A magnetostrictive motor

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Magnetostriction can be used to effect a linear incremental motion device. Bidirectional incremental motion can be achieved in which the step size is set by the magnetostrictive coil's current. Such a device possesses the variable step width, characteristic of analog devices (unlike salient pole stepper motors). Once the step size is selected by the coil's current, the device behaves as a digital device with incrementally selected steps. Magnetostriction is a nonlinear function, dependent on the material. For the small incremental motion we examined, operation was essentially in the linear portion of the strain versus magnetic field strength curve.

BACKGROUND

Magnetostriction has been used often in analog positioning problems.[1] Electrostrictive motors, too, have been described.[2] Magnetostriction is due to deformations of the crystal structure of the material (typically nickel) in the presence of an imposed magnetic field.[3] The forces associated with crystal deformation are high, but the size of the deformation is small. The magnetostrictive constant is defined by the relation[4]

$$-\Delta l/l = cB^2, \qquad (1)$$

where $c = -10^{14}\ \mathrm{m^4/Wb^2}$ for nickel. The magnetostrictive motor (Fig. 1) relies on the length l of magnetized element (shown as the dotted line) constricting until the energy stored,

$$\epsilon_{\text{stored}} = \int_{\text{dotted volume}} d\epsilon = \int \tfrac{1}{2}(\mu) H^2\, d(\text{vol}), \qquad (2)$$

is equal to the work available from the device,

$$\epsilon_{\text{available}} = \int F \cdot dl. \qquad (3)$$

The force F generated in the metallic structure of the magnetized element relaxes after removal of the magnetic field intensity H. The length dl represents the differential constriction of the moving member. Integration is over the constriction length.

By successively (a) constricting the moving member, (b) releasing one clutch, and (c) deenergizing the coil which causes magnetostriction, motion in one direction can be achieved. It should be noted that the spring constant contributes to an energy term which is linearly proportional to the compression of the bar, whereas the magnetic energy term is affected by the magnetic field intensity, which is proportional to the square of the coil current:

$$\Delta\epsilon_{\text{magnetic}} = \int \tfrac{1}{2}(\mu) H^2\, d(\text{vol}) = \int \tfrac{1}{2}(\mu) H^2 \pi a^2\, dl, \quad (4)$$

where the bar radius is a. This is balanced for a static position by

$$\Delta\epsilon_{\text{mechanical}} = \int k(l_0 - l)\, dl. \qquad (5)$$

The term $k(l_0 - l)$ is the mechanical force of the spring. $(l_0 - l)$ represents the compression from the equilibrium position l_0. The spring constant is k. Sliding friction, which is velocity dependent, contributes to the damping constant, resulting in a displacement which has a sinusoidally damped component.

RESULTS

A motor was constructed in the form of Fig. 1. The step size of the motor was controlled by the magnetostrictive coil's current. The moving element's displacement was measured after 1000 steps. A graph of moving element displacement versus cycles of energizing the coil current (with clutch engagement between coil current pulses) is shown in Fig. 2. A saturation of the magnetostrictive effect was observed at high currents. Low current data were not taken to avoid operation dominated by sticking friction.

The use of a uniform magnetostrictive element allows extended motion in either direction. Alternate configurations which use a region of lower reluctance (and corresponding lower restoring spring constant in the moving element) will behave in a manner similar to the uniform element case. Of course, localizing the region which accounts for device behavior restricts the range of excursion of the moving element.

The moving bar's mass and spring constant system can be described by the well-known second-order differential

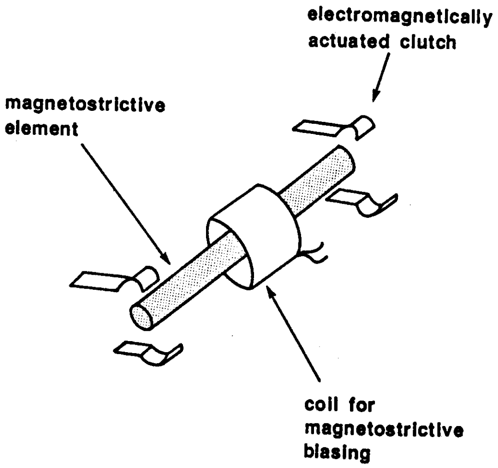

FIG. 1. Schematic diagram of the magnetostrictive motor.

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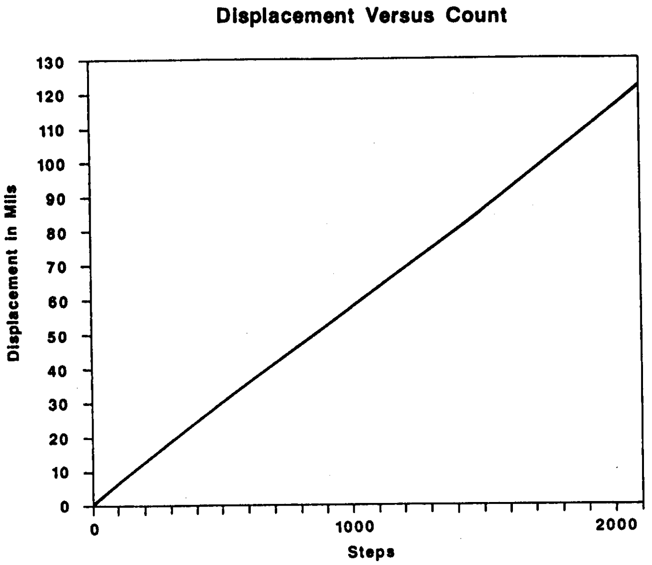

FIG. 2. Moving element displacement vs cycles of coil current energizing, or steps.

equation for damped oscillating systems. The high losses in the metal result in rapid damping of the oscillations within the time for the clutches to restrain bar motion.

The hysteresis and linearity of the device were tested by measuring the cumulative displacement for a fixed number of displacement steps. The device's hysteresis was negligible, affected mainly by nonuniformity in the clutch mechanism.

CONCLUSIONS

The peristoltic motion motor exhibited a repeatable step size. The step size was controllable by the current in the driving coil. Large linear excursions of the moving element, along with small step size, are features of the motor. Simplicity of construction and repeatability of function present attractive features for a motor.

[1] J. Strong, *Procedures in Experimental Physics* (Van Nostrand, New York, 1941).

[2] J. H. Bruning, in *Proceedings of the Fourth Annual Symposium on Incremental Motion Control Systems and Devices*, edited by B. C. Kuo, University of Illinois at Urbana-Champaign, 1975 (Dept. of Electrical Engineering, University of Illinois at Urbana-Champaign, Urbana-Champaign, IL, 1975).

[3] F. Pockels, *Encyklopaedie der mathematischen Wissenschaften* (Teubner, Leipzig, 1906), Vol. V, Part II.

[4] E. C. Jordan, *Reference Data for Engineers*, 7th ed. (Sams, Indianapolis, IN, 1985), pp. 4-28–4-30.