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Fast Valve for the National Synchrotron Light Source*

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ABSTRACT

A prototype fast closing, all metal, UHV-compatible valve has been built to protect the NSLS storage rings from sudden vacuum failures which may occur in the experimental beamlines. When triggered, an area of 10 x 140 mm is covered by a spring-driven, guillotine type blade, which forms a high impedance to the intrushing gas. This fast closure assures the protection of the ring vacuum from contamination before the slower UHV valve can be sealed off. Closing times on the order of 3-5 msec have been measured. The valve is triggered by a commercial solenoid, powered by a 16800 μ F capacitor bank at 100 volts. Because the valve is situated in a high radiation area, it is remotely resettable.

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1. Introduction

The two storage rings of the National Synchrotron Light Source facility are equipped with a large number of photon beamports for both VUV and X-ray research. The 700 MeV VUV ring has a total of 16 beamports, while the 2.5 GeV X-ray ring has a full complement of 28; each of these could, in turn, split up into two or more branch lines. The possibility of vacuum failures because of window breakage or other accidents in the beamlines is, therefore, substantial. To protect both the ring vacuum as well as the other beamlines from contamination due to such accidents, a prototype fast-closing vacuum valve has been built in our laboratory. Some of the preliminary results obtained with this valve will be reported here.

A number of fast valves of different designs have been built over the years for various purposes.¹⁻³ Fast valves have also been commercially available for some time.⁴ However, none of them were suited to the particular beamline geometries, beamsizes, and time requirements at the NSLS and made further development necessary.

2. Requirements

Our valve must conform to the following basic specifications:

- a. Beam aperture 10 x 140 mm.
- b. Closing time < 10 milliseconds, preferably 5 milliseconds.
- c. UHV-compatible, all-metal construction, and bakeable to 200°C.⁵
- d. Minimum flange-to-flange length.
- e. High impedance when closed; A leakrate of approximately 1 - 2 torr liter per second is acceptable.
- f. Valve is located in a shielded inaccessible area and should be remotely resettable.
- g. Low cost.

A closing time of less than 10 msec is desirable since for an average beamline length of 10 meters and a shockwave velocity on the order of one meter per millisecond⁵ in air, the shockwave will travel the length of a beamline in 10 msec. The velocity of a helium shockwave is about double that of air, and the closing time would have to be reduced to 5 msec. The use of baffles or acoustical delay lines will significantly reduce the shockwave velocities,⁶ and their use in helium lines, or short beamlines, is highly desirable.

In all the NSLS beamlines the fast valve is backed up by a main vacuum valve which separates the storage ring vacuum from the beamline vacuum. This is a commercial, all-metal UHV-compatible valve⁷ which closes and seals a 148 mm diameter opening in approximately two seconds. The fast valve, therefore, must provide a sufficiently high impedance to the intruding gas stream for the two second period it takes the high vacuum valve to close. It must also protect the ring vacuum from window particles and other debris which might otherwise be swept in. It is therefore, unnecessary to provide for a complete leaktight seal on the fast valve. This greatly decreases the complexity and expense of the valve.

3. Description of the Valve

a. General

Figure 1 shows an assembly drawing of the NSLS fast valve. The valve utilizes a spring-driven, guillotine-type blade to cover an opening large enough to let the photon beam through. Motion is transmitted into the vacuum enclosure through a suitable type of bellows. Most of the mechanical parts are arranged outside the vacuum enclosure and are readily accessible. By removing the valve from the beamline, access to the blade and sealing area is

possible through the flange opening. This makes it possible to exchange blades. The valve is triggered through a modified commercial solenoid, powered by a capacitor bank. A more detailed description of the working parts of the valve follows.

b. Construction

A 10 x 140 mm aperture area was chosen to provide sufficient clearance for a diverging ± 8 mrad photon beam. In the closed position this aperture is covered by a 1 mm thick aluminum blade Fig. 1(13), which fits accurately in a pocket formed by the valve seat on the aperture plate (12) on one side and a removable back plate (15) on the other side. This back plate has a similar aperture to let the photon beam through. Clearance between the blade and the pocket (0.01 - 0.05 mm) is kept to a minimum and is a trade-off between the friction of the blade in the pocket and the impedance of the valve in the closed position. The aluminum blade (13) is gold-plated to minimize possible galling of the sliding surfaces. To maximize the impedance to the incoming gas stream, the blade overlaps the aperture 10 mm on each side. The valve seat is ground flat and polished to an 8 RMS finish on the surface of the 22 mm thick stainless steel aperture plate (12).

The reverse side of the aperture plate is machined circular, and concentric with the center of the aperture slot. This provides a connection to attach a tube and a vacuum flange after the valve is assembled and tested. The aperture plate is bolted to a 25 mm thick stainless steel top plate (10) to form a T-section. These two parts form the basic frame on which the drive mechanism is mounted. It has the advantage that all the working parts of the valve can be assembled, adjusted, and tested before the final welding into the vacuum enclosure.

The vacuum enclosure (14) consists of a welded rectangular tubular section made from two sections of 3.2 mm thick stainless steel sheets bent into a U-shape. A separate bottom plate is welded in, while the top is formed by the aforementioned aperture plate assembly. Appropriate holes are machined in the broad sides of this enclosure for attachment of flanges.

c. Drive Mechanism

The driving force for this valve is obtained from a commercial compression spring^b Fig. 1(5). In order to establish a guideline for the selection of a suitable spring, some simple calculations of the necessary driving force were made. The estimated weight of all the moving parts except the spring and bellows is 100 gr. Then, for a stroke of 22 mm and a 10 msec closure time the force necessary to accelerate this mass is 4.5 kg. For a 5 msec closure time the necessary force is 18 kg. The spring selected has a load rating at the rated compressed length of 19 kg. The force of the bellows due to the one atmosphere differential pressure is added to the spring force. For the 9 cm² effective area, the bellows force equals 9 kg. A total driving force of 28 kg is thus available and will compensate for possible forces due to friction.

The mass of the moving parts is kept as low as possible by using a piece of thin-walled stainless steel tubing for the main shaft (8). The shaft extension with a detent for the catch (7) is welded to the shaft and guided in a ball bushing. The spring seat (6) is an aluminum dish and is also utilized as a stop at the end of the stroke where a rubber ring (9) acts as the shock absorber. The welded bellows^y (11) is carefully chosen with a low spring rate (large OD/ID ratio) to give maximum flexibility. An air cylinder (1) provided with an inverted U-shaped connecting rod engages the spring seat (6)

to recompress the spring after firing. When the catch is engaged, the air piston returns to its lower position and the valve is ready to fire again. A hardened steel catch (7) keeps the valve in cocked position under light spring tension. A commercial solenoid¹⁰ (3) with a 1.5 mm stroke releases the catch when energized. To improve the reaction time of the solenoid, we replaced the standard 3.2 Ω coil with one of our own with a total resistance of 30 m Ω . Also, a replica of the standard plunger was made with the core section bored out, to significantly reduce the mass.

4. Testing and Results

The valve is first assembled without the vacuum enclosure, so that some extensive bench testing can be done. The firing circuit used for the test is shown in Fig. 2. The capacitor (C_1) consists of six series-parallel connected capacitors each of 5600 μ F - 50 VDC, for a total of 16,800 μ F - 100 VDC. The capacitor (C_1) is charged with a 125 VDC power supply through a 1 k Ω series resistor. The system is triggered by a pushbutton, which applies a small voltage to the gate of a SCR, (D) making it conductive, and discharges the capacitor (C_1) through the solenoid (S). The same voltage that triggers the SCR is used to trigger a storage oscilloscope (HP 1741A) and starts to trace the output of a photo diode which is mounted on the aperture slot. In closing the valve, the blade intercepts the light from a small light bulb directed onto the photo diode, and reduces the output to zero. A typical trace is shown in Fig. 3. The average closing time was found to be 5 msec at a capacitor voltage of 100 V. An increase in the voltage on the capacitor from 31 to 124 V, only changes the closing time from 5.8 to 4.8 msec. Doubling the capacitance to 30,000 μ F had no real effect on the closing time.

The valve was next welded into its vacuum enclosure and mounted on a T-section together with a 200%/sec sputter ion pump. Viewports were mounted on both sides of this assembly, giving an unobstructed view through the valve. A Physics Spectra #155 laser was used as a light source in the vacuum test. The source was placed on one side of the valve, and the photo diode was mounted on the opposite viewport outside the vacuum. The laser beam was aimed at the lower edge of the aperture to indicate the moment of closing of the valve. The firing circuit was the same as previously indicated. The vacuum pressure during this test was 1×10^{-6} torr, and the results are as shown in Fig. 4, which is an actual scope trace. Test results consistently showed a closing time of 3.4 msec in vacuum at a capacitor voltage of 100 V.

A life-cycle test of 500 closings showed only insignificant wear on the blade. Substantial wear appeared on the catch mechanism which had to be modified several times.

With the valve in the closed position at atmospheric pressure, the mass-flow rate was measured through the valve by increasing the pressure on the seal side. It was found that the sealing capabilities of the valve improved with higher differential pressure across the valve seat. The pressure on the back of the blade presses it firmly against the seat, reducing the conductance of the valve.

5. Conclusion

The prototype fast valve so far has met all the requirements set out in Section 2. Extensive dynamic vacuum testing is planned for the near future. Production models of fast valves are currently being fabricated at BNL. Each is expected to cost approximately 8 k\$. Figure 5 shows a photograph of the completed prototype valve.

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Figure Captions

Figure 1. Schematic diagram of the NSLS fast valve.

1-Air-Cylinder; 2-Connecting Rod; 3-Solenoid; 4-Spring Housing;
5-Compression Spring; 6-Spring Seat; 7-Catch; 8-Shaft; 9-Shock
Absorber; 10-Top plate; 11-Bellows; 12-Aperture Plate; 13-Blade;
14-Vacuum Enclosure; 15-Back Plate.

Figure 2. Firing circuit of the fast valve.

S-Solenoid, 35W #14-.03 μ ; C_1 -3 x 2 - 5600 μ F 50 VDC;
 C_2 -1 μ F 50 V R_1 -1 k Ω ; D-SCR, 2N1597; B-Battery 6 V.

Figure 3. Closure test at atmospheric pressure.

Vert. - 0.5V/div. Horiz. - 1 msec/div.

$V_C = 124$ V $C = 16,800$ μ F

Figure 4. Closure test under vacuum conditions.

Vert. - 2V/div. Horiz. - 1 msec/div.

$V_C = 99.3$ V $C = 16,800$ μ F

$P = 1 \times 10^{-8}$ torr.

Figure 5. NSLS prototype fast valve.

0 10
cm

FIG. 2