Experiments with a new Piezoelectric Rotary Actuator

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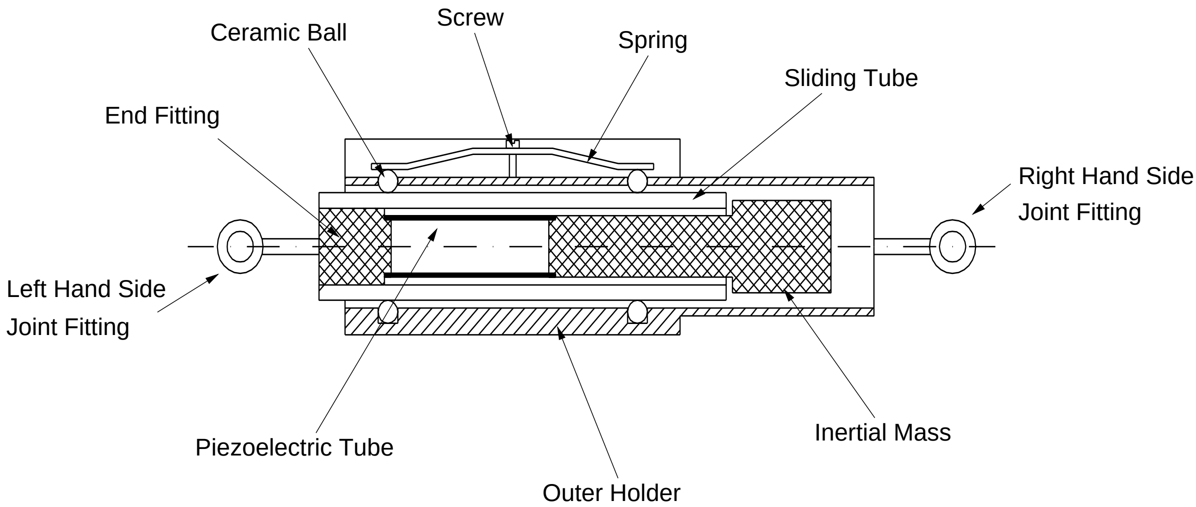
1998 IEEE International Frequency Control Symposium

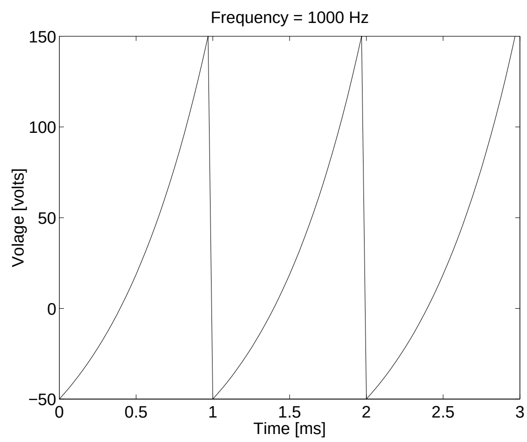
May, 27 1998

Contents

Background

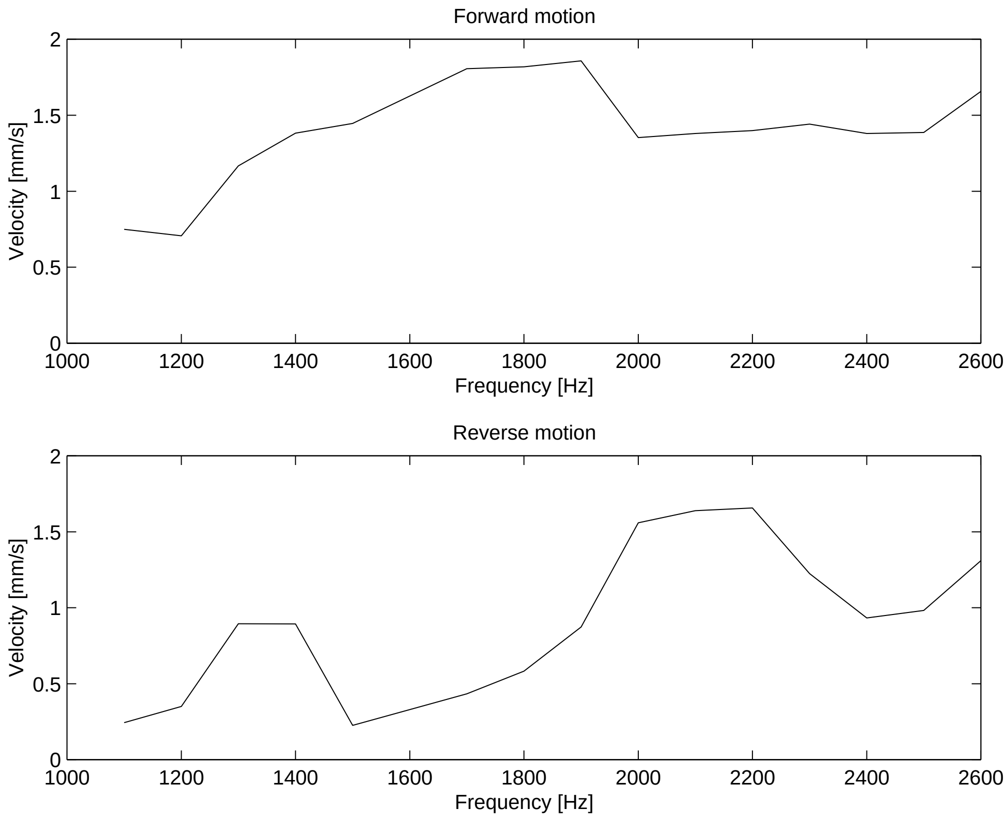
Concept of Linear Stick-Slip Actuator





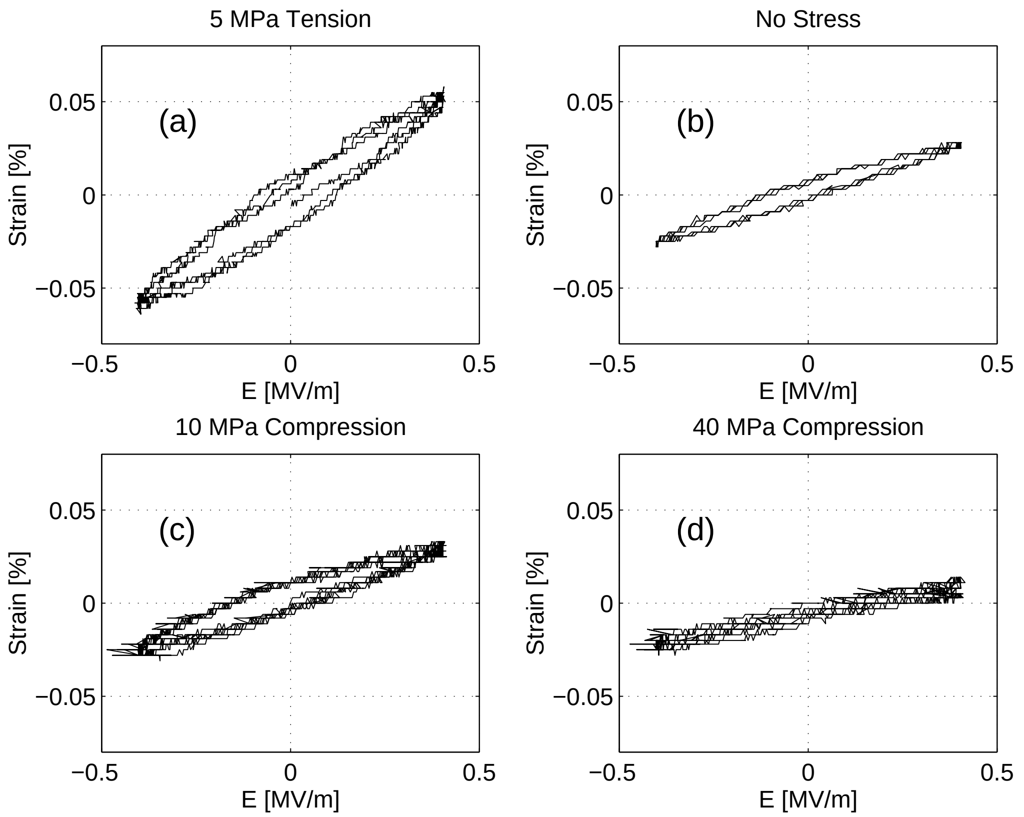
- standard piezoelectric tube element ($d_o = 8\ mm, d_i = 7\ mm, l = 25\ mm, PZT5h, d_{31} = -274\ pm/volt$)
- mechanically simple
- resolution of about 1 μm

Velocity vs Frequency



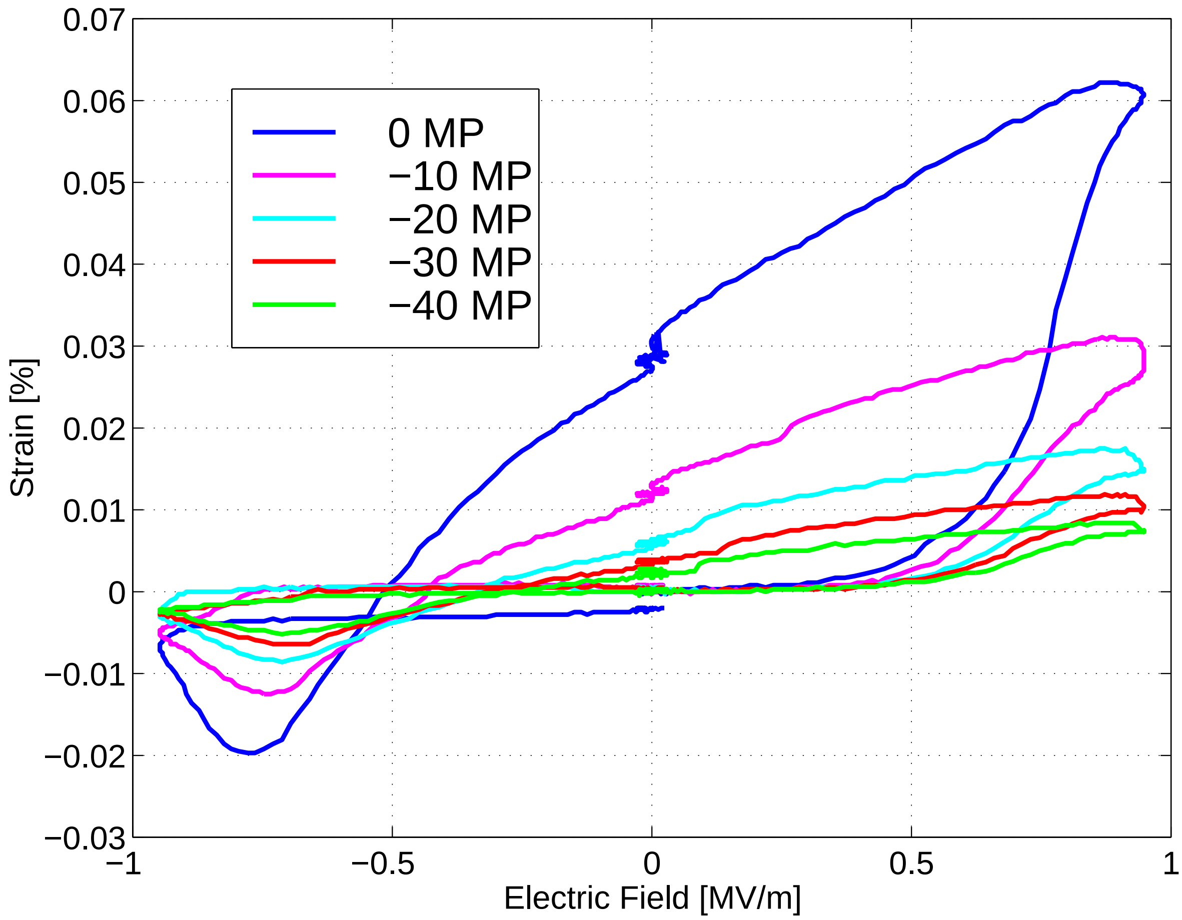
- different velocities for forward and reverse motion
- successful for some working frequencies but difficult to predict using a linear model
- decided to test the inner part of the linear actuator, i.e. the piezoelectric tube and inertial mass, under quasi-static and dynamic conditions

Quasi-Static Experiments on Piezoelectric Tubes



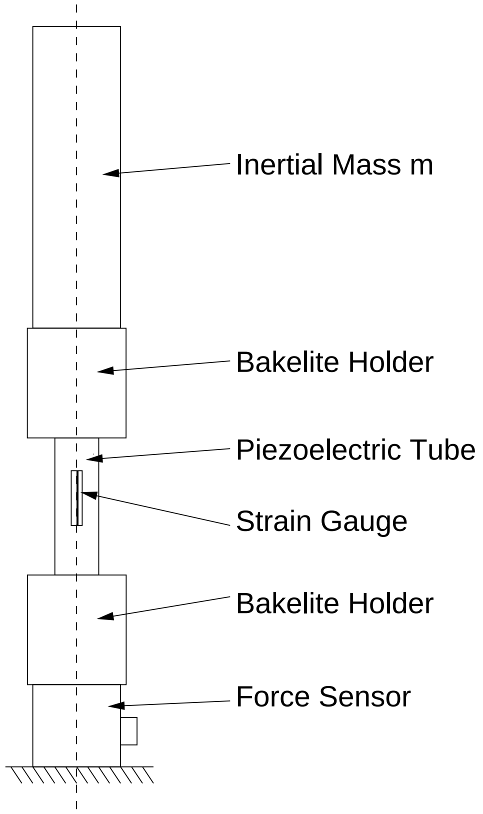
- large strain under constant tension
- strain decreases with increasing compressive load
- one reason for non-linear behaviour of actuator

Hysteresis Loops



- larger electric fields result in non-linearity
- strain decreases with increasing compressive load
- switching in the material
- tube is initially poled, hence non-symmetric butterfly hysteresis loop

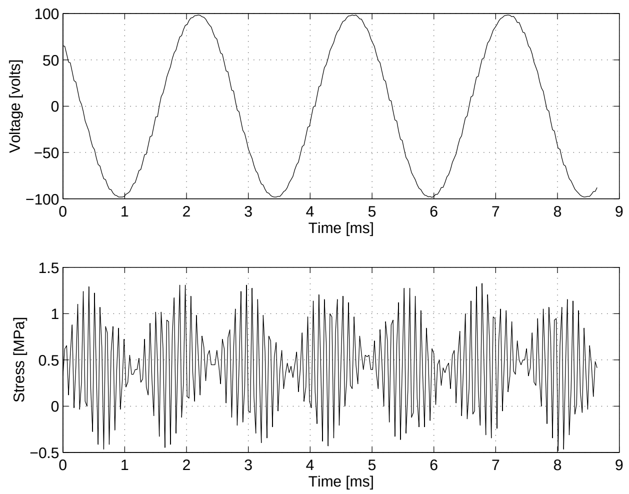
Dynamic Experiments



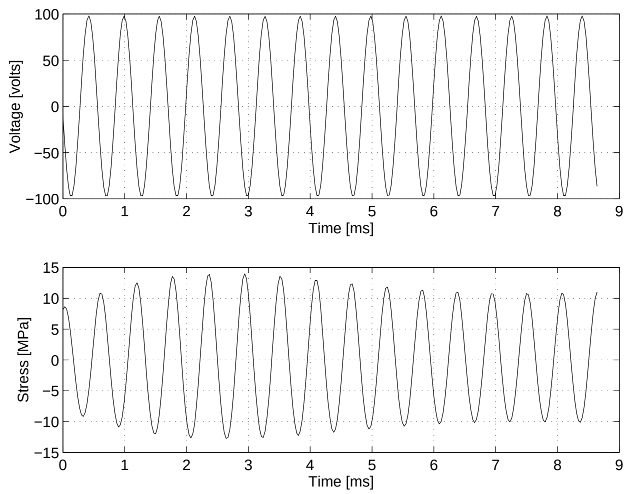
- driving frequencies between 200 Hz and 6000 Hz for two mass configurations
- sinusoidal excitation
- rampwave excitation

$m = 90\ g$

- 400 Hz



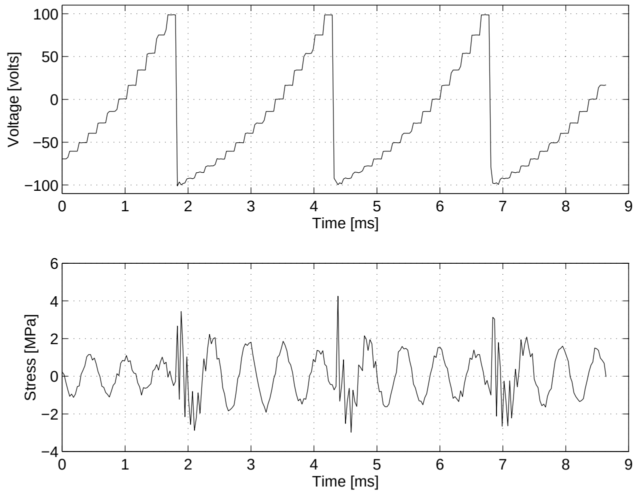
- 1800 Hz



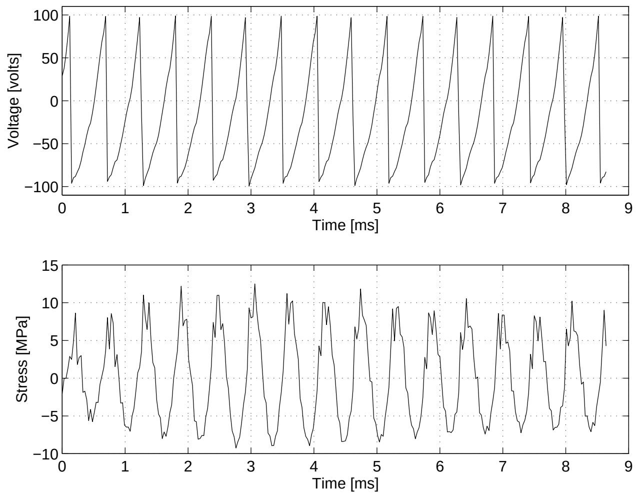
- small oscillation in stress measurements for 400 Hz excitation
- resonance at 1800 Hz

$m = 90\ g$

- $400\ Hz$

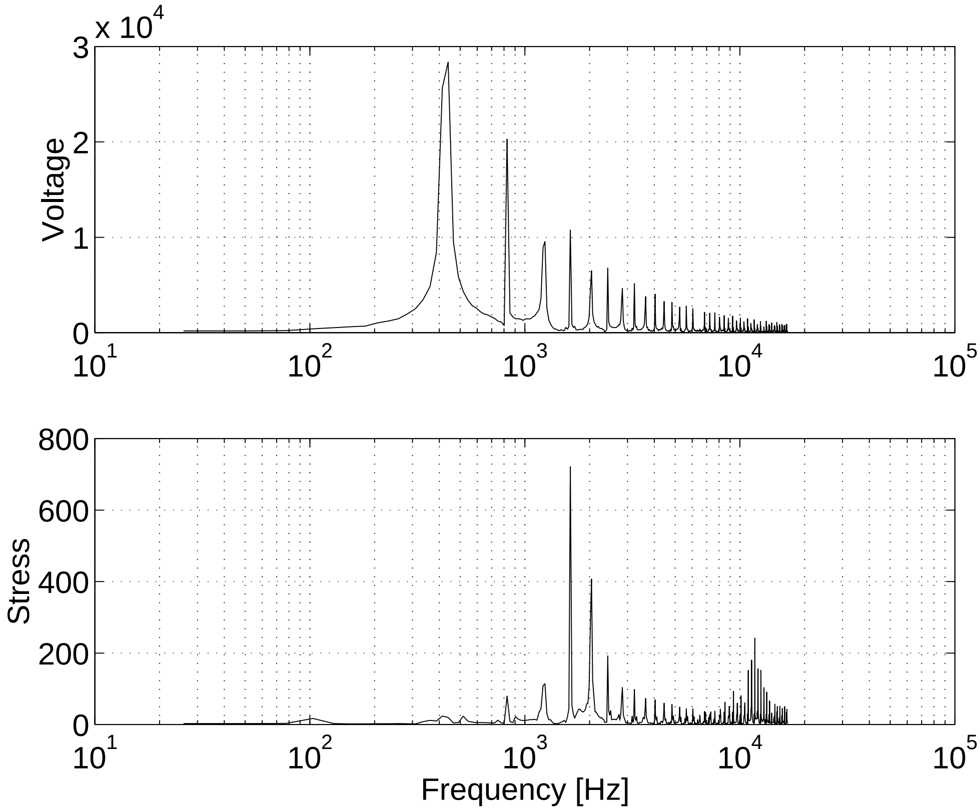


- $1800\ Hz$



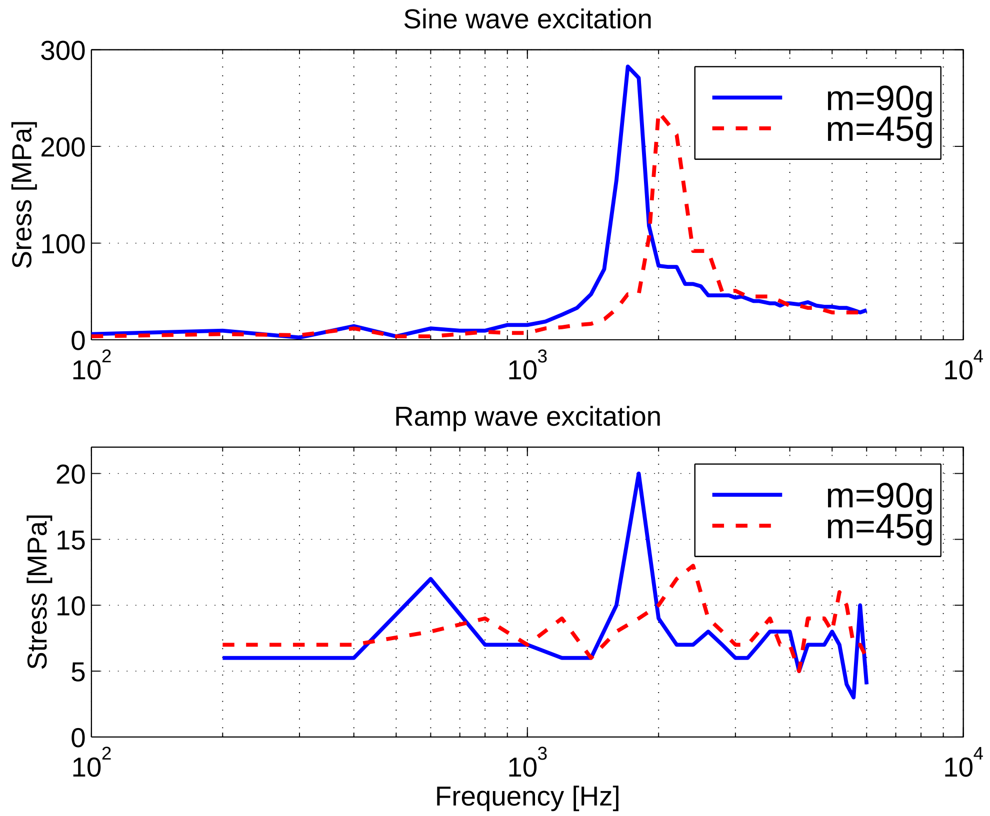
- small oscillation in stress measurements for $400\ Hz$ excitation
- resonance at $1800\ Hz$
- slightly larger positive stress, hence movement of actuator

FFT of Response



- high frequency components
- large peak at 1800 Hz, hence small force amplitude

Stress Amplitudes

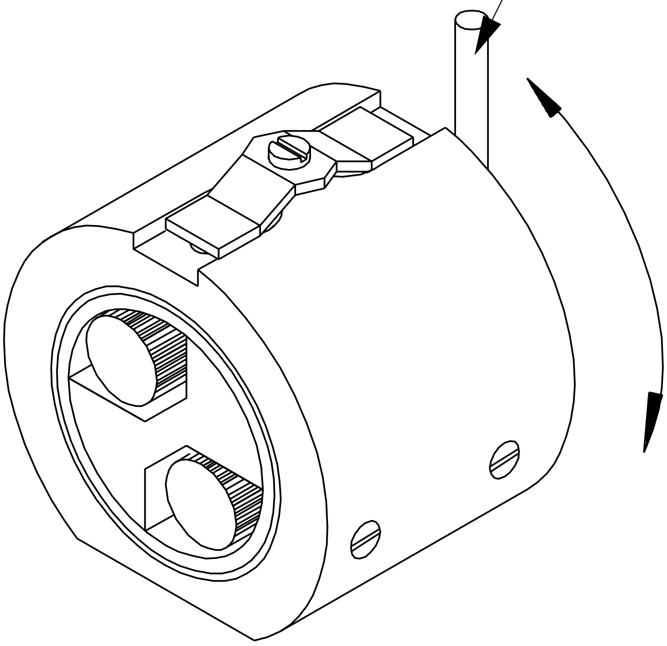


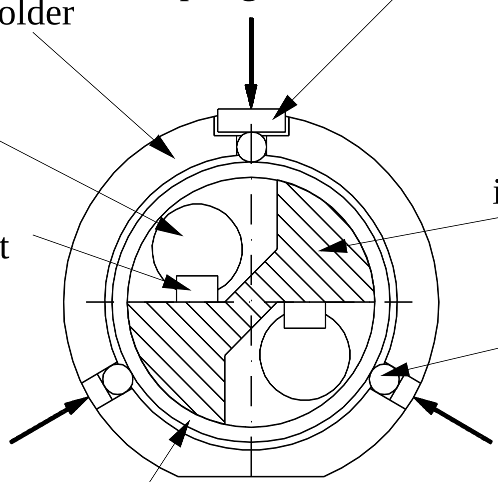
- large peak at resonance for both excitation waveforms
- further peaks at lower frequencies for rampwave excitation
- high frequency components of rampwave excite resonance

Way forward

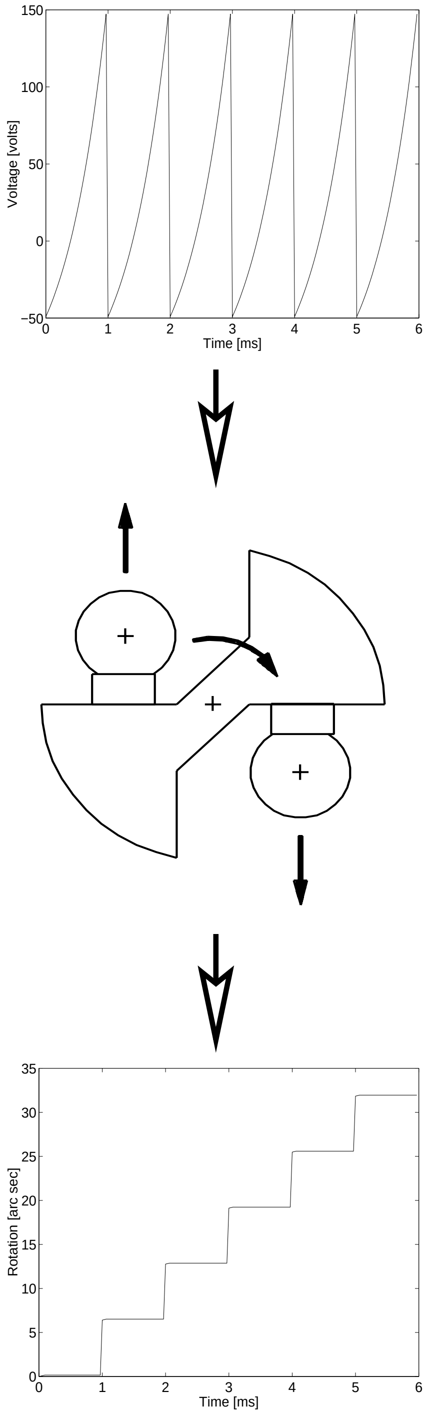
- very complex to model the behaviour of the actuator
- however, we can always find particular frequencies at which an actuator works well
- hence, the success of the linear actuator has encouraged us to use the same working principle for a rotary stick-slip actuator

Stick-Slip Rotary Stack Actuator

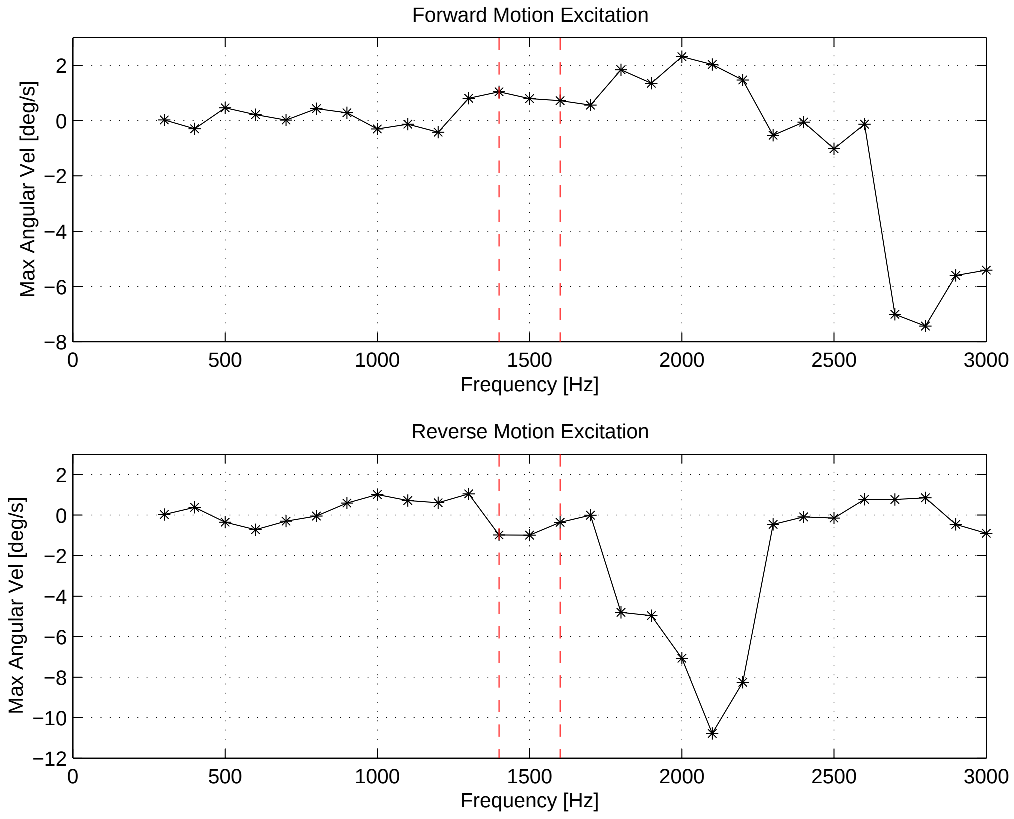




Schematic Actuator Diagram

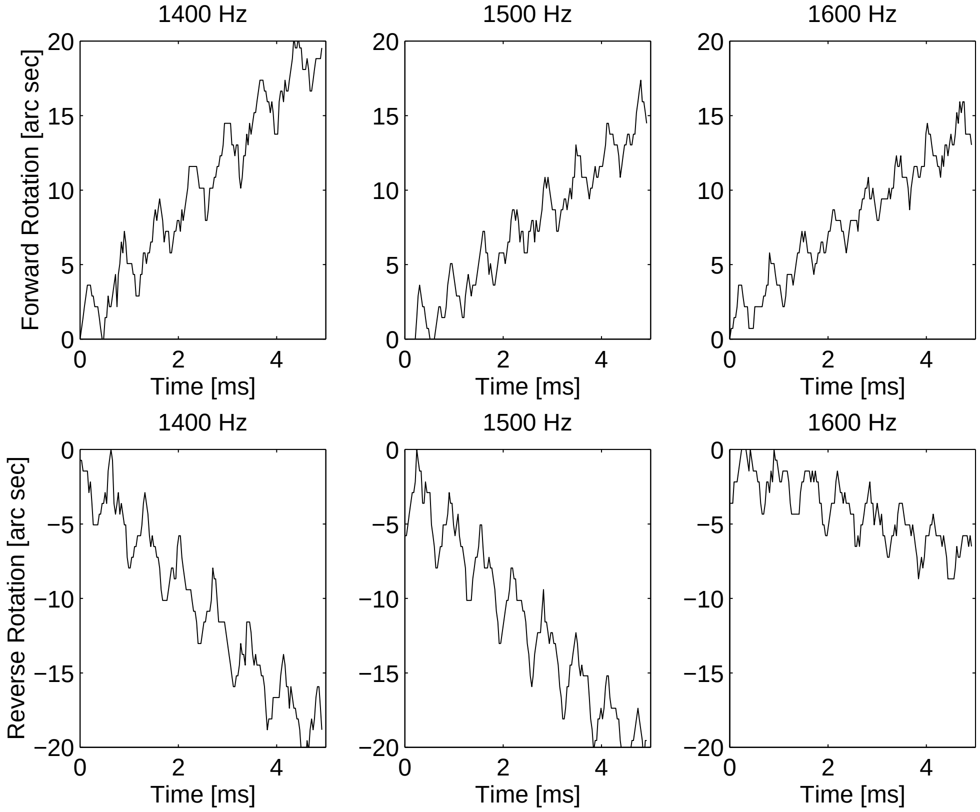


Angular Velocity vs Frequency



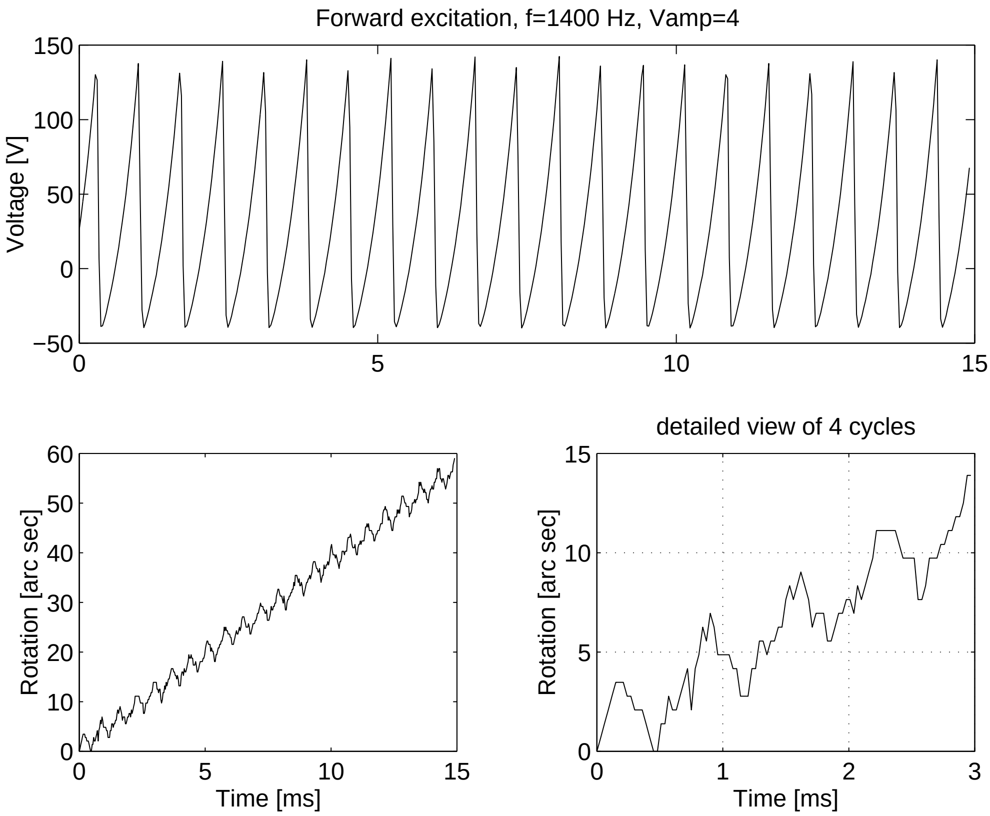
- two directions of motion for forward/reverse motion excitation
- non-linear interaction of piezo element and inertial mass, i.e. difference for tension and compression
- selected frequency region dependent on application

Rotation for Forward and Reverse Motion Excitation



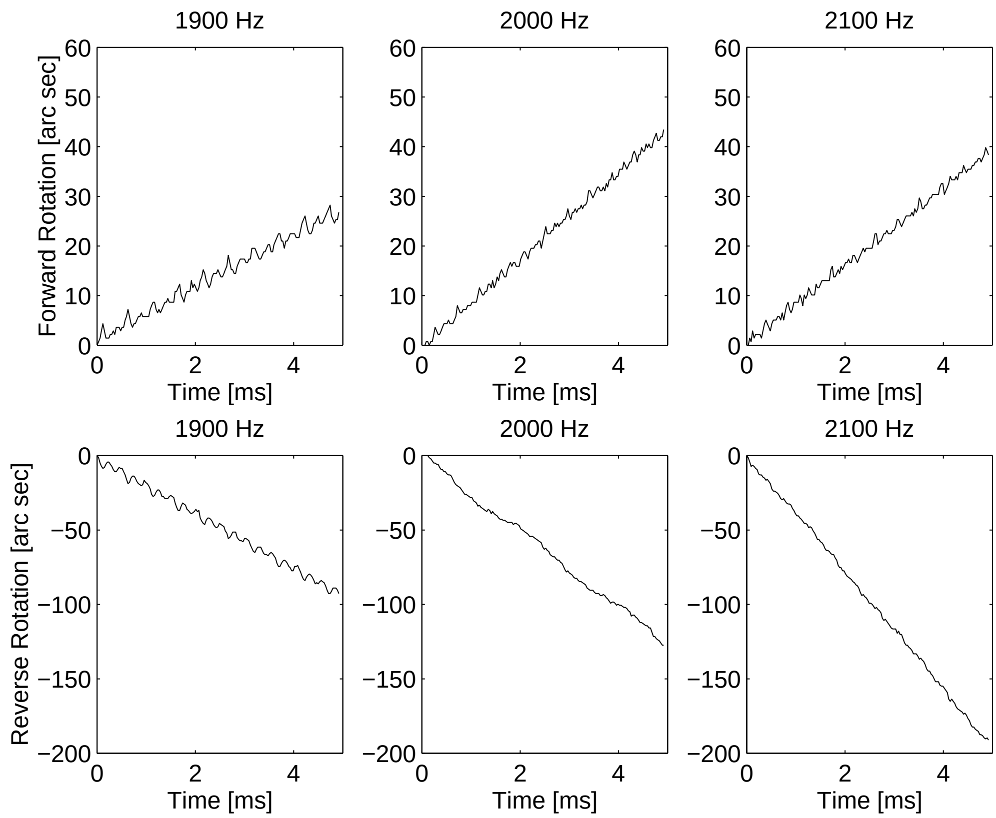
- three different frequencies, 1400 Hz, 1500 Hz and 1600 Hz
- 1400 Hz seems best frequency for this region

Excitation Waveform - Forward Rotation at 1400 Hz



- resolution of about 2 $arc\ sec$
- maximum amplitude
- velocity of 1 deg/s

Rotation for Forward and Reverse Motion Excitation



- three different frequencies, 1900 Hz, 2000 Hz and 2100 Hz
- 2000 Hz and 2100 Hz forward and reverse motion excitation result in large velocity

Performance of the Rotary Actuator

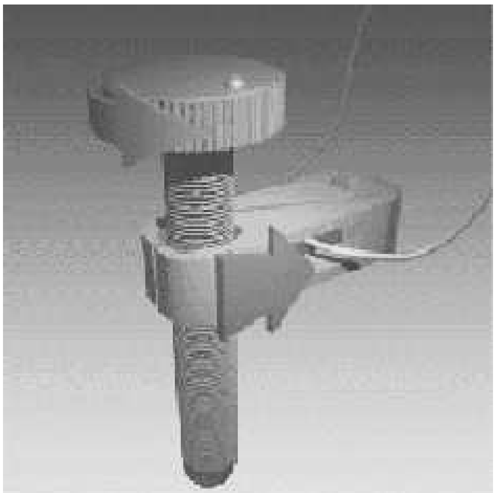
	Forw. Motion	**Rev. Motion**
Max Torque	10 Ncm	10 Ncm
Max Velocity	2.3 deg/s	10.8 deg/s
Max Resolution	0.2 $arc\ sec$	0.2 $arc\ sec$

- small resolution and large angular velocities achievable
- different performance for a chosen frequency
- is it a good tool?

Comparison with other Actuators

- stepper motors with micro-stepping software are capable of a 25 $arc\ sec$ resolution
- torque of about 1 Nm but the design is not as compact

- Picomotor (New Focus)
- rotational and linear motion at the same time
- resolution of < 120 $arc\ sec$
- torque of 0.18 Ncm



Conclusion and Further Work

- Conclusion:
  - Rotary Actuator has very good resolution ($< 1\ arc\ sec$)
  - Max Torque of 10 Ncm achievable
  - possible to select a working frequency for particular application
  - competitive with existing actuators
- Further Work:
  - Active Spring Control for Rotary Actuator
  - Combined version of Linear and Rotary Actuator