

Dynamical Modeling and Characterization of a Surface Micromachined Microengine

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Abstract

The practical implementation of the surface micromachined microengine [1,2] to perform useful microactuation tasks requires a thorough understanding of the dynamics of the engine. This understanding is necessary in order to create appropriate drive signals, and to experimentally measure fundamental quantities associated with the engine system. We have developed and applied a dynamical model of the microengine, and used it to accomplish three objectives: 1) drive inertial loads in a controlled fashion, i.e. specify and achieve a desired time dependent angular position of the output gear, 2) minimize stress and frictional forces during operation, and 3) as a function of time, experimentally determine forces associated with the output gear, such as the load torque being applied to the output gear due to friction.

The dynamics of the microengine (Fig. 1) were theoretically examined for square wave drive signals in a previous analysis. [1] In the present work, we take an alternate approach to modeling that addresses previous limitations. Rather than computing the dynamical behavior for a specific set of drive signals, such as square waves, we directly compute the drive signals required to achieve a preferred dynamical behavior. The model includes inertial effects, thus accounting for forces during rapid acceleration and deceleration of structures driven by the engine. We have developed and successfully applied techniques to experimentally determine fundamental quantities essential to the model, such as spring constants, electrostatic force constants, damping coefficients, and frictional load forces. Once the device parameters are experimentally measured, the desired drive signals are computed. Fig. 2 shows how the experimentally determined frictional load torque can be reduced using the model. Two drive signals are created that result in different normal forces between the gear and hub; the lower normal force results in lower frictional load.

To further illustrate the impact of the modeling approach, an engine was operated using drive signals theoretically computed for a constant angular speed of 172,000 revolutions per minute. This is well above the resonant frequency of the comb drives (~104,000 rpm), so linear inertial forces are significant. The resulting uniform rotation (Fig. 3) is a significant performance feat that enhances the value of the microengine as a power source.

Another result of the dynamical model is the ability to drive inertial loads, such as the gear shown in Fig. 4. The process of accelerating the load gear up to some final speed requires the transfer of energy from the engine (electrostatic energy) to the load gear (rotational kinetic energy), and requires a finite amount of time. Since the model includes the effects of linear and rotational inertia, appropriate drive signals can be created. Engine speeds in excess of 140,000 rpm have been experimentally achieved while driving a load gear 30 times the diameter of the drive gear; this is not possible without properly engineered drive signals. A typical set of drive signals used to start and stop the large gear are shown in Fig. 5. The demonstrated ability to rapidly accelerate inertial loads to high speeds is a valuable feature of the microengine, and is a direct result of the present dynamical model.

References

- [1] E. J. Garcia, J. J. Sniegowski, "Surface micromachined microengine", Sensors and Actuators A, Vol. 48, (1995) pp. 203-214.
- [2] J. J. Sniegowski and E. J. Garcia, "Microfabricated actuators and their application to optics", Proc. SPIE Miniaturized Systems with Micro-Optics and Micromechanics, Vol. 2383. San Jose, CA, Feb. 7-9, 1995, pp. 46-64.

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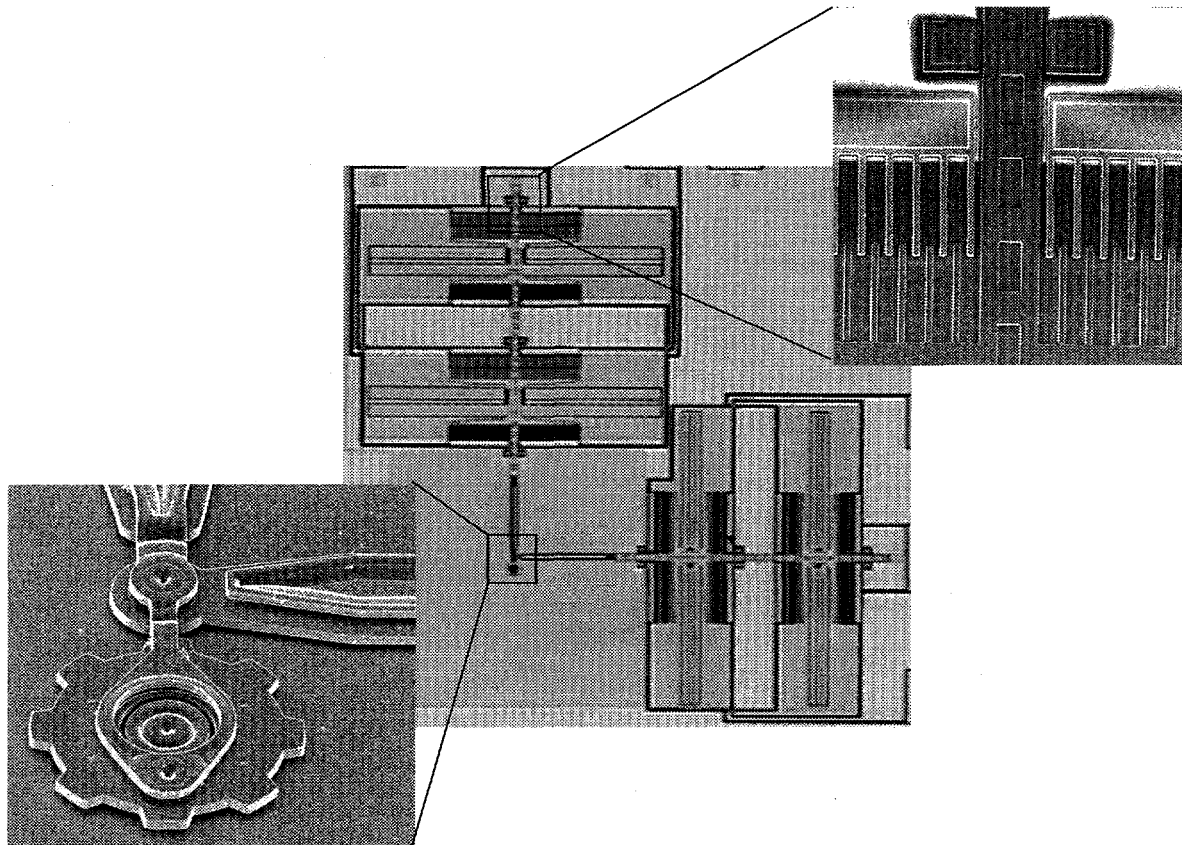


Fig. 1 The microengine converts force from linear actuators into torque that can drive an external load. The dynamical properties of the engine are modeled to allow control and measurement of its operation.

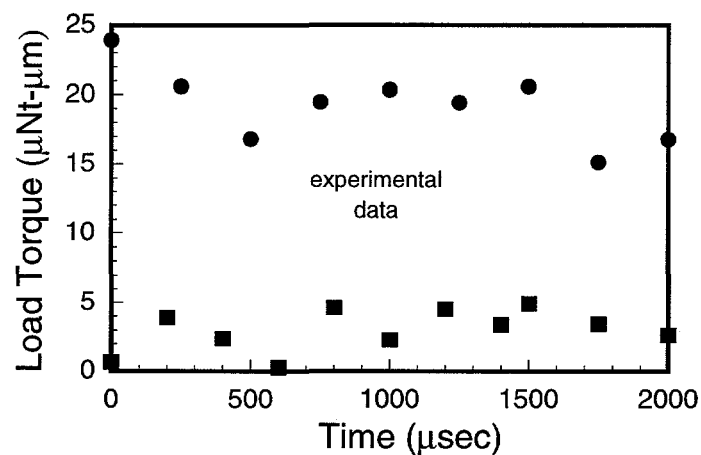


Fig. 2 The dynamical model permits the experimental measurement of the load torque acting on the gear due to friction. The two sets of data result from two different drive signals. The drive signal for the squares (■) was created to result in a lower radial force between the gear and hub, resulting in reduced friction compared to the circles (●). Using this method, the coefficient of friction is experimentally measured to be ~1.5.

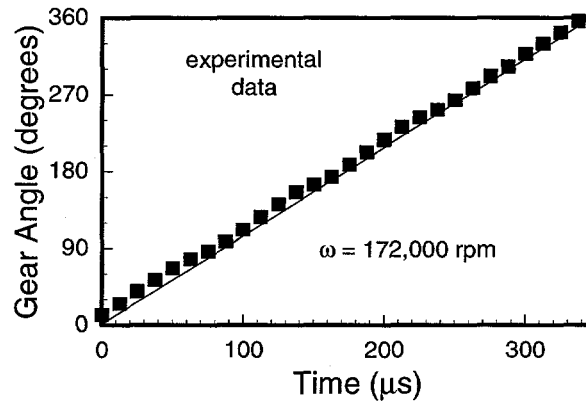


Fig. 3 Operation using theoretically computed drive signals results in uniform rotation at speeds in excess of the resonant frequency (104,000 rpm) of the comb drives. Measurements are made using a time-delayed strobe technique.

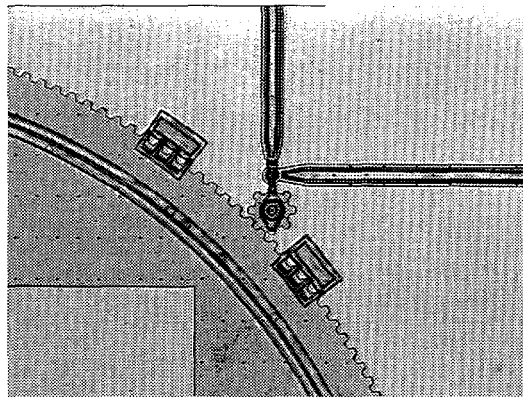


Fig. 4 The 50 μm diameter output gear of the microengine is used to power a 1600 μm diameter load gear using drive signals created with the dynamical model.

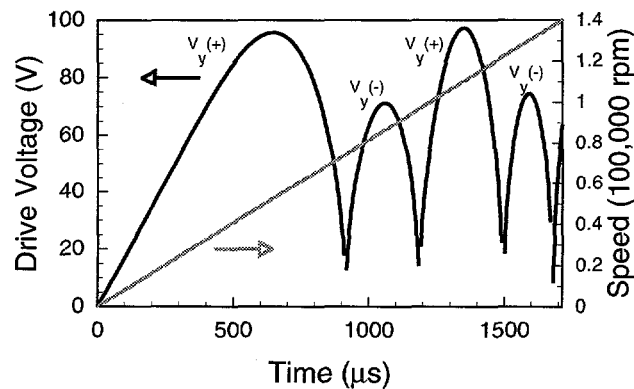


Fig. 5 Drive signals to achieve an engine speed of 140,000 rpm in two revolutions by linearly increasing the speed, while at the same time driving the large load gear. For clarity, only the voltages on two of the four combs are shown. The drive signals are created using the dynamical model with experimentally measured model parameters. The maximum engine speed achieved thus far, while driving a load gear like that in Fig. 4, is 146,000 rpm.

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