

<sup>1</sup>H. J. Hovel, in *Semiconductor and Semimetals*, edited by R. K. Willardson and A. C. Bear (Academic, New York, 1975), Vol. 11, pp. 79–82, 189.  
<sup>2</sup>*Solar Cells*, edited by Charles E. Backus (IEEE, New York, 1976), pp. 118–123.  
<sup>3</sup>P. F. Kane and G. B. Larrabee, *Characterization of Semiconductor Materials* (McGraw–Hill, New York, 1970), p. 274.  
<sup>4</sup>W. R. Runyan, *Semiconductor Measurements and Instrumentation*

(McGraw–Hill Kogakusha, Tokyo, 1975).

<sup>5</sup>P. K. Basu and D. Biswas, *Indian J. Technol.* **14**, 669 (1976).

<sup>6</sup>J. D. E. Beynon, G. G. Bloodworth, and I. M. Mcleod, *Solid State Electron.* **16**, 309 (1973).

<sup>7</sup>S. M. Sze, *Physics of Semiconductor Device* (Wiley Eastern Limited, New Delhi, 1979), p. 284.

## Magnetically coupled digital motor for producing vortical motion in liquids in tubes

Douglas Jewett

*Cyclotron/PET Facility, Division of Nuclear Medicine, University of Michigan, Ann Arbor, Michigan 48109*

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Vortical motion of liquids in tubes, for the purpose of mixing or evaporation in small-scale chemical process streams, is produced by a magnetically coupled digital drive mechanism. The latter consists of an eight-pole stator, to which a continuously commutating magnetization is applied, one pole at a time, and a rotor consisting of a magnetically soft steel ring surrounding and fixed to the liquid-containing tube. The power to the stator windings is controlled by MOSFET transistors driven directly by a CMOS counter decoder. The clock signal is derived from the 60-Hz ac line, eliminating the need for a filtered power supply.

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Mechanically generated vortices are widely used in devices for mixing or evaporating small volumes of liquid.<sup>1</sup> Commercially available devices derive the vortical motion by means of an eccentric coupling to a conventional motor. For automated radiochemical syntheses I required several steps of mixing and evaporation within the limited space of a small shielded cell, and thought that the required vortical motion might be obtained by magnetic coupling without the mechanical complexity inherent in existing devices. To that end I built a simple mechanism which can be adapted to a variety of situations where mixing or evaporation of small volumes of liquid are required. The mechanical simplicity of the device permits miniaturization and flexibility of design. The use of Teflon for electrical insulation and connecting tubing would permit operation above 200°.

The device, shown schematically in Fig. 1(a) consists of a stator with eight poles, modified from a commercial stepper motor,<sup>2</sup> or made from a laminated stator core,<sup>3</sup> and a rotor consisting of a magnetically “soft” steel ring surrounding and fixed to the fluid-containing vessel. The diameter of the rotor is smaller than that of the space within the stator, allowing the former to move eccentrically when a commutating magnetization is created in the latter. A thin covering of rubber on the metallic surfaces reduces noise and damps unnecessary vibration.

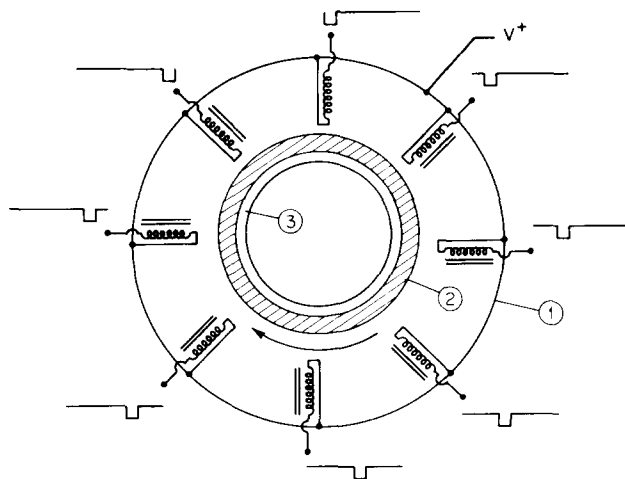
Commutated dc power to the windings is generated by a divide-by-eight counter/decoder driving 8 MOSFET transistors. A block diagram of the circuit is shown in Fig. 1(b). The clock input to the counter is obtained by full-wave rectification and clipping by a zener diode of the output of a step-

down transformer. The dc power supply to the stator windings is obtained by full-wave rectification of the output of a transformer. The resulting synchronization of the gate and power inputs to the transistors provides automatic switching at zero crossing and eliminates the need for filtering the power supply.

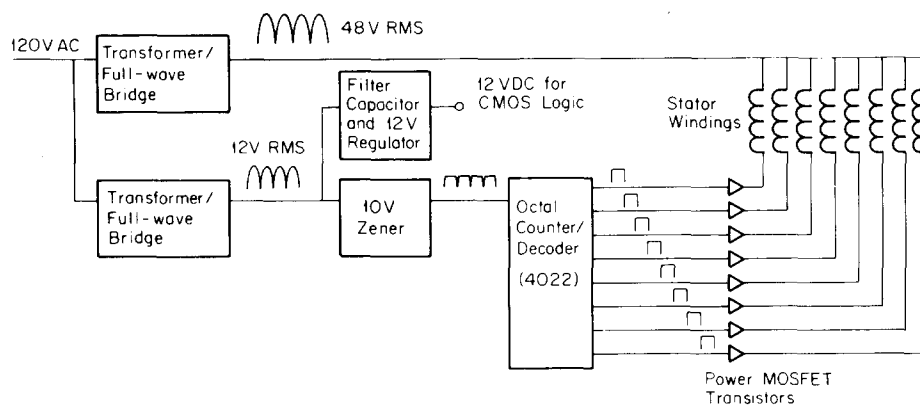
The 60-Hz power supply frequency results in a rotor frequency of 15 rpm, which produces strong vortical motion in liquids in tubes of 1–2-cm diameter. For larger tubes or heavy vessels, lower frequencies can be obtained by adding a binary counter<sup>4</sup> before the counter decoder. For tubes of a few millimeters diameter, higher frequencies are required than can be obtained from the 60-Hz line. For the device shown in Fig. 2(b), I used a filtered dc power supply and drove the counter decoder by a continuously variable clock to achieve rotor frequencies as high as 100 rpm.

Figure 1(c) is a detailed schematic of the circuit. The transistors are protected by zener diodes across the gates and by clamping and zener diodes at the outputs. Because the FET power transistors are currently expensive and the consequences of failure in my application very serious, I have not determined if all the above precautions are necessary. Before installation of zener diodes across the gates, transistors failed on two separate occasions, both times at the instant when the stator coil was disconnected while power was applied. Situations where this may occur should be avoided.

Figure 2(a) shows the application of the above device to a mixer–evaporator used in a system for automatic radiochemical synthesis. Not shown in the diagram are several small-diameter Teflon tubes extending into the glass

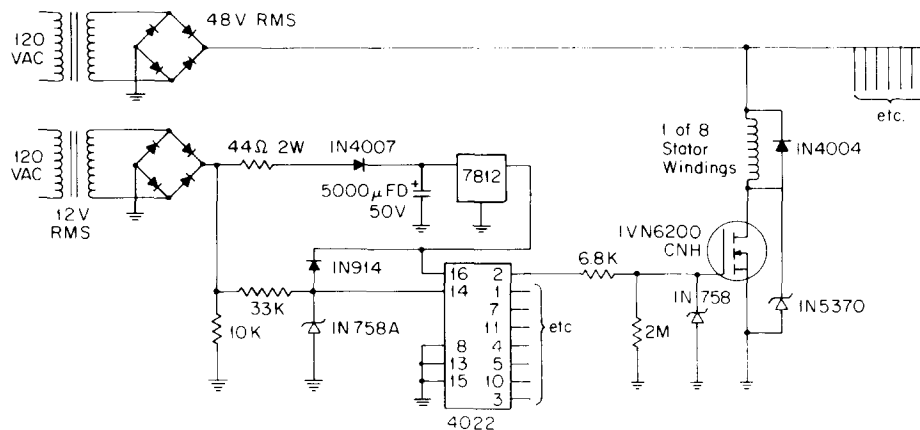


a



b

FIG. 1. Schematic diagram of the mechanism for achieving eccentric magnetization by means of commutated magnetization. (a) Eight-pole stator (1) with windings energized in the timing sequence shown, and steel rotor (2) fixed to fluid-containing tube (3). (b) Block diagram of circuit for obtaining commutated power to the stator windings. (c) Detailed schematic of circuit. Only one of eight identical transistor amplifier stages is shown.



c

centrifuge tube for the transfer of liquids. Power is supplied remotely by a nine-wire cable so that only the components shown in Fig. 2(a) need occupy the limited space within the radiation shield. Heat for evaporation is supplied by a hot air gun.

Since a number of rotary and vortex evaporators are commercially available, it is useful to discuss the relative advantages and disadvantages of a magnetically coupled de-

vice such as that in Fig. 2(a). The latter, because of its compactness and lack of moving parts, is useful where space is an important constraint—in radiation-shielded cells, glove boxes, ovens, etc. Since there are no rotating seals, by proper choice of materials, it should be possible to make devices to operate in inaccessible areas for long periods without maintenance. Because the coupling between the rotor and stator is nonrigid, the magnetically coupled device is subject to the

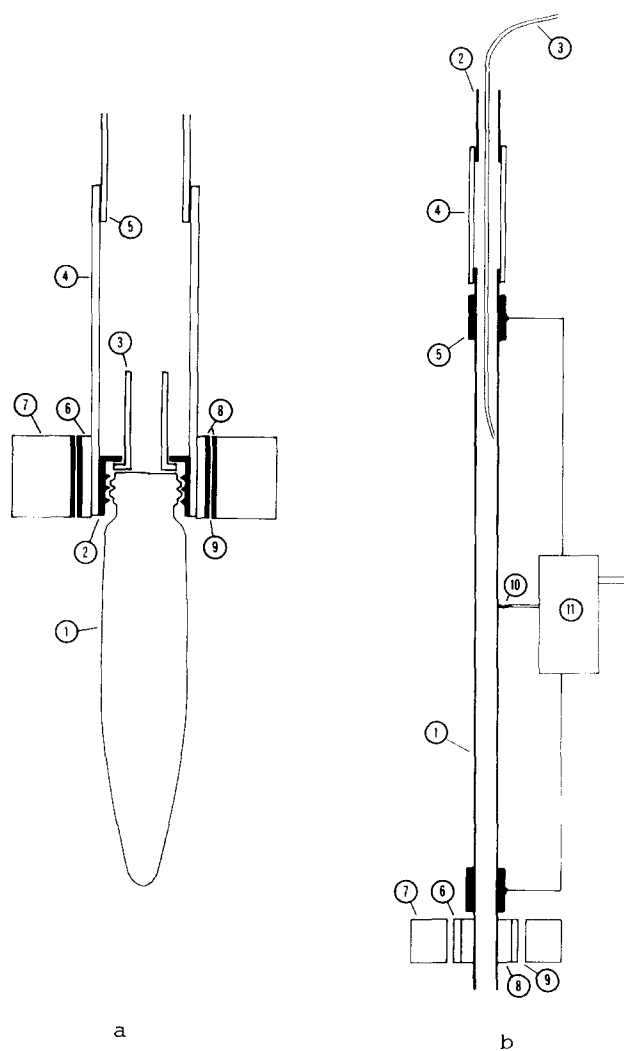


FIG. 2(a). Vortex evaporator. (1) 50-ml glass tube, (2) fitting made by drilling hole in phenolic tube cap, (3) Teflon seal with extension to prevent reflux of solvent, (4) tygon tubing (internal spring for reinforcement not shown), (5) glass tube leading to cold trap and vacuum, (6) steel ring cut from electrical conduit, 40 mm diam, (7) stator, (8) urethane cushion, (9) gap between rotor and stator, 2 mm, 2(b). Prototype in-line evaporator for GLC interface. (1) Thin-walled stainless-steel tube, (2) stainless-steel tube attached to supporting structure, (3) Teflon tube from pump to introduce solution to be evaporated, (4) flexible Teflon tube, (5) copper sleeve, (6) steel ring, 25-mm diam, (7) stator, (8) cork ring attaching rotor ring to tube, (9) gap between rotor and stator, 1 mm, (10) thermocouple, (11) thyristor temperature controller.

effect of resonance. Changing the diameter or weight of the load attached to the rotor changes both the frequency and power required for optimization. Thus the devices described above are better suited for dedicated automatic systems than for general laboratory use.

A second example of a possible application of a magnetically coupled eccentric mechanism is a method for reducing the amount of solvent in a sample for injection into a gas-liquid chromatograph (GLC). A problem in the integration of a GLC into a system for automated radiochemical synthesis lies in the introduction of the product to the heated column. Usually the product must be transferred from several milliliters of solvent to a volume of 100  $\mu$ l or less for instantaneous atomization and evaporation at the inlet of the column. An efficient way to do this would be to evaporate several milliliters of solution on the walls of a heated tube of small diameter from which the solute could be subsequently transferred to the column by a small slug of volatile solvent. It is difficult to evaporate such a volume of solvent in narrow tubes because the solvent vapors force the unevaporated solvent out. However, with the aid of a stroboscope, I observed that rapid vortical motion applied to a 4-mm-i.d. tube caused liquids flowing in it to be closely confined to the wall, leaving the lumen free for the passage of vapor. In the apparatus shown schematically in Fig. 2(b), 10 ml of Freon-11 or methylene chloride were evaporated within a 5-mm-i.d. tube in about 5 min. Without the application of rapid eccentric motion to the tube, the injected liquid sprayed out violently.

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<sup>1</sup>For example, the "Vortex-Evaporator," Buchler Instruments, Ft. Lee, NJ 07024.

<sup>2</sup>For example, the device shown in Fig. 2(a) employs the stator from a synchronous stepping motor; type SS50-1272, Superior Electric Co., Bristol, CT. The existing connections were removed, and one side of each winding was soldered to a separate lead.

<sup>3</sup>For example, the device shown in Fig. 2(b) employs stator No. 1020 ST, Magnetic Metals Corp., Camden, NJ 08101. Each pole is wound with 400 turns of No. 30 magnet wire.

<sup>4</sup>4024 seven-stage binary counter.