FAST-ACTING VALVE*

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Summary

In areas of the Zero Gradient Synchrotron (ZGS) accelerator where high energy proton beams or other nuclear particles are extracted from the interior of the synchrotron into experimental areas, thin mylar or aluminum windows are used to minimize energy losses. Rupture of these windows (as large as nine inches in diameter) could cause considerable damage.

A 9-inch, fast-closing valve has been designed and a prototype has been built and tested. The valve can operate in vacuum or at atmosphere. Closure of the valve requires no circuits, signals, or mechanical actuators, but rather is activated by the energy of the inrushing gas itself. An electrically triggered clutch arrangement can be incorporated for mechanical closing, if so desired, with no interference when the fast mode of closure is necessary.

The results of the fast mode of closure indicate closing times of 17 to 30 ms. "Blowby," before closure of the valve is completed, is approximately 2.5 ft^3 of air (at one atmosphere). With such a valve, the entire ring vacuum system will not reach pressures greater than 300 microns (0.3 mm Hg), should a 9-inch diameter window rupture.

Problem

The ring vacuum system of Argonne National Laboratory's ZGS is a differentially pumped system. The inner chamber of this vacuum system cannot withstand large pressure differentials across its walls. Blow-out plugs installed on either end of the eight 54-foot long inner chambers have provided adequate protection thus far. Several areas of the ZGS accelerator are used for the extraction of high energy protons or other nuclear particles from the interior of the machine out to experimental areas. At these locations thin mylar or aluminum windows are used to isolate the ring vacuum system. These windows can be as large as nine inches in diameter and in some instances are subjected to a full atmosphere of pressure. If such a window should break, all 16 blow-out plugs on the inner vacuum chambers could be ruptured; the oil in all 17 diffusion pumps would be subjected to oxidation; and there is a good possibility that some of the inner chambers, subjected to high stresses from shock wave formations, would open up at the seams.

The following assumptions and calculations set forth the flow and pressure conditions which probably would exist if breakage of a 9-inch window should occur.

Assumptions

1. Pressure, volume and temperature all vary so the process involved is isentropic.

2. Flow is at a maximum; i.e., the exit pressure is the critical pressure or 0.53 of the inlet pressure.

3. Let the initial pressure $p_1 = 15\ \mathrm{lbf/in}^2$ and the initial temperature $T_1 = 70^\circ$ F and neglect the effect of the initial velocity.

4. The final pressure $p_2 = p_c = 0.53\ p_1 = 8\ \mathrm{lbf/in}^2$ and the expansion is isentropic.

Calculations[1]

1. Initial specific volume:

$$v_1 = \frac{RT_1}{p_1}$$

where

$R = 53.3$
$T_1 = 530$ (degrees Rankine)
$p_1 = \mathrm{lbf/ft}^2$

then

$$v_1 = 13.1\ \mathrm{ft}^3/\mathrm{lb}\ .$$

2. At $p_2 = 0.53\ p_1 = 8\ \mathrm{lbf/in}^2$, the specific volume is:

$$v_2 = v_1 \frac{p_1}{p_2}^{1/K} \quad .$$

Where K is 1.4, then

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*Work performed under the auspices of the U.S. Atomic Energy Commission.

$$v_2 = 20.4\ \mathrm{ft}^3/\mathrm{lb} \quad .$$

3. The velocity at $p_2 = 0.53\ p_1$ is:

$$V_{s_2} = 223.7 \left\{ c_p T_1 \left[1 - \left(\frac{p_2}{p_1} \right)^{(K-1)/K} \right] \right\}^{1/2} \quad .$$

Where $c_p = 0.24$, then

$$V_{s_2} = 1057\ \mathrm{ft/s} \quad .$$

4. Volume (v_e) of gas entering the ring vacuum system at pressure condition assumed, $p_2 = 0.53\ p_1$ is:

$$v_e = \left(V_{s_2} \right) \left(\frac{\pi d^2}{4} \right) \quad .$$

Where d = ID of valve, then

$$v_e = 467\ \mathrm{ft}^3/\mathrm{s} \quad .$$

Atomspheric equivalent volume is:

$$\frac{p_2}{p_1} \left(v_e \right) = 249\ \mathrm{ft}^3/\mathrm{s} \quad .$$

Under the above conditions and with a volume (v_s) of approximately 4000 ft^3 in the ring vacuum system, the pressure will rise in one second from the operating pressure region of 10^{-6} Torr to P, where

$$P \approx \frac{\left(p_2 \right) \left(v_e \right)}{v_s} \approx 0.935\ \mathrm{lb/in}^2 \approx 46.7\ \mathrm{Torr} \quad .$$

Solution

A fast-acting valve to prevent the above results has been designed and a prototype has been built and tested (Fig. 1). Closure of the fast-acting valve requires no circuits, signals or mechanical actuators, but is actuated by the energy of the inrushing gas and the pressure differential created across the gate itself. The gate, which is the heart of the valve, is held poised above the opening by a very weak spring. Breakage of the thin window and the resulting inrush of gas is all that is necessary to activate the approximate one pound mass of the gate. Deceleration is eased by a tapered elastomer gasket at the point of impact.

The idea of this fast-acting valve is not original. It is based on a 4-inch valve used in conjunction with the 170-inch synchrocyclotron in the Institute of Nuclear Studies at the University of Chicago (Fig. 2). Direct scale-up of the small valve was not possible nor practical, because of the mass involved and the acceleration required for the 9-inch valve. Material selection (6061 aluminum), utilization of ribbing and elimination of certain parts were necessary to achieve the most satisfactory results.

The fast-acting valve is not intended to be a vacuum tight valve, but is designed to interrupt the high velocity inflow of gas and thus permit a much slower standard high-vacuum gate valve to close. The high-vacuum gate valve receives its signal to close from an interlocking source sensing rise in pressure when the window is broken.

Pressure measurements of the vessel before and after a test to determine "blowby" were made with a mercury manometer. The manometer and pumping system were isolated from the vessel during the test. A lucite plate on one side of the fast-acting valve permitted filming of closure with high-speed camera equipment and referencing of gate position with time during period of closure. Rupture of the thin window was accomplished by a large current passing through a high resistance wire cemented to the outer periphery of the window.

Utilization of sails in conjunction with the fast-acting valve to flip the gate into the stream of incoming gas proved detrimental to rapid acceleration (Test No. 1, Fig. 3) and were eliminated. Elimination of the sails also removed the necessity of keying the gate to the shaft or having to rotate the shaft itself. Test No. 2, Fig. 3, with the gate in vacuum and Test No. 3, Fig. 3, with the gate at atmosphere, determined the reduction in time due to the changes made. The results are graphically illustrated in Fig. 4. The shorter closure period of Test No. 3 is probably due to a larger pressure differential existing across the gate at the moment of rupture. "Blowby" results may be explained by the proximity of the gas to the gate as governed by the position of the mylar window in each case.

A 15 ft^3 volume vessel was used with the above tests. Since a substantial back pressure buildup could affect "blowby", a 65 ft^3 volume vessel was substituted for the smaller vessel in subsequent tests (Fig. 5). Figure 6 indicates the increase in "blowby" when back pressure becomes insignificant.

The preformance of Test No. 3 in the above experiments suggested that this mode of operation, i.e., with the gate at atmosphere, would work without the necessity of a housing. An adapter ring for the fast-acting gate was designed to mount directly to the existing thin window mounting ring (Fig. 7). Two tests were then performed. The first utilized a lucite shield to restrict the flow of gas to the top and the front (Fig. 8). No shield was used with the second test. Results (Fig. 9) indicate a definite advantage with the use of a shield.

Thin windows, particularly those made of mylar film, do not necessarily break open completely when penetrated by a small sharp tool or a small projectile. Under these conditions, the inflow of gas does not generate sufficient energy or create a sufficient pressure differential across the gate to close it. Tests indicate that the minimum hole necessary to activate the gate is approximately two inches in diameter. Where penetration is less than two inches in diameter, the slower high-vacuum gate valve appears to be adequate. "Blow-by" results are not significantly greater than that experienced with a complete break and closure of the fast-acting valve. A clutch arrangement can be added, which would rotate the shaft on signal to engage the gate and close it. The engaging mechanism would not interfere with high speed closing.

The installation of this type of valve will provide a protection and prevent loss of valuable operating time. With such a valve, the entire ring vacuum system is not expected to reach pressures greater than 0.3 Torr if a 9-inch diameter window is ruptured. Even if such an event would occur during isolation of a segment of the ring where a thin window is present, the pressure rise would be no greater than approximately three Torr.

Acknowledgment must be given to Mr. Leonard Balka for originality and much effort which was necessary to prepare for the various tests and also to Mr. Donald Little, who aided him in many of the control problems.

The credit for the high speed photography must go to Mr. Norman Abderhalden. Without the excellent data obtained from this film, results and development would have been difficult.

I wish to also credit Mr. Herbert Lucks for having brought the information of this type valve to the Laboratory from the University of Chicago.

References

1. Virgil Moring Faires, "Applied Thermodynamics", The MacMillan Co., New York, (1947)

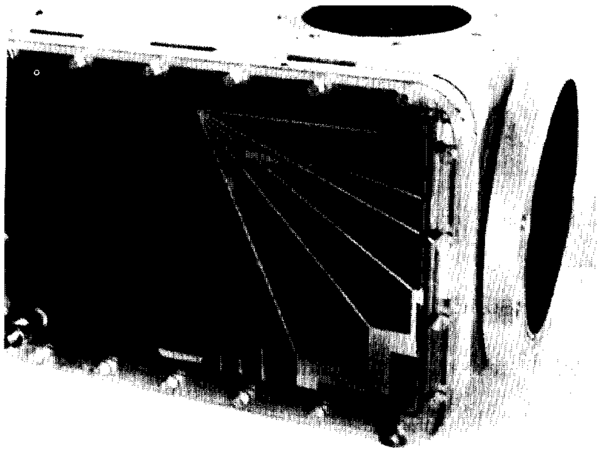


Figure 1. 9-Inch Fast-Acting Valve With Housing

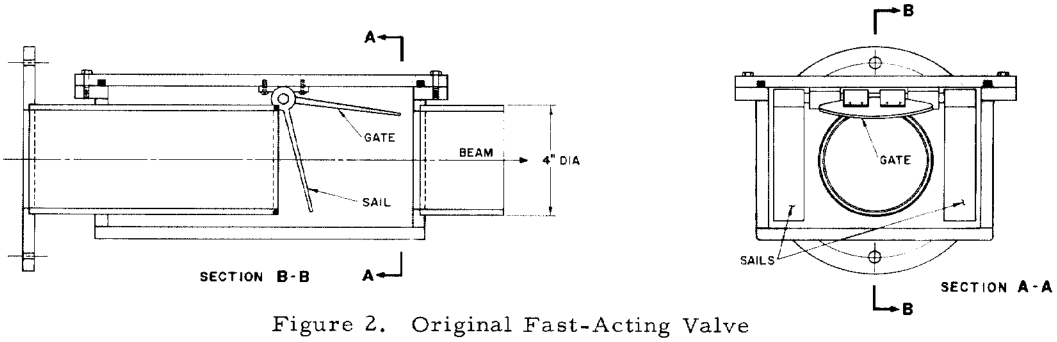


Figure 2. Original Fast-Acting Valve

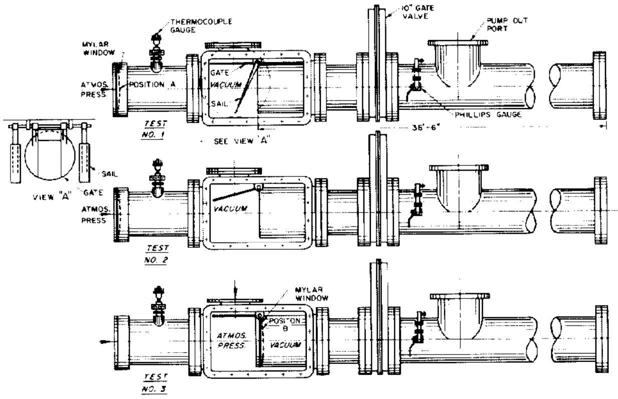


Figure 3. Valve Mounted to 15.1 Ft^3 Volume Vessel

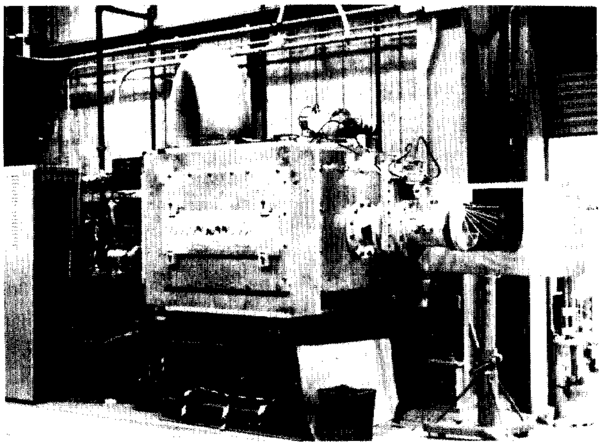


Figure 5. Valve Mounted to 65.5 Ft^3 Volume Vessel

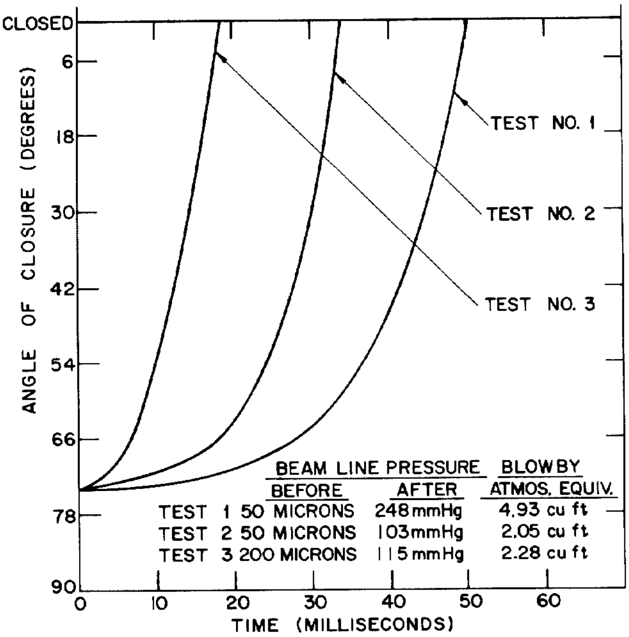


Figure 4. Fast-Acting Valve - Test Results

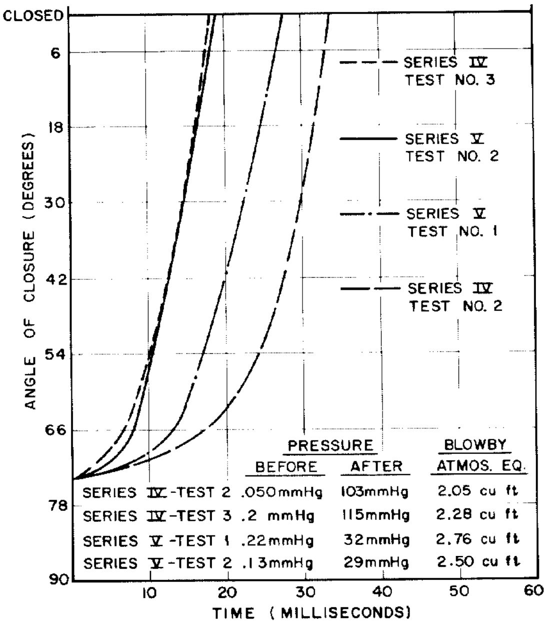


Figure 6. Fast-Acting Valve - Test Results
Series IV Tests With 15.1 Ft^3 Volume
Series V Tests With 65.5 Ft^3 Volume

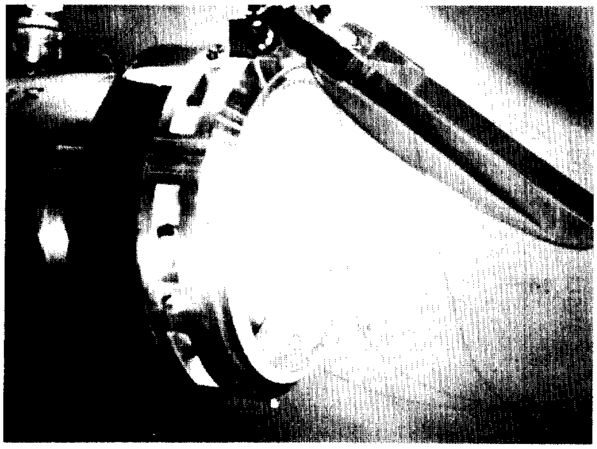


Figure 7. 9-Inch Fast-Acting Valve With No Housing

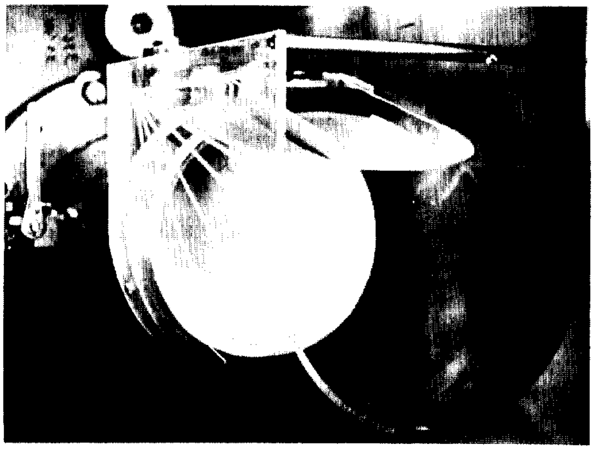
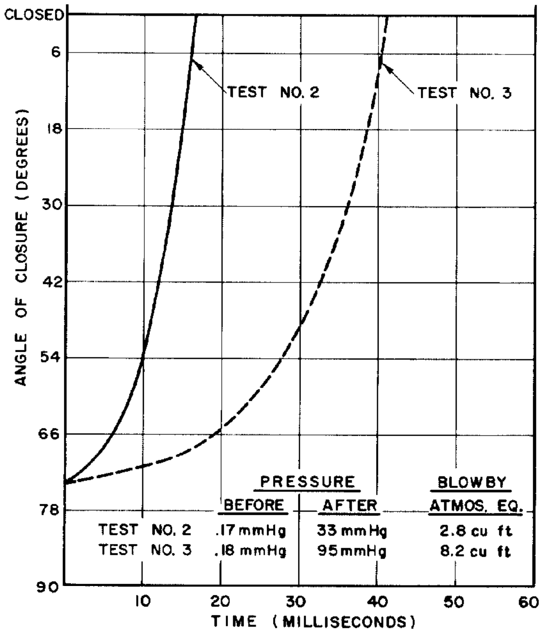


Figure 8. 9-Inch Fast-Acting Valve With Shield



	PRESSURE		BLOWBY
	BEFORE	AFTER	ATMOS. EQ.
TEST NO. 2	.17 mmHg	33 mmHg	2.8 cu ft
TEST NO. 3	.18 mmHg	95 mmHg	8.2 cu ft

Figure 9. Fast-Acting Valve
Test No. 2 - With Shield
Test No. 3 - Without Shield