A high bandwidth, short stroke rotary shaker for MEMS testing

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Abstract

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First results of a prototype design of a small precision mechanical rotary shaker, which targets the MEMS testing industry and its specific testing requirements is presented. The very small rotation angles allowed us to use a mechanical design where radial flexures guide the reciprocating rotary motion. The system was driven by a wide band current amplifier producing a sufficiently flat open loop response up to 1.5kHz.

Introduction

Many new applications of MEMS accelerometers and gyros have become possible due to their low cost, light weight, small dimensions and high insensibility to shock. The new MEMS sensor generation requires new testing methods which are tailored to the MEMS specific properties. In particular the industry is asking for a high bandwidth short stroke rotary shaker. The single axis test simulator should be continuously variable in frequency from 100Hz to at least 1.5kHz sinusoidal motion at a constant maximum velocity of typically 10 deg/s. The cross axis talk should be minimum, whereas the total harmonic distortion is not a critical parameter.

Dynamics

For a 10°/s rate the position amplitude range is 0.016° at 100Hz to 0.0011° at 1.5kHz and the corresponding acceleration ranges from 6'300 $°/s^2$ up to 95'000 $°/s^2$.

Mechanical Design

The tiny rotation angles, allowed the usage of a flexure bearing. Here the shaft of the mounting table is supported by eight flexure blades that extend radially from the shaft and are clamped at the base. The blades can be pre-tensioned in order to assure that each blade remains in tension when the table is rotated through its working range. The total inertia of all moving parts adds up to about 4.3E-05 kgm^2.

This particular bearing has several advantages including low rotational inertia, a non-wandering rest position, high bending (lateral) stiffness, and low torsional stiffness. The bearing supports a hollow shaft with a small mounting table designed specifically for mounting printed circuit boards.

Electrical Design

A pair of commercially available Lorentz force actuators drive the shaft and table. The diagonally opposed actuators result in a net torque on the rotor with no net force on it. Each actuator had a torque constant of 0.11Nm/A, a maximum torque of 0.23Nm and continuous torque of 0.09 Nm at 0.8A.

A commercial wide band (20kHz) current mode power amplifier was used to drive the inductive (L/2=0.005H) and resistive (R/2=6.5Ω) load and the back-EMF (0.11 V/rad/s) of the actuators. Using the peak continuous current rating of I_c=0.8A, results in a inductive load of $L \cdot dI_c/dt = 0.005 \cdot 7536 = 38V$ significantly larger than the resistive load of $R \cdot I_c$=5.2V. Compared to these values the peak back-EMF of 0.6V at maximum speed 10°/s is negligible.

Modelled Dynamics

A very simple model of the mechanical plant consists of two coupled inertias with one of them connected to ground. The moving parts of the motor have Inertia I_m and rotation angle Θ_m. It is driven by the motor producing torque T_m. The inertia of the shaft and table is coupled to the moving part of the motor with a torsional spring k. It is also coupled to ground with torsional spring k_{flex}, where k_{flex} represents the torsional constant of the flexure blades.

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This model depicts a coupled torsional mode of about 100Hz and an uncoupled torsional mode (both inertias in phase) of higher than 4kHz.

Measured Dynamics

For test purposes the tangential acceleration was measured with a COTS accelerometer which was fixed directly on the mounting table. The open loop transfer function of the acceleration is shown in Figure 1. The magnitude of the ratio of constant voltage (0.2V) to the current amplifier to sensor voltage (1V/g) is plotted as a function of frequency. The coupled torsional mode, where the shaft and motor oscillate in phase produces a peak at 112 Hz. The uncoupled mode is not shown. Note that for constant acceleration the rate reduces with 1/f and the response is sufficiently flat over the required frequency range.

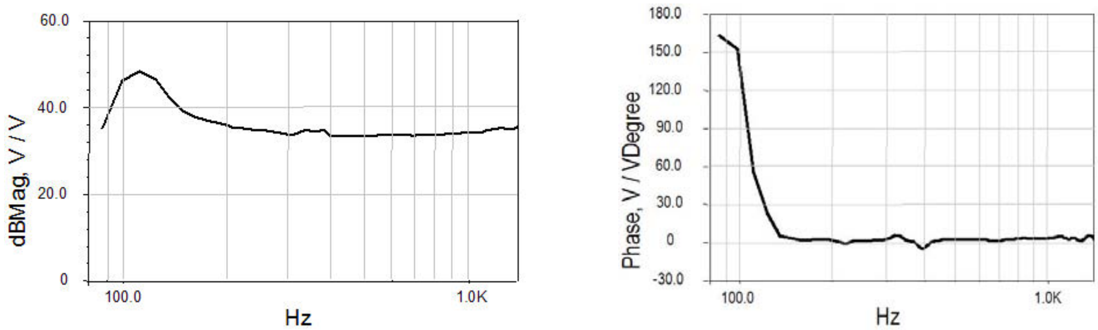

Figure 1: Open loop transfer function of the acceleration. Left, magnitude and right phase. Note the resonance at 112Hz, which represents the coupled torsional mode of the shaft and motor, which are oscillating in phase.

Conclusion

First results of a small rotary shaker which targets the MEMS industry were presented. This system can operate successfully in the frequency range of 100Hz to 1kHz at a rate of 10°/s. Future developments will require an increased frequency range. Such an increase will be possible using the same basic mechanical design of, which consists of flexure bearings.