RAPID CYCLING VALVE FOR 30-HZ PULSED H^- ION SOURCE*

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Summary

This valve is used to reduce the gas loading on the vacuum system of a multipulsing H^- ion source. It is a self-aligning chopper type. A mechanism of this construction assures the reilability required for an ion source of this nature. The reliability of this mechanism is due to the fact that the disc of the chopper is rotated at a relatively slow constant velocity and no wearing parts of the assembly are subjected to the extreme vacuum atmosphere. The entire valve assembly is very simple in construction. It is driven with a synchronous motor to keep it in step with the accelerating frequency. Vacuum integrity is maintained with the use of a ferromagnetic fluid coupling as part of the drive system. All bearings, motors, and drive mechanisms are external to the vacuum cavity.

Introduction

A tandem-acceleration H^- ion source is required for the injection of a negatively charged beam into the Zero Gradient Synchrotron (ZGS) booster. This ion source has been under constant development to make it suitable for use in a rapid cycling manner (30 Hz/s). The production of a suitable H^- beam has been dependent upon maintaining the proper gas pressure in various portions of the ion source and charge exchange assembly. Figure 1 illustrates the apparatus involved. The pressure in the ion source is in the region of .200 torr and the charge exchange cell has a pressure of .015 torr.

The maintenance of these gas pressures is governed to a great extent by the amount of gas being introduced into the ion source and the flow of this gas through various apertures and spaces. The gas pressures are also based upon the pumping speed of the vacuum system which is applied at the far end of the apparatus. The vacuum at the transition to the preaccelerator and to the vacuum pumping system is in the region of 10^{-6} torr or less. The pressures in the various regions described are possible with a flow of 10 cm^3/min of H_2 gas. A flow of this magnitude on a continuous basis places an enormous burden on the vacuum pumping system. Since injection occurs for durations of 200-500 μs during each 33.33-ms period, it appears reasonable that the gas flow could be done on a cyclic basis to reduce the pumping load.

Valve Design Criteria

The rapid cycling ion source is to be operated at a rate of 30 cycles/s for a 1-s interval during a 4-s period, repeated continuously on a 24-h a day schedule. Valve operations/day = $30 \times 60/4 \times 60 \times 24$ = 648,000. An operational demand of this nature indicates that reliability is a must.

The physical location of the valve in the ion source assembly requires that it be of a straight through opening type with a flapper, plug, or shutter type gate. Of the three types of gates, the shutter approach seems the most logical from the longevity and reliability standpoint.

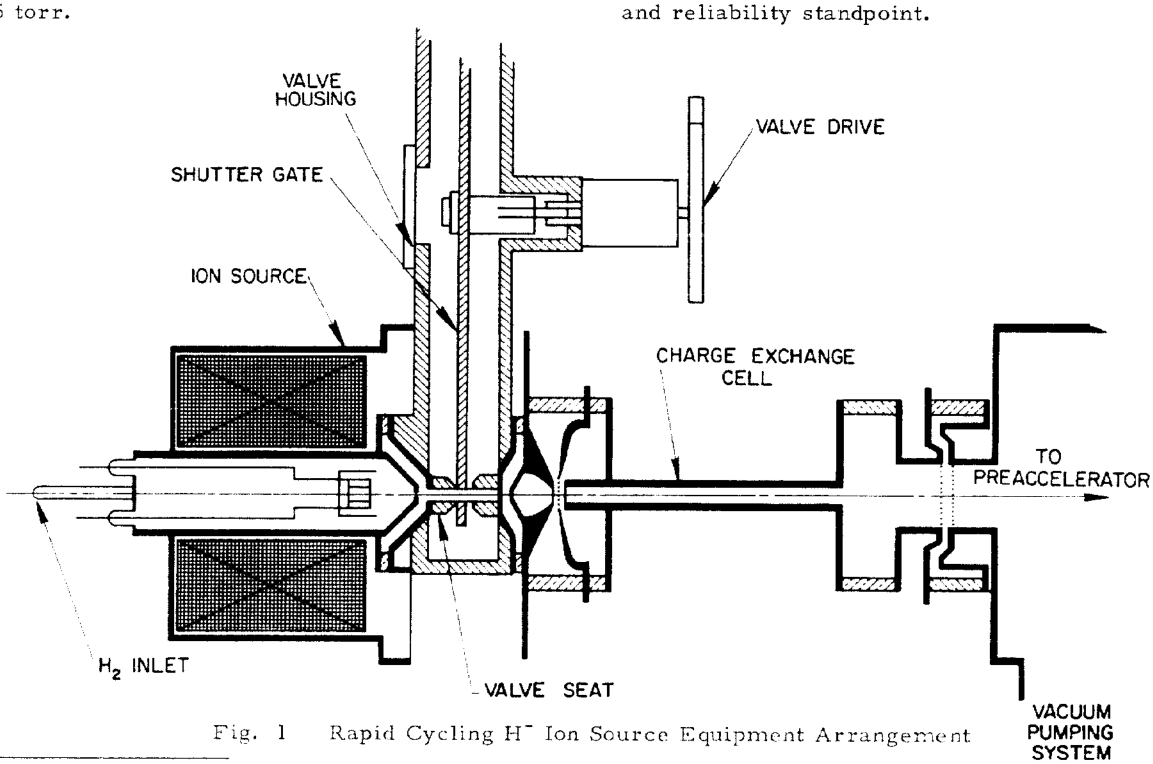

Fig. 1 Rapid Cycling H^- Ion Source Equipment Arrangement

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

The shutter can be run at a constant velocity with no start or stop action. With no acceleration and deceleration action, very little wear and tear is to be expected. Further, no physical mechanical contact is needed when using the shutter type.

Shutter Design and Considerations

The pulse rate of the booster is 30 cycles/s, thus the interval of operation of the shutter is once per 33.3 ms. During each of these 30-cycle intervals, injection will take place. It lasts for about 200 μs at a precise instant during the cycle. Although this injection time is very short, the opening of the valve must occur 2-3 ms prior to the injection so that the gas pressure has time to reach a desirable level in both the ion source and the charge exchange cell.

Another consideration enters into the picture and that is a physical one--the disc used as the shutter must be at least 7 in in radius so that the drive shaft mechanism can clear parts of the ion source housing. The shutter part of the valve is a constant speed affair, and its angular velocity is governed by the number of holes it contains. The slower the speed, the less wear and tear on the mechanisms; so if we consider eight holes in the disc, its rotational speed need be 1800/8 = 225 rpm. The disc has its holes on a 6-in radius making the distance between the holes

$$2\pi 6/8 = 37.7/8 = 4.71 \text{ in} .$$

Being of the straight through design, the disc must be made of an inorganic material to avoid decomposition due to the heat of the plasma going through the valve. For the sake of economy, in our preliminary design we are using Mykroy, a mica glass-filled material, for the disc.

Valve Characteristics

The bore in the seat of the valve must be at least 3/8 in in diam to accommodate the plasma going through it. Using the 3/8-in hole, we can determine the open time of the valve on a cyclic base. The 3/8-in hole in the disc must line up with the one in the base for a full open condition. The growth of the opening as the hole in the disc and the base approach each other and the closing of the aperture are shown in Fig. 2. The base or seat hole is 3/8 in in both cases.

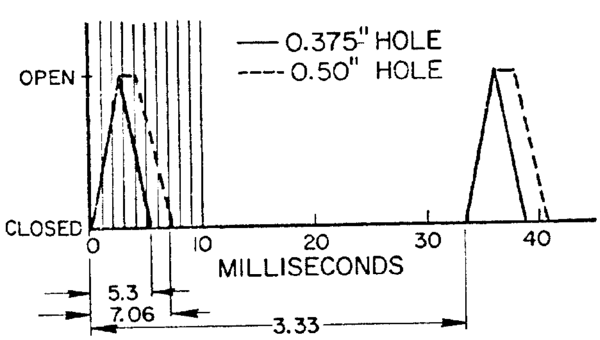

Fig. 2 Opening, Full Open, and Closing Times of Valve with 3/8- and 1/2-in Holes in Shutter

Valve Effectiveness

The effectiveness of the valve is not based on the full flow vs. no flow condition but rather on its ability to reduce the average flow by its impedance characteristics while rotating and yet permits proper density during the open interval.

Considering all other conditions being equal, temperature, pressure differential, laminar flow, etc., the amount of gas flow is proportional to the area of the opening. When fully opened, the area of the valve is

$$\pi(.375/2)^2 = .1105 \text{ in}^2 .$$

The shutter is aligned about .002 in away from the seat; thus in a fully closed condition, the gas flow area is the circumference of the hole times the space between the disc and the seat.

$$.375 \times \pi \times .002 = .00236 \text{ in}^2 .$$

The impedance ratio is

$$\frac{\text{flow area open}}{\text{flow area closed}} = \frac{.1105}{.00236} = \frac{47}{1} .$$

The effectiveness of the valve has been determined experimentally and is shown in Fig. 3.

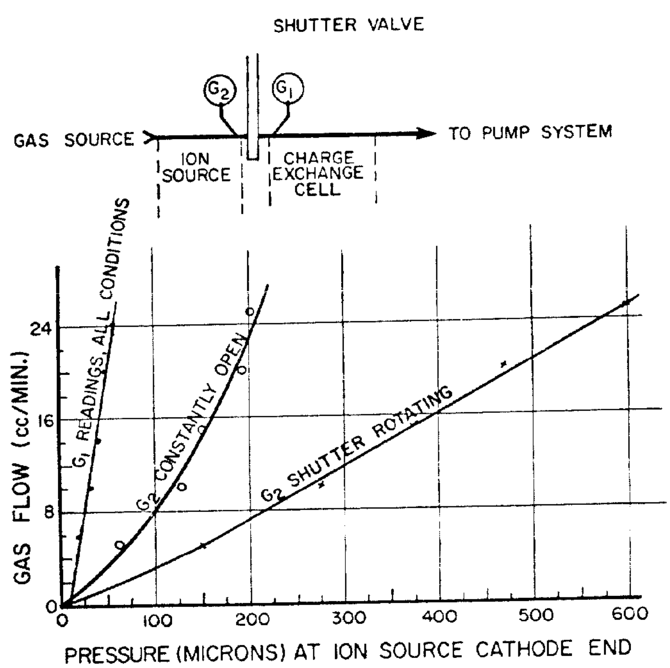

Fig. 3 Gas Flow vs. ΔP Across Valve Using Nitrogen Gas

Shutter Mounting and Aligning Detail

It is important that the spacing between shutter disc and the seat of the valve be as small as possible and yet not touch one another to cause friction and excessive heating. The disc must be ground flat to be effective. It is then mounted on an adjustable hub. It is impossible to make a true hub and seat arrangement because of the vacuum load on the valve housing. To avoid alignment problems, the mounting hub is made adjustable in several directions. The arbor is adjustable along the shaft to permit the desirable depth for the disc backing flange. This backing flange serves as the base for the belleville spring washer (cupped washer). See Fig. 4 for details. The shutter disc is placed against this cupped washer. The locking flange is added to hold the entire assembly. Set screws placed at 120° intervals in the locking flange are finally adjusted to make the shutter disc truly perpendicular to the drive shaft and parallel to the valve seat. The adjustment is a very delicate one, and is tested by listening to the assembly while it is driven. The adjustment of the disc is done while it is exposed to atmosphere. It is also checked when the valve housing is put under vacuum. It is a slow but simple matter to position the disc to compensate for the vacuum deflection.

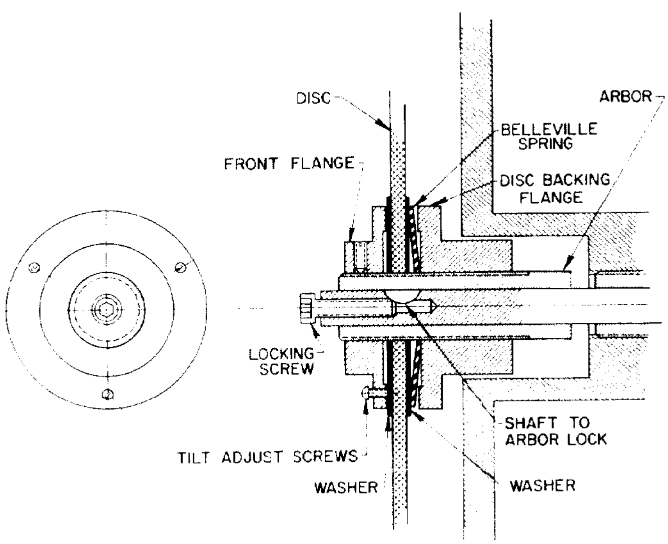

Fig. 4 Disc Mounting and Alignment Detail

Valve Drive System

All the drive bearings are external to the vacuum atmosphere of the valve housing. The drive penetration into the housing is done with a ferromagnetic coupling. It is a patented item wherein the drive bearings are housed in a container for mechanical shaft support. Vacuum integrity is maintained with a mechanical labyrinth affair containing a low vapor pressure grease retained by means of a magnetic field and ferrous particles. This device permits penetration and stable support of a rotation member in a vacuum without exposing the bearings to the hostile environment of a low vacuum.

Valve Drive Motor

The motor used to drive the disc is a hysteresis synchronous motor which stays in step with the line frequency. It is important that the disc be synchronized with the line frequency supplying power to the ac generator exciting the booster accelerator. The synchronous motor is mounted on axial trunnion bearings so that it can be rotated with a small dc phase adjusting motor attached to the drive motor housing with a worm gear drive. This permits phase corrections whenever necessary. The drive arrangement is show in Fig. 5.

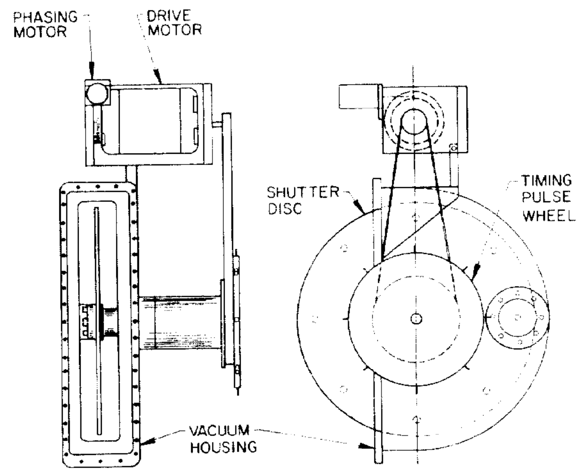

Fig. 5 Drive and Valve Arrangement

The synchronous motor is a 900-rpm device, and it is necessary to reduce its speed for the shutter drive with a 4:1 timing belt and pulley arrangement.

Motor Power

The entire rapid cycling valve installation is part of the ion source which is mounted in the dome of the preaccelerator. This whole structure is at a potential of 750,000 V above ground. In our particular case, the power generator in the terminal is a 400-cycle power system. Power is converted for the 60-cycle synchronous motor with the use of a 400-cycle, 110-V input and 28-V dc output power supply. This dc is fed into the dc-to-ac inverter with a 110-V, 60-cycle output. The inverter is locked in step with the 60-cycle power frequency by means of a signal fed to the master oscillator with a light pipe from earth. Two other signals are transmitted through the light pipes in addition to the frequency pulse. A two-level dc control signal is fed from earth to actuate the dc phasing motor in either direction. The third bit of information transmitted via light pipes is a synchronizing pulse generated by the rotating shutter to indicate the full open position of the valve as it passes the valve seat. The signal is used in the process of initiating the ion source for injection.