Response of Air-Filled Ion Chambers to High-Intensity Radiation Pulses

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Abstract

Ion chambers are one of the most popular types of detectors used for beam loss-monitor systems. To provide a foundation for the development of future loss-monitor systems, and to fully characterize the ion chambers in use at LAMPF, we have studied the response of air-filled cylindrical ion chambers to high-intensity, short-duration radiation pulses. The most intense pulses were about 180 rad in 250 ns (the equivalent steady-state dose rate was about 700 Mrad/h). We filled our chambers with nitrogen gas at 760 Torr and air at 600 Torr. The ion chambers were driven into extreme nonlinear response. We hope these data will be used to design loss-monitor systems based on air-filled ion chambers, thus eliminating the need for gas-flow systems and/or air-tight ion chambers.

I. INTRODUCTION

Most loss-monitor detectors at the Los Alamos Proton Storage Ring (PSR) facility are ion chambers filled with nitrogen gas at 1 std. atm. The idea behind this combination of gas and pressure is, if the ion chamber leaks, and the gas is exchanged for air at local pressure (about 80% of 1 std. atm.), the sensitivity of the ion chamber will decrease by about 20%. This 20% change is small enough that the safety of the system will not be seriously compromised, yet large enough that we can detect it with a radioactive source check.

The main advantage of using ion chambers filled with air at local pressure is that one would not have to worry about leaks or gas-handling systems. The disadvantages are:

1) the response becomes nonlinear at smaller radiation pulses;
2) to control the sensitivity of the ion chamber, one may vary the volume of the gas, but not the pressure;
3) the sensitivity of the ion chamber may change in proportion to local barometric changes;
4) possible undesirable effects due to water vapor migrating into the ion chamber gas. We have not yet studied these effects.

At the Los Alamos Meson Physics Facility (LAMPF), the function of the PSR is to compress the proton beam from the 800-MeV linear accelerator. A typical pulse of about 600 μs is compressed to just 250 ns. The PSR is therefore an ideal source for short, intense pulses of radiation. On the other hand, monitoring beam losses from such a beam is a challenging task for some types of detectors, for example, those based on photomultiplier tubes.

II. EXPERIMENTAL SETUP

To determine the suitability of air-filled ion chambers for use at LAMPF, we conducted two sets of measurements – one in the Fall of 1991, and one in the Fall of 1992. For the first data set, we steered the PSR beam into the side of the beam pipe. Two ion chambers, one of the usual type filled with nitrogen gas at 1 std. atm., and one filled with air at local pressure, were placed about 1 m transversely from the beam pipe. For the second data set, beam was directed onto a beam plug in the PSR extraction line, and the ion chambers were placed directly alongside the plug. We chose this scenario because it is the worst-case test available at the PSR (not including actually directing the beam through the ion chamber). The location of the beam plug is such that it can intercept either beam from the linac or beam from the PSR. This gives us some flexibility on the length of the beam pulse, and therefore on the duration of the radiation pulse. For our 1992 tests the linac beam pulse length was set to 800 μs.

As shown in Fig. 1, the active volume of our ion chambers is contained between two concentric cylinders. The outer diameter of the center electrode is 1.59 cm, the inner diameter of the HV shell is 4.19 cm, and the active volume is about 180 cm^3. When filled with nitrogen gas at 1 std. atm. the sensitivity is 56 nC/rad, and when filled with air at local pressure (600 Torr) the sensitivity is 44 nC/rad. The data shown are for -1 kV and -2 kV applied to the outer cylinder. We use negative voltages because we have empirically found that negative voltages result in a more linear ion chamber response. The center electrodes of the ion chambers were connected to 0.22-μF integrating capacitors, followed by a digitizing `scope with a 1-MΩ input impedance.

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III. DATA

As shown in Table 1, the 1992 data set, with beam directed onto a beam plug, offered considerably more intense radiation pulses. In Figs. 2 and 3 we plot the ion-chamber output divided by the intensity of the radiation pulse (nC/rad, or sensitivity). Such a plot should give a straight horizontal line when the ion chamber is operating in its linear region. The plot should then descend towards zero as the ion chamber begins to operate in its nonlinear region. From the figures we see that the ion chambers were clearly driven into the nonlinear response region.

As expected, the plots show that at higher voltages the ion chamber response remains linear up to higher-intensity radiation pulses, and that the sensitivity of air at local pressure is about 20% lower than nitrogen at 1 std. atm. The latter is due to the 760 vs. 600-Torr pressure difference. We also see that the response of the air-filled ion chamber becomes nonlinear at lower-intensity pulses than the nitrogen-filled ion chamber. This could be due to the large electronegativity of oxygen. Neutral oxygen atoms tend to attract electrons to form negative ions, which combine with the positive ions to reduce the ion chamber output.

IV. CONCLUSIONS

We have measured the response of air-filled and nitrogen-filled ion chambers to high-intensity radiation pulses. The most intense pulses drove the ion chambers well into the nonlinear region. We found that, compared to the nitrogen-filled ion chamber, the response of the air-filled ion chamber becomes nonlinear at lower-intensity radiation pulses. Although the ion chamber responses were highly nonlinear for high-intensity radiation pulses, they did not exhibit any other failure modes. We hope our data can be used to develop other loss monitor systems that are simpler and more reliable through the use of air at local pressure as opposed to pure gas under pressure. If air can provide sufficient sensitivity, and if nonlinear response for high-intensity pulses is not a problem, then the advantages of air-filled ion chambers should be considered.

Table 1. Intensity and duration of radiation pulses incident on the ion chambers.

Data set	Intensity of radiation pulse	Duration
1991	0.036 to 2.3 rad	250 ns
1992	1.0 to 160 rad	250 ns
1992	1.3 to 260 rad	800 μs

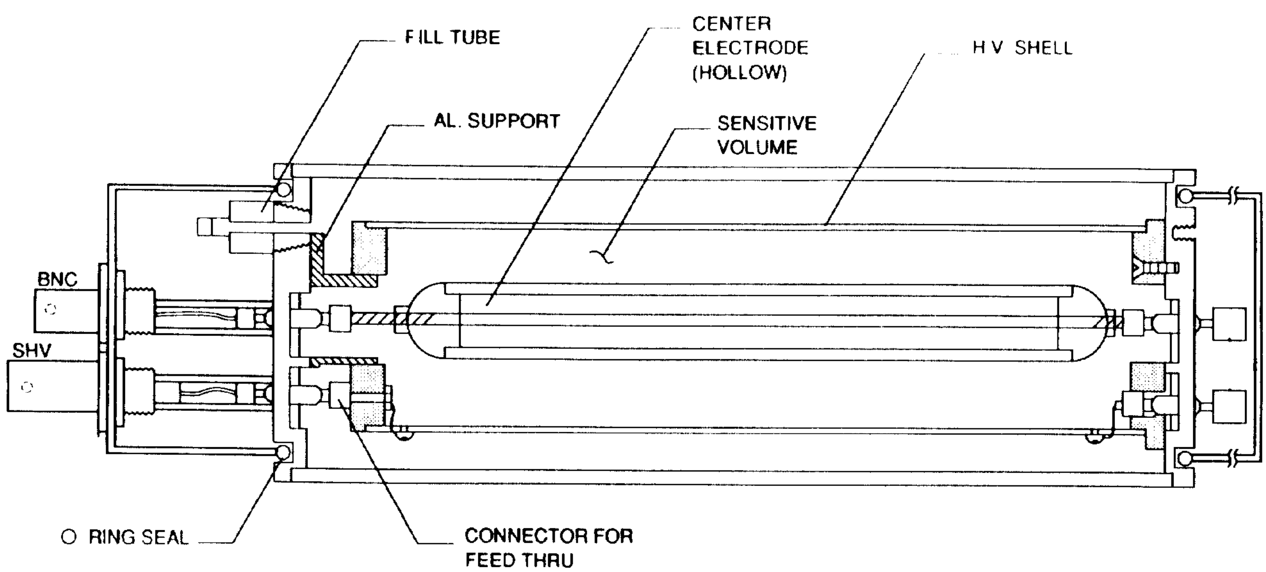

Fig. 1. The ion chamber used in our tests. It's a Model 1054A from Health Physics Instruments, Goleta, CA.

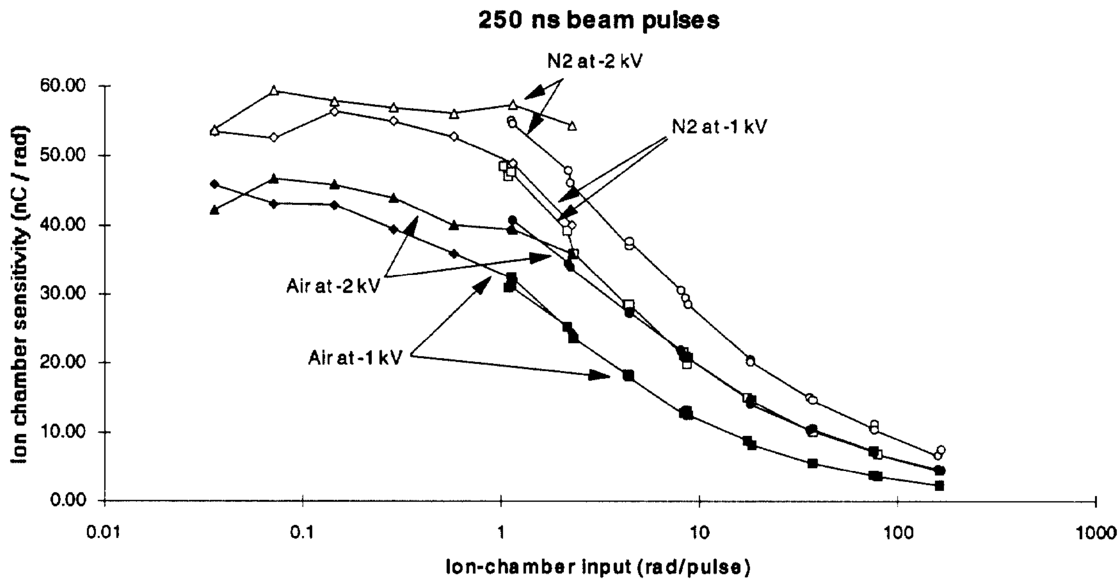

Fig. 2. 250-ns beam pulses. Data from the 1991 and 1992 tests. The air-filled ion chamber begins to become nonlinear at about 0.2 rad, and the nitrogen-filled ion chamber begins to become nonlinear at about 0.5 rad. The difference in sensitivity at low radiation pulses is due to the difference in gas pressure.

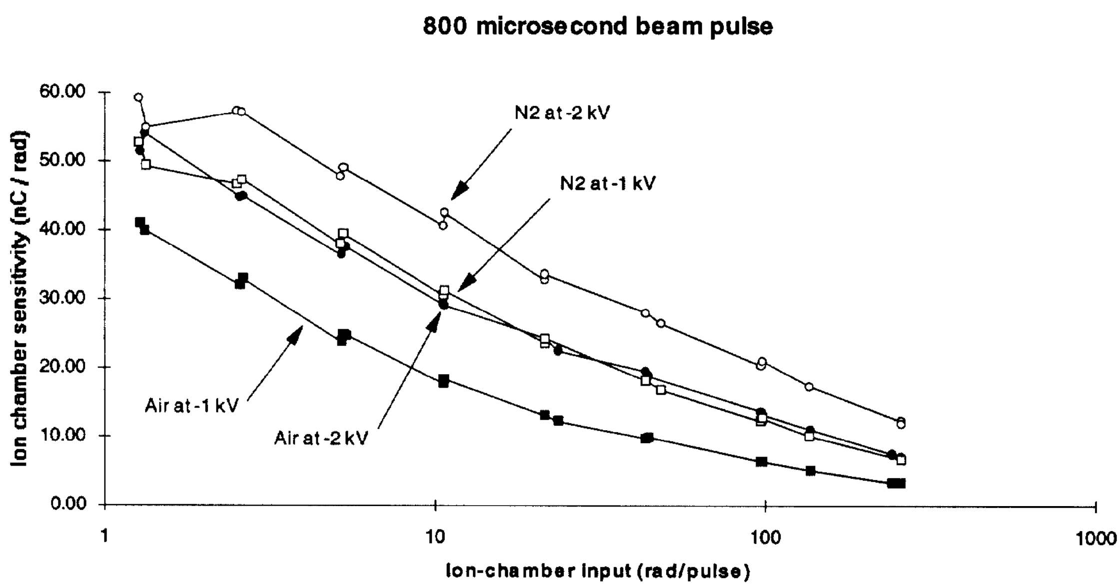

Fig. 3. 800-μs beam pulses. Both the air-filled and nitrogen-filled ion chamber are nonlinear even at the lowest radiation pulse tested. For a given ion-chamber input (rad/pulse), the ion-chamber output (nC/rad) is higher for the 800-μs beam pulse than for the 250-ns beam pulse.