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PRESSURE INDUCED BEAM INSTABILITIES IN THE FERMILAB ACCELERATOR

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SUMMARY

Beam instabilities resulting from localized pressure bumps in the Fermilab main ring have become more significant as the beam intensity has increased. The instability threshold depends on pressure, beam intensity, and machine tune. Experiments are described which explore this threshold using both time dependent and time independent pressure bumps. The effects of gas variations, bump length and time duration are reported.

INTRODUCTION

The main-ring vacuum system maintains an average pressure of $\sim 1 \times 10^{-7}$ torr or better, but in several localized areas the pressure is as high as $\sim 1.5 \times 10^{-6}$ torr. There have been occasions when attempts were made to run the machine when known vacuum leaks maintained a peak pressure of 1×10^{-5} torr. Beam was successfully accelerated under such conditions until the Summer of 1974 when increased intensity ($\sim 1 \times 10^{13}$ ppp) resulted in beam blowup. Noting that the blowup was intensity dependent the question was raised as to what would be the maximum allowable localized pressure at the design intensity (5×10^{13} ppp). Another question was raised concerning the gas jet used in the Internal Target Laboratory, particularly with respect to the use of He which might be pumped less efficiently than the H_2 presently used.

With these questions in mind a series of experiments were made to determine the onset of instability or beam blowup for increasing intensity as a function of pressure in a localized bump. These experiments involved looking at blowup thresholds for N_2, He and H_2. Pump configurations were changed to increase bump length for a given peak pressure, and intensity was varied to determine the threshold for a fixed peak pressure.

PRESSURE BUMP LENGTH

The beam tube is pumped at the end of each 20-foot bending magnet by a nominal 30 ℓ/s ion pump. The pump current is used to measure pressure at that point. The conductance of the beam tube through a bending magnet is roughly 35 ℓ/s. A remotely controlled variable leak which could be fed a selected gas was inserted in the lattice to create the desired pressure. The pressure distribution vs. pump number is displayed by computer as shown in Figure 1. The pressure drops by a factor of ~ 2.6 between pump locations on moving away from the leak. Thus, the pressure drops by more than an order of magnitude at a distance of 60 feet from the leak, giving a rather localized pressure bump compared to the 4-mile circumference of the machine.

Turning off various combinations of pumps allows one to extend the high pressure region. This was done by first turning off every other pump and turning off two out of three pumps. In both cases the blowup threshold did not change measurably.

THRESHOLD, STATIC BUMP

The beam intensity was varied to determine the blowup threshold as a function of pressure. As can be seen from Figure 2, with 13 booster pulses injected into the main ring (filling the ring), the beam was scraped with a pulsed orbit bump to decrease intensity until the beam was found to be stable. It is also noted that as intensity decreased the beam loss occurred progressively later in the cycle which might indicate that if the cycle time were longer the threshold would be lower than that measured.

Near the threshold one would observe that the beam would oscillate transversely and blowup without leaving the machine, however, losses would be experienced in the extraction channel which has a reduced vertical aperture. If either the pressure or intensity were increased from this point, beam would be lost during acceleration. Conversely if the intensity or pressure were reduced blowup would not be experienced.

The pressure was set at four different values by continuously bleeding N_2 and the intensity was varied to determine the threshold for each pressure. As can be seen from Figure 3 for a peak pressure of 2×10^{-5} torr the threshold is at an intensity of 9.5×10^{12} ppp. For a peak pressure of 6×10^{-5} torr, 1.1×10^{-4} torr, and 7×10^{-4} torr the thresholds were 5.5×10^{12} ppp, 3.5×10^{12} ppp and 1.0×10^{12} ppp respectively. These measurements were made with all ion pumps operating.

The same experiment was repeated using He instead of N_2. Figure 3 also shows these results. The plot for He is corrected for the proper gauge factor and the results show that a higher pressure of He than N_2 is tolerated by the beam. For an intensity of 8×10^{12} ppp the threshold is at 3×10^{-4} torr and at 2.4×10^{12} ppp the threshold is 2×10^{-3} torr. The slopes of both curves appear to be the same, and would seem to indicate that at the design intensity of 5×10^{13} ppp the peak pressure for any localized high pressure region should be less than 2×10^{-6} torr.

GAS JET, TIME DEPENDENT BUMP

The Internal Target Laboratory is located in a long straight section (170 ft.) of the ring. The gas jet is nearly centered in this section flanked by 2400 ℓ/s diffusion pumps. The first of two such upstream pumps is 4 ft. from the jet, the second 10 ft., and one diffusion pump is located approximately 6 ft. downstream from the jet. Near each end of the straight section, ~ 75 ft. from the jet, are located two 600 ℓ/s ion pumps. The majority of vacuum chamber between the diffusion pumps and the ion pumps has a rectangular cross section 2 in. by 5 in. In normal operation a stream of hydrogen from the jet is directed into a cryopump at liquid He temperatures which traps a large fraction of the gas, however, the experiments described here were performed without the use of the cryopump.

The jet is pulsed with solenoid operated valves. Valve 1, which releases gas into the vacuum from a fixed volume with variable pressure, is opened at a selected time T_1 in the acceleration cycle, and remains open for some time T_2, typically 20-200 msec. The second valve is opened after some delay T_3 following the closing of valve 1, and valve 2 remains open for sometime T_4, typically 300 msec, replenishing the fixed

*Operated by Universities Research Association, Inc., Under Contract With the U. S. Energy Research and Development Administration volume from a pressure regulated source. Both valves require a minimum of 18 msec to unseat and appear to take ∿ 100 msec to fully open or fully close.

In the absence of cryopumping the pump-down time for reducing the pressure by 1/e following a jet pulse is ∿ .4 sec. The pressure vs. time structure is shown in Figure 4. The pressure has been measured within 6 in. of the jet using both a pig gauge and ion gauge. The gauge signals and the ion pump current are recorded on a multipen chart recorder. The pig gauge circuitry saturates at a pressure of 6×10^{-4} torr; the ion gauge is capable of reading 1×10^{-2} torr, however, above 5×10^{-3} torr it tends to read high. As can be seen from the ion gauge signal if valve 1 is held open long enough to substantially drain the fixed volume and valve 2 is opened with no delay ($T_3 = 0$), the slow closing of valve 1 results in a second increase in pressure due to both valves being partially open simultaneously.

The pressure rise due to the jet is substantially attentuated by the diffusion pumps and is greatly dispersed in traveling down the beam tube. The peak pressure seen by the ion pumps is approximately two orders of magnitude smaller than that seen at the jet and occurs on the order of 1.75 sec. after the peak at the jet. The first noticable pressure increase at the ion pumps occurs ∿ .25 sec. after the pulsing of the jet. Thus, the time structure of the pressure bump as seen by the beam is rather complex.

EFFECT ON BEAM

Pulsing the H_2 jet at 50 GeV and 200 GeV during the 380 GeV acceleration cycle did not appreciably change its effect on the beam. With the jet pressure set at 10 psia and a beam intensity of 9×10^{12} protons per pulse, a peak pressure at the jet of ∿ 5×10^{-3} torr was required to blow up the beam. This is substantially higher than experienced with a continuous leak with either N_2 or He.

The ability to selectively pulse the jet on a given acceleration cycle led to the discovery that near and above the blowup threshold, pulsing the jet changed the position of the extracted beam. Figure 5 shows the extracted beam moved horizontally by almost 6 mm as a result of the jet. This movement would appear to indicate that the pulsing of the jet alters the tune of the machine.

The main ring is nominally operated at a tune of $\nu_y = 19.42$, $\nu_H = 19.37$ throughout the acceleration cycle with horizontal half integer resonant extraction combined with pinged fast extraction during flattop. Tune bumps were added during acceleration to bring the tune near $\nu_H = \nu_y = 19.25$. This resulted in the loss during acceleration as shown in Figure 6 of nearly 70% of the injected beam whenever the jet was pulsed at threshold conditions for the injected intensity and normal operating tunes. When the jet was not pulsed under these conditions beam loss was not observed. The tune bumps were then changed to $\nu_H = 19.20$, $\nu_y = 19.27$ and the beam loss as a result of jet pulsing was reduced to ∿ 30% under the same conditions as above.

These experiments seem to indicate that pulsing the jet alters the dynamic tune of the machine and that the operating tune or the proximity to resonance stopbends is a factor in the blowup threshold for a localized pressure bump.

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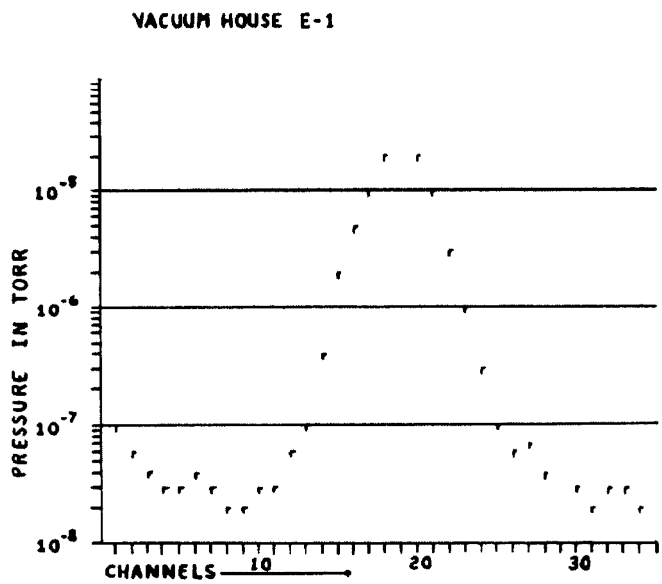

Fig. 1. Each ion pump in the main ring is monitored and its current used to indicate pressure, which can be displayed by the computer, giving a vacuum profile for any selected segment of the ring. To simulate a localized pressure bump a remotely controlled variable leak was inserted in the lattice near house E1 at pump 19. A variety of bumps were created similar to the one shown and the beam intensity was varied to determine beam instability thresholds as a function of peak pressure and intensity.

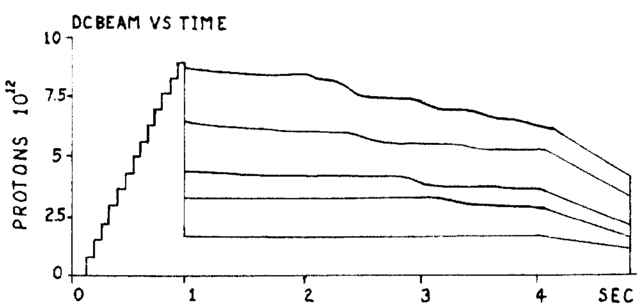

Fig. 2. During front porch (0 to 1 sec) 13 batches of booster beam are injected into the m[illegible]n ring; the beam is then accelerated to full energy and extracted during flattop (4 to 5 sec) with a combination of slow and fast spill. A localized pressure bump causes the beam to blowup and be lost during acceleration at high intensity. This instability can be avoided by reducing the intensity or peak pressure in the poor vacuum region. In this case the intensity is reduced by scraping the beam with a pulsed orbit bump at 1 sec. As the intensity is lowered beam loss occurs progressively later in the acceleration cycle until the beam is stable throughout. The maximum intensity at which the beam is stable for a given pressure bump is referred to as the blowup threshold.

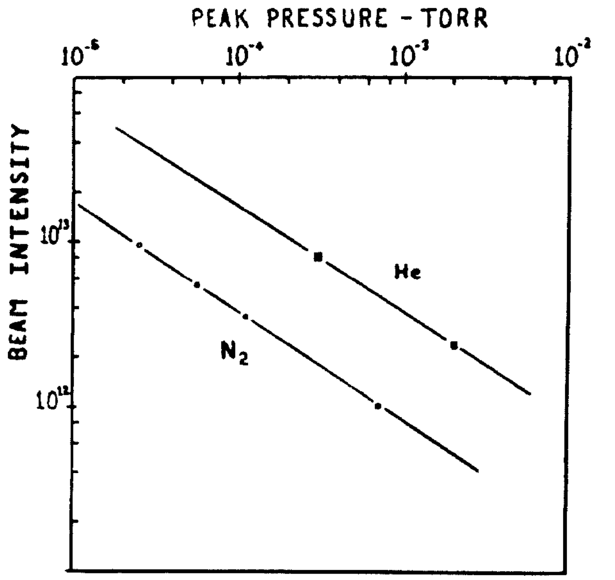

Fig. 3. The threshold for beam blowup is plotted as a function of peak pressure and beam intensity for localized pressure bumps of N_2 and He; above the lines the beam is unstable. A higher peak pressure of He is tolerated by the beam than for N_2.

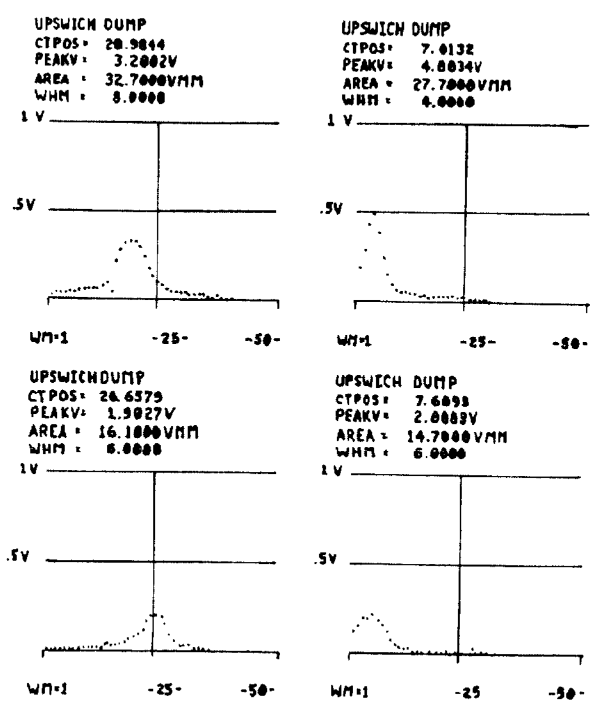

Fig. 5. The extracted beam profile, as measured at the main ring dump, is measured both horizontally (left) and vertically (right). The upper plots are taken with no jet and the lower plots are taken on a cycle when the jet was pulsed. The most striking difference between the two measurements is the change in the horizontal position of the extracted beam indicating a possible tune shift.

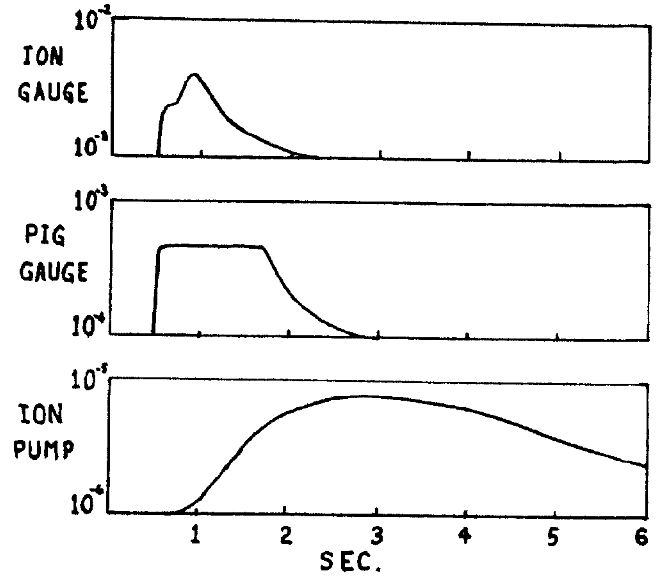

Fig. 4. The gas jet in the Internal Target Laboratory produced a pressure rise whose time dependence is shown for a jet pressure of 5 psi and valve open time of 200 msec. This pressure pulse is measured locally on both an ion gauge and pig gauge. The ion gauge reads 10^{-2} torr full scale whereas the pig gauge circuitry saturates at 6×10^{-4} torr. The second pressure rise seen by the ion gauge is due to the slow closing time of the jet valve which results in it being partially open simultaneously with a second valve which primes the jet from a pressure regulated source. Approximately 100 msec are required to fully open or close the two valves and the second valve is characteristically opened with no delay following the closing of the jet valve. Whenever the jet is pulsed an attenuated and dispersed pressure rise is seen at the ion pumps 75 feet from the jet. The ion pump current is converted to a pressure reading in torr.

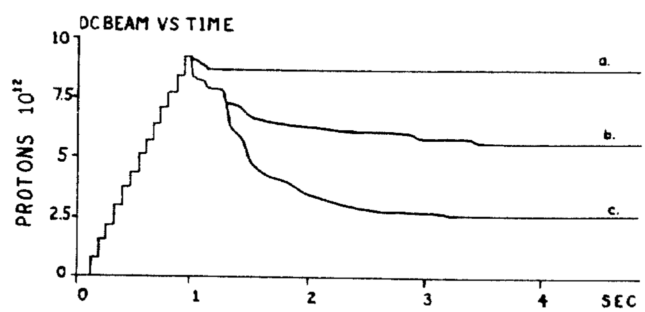

Fig. 6. Beam loss and blowup threshold vary as a function of machine tune. Maintaining a tune of $\nu_H = \nu_y = 19.25$ during acceleration (normal tune being $\nu_y = 19.42$, $\nu_H = 19.37$) resulted in very little beam loss (trace a) except when the jet was pulsed (trace c) which resulted in $\sim$ 70% beam loss. Changing the tune to $\nu_H = 19.20$, $\nu_y = 19.27$ reduced the loss to $\sim$ 30% when the jet was pulsed (trace b) and under the same jet operating conditions no loss was experienced at the nominal operating tune. This appears to indicate that the proximity to resonance stopbands is a factor in the blowup threshold.