Note: He puff system for dust detector upgrade

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Local detection of surface dust is needed for the safe operation of next-step magnetic fusion devices such as ITER. An electrostatic dust detector, based on a grid of interlocking circuit traces biased to 50 V, has been developed to detect dust on remote surfaces and was successfully tested for the first time on the National Spherical Torus Experiment. In this note, we report a helium puff system that clears residual dust from this detector and any incident debris or fibers that might cause a permanent short circuit. Two consecutive helium puffs delivered by three 0.45 mm nozzles at an angle of 30º cleared the entire 5 cm × 5 cm surface of the detector. © *2011 American Institute of Physics*.
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Dust production in next-step magnetic fusion devices will be significantly higher than in contemporary devices due to the more intense plasma wall interactions and the increase in erosion levels.[1] Local measurements of surface dust are part of the ITER dust strategy[2] and an absolute detection accuracy of 50% has been specified.[3]

A novel device to detect the settling of dust particles on a remote surface has recently been demonstrated on the National Spherical Torus Experiment (NSTX) (Ref. 4). A grid of two closely interlocking conductive traces on a circuit board was biased to 50 V. Dust particles that fall on the detector cause a transient short circuit and create a voltage pulse that is recorded by counting electronics. The total number of counts is proportional to the mass of dust impinging on the detector.[5] Typically 90% of the total number of particles that land on the detector are vaporized by the current pulse and ejected from the detector, however, about 10% may remain on the surface of the detector.[6] These may produce signals at a later time, complicating efforts to correlate the dust signal with plasma events. Initial work on a helium puff system to clear residual dust from the detector used a volume pressurized with helium gas, a piezoelectric valve and a nozzle aimed at the surface of the detector at an angle of 45º.[7] The gas puff system was able to clear a 4 cm × 4 cm area of carbon particles and a 3 cm × 3 cm area with tungsten particles but limitations in the throughput of the piezoelectric valve controlling the gas flow prevented coverage of the entire 5 cm × 5 cm surface of the detector.

We report on the development of a new system based on high throughput pneumatic valves that feed a manifold of small nozzles aimed on the surface of the detector. We note that such a puffer system may also be useful for an alternative dust detection technique based on a capacitive diaphragm manometer that measures the accumulated mass of dust.[8] Rezeroing such a detector by removing dust with a helium puff could address concerns with long-term drifts.

The objective was to completely clear the surface of the detector of residual dust, with a minimal helium puff that could be easily handled by the tokamak pumping system. High throughput pneumatic valves were used to increase the gas flow rate from several nozzles that were aimed to cover the whole surface of the detector. The nozzles were designed to fit in the restricted space between the detector and the NSTX torus interface gate valve.

The system consists of a helium tank, a regulator, a shut-off valve, a pressure gauge, and two pneumatic valves that confine a pressurized plenum and output nozzles. The pneumatic valves have an i.d. of 3.8 mm and a flow coefficient, Kv, of 0.26 m^3/h and are compatible with the magnetic environment of a tokamak. The total volume of the plenum (including the internal volume of the valves) was measured by filling the volume with ethanol from a burette and was found to be 5.2 cm^3. To deliver a helium puff, the helium tank valve was opened and the plenum was pressurized up to 6 bar. The first pneumatic valve was then closed and the helium puff was released by opening the second pneumatic valve. The plenum was connected to the exit nozzles by a short 1 cm^3 volume tube to maximize the gas puff pressure at the detector. The total expelled helium per puff was 32.4 bar · cm^3 when the puff system operated at a pressure of 6 bar.

The system configuration was first optimized in air by digitally imaging the area cleared from sand particles at backing pressures of 2, 3.5, 5, and 6 bar, and nozzle inclinations of 30º, 45º, 60º, and 90º. The maximum clearance of the surface of the detector was obtained with a plenum pressure of 6 bar, an incidence angle of 30º, and the nozzle positioned at the edge of the surface to be cleared at a height of 1 mm. With one nozzle, 80% of the 5 cm × 5 cm detector area was cleared; however, some sand was left at the corners. In order to attain complete clearance of the surface, two additional nozzles were added to the previous setup. These are parallel to and at 13 mm either side of the first nozzle. In the perpendicular plane all three nozzles had the most efficient incidence angle of 30° and the height of 1 mm above the detector optimized previously.

Digital images of the three-nozzle manifold operated in vacuum showed that one puff was able to clear the entire surface, however, some sand particles landed back on the surface after bouncing off the vacuum chamber walls. After a second puff the area was totally cleared.

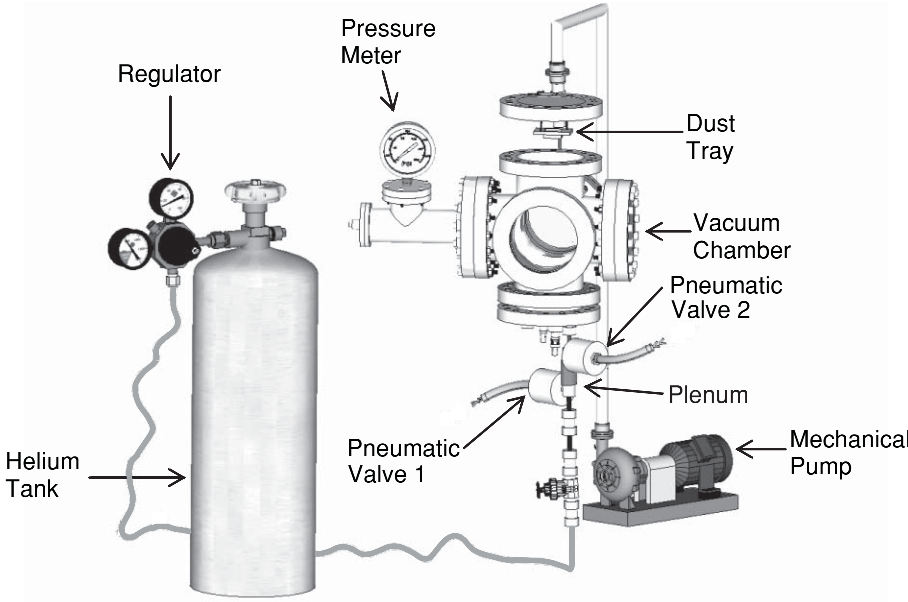

FIG. 1. Setup used for He puffs in vacuum. The upper flange is raised to show the dust delivery tray.

The cleaning efficiency was then measured with the dust detector itself, which can detect particles of micrometer scale that are not resolved in the photographic images. The helium puffer was set up along with the dust detector on a 15 cm flange in a vacuum chamber as shown in Fig. 1. The detector was connected to the detection electronics described in Refs. 4 and 5. To limit the potential overpressure hazard in case of failure of the pneumatic valves or the mechanical pump, a pressure relief valve was mounted on the chamber that automatically vents pressures in excess of 0.5 bar above atmospheric. In addition, lexane shields covered the viewports.

The chamber was evacuated by a mechanical pump to a pressure below 5 mTorr. Carbon particles, scraped from ATJ tiles were dried by baking them in an oven for 4 h at 100 °C to minimize moisture effects and simulate dust in the NSTX vacuum chamber. The particles were delivered by a tray with a mesh bottom mounted on the upper flange as described in Ref. 9. After knocking on the upper flange of the chamber until a predetermined number of counts was reached on the detector electronics,[5] the chamber was then slowly vented and the dust tray was removed to prevent further dust falling on the detector. Once the chamber was again sealed and evacuated without the dust tray, helium puffs were used to clear the residual dust from the surface of the detector.

Any residual dust that remains on the detector can be disturbed by the helium puff or a mechanical knock. Dust that produces breakdown between the energized traces will generate a current pulse and be detected. The efficiency of the puff system was tested by performing a sequence of helium puffs and mechanical knocks and observing any increase in the total number of counts. This was repeated until no additional counts were triggered after several knocks indicating that the entire surface of the detector was cleared of dust.

Figure 2 shows the percentage of additional counts that occurred after successive puff–knock events. It can be seen that the first puff could trigger about 3% of additional counts followed by about 1% due to a knock on the chamber. Subsequent puffs after the first two, caused less than 0.5% of additional counts indicating that two puffs were sufficient to almost entirely clear the surface of the 5 cm × 5 cm detector of residual dust.

In NSTX, the dust detector was protected from larger debris and fibers with a cover mesh of 60% optical transmission and some particles were held up on the wires of the mesh.[5] A cover mesh was added 18 mm above the detector to mimic this setup in the laboratory.[4] The mesh was supported by two walls parallel to the direction of the flow of helium with four

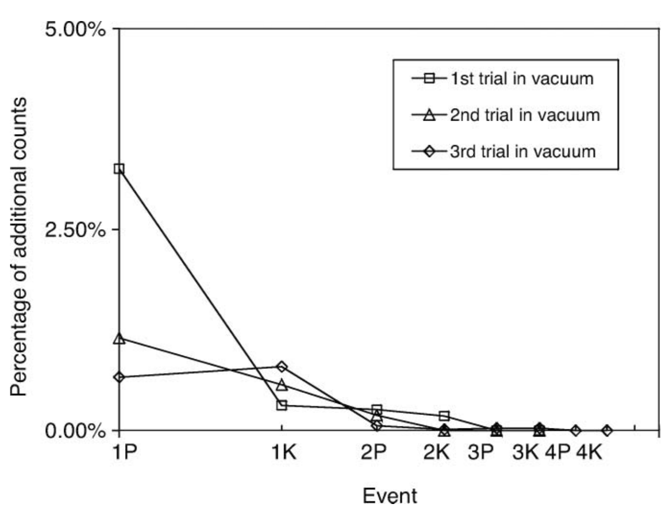

FIG. 2. Percentage of additional counts triggered by consecutive puffs labeled 1P, 2P, 3P, ... and knocks labeled 1K, 2K, 3K, ... in vacuum conditions without cover mesh and with the three-nozzle manifold. For three trials the percentage of additional counts triggered by a knock event after a second puff was lower than 0.5%.

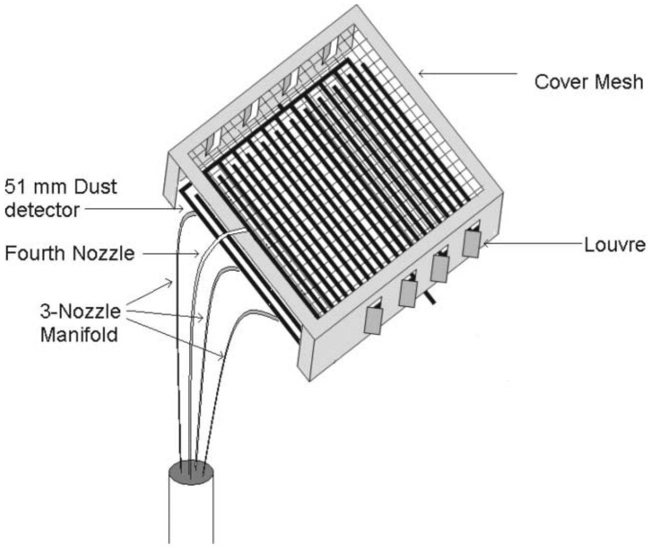

FIG. 3. Puff system setup with the 5 cm × 5 cm dust detector and cover mesh as used previously in NSTX (Refs. 4 and 5). The detector is shown schematically by the thick lines under the cover mesh. For clarity the mesh porosity is not to scale. Three of the nozzles are aimed on the surface of the detector and the fourth nozzle is aimed at the surface of the mesh.

louvers on each wall to facilitate flow of dust particles away from the detector and prevent them from bouncing back on the detector. A fourth nozzle was added 1 mm above the mesh at an angle of 30° to clear dust from the mesh as shown in Fig. 3, and the system was tested in vacuum with carbon particles.

Figure 4 shows the percentage of additional counts that occurred after successive puff–knock events. It was observed that after one initial helium puff up to 6% of additional counts were triggered by the first knock event. After a second puff, this number fell to less than 1% even after applying three successive knocks on the lower part of the chamber. This indicates that a significant amount of dust was held up on the wires of the cover mesh and fell on the detector after the first knock event. This is consistent with previous results[6] that showed a small decrease in the sensitivity of the detector due to dust holdup on the cover mesh.

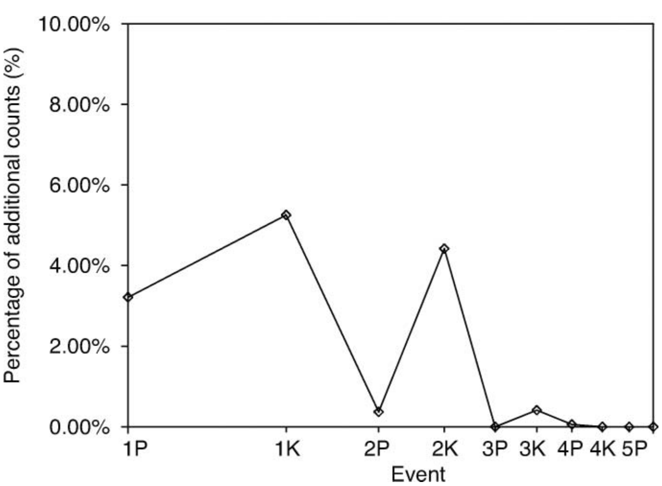

FIG. 4. Percentage of additional counts triggered by consecutive puffs labeled 1P, 2P, 3P, ... and knocks labeled 1K, 2K, 3K, ... in vacuum conditions with the cover mesh and four-nozzle manifold. After two puffs an insignificant number of additional counts were triggered by a knock event indicating that the entire surface of the detector was cleared.

It can be seen that around 8.7% and 10.8% of total additional counts for the tests in vacuum without and with the cover mesh, respectively, were triggered by two consecutive puff–knock events. The amount of additional counts dropped to less than 1% and no counts were triggered by puff–knock events after the fifth puff. These percentages are calculated from the counts generated by the puff–knock events divided by the initial counts recorded from the dust falling on the detector. The additional counts represent the amount of dust that did not promptly vaporize from the surface of the detector or was held on the wires of the cover mesh and was cleared by the puff system. These results are consistent with results from Ref. 6, which reported that about 90% of the incident dust was vaporized and 10% remained on the surface of the detector. The present experiment showed that after two consecutive helium puffs less than 0.05% of residual dust was left on the surface of the detector.

In summary, we have demonstrated a multinozzle He puff system with high throughput pneumatic valves to clear residual dust particles from a 5 cm × 5 cm electrostatic dust detector. Two He puffs cleared dust particles from the detector and cover mesh with 99.9% efficiency.

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