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# PERFORMANCE OF A RAPID CYCLING HYDROGEN BUBBLE CHAMBER*

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ABSTRACT

A small hydrogen bubble chamber consisting of a convoluted bellows and driven by a loudspeaker-like coil expansion system was developed and tested to cycling rates of 90 Hz.

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Present theory and research[1,2] indicate that under fairly conventional operating conditions in a hydrogen chamber, track bubbles can be grown to visibility in about 0.25 millisecond, and completely condensed in roughly 4 to 5 times the growth period. The only basic time limit on expansion and recompression is the time required for a pressure wave to cross the chamber at the velocity of sound, which is approximately 1 meter per millisecond in liquid hydrogen. Therefore based solely on these theoretical limitations even a large chamber should have an upper limit of several hundred cycles per second.

Our approach was to investigate one class of rapid expansion system: the electromagnetic coil in a dc magnet, available commercially as a vibration table. All initial tests were made on a small cylindrical chamber 5 cm in diameter and 5 cm deep. The small volume effectively removes any refrigeration restrictions or limitations resulting from power requirements of the expansion system, and allowed us to concentrate on conditions specifically associated with fast cycling rates.

Figure 1 is an assembly drawing of the entire system. Pertinent details are:

1. The chamber body consists of a multiple convolution bellows[3] with a wall thickness of 0.04 cm, immersed in a bath of liquid hydrogen. This takes maximum advantage of the refrigeration system and reduces temperature variations to a minimum with the chamber. The original bellows has undergone several million cycles without failure.

2. This bellows is connected by a stainless steel tube to the driving rod of a modified MB Electronics Model S3 Vibration Exciter,[4] which with the associated electronics, comprises our expansion system.
3. A stainless steel spherical mirror with a 30 cm focal length is mounted at the top of the chamber. Dark field illumination is obtained by flashing an external light on this mirror and positioning the camera just outside the reflected light cone. This system allows us to observe bubbles of smaller radii than would be possible with the usual Scotchlite[5] backing.
4. The window is mounted in its flange with a mylar seal 0.0125 cm thick. This is sufficient to seal the chamber at pressures up to 15 atm, and at the same time produces no visible boiling in the liquid.

In the initial design stage there was some choice of parameters such as the chamber body stiffness, its aspect ratio, the piston weight, and the coil response. We adjusted these to allow for operation at 60 Hz, and later measured the natural frequency of the resulting system to be 75 Hz. After successful operation at 30 and 60 Hz, the piston and coil were modified slightly for a higher frequency response. Also, external springs were added to stiffen the system. These changes raised the natural frequency to approximately 110 Hz.

The coil is driven by pulses from a capacitor-SCR network, supplied by a conventional 350 V, 8 A variable regulated power supply. The circuit can operate at any frequency up to 120 Hz, the limit resulting from the charge and discharge times of the present power supply, capacitors, and coil.

We can divide the frequency range of the chamber into two classes of operation: "pulsed" and "oscillating." For purposes of the present discussion the following arbitrary ranges apply:

1. If the expansion period is long enough for the amplitude of the oscillations to die down to about 30%, we say the chamber is "pulsed."
2. If the chamber is driven at approximately its natural frequency, it is said to be "oscillating."

These ranges are illustrated in Fig. 2. Note that even in the oscillating mode we are using the capacitor-SCR system to generate pulses, the distinction being that the pulses drive the system near its natural frequency.

In the pulsed mode the chamber was sensitive to minimum ionizing radiation, both from a $Co^{60}$ source and the SLAC electron beam, at 30 Hz and 60 Hz, with the following nominal operating conditions:

30 Hz: $p_0 = 7.0$ atm, $p_{vapor} = 5.2$ atm, $\Delta p \geq 3.1$ atm

60 Hz: $p_0 = 7.9$ atm, $p_{vapor} = 6.0$ atm, $\Delta p \geq 3.3$ atm

In general, sensitivity can be achieved at pressures as much as 0.3 to 1.0 atm different from the $p_0$ values quoted, provided the approximate relationship between $p_0$, $p_{vapor}$ and $\Delta p$ is maintained. As a rule, one has a narrower pressure band of sensitivity at the higher cycle rates. At these frequencies the system was stable, that is, the sensitivity did not change over periods of 15-20 minutes of continuous operation. At 60 Hz with the beam injected at the pressure minimum and a 0.25 msec light delay, the bubble image had a diameter of approximately 75 microns in real space. Figure 3 is a photograph of two tracks passing through the chamber under these conditions. We have chosen a rather small depth of field to give maximum definition to bubbles in one region of the chamber; consequently one track is seen in sharp focus, whereas the other is out of focus. These tracks have a bubble density of 14 bubbles per centimeter. For light delays of 0.75 msec or less there is no visible distortion or turbulence. Furthermore, no track "residue" was observed from cycle to cycle. This was checked by photographing the expansion following the one in which a beam was injected. All such pictures were clear and without any remnant of the tracks from the previous cycle.

Refrigeration requirements depended very strongly on the level of spurious bubbles and "plumes" from the valves, and on the exact operating conditions. So far we have made no attempt to optimize these to reduce the heat load. The nominal refrigeration load was $1.7 \times 10^{-2}$ joule per cycle at 60 Hz, with a chamber volume of about 100 $cm^3$.

At 90 Hz, the driving rate approximates the natural frequency sufficiently well so that the chamber runs in the "oscillating" mode. Under these conditions, the main difficulty lies in completely condensing bubbles which are formed in one expansion half-cycle, before the next expansion occurs. This is obviously much more crucial for the oscillating mode than the pulsed mode, where for a given $p_0$, $p_{vapor}$, and $\Delta p$ the system is above the vapor pressure for a greater fraction of each cycle. To insure that all bubbles are condensed from one cycle to another, it is necessary to have a much greater pressure differential $p_0 - p_{vapor}$ for the oscillating mode. The sensitivity is also limited to a rather narrow pressure band of $\pm$ 0.2 atm. Our operating conditions at 90 Hz were $p_0 = 9.2$ atm, $p_v = 6.8$ atm and $\Delta p = 3.7 - 3.9$ atm. Whereas the "tuning" of the system is considerably more difficult in the oscillating mode, the approximate resonant behavior consumes about four times less power per expansion. Figure 4 is a photograph of tracks under these conditions. Again at 90 Hz no "residue" of previous cycles was observed.

We are currently testing a 10 cm diameter, 7 cm deep chamber of similar configuration, coupled to a larger vibration exciter. This chamber has proved to be sensitive to minimum ionizing particles over the frequency range of 45 to 90 Hz. Initial results indicate that overpressures, $p_0 - p_v$, as low as 1 atm are feasible provided that $\Delta p$ exceeds the overpressure by at least 1 to 1.3 atm.

To summarize, the purpose of these tests was to determine the feasibility of achieving high cycling rates in hydrogen bubble chambers. We have not nearly approached a power limit for commercially available vibration tables or a refrigeration limit, which suggests that larger chambers can be built and higher frequencies attained using this expansion principle. If such a chamber can be constructed having a diameter of 25 to 35 cm, and an operating frequency of about 120 Hz, it would be extremely useful as a "visible target" for numerous counter, wire chamber, spark chamber, streamer chamber, or missing mass spectrometer experiments.

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## REFERENCES


1. G. Harigel, G. Horlitz and S. Wolff, "Measurements on the formation, growth and recompression of bubbles in liquid hydrogen," Report No. DESY 67/14 (1967).
2. G. Harigel, G. Horlitz and S. Wolff, "On the thermodynamics of bubble chamber expansions, Report No. DESY 68/43 (1968).
3. This possibility was suggested by J. Mullins, California Institute of Technology (1966); private communication.
4. M. B. Electronics Manufacturing Co. Inc., New Haven, Connecticut.
5. Registered trademark of the Minnesota Mining and Manufacturing Company.

## LIST OF FIGURES

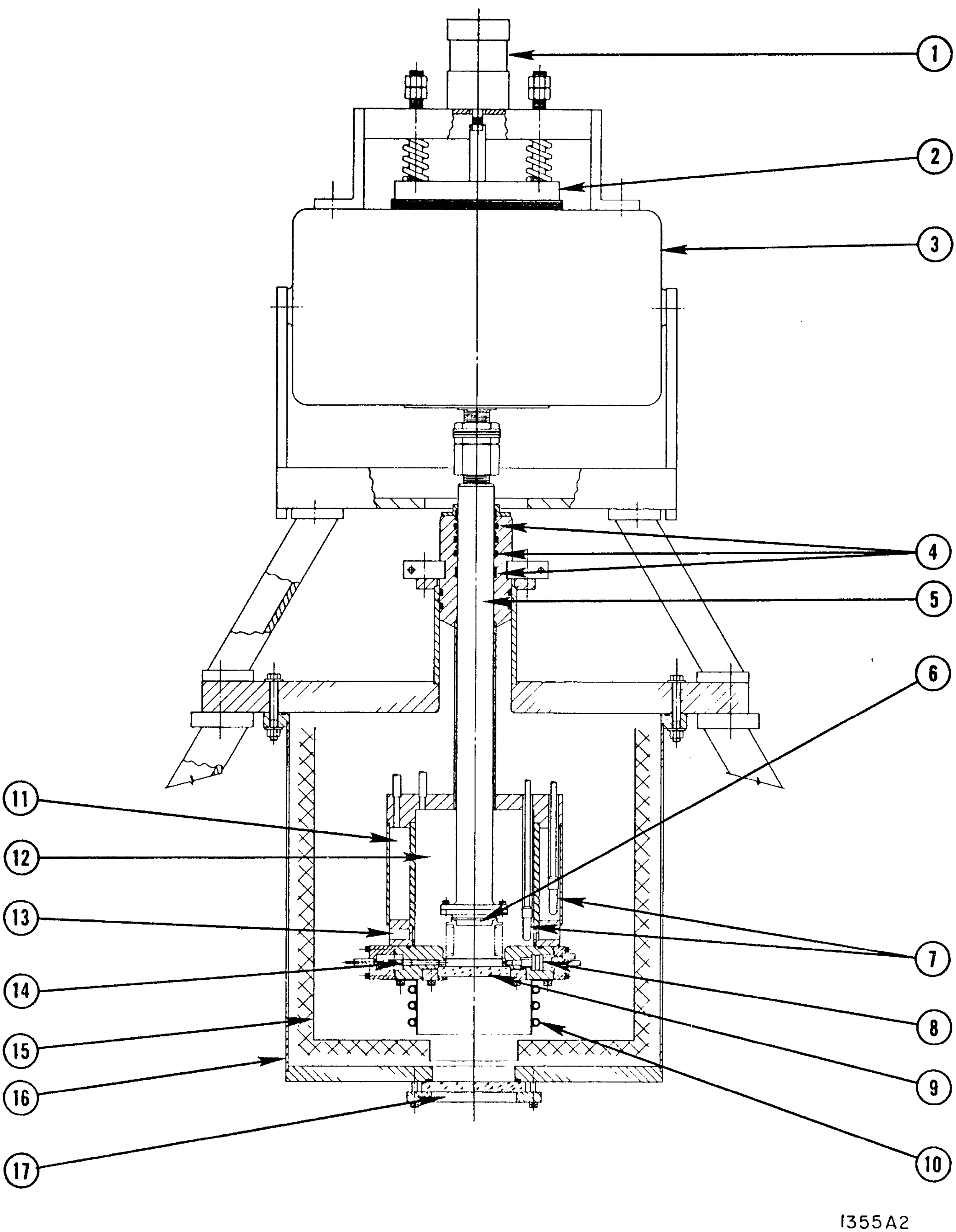


Fig. 1

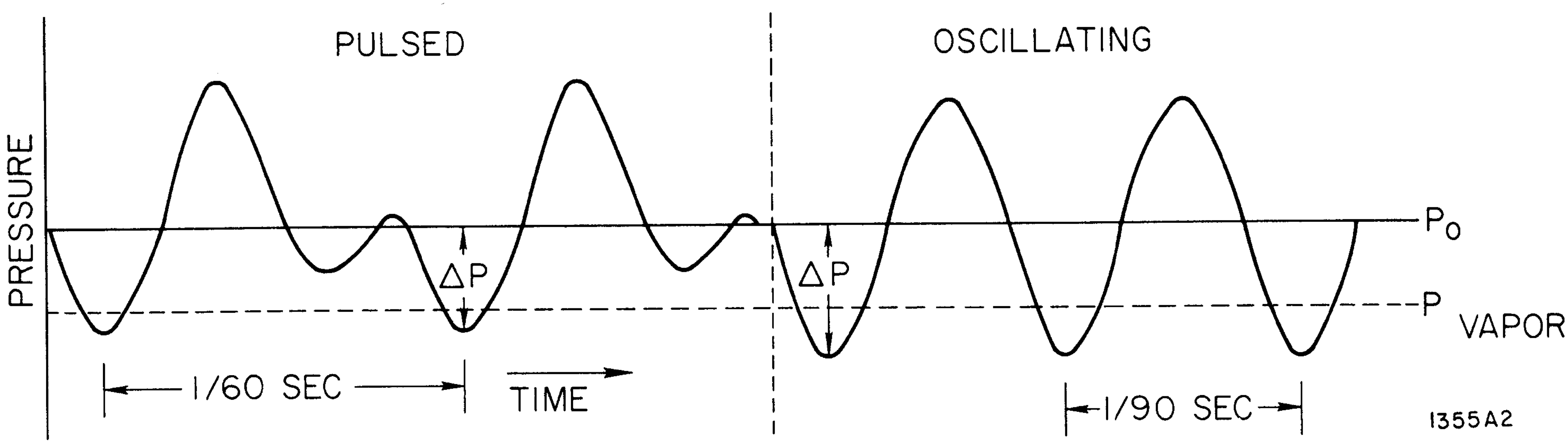
PULSED
OSCILLATING
PRESSURE
ΔP
ΔP
$P_0$
P VAPOR
1/60 SEC
TIME
1/90 SEC
1355A2

**Fig. 2**

Fig. 3

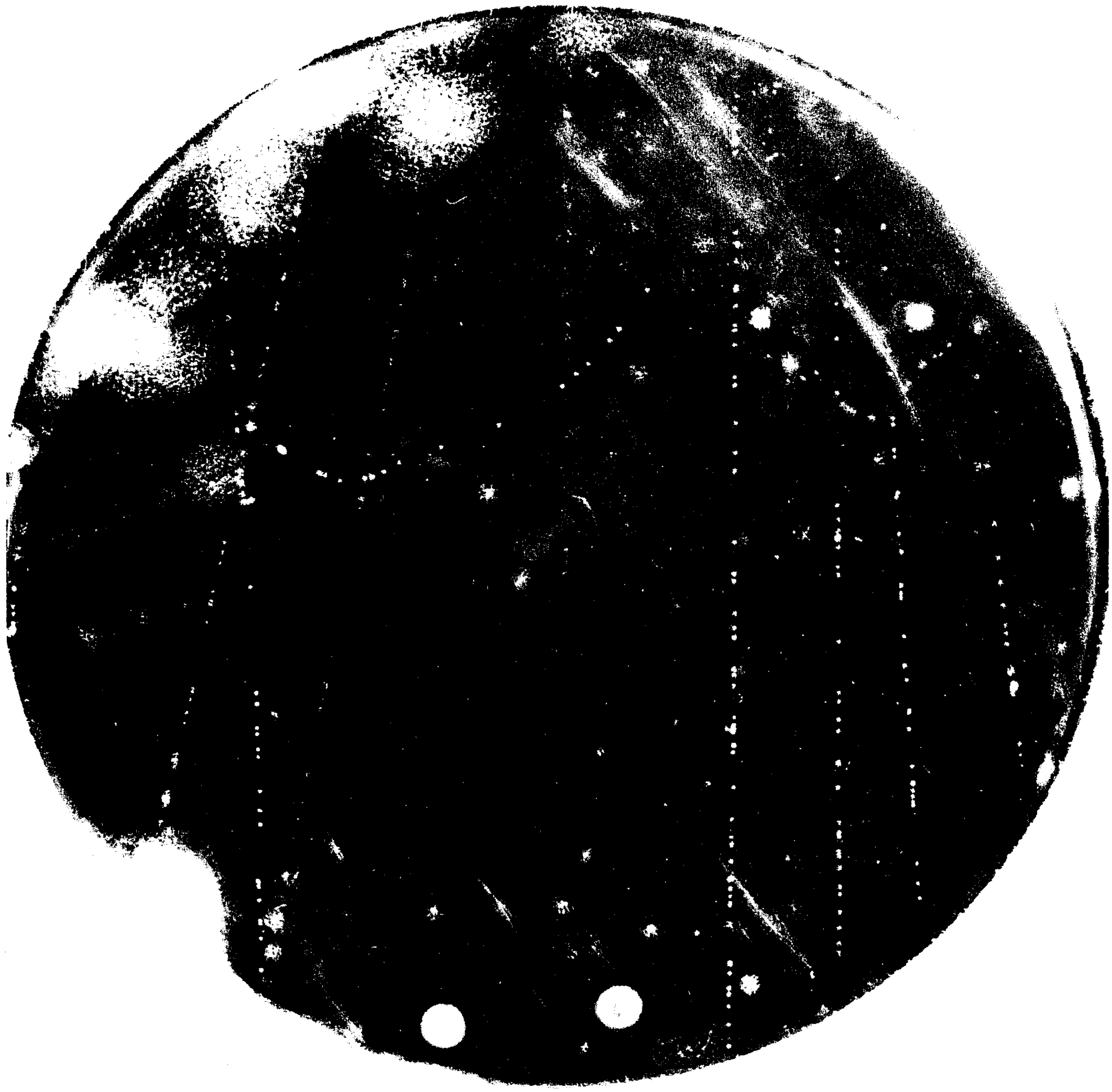

Fig. 4