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A simple recirculating pump for highpressure highpurity gas

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$d = 4$. The PPD, divided by 16, is then well below the threshold of damage of the filter.

Two lenses were tried, one with $f = -20$ mm, the other with $f = -12$ mm, with quite equivalent results. If the lens is not antireflection coated, the reading of the power meter has to be multiplied by ~ 1.1 to account for reflection losses, but a more accurate calibration versus wavelength is also possible.

Moreover, the use of an uncoated divergent lens offers another interesting characteristic. In order to reduce the overall size, short focal lengths f, provided by plano-concave lenses, are preferable and it is better to mount the lens with its concave surface towards the exterior of the power meter. Then the beam reflected by the second (plane surface) of the lens is strongly divergent, while the beam reflected by the concave surface is focused at $f/2$ in front of and very near the lens. Beyond the focus, this second beam is also strongly divergent. Thus, contrary to the case when the filter is used directly, there is no risk of feedback into the laser. Furthermore, at pulse energy higher than 200 mJ and pulse duration 10 ns, a plasma is generated at the focus of the second reflected beam. This plasma absorbs nearly 50% of the reflected energy (and also a very small fraction of the incident beam energy). The intensity and stability of this plasma are at a maximum when the lens is correctly positioned, hence it provides a means of adjustment of this lens.

In the case of laser beams of high PPD and of diameter $\leqslant 6$ mm, a simple mean to protect the filter of the power meter is to use a divergent lens in front of it. In addition, this setup eliminates the risk of feedback into the laser.

A simple recirculating pump for high-pressure high-purity gas

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A bellow-pump allows to circulate high-purity gas at high pressure without contaminating the sample. Its main features are low cost, simple design, easy operation, all-metal construction, and adjustable flow rate.

The electronic transport properties in fluids may be very sensitive to the presence of extremely small amounts of impurities (in the range of parts per billion). Scavenger molecules like O_2 have been proved to be very effective in dense Hydrogen, Helium and Neon gases.[1] Gas samples with an impurity content less than 10^{-6} can hardly be obtained from manufacturers: outgassing from the cylinder walls will soon spoil the sample purity.

Using ultra pure gases requires therefore *in situ* purification systems. When using a very effective purifier and very clean measuring cell, the gas may simply enter the cell after passing once through the purifier. This setup may be inadequate when the impurity concentration must be pushed to ppb levels. In this case a closed cycle system should be preferred: the gas sample is circulated many times through the purifier and the cell by means of a gas displacer, which must provide the required pressure drop,[2] *without introducing extra impurities into the gas sample.* At each cycle the impurity content is therefore reduced by a finite amount and the purifier efficiency becomes a less important parameter.

Rotary-vane pumps in oil bath or piston-pumps must therefore be avoided, due to the presence of contaminating oil and gaskets. Several magnetically-driven recirculating pumps have been described in the literature,[3] but no one provides the important feature of all-metal construction required for a very clean performance: the presence of teflon or epoxy resins in the device may in fact significantly affect the gas purity.

The recirculating pump here described is essentially made of a stainless-steel bellow hydraulically driven by a small oil compressor, in series with two metal check valves. The block diagram is shown in Fig. 1. The bellow, with a closed end, is a "welded diaphragm-type",[4] mounted in a destroked configuration to extend its lifetime. The nominal lifetime is 10^4 strokes with a swept volume $\Delta V \approx 40$ cc: a reduction of an order of magnitude in ΔV should provide a practically infinite lifetime. The bellow is soldered to a stainless-steel flange carrying the input and output ball-valves, and is surrounded by a degassed oil bath connected to a commercial oil compressor.[5] The compressor, driven by compressed air, displaces, to and from the bath, a fixed oil volume per stroke. A simple modification of the commercial compressor is required: the outlet and inlet valves are removed, one of the two ports is used for connecting to the oil bath and the other is plugged (or attached through a shut-off valve to a vacuum line for easier oil filling by suction).

The oil must be carefully outgassed in order to decrease its compressibility, and to allow evacuating the gas-side of the bellow without overstressing it. An efficient outgassing may be easily obtained by pumping and heating the oil before introducing it into the device.

The gas-flow rate is determined by the swept volume,

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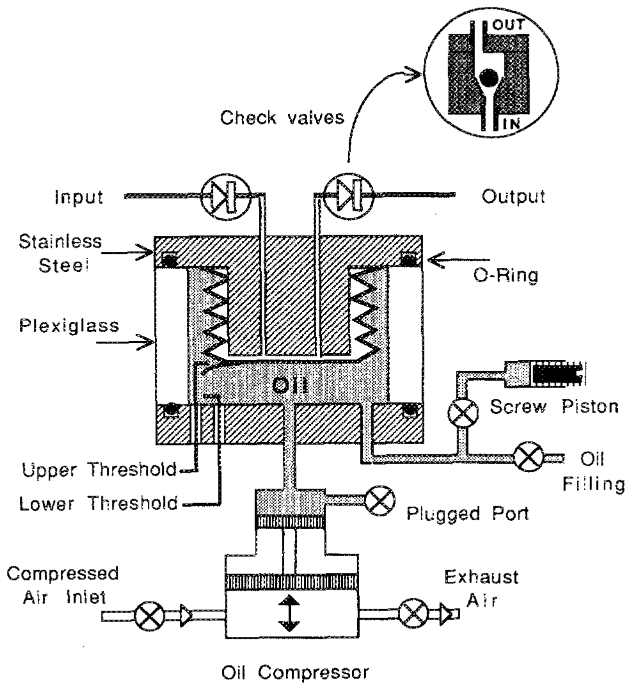

FIG. 1. Schematic of the bellow recirculating pump.

and by the compressor speed. Low oil viscosity allows a higher maximum compressor speed but also increases the leak rate, thus imposing more frequent oil refillings. A minimum gas pressure of few Atm is required to drive the ball check valves, while the maximum working pressure is limited only by the compressor performance. The bellow in fact is kept in a "stress-free" condition by the presence of the oil bath, so that no differential pressure builds up across its walls when high pressure is applied to the gas. Working at lower pressures would be made possible by driving the check valves with a solenoid (using a steel ball and a brass seat).

The transparent plexiglas lateral wall of the oil container makes it easier to trim the distance between the bellow's closed-end and the flange, by means of a screw-piston. This distance should be minimized (with the compressor piston at full stroke) in order to reduce the dead volume, but any contact must be carefully avoided (it would completely destroy the bellow, which cannot withstand large differential pressures).

For greater safety, two alarm thresholds monitor the position of the bellow's closed end by means of electrical spring-contacts placed in the oil bath.

The head pressure ΔP of the pump is determined by the ratio between the swept volume to the dead volume V_o: $\Delta P = P_o \Delta V / V_o$, where V_o include the volume between the outlet valve and the (high impedance) purifier. To maximize the gas flow, the diameter of outlet tubing should therefore be chosen as a compromise between low impedance and small volume.

A bellow of $\approx 2''$ diam-20 convolutions, with a stroke of 4 mm, has been successfully used for circulating Neon[1] gas at a pressure up to 100 Atm, with a flow rate up to 4.0 cm^3/s, and a compression factor $P_{out}/P_{in} \approx 1.4$. The maximum working pressure was limited by the available pressure of compressed air in our laboratory (5 Atm); the low-cost ($500) oil compressor used here can give 240 Atm output with air input of 11 Atm. Greater flow rate may be easily obtained using a larger diameter bellow and a compressor with greater swept volume. Once the system is properly set, no control is required for operating the device: the compressor speed is adjusted simply by regulating the pressurized-air flow rate; the pump start and stop is controlled by a normal air shut-off valve.

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[1] L. Bruschi, M. Santini, and G. Torzo, J. Phys. E **18**, 239 (1985); A. F. Borghesani, L. Bruschi, M. Santini, and G. Torzo, Phys. Rev. A **37**, 4828 (1988).

[2] The more commonly used purifiers for cleaning rare gases are cold traps filled with molecular sieves (activated charcoal, alumina, zeolite, silica-gel) or room temperature getters, or high temperature ovens. The purifier efficiency is proportional to the collision frequency between the impurity molecules and the scavenger material. Therefore for a given material, increasing efficiency requires increasing the purifier impedance.

[3] W. M. Hisham and S. W. Benson, Rev. Sci. Instrum. **60**, 1349 (1989); D. H. Ziegler and C. A. Eckert, *ibid.* **653**, 1296 (1982); F. J. Torre, D. M. Eshelman, M. W. Lee, P. Neulfeld, and W. Watson, *ibid.* **47**, 1142 (1976); C. J. Sterner, *ibid.* **31**, 1159 (1973); H. J. Hiza and A. G. Duncan, *ibid.* **40**, 513 (1969); K. L. Erdman, J. R. MacDonald, G. A. Beer, and D. A. Axen, *ibid.* **35**, 241 (1964); RF. B. Canfield, J. K. Watson, and A. L. Blancett, *ibid.* **34**, 1431 (1963).
[4] Metal Bellow Corporation, Chatsworth, USA.
[5] Maximator MSF-22L, Schmidt Kranz & Co., Gmbh, Langenberg, Germany.