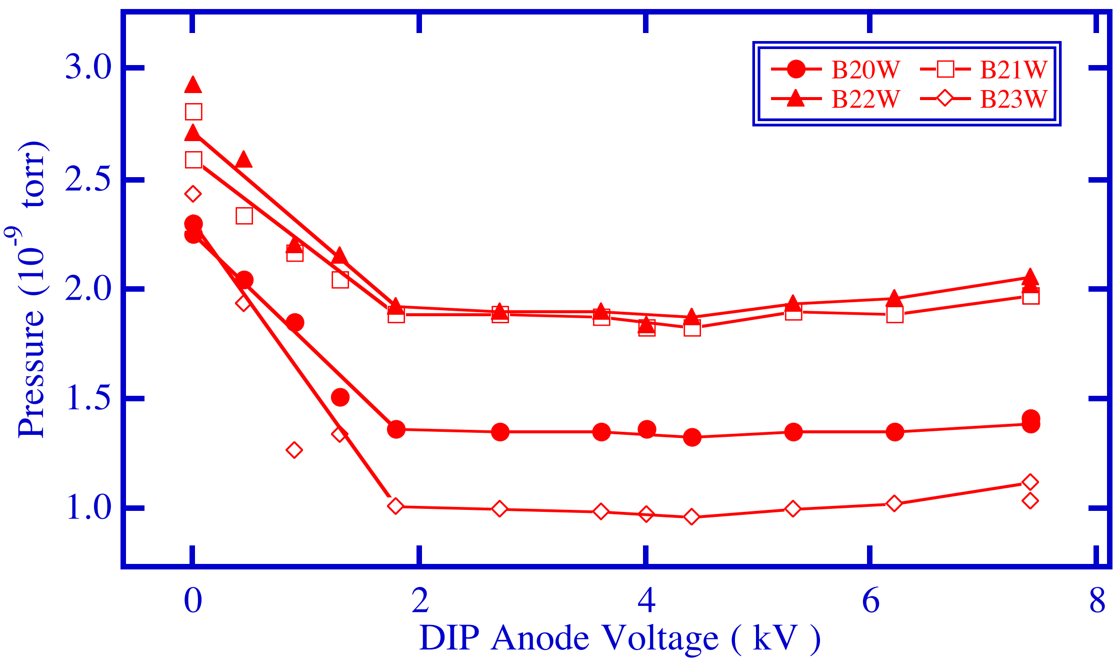


Figure 3. Bending chamber center pressures vs pump anode voltages with 200 mA total stored beam in CESR

The results in Figure 4 show that with beam stored in CESR, the DIP pumping speed is approximately constant with anode voltage from 1.8 kV to the 'normal' operating voltage of 7.6 kV. In fact, the DIPs seem to have a maximum pumping speed at around 4.5 kV. For comparison, we also measure relative DIP pumping speed as a function of the anode voltage with no stored beam in CESR, as shown in Figure 5. One can see that the behavior of the DIPs without the stored beam is dramatically different from that with stored beam in CESR. With no stored beam, the DIP pumping speed is always lower with decreasing anode voltage, and it drops rapidly to zero when the anode voltage is reduced below 5 kV. It is clear from these measurements that stored beam in CESR has a significant effect on the DIPs.

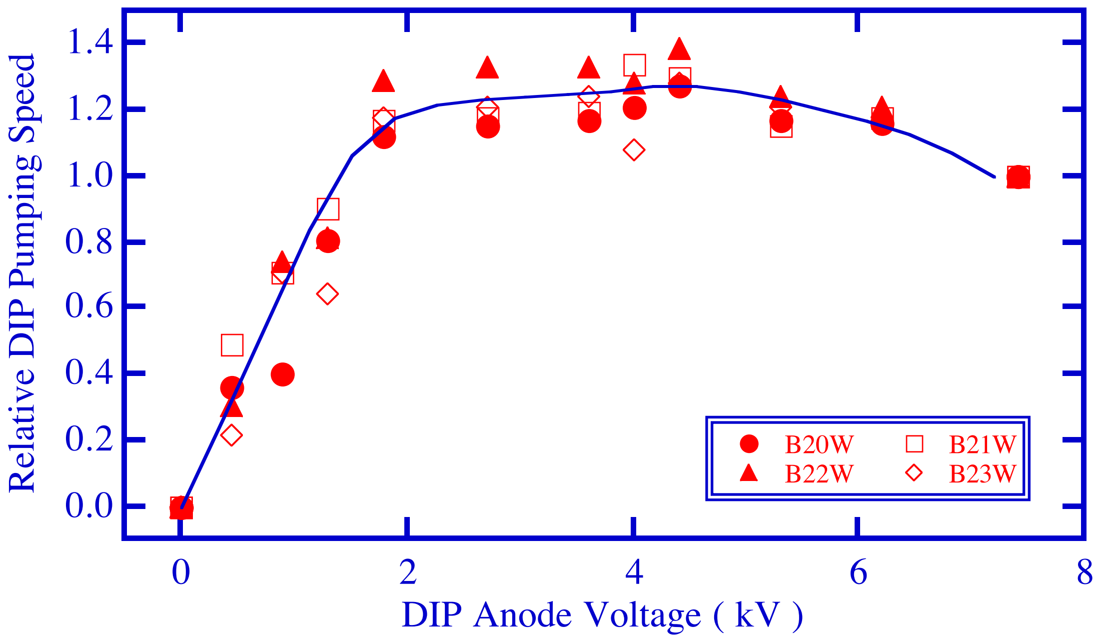


Figure 4. DIP relative pumping speed vs pump anode voltage at 200 mA total stored beams in CESR

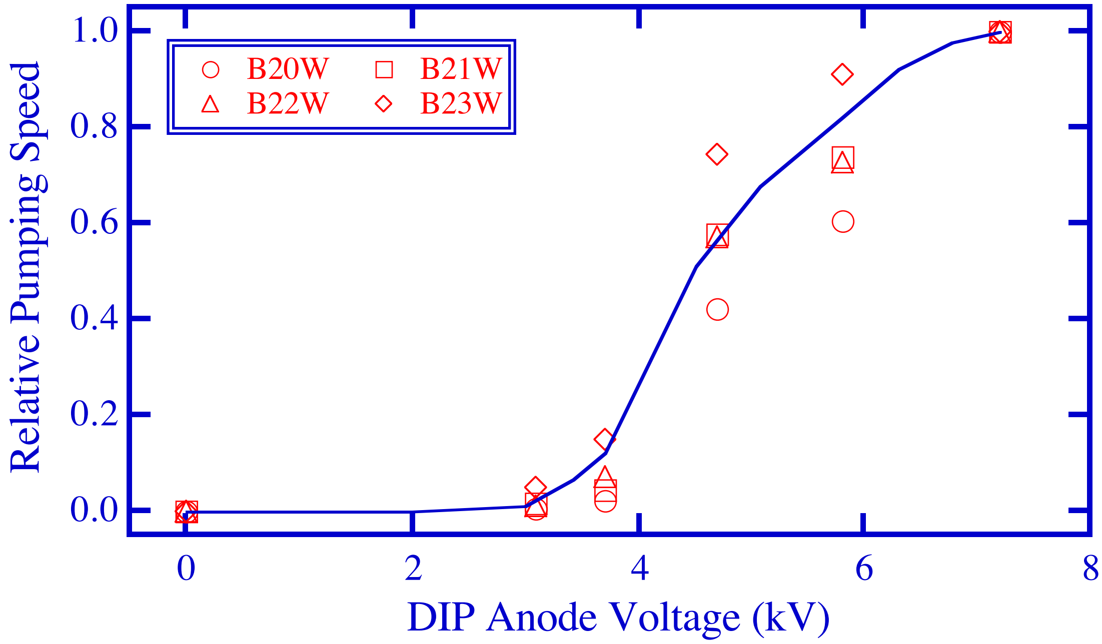


Figure 5. DIP relative pumping speed vs pump anode voltage, no stored beam in CESR

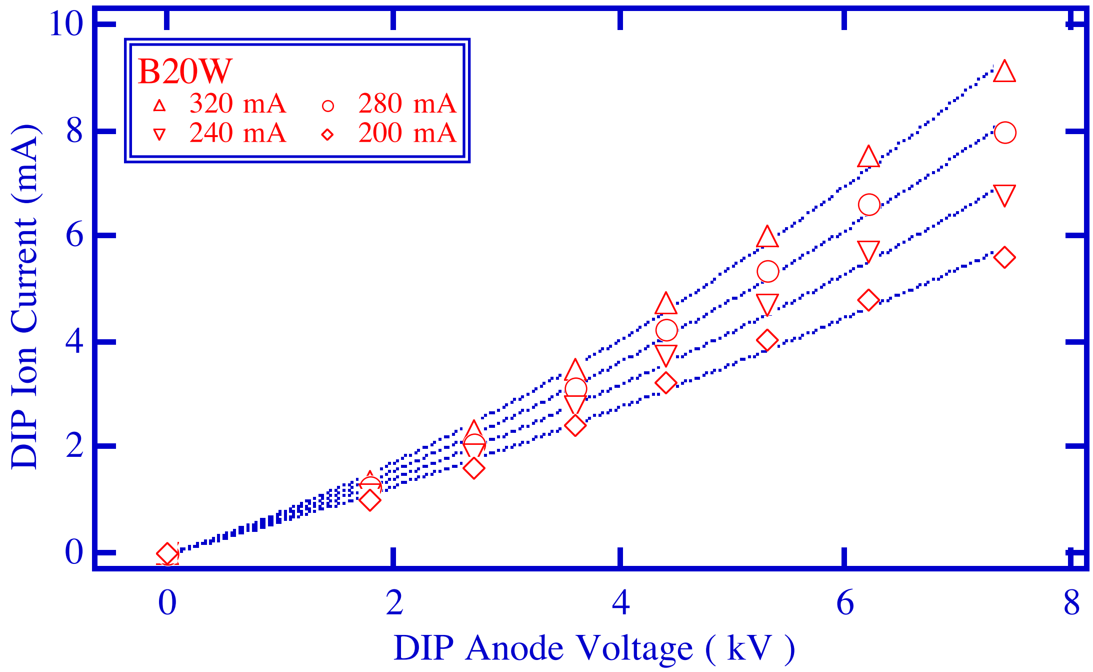
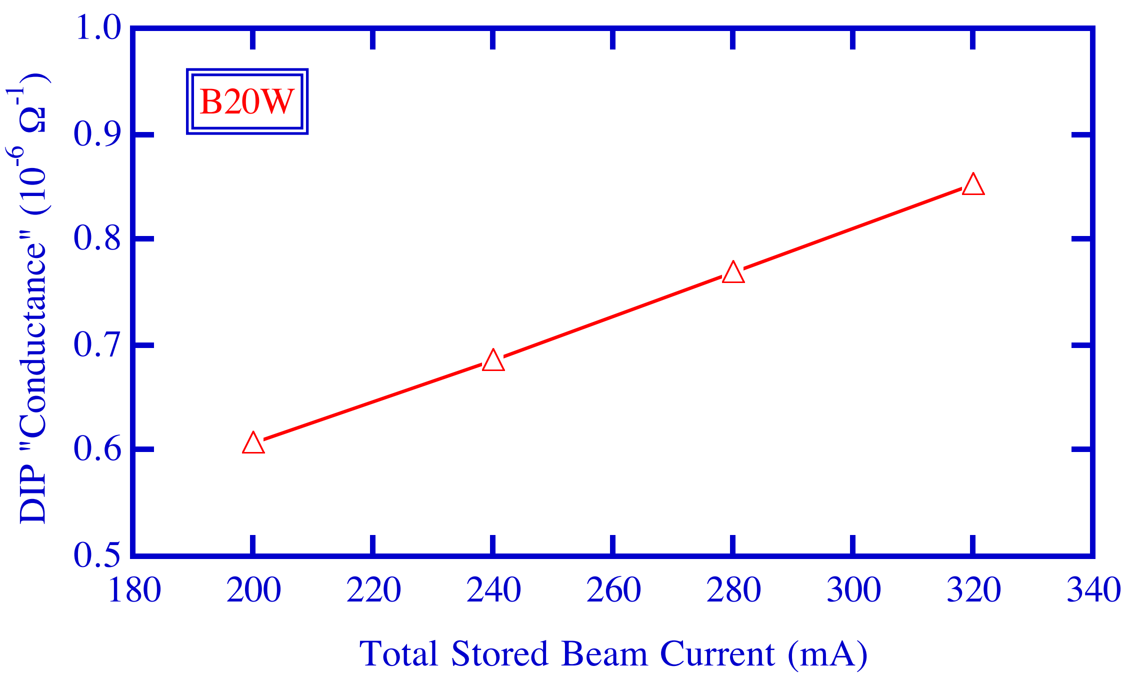


Figure 6. DIP pump current vs anode voltage at various stored beam currents in CESR



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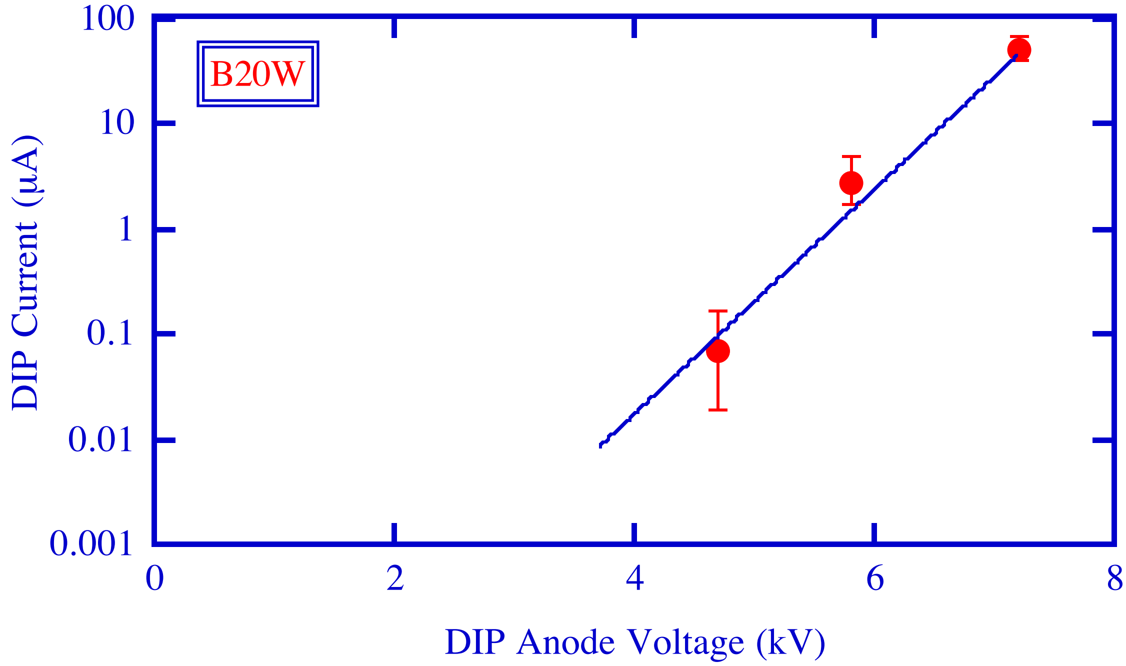

Figure 8. Exponential rise of DIP pump current vs anode voltage with no stored beam current in CESR

4. Discussion

There are two type of DIPs in CESR. One type is the so-called "Normal-bend DIP". In this type of DIP, there are pumping slots directly connecting the pump chamber to the beam chamber, as shown in Figure 1. All four DIPs in the instrumentation section are the Normal-bend DIPs. The other type of DIPs is contained in the so-called "Hard-bend" dipole magnets, which have higher magnetic field than that of normal bending dipole magnets and very high photon fluxes. In the Hard-bend DIPs, additional copper shield plates are inserted between the pumping slots and the DIP pumping elements. These shields have slots that are not aligned vertically with the slots in the chamber wall.

We have measured very large pump currents (milliamps) in the normal bend DIPs when there is stored beam in CESR, and have found that the pump currents have no correlation with the pressures in the pumps. In contrast with the normal bend DIPs, the pump currents in the hard bend DIPs, which have inserted shield plates, are in the order of tens of microamperes and the pressures derived from the pump currents agree with the CCG measurements. We conclude that the rather high current in the normal bend DIPs originates from some kind of coupling between the stored beams in CESR and the DIPs through the pumping slots between the beam chamber and pump chamber. There may be two mechanisms contributing to the coupling. One is the higher-order-mode (HOM) RF coupling as the image currents of the stored beams propagate along the slotted chamber wall. The other mechanism is due to scattered photons producing a large photoelectron current in the DIPs. The two coupling mechanisms have very different signatures. The HOM RF coupling is very sensitive to the bunch structure and orbit of the stored beam in CESR. On the other hand, the photo-electron induced DIP current should only depend on the total synchrotron radiation (SR) flux in one bend chamber. The total SR flux is directly proportional to the total stored beam current, and is only slightly dependent on the beam orbit. But it should be independent of the bunch structure of the stored beam. At tested anode voltages, the normal bend DIP pump current is found to be approximately a linear function of the total beam current in CESR. It is also observed that the normal bend DIP is only slightly dependent on the bunch structure and the beam orbit of the stored beam in CESR. Based on these observations, we believe that the observed high pump current in the normal bend DIPs is mostly due to the photoelectrons generated in the DIPs by the scattered SR photons.

Though the pump currents in the normal bend DIPs do not provide information about the pressures in the pump chambers, they may shed light on the physical phenomena happening in the pumps. We measured DIP pump currents as functions of the pump anode voltages with and without stored beam in CESR. For the case of with stored beam, the result is shown in Figure 6 for a typical DIP, namely B20W. All the normal bend DIPs has similar behavior as in Figure 6. The pump current increases approximately linearly with the anode voltage at given stored beam current in CESR. We have suggested above that the measured pump current is dominated by the photo-electrons generated in the DIPs by the scattered photons through the pumping slots. The collection efficiency of the photoelectrons, hence the pump current, will increase with higher anode voltage. The slope of the pump current vs the anode voltage , or the DIP "conductance", may thus be a measure of the coupling between the stored beam and the pump current. The pump current increases linearly with the total stored beam current in CESR, as shown in Figure 7, because the SR flux is simply a linear function of the stored beam current.

When there is no stored beam in CESR, the DIP pump current varies with the anode voltage in a very different way. In Figure 8, the pump current for B20W is plotted as a function of the anode voltage. Without stored beam in CESR, the pump current drops exponentially with the anode voltage.

There are many factors that affect pumping speed of a sputtering ion pump. Among all the factors, two are fundamental for a given sputtering ion pump. They are charge density in the pump, and the sputtering yield of energized ions on the pump cathode. At low pressure, an increased pumping speed can be expected with higher charge density in the pump and with higher sputtering yield[2]. At any particular operating condition, one of above two quantities may have more important effect on the pumping speed than the other. In the 'normal' situation where there is no stored beam in CESR, the pumping speed is limited by the density of electron charge in the pump cell at low pressure ($<10^{-8}$ torr). The discharge in the pump cell is ignited and maintained by field emission that depends on the strength of the electric field exponentially. As the anode voltage decreases, the electron density in the pump cell will drop exponentially. This explains the observed exponential dependence of DIP ion current on the anode voltage since the ion current in the pump is directly proportional to the electron density at low pressure. As a result of the decrease of the electron density, the pumping speed of the DIPs decreases with reduced anode voltage. With stored beam in CESR, a sufficient high electron density is always maintained in the pump due to the large photoelectron current produced in the DIPs by the scattered photons. In this case, the DIP pumping speed is limited by the sputtering yield of the energized ions on the pump cathode. For titanium cathode (as in CESR), the sputtering yields with typical residual gas ions decease slowly with decreasing kinetic energy of the ions when the ion energy is above 2 keV. However, the sputtering yields for those ions start to drop relative rapidly as the ion energy falls below 1~1.5 keV[3]. As a result of the decreased sputtering yield, the DIP pumping speed decreases with the anode voltage when the voltage is reduced below 1.8 kV. The pumping speed also decreases slowly with increasing anode voltage *above* 5 kV. This, too, is due to the decrease in sputtering yield of Ti by residual gas ions above energies of 5 kV. This simplified picture describes DIP operation at pressure below 10^{-8} torr. At higher pressures, space charge in the anode-cathode space plays an increasing role. The space charge screens the electric field seen by the ions. As a result, the optimum sputtering yield is shifted up to applied anode voltages of 6 kV to 7 kV, so that the effective field results in ions of optimum energy of 3 keV~4 keV. Thus we expect to run DIPs in CESR around 7 kV in start-up mode, but decrease the anode voltage to as low as 2.2 kV during normal operation in the nanotorr pressure range.

5. Conclusions

This study has shown that the stored beam in CESR has a significant effect on the pumping behavior of the normal CESR bend distributed ion pumps. We have observed that the pumping speeds of the DIPs are not sensitive to the pump anode voltage as low as 1.8 kV, due to the photoelectron current produced by the SR photons in the DIPs. On the other hand, a much higher anode voltage is required to maintain efficient pumping speed for the DIPs when there is no stored beam in CESR.

Based on the above results, we have begun to modify the power supplies for all CESR normal bend DIPs. With the modified power supplies, the DIP anode voltages may be switched remotely between 6.6 kV and 2.2 kV. When there is stored beam in CESR, the normal bend DIPs are operated at anode voltage of 2.2 kV. At this reduced DIP anode voltage, the anomalous antidamping is suppressed significantly, and the DIPs also see much smaller pump current. When there is no stored beam in CESR, especially during any machine shutdown or during machine start-up, the DIPs will be switched to the higher anode voltage to provide effective pumping. This mode of operation has been implemented in most part of CESR and experience of long-term (more than half-a-year) operation shows no degradation of the pumping speed of the DIPs operated at the reduced anode voltage.

References

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