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## ABSTRACT

In order to determine the time interval between catastrophic failure of a vacuum component and the arrival of the resulting shock wave at some critical point in the rest of a long vacuum pipe, e.g. the beam line system at synchrotron radiation storage rings, experiments were performed with various entrance geometries and pipe diameters. An important conclusion that can be drawn from these experiments is that a slit, e.g. the exit slit of a monochromator, serves very effectively to slow the shock wave down. Thus if accidents can be restricted to the experimental chambers employed on beam line systems behind a monochromator, shock wave flight times of greater than 30 ms can be easily reached in a length of 3 meters.

The problems resulting from the accidental venting of a synchrotron-storage ring are sufficiently weighty, as to warrent an experimental examination of the shock wave produced by catastrophic failure of some vacuum component, for example, a window. In the past, several such shock wave experiments have been conducted[1-4]. Out of these efforts emerged in particular two facts: (1) The absolute velocity of a shock wave into vacuum ( < $1o^{-3}$torr) is about 1 m/ms and (2) the velocity can be reduced with baffles by a factor of 3-5 while maintaining an open line-of-sight optical path. Thus by incorporating into a beam line on a storage ring a section of pipe with the aforementioned baffles, a delay line, the time necessary for a shock wave to reach either the storage ring itself or a branching point leading to other experiments can be made sufficiently long that a fast closing valve can be closed. Thus, from the standpoint of protecting the ring etc. from accidental ventings, the essential parameters for the design of beam lines are: 1. flight time of a shock wave; 2. closing times of available valves and 3. the cost of the valves.

Regarding points 2 and 3, presently available all metal (bakeable) valves have closing times of 2o-3o ms and cost on the order of \$ 1o,ooo each. There is reason to believe that valves with a closing time of about 1o ms will be commercially available in the next year or so. The development of still faster all metal valves does not appear likely.

The work presented here deals with point 1 above, that is, the flight time of a shock wave in a beam line for several common configurations. In particular, the assumption is made here that such a "catastrophic failure" of some component will most likely occur on an experimental chamber at the end of the line and not on the beam line itself, the latter consisting of absorbers, valves, shutters, mirror boxes, piping and a monochromator. Experiments were performed in order to determine the effectiveness of an exit slit of a monochromator and a scattered light baffle in slowing down the influx of air into the beam line. Thus, instead of inserting a delay line, which is sometimes not readily feasible, we propose to use the exit arm of the monochromator as such: it is already there, and it represents as well the furthest point from the storage ring that is relatively impregnable. Furthermore, the shock is limited at its inception and the remaining plumbing is therefore optimally effective in yielding long shock wave flight times.

The following general configurations were tested (for full details, see "Results" section).

1. Optical slit + 8 meters of pipe
2. Optical slit + scattered light baffle + 8 m of pipe
3. Optical slit + 8 m of pipe with 90° bend.
4. Larger openings + the above combinations.

In addition, the 8 meters of pipe were arranged in two configurations: 1, experiment (window to be destroyed) + smaller pipe (100 mm) + larger pipe (150 mm) for a converging optical beam, e.g. the exit side of a mirror box or monochromator and 2, larger pipe (100 mm) + smaller pipe (63 mm) for a diverging optical beam e.g. for direct, non-refocused radiation from a storage ring. Finally, several slit configurations were employed, from 0.20 x 6.0 mm to a 60 mm diameter hole. The 90° bend was introduced to simulate the deflection due to a monochromator or mirror.

## Experimental:

As experimental set up we used the beam line test station at the Hamburger Synchrotronstrahlungslabor HASYLAB[5] modified for our experiments.
A schematic diagram of the experimental setup is shown in Fig. 1 and relevant information regarding pumps and gauges is provided therein. The rise times of presssure gauges P1, P3 and P4 were previously established to be less than 1 ms for full scale read-

out. Not shown in Fig. 1 are the separate pipe parts which were connected by means of standard ultra high vacuum flanges. The base pressure in the line was of the order $1 \times 10^{-6}$ torr. It was experimentally established that the results (flight times) were unaffected for starting pressures of less than $3 \times 10^{-5}$ torr, and most tests were made at $1.5 \times 10^{-5}$ torr starting pressure. The pumps (TMP) were allowed to pump during tests.

The timing measurements were made as follows:

P1 (see Fig.1) served as the trigger signal for two instruments:

1. Time interval meter (good to nanosecond region)
2. Storage oscilloscope

P3 served as the Stop signal for the time interval meter.
P4 was the analog signal of a 0-1 torr capicitance manometer and was displayed on the storage oscilloscope.

Both P1 and P3 produce an output pulse when a pressure of $3 \times 10^{-5}$ torr is reached. Fig. 2 shows typical results obtained, 2a is for an 0.25 x 8.0 mm slit without aperture and 2b is for an 8.0 x 9.0 mm "slit" without aperture. In the latter case, a disturbance of the pressure rise is clearly visible. This point is discussed in the "Results" section.

The location of P1, between the film and the slit, gives the best sensitivity and earliest warning. Such a sensor would be mounted either on an experimental chamber or on the exit slit housing of the monochromator behind the exit slit. In practice it is recommended that two such sensors, located at the same point, be used in coincidence with each other since noise spikes could otherwise accidently close the fast closing valves.

The mylar film (0.1 mm) had a window area of 60 mm diameter as was destroyed with a pendulum mechanism with a 30 mm diameter serrated, sharpened face. The reproducibility of the results was not dependent upon whether the pendulum was forcibly swung against the film or allowed to swing freely against it.

The slit plate is general consisted of a 1.1 mm thick stainless steel disk mounted and sealed in the tube with an O-ring at the point shown in Fig. 1. The only leak is through the slit itself. The o.2o x 6.o mm slit was such a disk with a slit milled through with a o.2oo mm thick saw. It was thus a relatively thick slit. To be certain that only the slit opening is important and not the depth, a second slit was made. It consisted of a disk with an 8.o x9.o mm hole milled in the middle. Two pieces of o.25 mm thick stainless steel shim stock were securely spot welded to form an approximately o.2o mm wide slit. It was measured on a microscope table and found to be wedge shaped, o.2o mm at one end and o.3o mm at the other. The length of the slit was 8.o mm. In table 1, this slit is referred to as a o.25 mm slit. The same disk with the 8.o x 9.o mm hole was also used as a slit without the shim stock slit "jaws".

The 15 mm diameter aperture was a conical skimmer the lip of which was located 26 cm behind the slit. It corresponds to a 58 mrad x 35 mrad aperture when used with the o.2o x 6.o mm slit. The 8x9mm aperture was like the 15 mm diameter one (conical) only a rectangular opening milled out. It corresponds to an aperture of 3o mrad x 12 mrad when used with the o.2o x 6.o mm slit. It had been previously found (4) that a spacing between delay elements of 25-3ocm yielded the most effective delays.

The 9o° bend is a mitered and welded 1oo mm pipe i.e. an abrupt right angle. The total length of the 9o° bend including flanges was 29 cm along the centerline.

The chamber at the (storage ring) end of the line was 3o cm in diameter and 5o cm long and was concentric with the pipework. It has a volume of approximately 41 liters with the sidearms included.

The measurements were performed as follows:

The mylar film (window) was mounted and the system pumped out to at least 2 x 1o$^{-5}$torr. All pressures were recorded. The pumps were allowed to run. The timing devices were armed and the film destroyed with the pendulum device. The stored oscilloscope display was photographed and then the pumps and gauges shut off. Since the reproducibility was always within ± 5%, only two tests were made for each beam line configuration.

## Results:

The data obtained in the measurements were: 1, the time (T1) for the shockwave to cause a pressure rise in the chamber (P3) to 3 x 1o$^{-5}$torr; 2, the pressure rise with time over the range o-1 torr (P4) also measured in the chamber. From 2, the time required for the chamber pressure to reach ca. o.o2 torr, T2, the smallest significant signal from P4 on the storage oscilloscope, was obtained as well as the time required to reach 1 torr (T3) and the rate of pressure rise in the high pressure region (>o.2 torr).

All of the results are given in table 1 along with the relevant beam line configuration for each case. Since the beam line was approximately 8 meters long, the average velocity is readily obtained and ranged from 1 m/ms to o.o5 m/ms.

Several generaliations are immediately discernable:

1. The 9o° bend contributes less than 5% to the flight time (length corrected for). Thus non-linear geometries (monochromators, mirror boxes) offer essentially nothing than a length for a delay.

2. Slit construction, i.e. thick or thin, is not critical.
3. Slit size is of deciding importance for the flight time. The product of slit area with the T1, T2 and T3 correlate fairly well for small slits, all other things remaining constant. This conclusion is drawn from the two directly comparable measurements, Expt. 2 and 5.

4. One (conical) 15 mm diameter aperture, 26 cm behind a slit, delays the shock wave between 4o and 7o% for T1 (3 x 1o$^{-5}$torr), between 17 and 61% for T2 (o.o2 torr) and between 2 and 52% for T3 (1 torr). Thus the effectiveness of an aperture is greater at the earlier (low pressure) times.

5. One 8 x 9 (conical) aperture increased T1 by 6o% for the o.2o x 6.o mm slit by 116% for the 8.o x 9.o mm "slit". Thus, one scattered light aperture would serve well as a delay element.

6. The T3 (1 torr) times and pressure rise values correlate roughly with slit size, i.e. at long times the rate is simply that of a leak, dependent primarily on the cross section of the leak and not on subsequent apertures, geometry, or pipe diameter.

7. The volume of the system has only a small effect on the T1 times. The total volume was changed by a factor of 2 on going from the 15o mm pipe to the 63 mm pipe, while the total length remained at about 8 meters. For the narrow slit, T1 changed by 4o% but for the 8.o x 9.o mm "slit" and for no slit (6o mm diameter hole) the change in T1 was ca. 1o%.

It was not possible to directly measure whether the shock waves accelerate as they propagate. However, the fact that the different pipe sizes yielded flight times that were comparable, except for the smallest slit, indicates that the velocity of the shock waves is independent of pipe size and is therefore probably constant. Thus, it seems safe to assume that the times given in table 1 can be scaled for other overall lengths.

In all of the experiments reported here, air from the laboratory i.e. mainly nitrogen, was the gas that was admitted to the system. Other gases, especially helium and hydrogen, have higher velocities, helium about double that of air (4).

The 8.o x 9.o mm "slit", when used without an additional aperture, exhibited a hitch in the pressure rise curve (see fig.2b) which correlates well with twice the T1 time. This hitch is attributable to a reflection of the shock wave from the chamber end of the pipe. Unexpected is the fact that the leak rate observed, when the reflection is present, is significantly higher than otherwise, and the T3 time significantly shorter, although not correspondingly so. The use of an aperture eliminated the reflection in all cases. There was no correlation between the use of th 9o° bend and a reflection.

## Conclusions:

The exit slit of a monochromator along with a scattered light aperture some 25-3o cm behind it form a very effective delay line, yielding shock wave flight times as long as o.o5 m/ms for the case of a o.2o x 6.o mm slit with an 8 x 9 mm conical baffle. Thus, in principle, a beam line 1.4 m long with such an arrangement would yield a delay of 25 ms, about the time required to activate and shut presently available fast closing valves. Larger slit openings can be considered by scaling the results presented here. A factor of 2 for the necessary length of pipework should be used if helium or hydrogen are likely to be the gas admitted. Larger openings are also discussed and data presented.

## Acknowledgement:

The experiments described herein were performed at the Hamburger Synchrotronstrahlungslabor HASYLAB at Deutsches Elektronen-Synchrotron DESY in Hamburg, Germany. We would like to express our appreciation to the HASYLAB staff for the productive cooperation during the course of the experiments.

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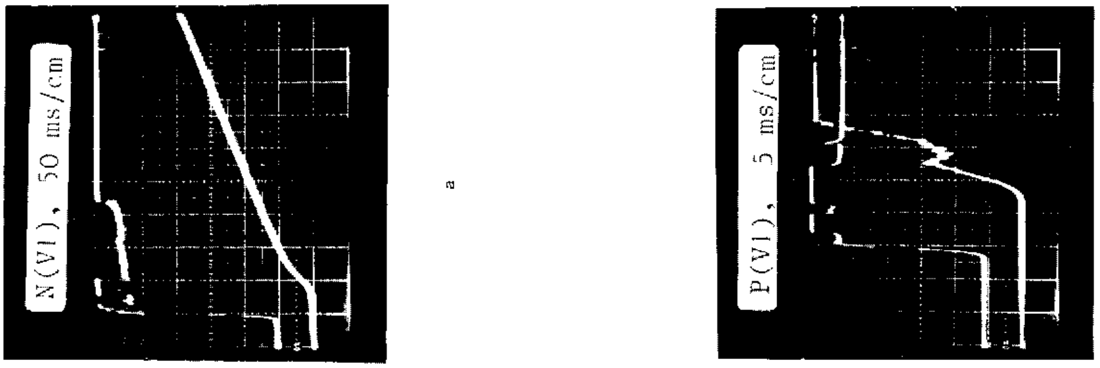
TABLE 1

| Expt. No. | Slit (mm) | Conical Aperture | $9o^{o}$ Bend | Length of 1oomm Pipe (cm) | Length of 15omm Pipe (cm) | Length of 63mm Pipe (cm) | T1 3x1o$^{-5}$torr (ms) | T2 o.o2 torr (ms) | T3 1 torr (ms) | Rate of pressure Rise (torr/ms) |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | o,2o x 6,o | - | yes | 261 | 529 | - | 63 | 12o | 11oo | 9.o x 1o$^{-4}$ |
| 2 | o,2o x 6,o | 15mm Dia. | yes | 261 | 529 | - | 87 | 14o | 84o | 1.4 x 1o$^{-3}$ |
| 3 | o.2o x 6,o | - | no | 232 | - | 5o4 | 87 | 16o | 76o | 1.6 x 1o$^{-3}$ |
| 4 | o,2o x 6,o | 8.ox9.o mm | no | 232 | - | 5o4 | 14o | 23o | 83o | 1.8 x 1o$^{-3}$ |
| 5 | o,25 x 8,o | 15mm Dia | yes | 261 | 529 | - | 76 | 15o | 69o | 1.6 x 1o-3 |
| 6 | o,25 x 8,o | 15mm Dia | no | 232 | 529 | - | 72 | 12o | 69o | 1.6 x 1o$^{-3}$ |
| 7 | o,25 x 8.o | - | no | 232 | 529 | - | 47 | 9o | 64o | 1.7 x 1o$^{-3}$ |
| 8 | 8,o x 9,o | - | yes | 261 | 529 | - | 16 | 27 | 37 | o.1 |
| 9 | 8,o x 9,o | 15mm Dia | yes | 261 | 529 | - | 26 | 4o | 53 | o.o9 |
| 1o | 8,o x 9,o | - | no | 232 | 529 | - | 14 | 23 | 33 | o.2 |
| 11 | 8,o x 9,o | 15mm Dia | no | 232 | 529 | - | 24 | 38 | 5o | o.o8 |
| 12 | 8,o x 9,o | - | no | 232 | - | 5o4 | 16 | 31 | 45 | o.o8 |
| 13 | 8,o x 9,o | 8.ox9.o mm | no | 232 | - | 5o4 | 34 | 53 | 76 | o.o6 |
| 14 | 6o mm Dia | - | no | 232 | 529 | - | 8.o | 13 | 17 | o.4 |
| 15 | 6o mm Dia | - | no | 232 | - | 5o4 | 8.4 | 13 | 2o | o.4 |

## Figure Captions

1. Schematic layout of the test apparatus. The drawing is approximately to scale in the horizontal direction.

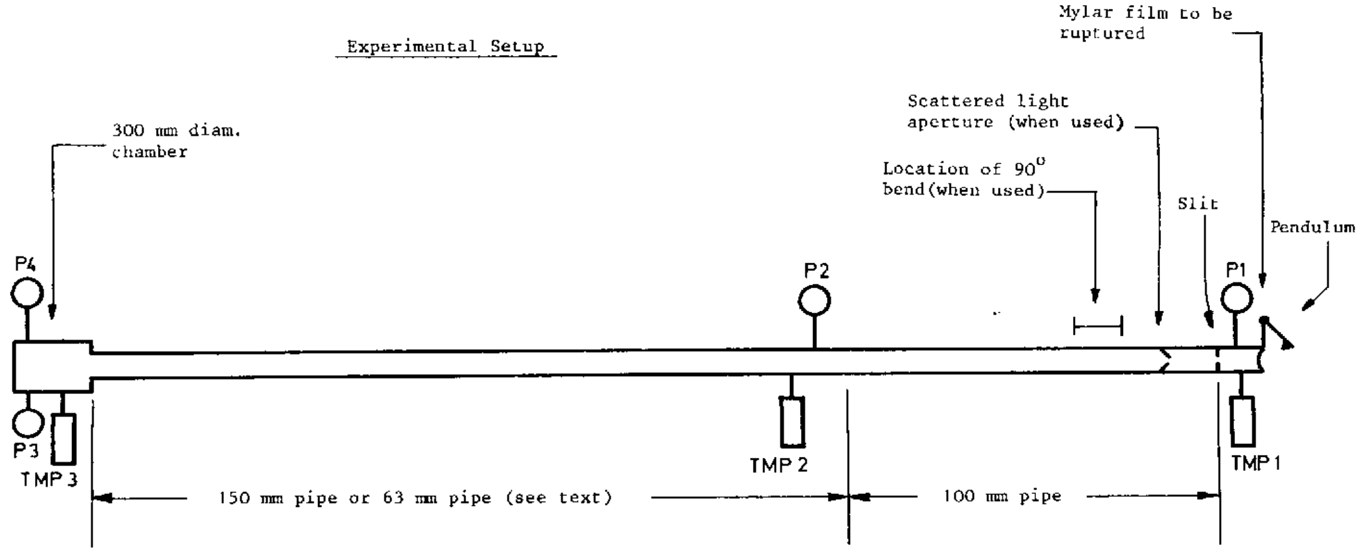
2. Oscilloscope traces of two runs. (a) o,25 x 8.o mm slit without aperture or $9o^{o}$ bend (Expt. 7, Table 1). Abcissa is 5o ms/cm. Ordinate is o.2 torr/cm.
(b) 8.o x 9.o mm "slit" without aperture or $9o^{o}$ bend (Expt 1o, Table 1). Abcissa is 5 ms/cm. Ordinate is o.2 torr/cm.



a

b

FIG. 2


Experimental Setup

P1, P3 — 2 l/s Ionpumps. Specially wired as Pressure Sensor. Trigger signal obtained at $3 \times 10^{-5}$ Torr

P2 — Penning Gauge for general pressure measurement. Not used for timing.

P4 — Capacitance manometer

TMP 1 — 70 l/s Turbomolecularpump

TMP 2 — 140 l/s Turbomolecularpump

TMP 3 — 140 l/s Turbomolecularpump

FIG. 1