# Nanomotion
# Precision Piezo Ceramic Motors

# The Company

Nanomotion was founded in 1992

Developed enabling technology for ultrasonic piezo-ceramic motors

Entered the market in 1996, selling products to leading companies in the U.S., Japan, Europe and ROW.

Nanomotion is a privately-held company

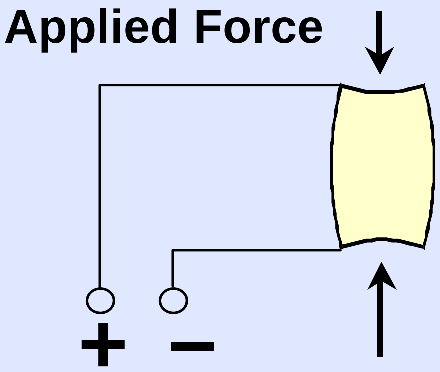
# The Piezoelectric Effect

- **Direct Effect: a well-known effect used in microphones, accelerometers etc.**

  **Converts mechanical strain into voltage.**
- **Reverse Effect: a well-known effect used as a limited motion actuator, ultrasound transducer etc.**

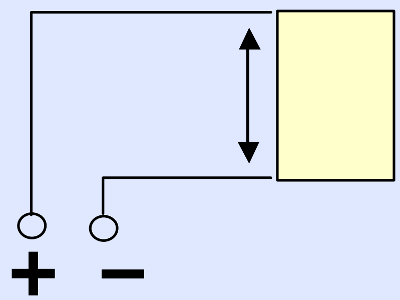
  **Converts electrical fields into motion.**

**Direct Effect**



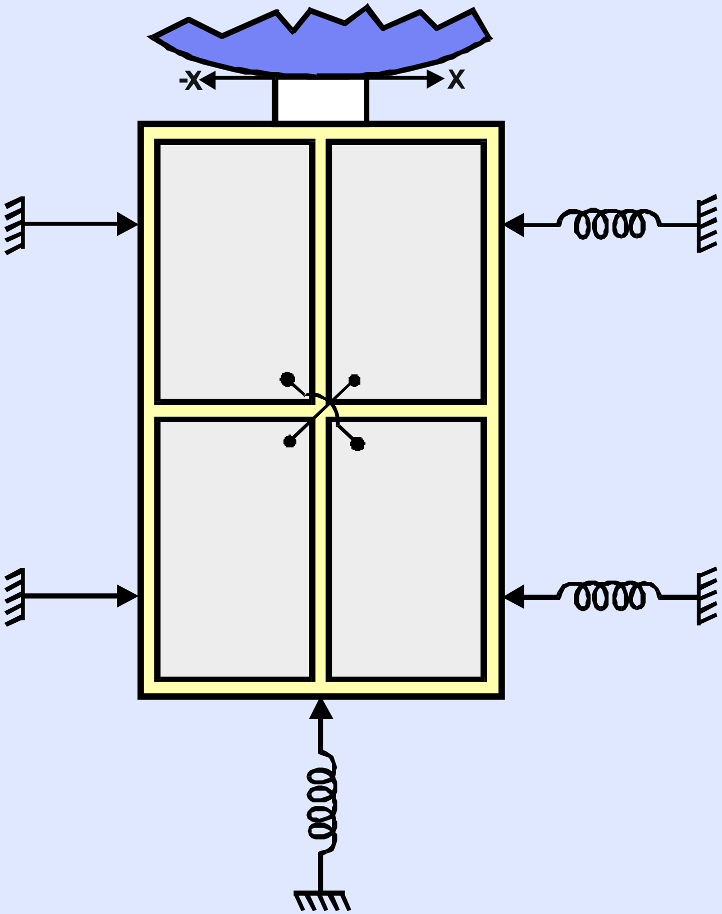

**Output voltage created by force**

**Reverse Effect**

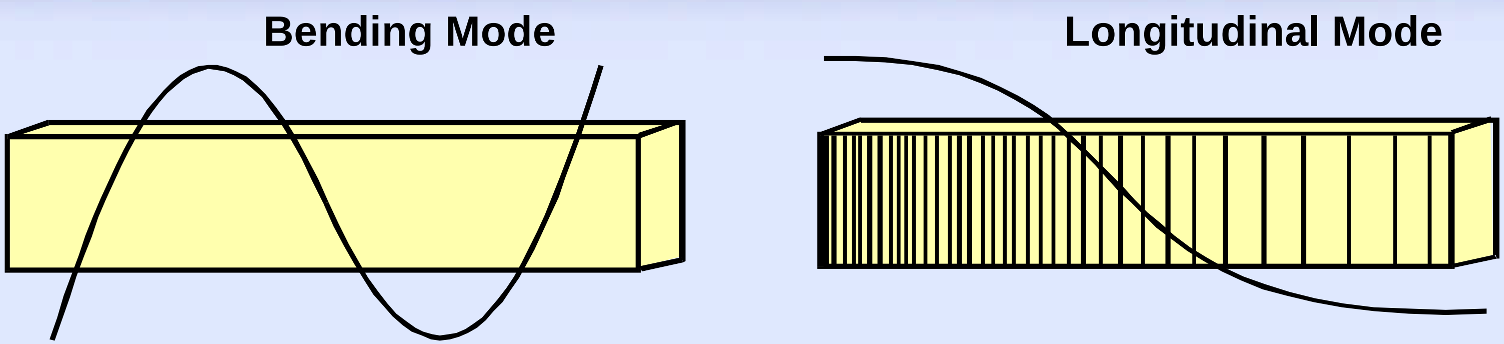



**Applied voltage creates movement**

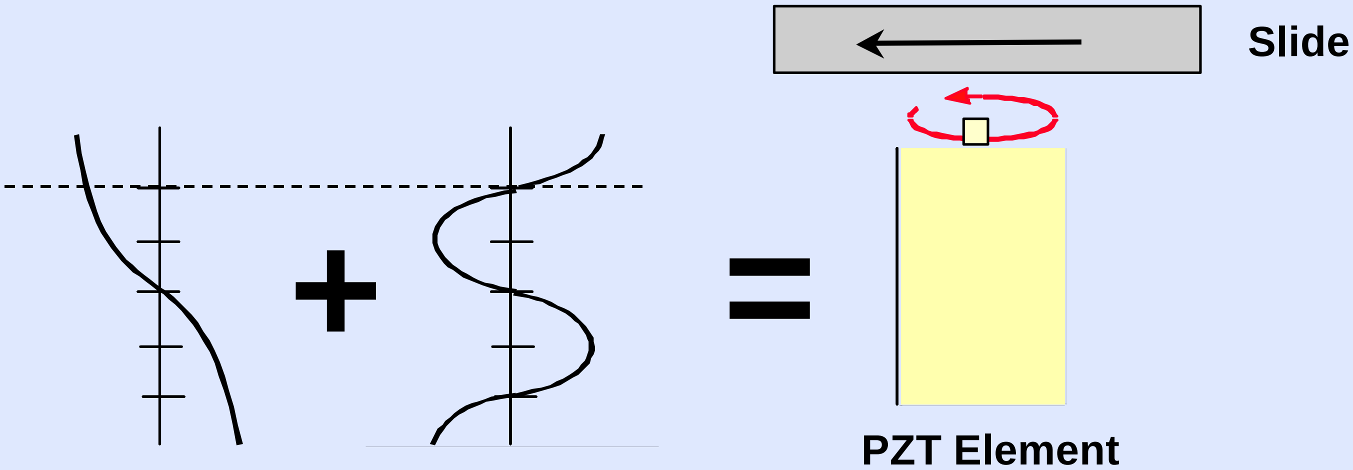
# The Invention



# Nanomotion Motor Basics
# Ultrasonic Standing Waves

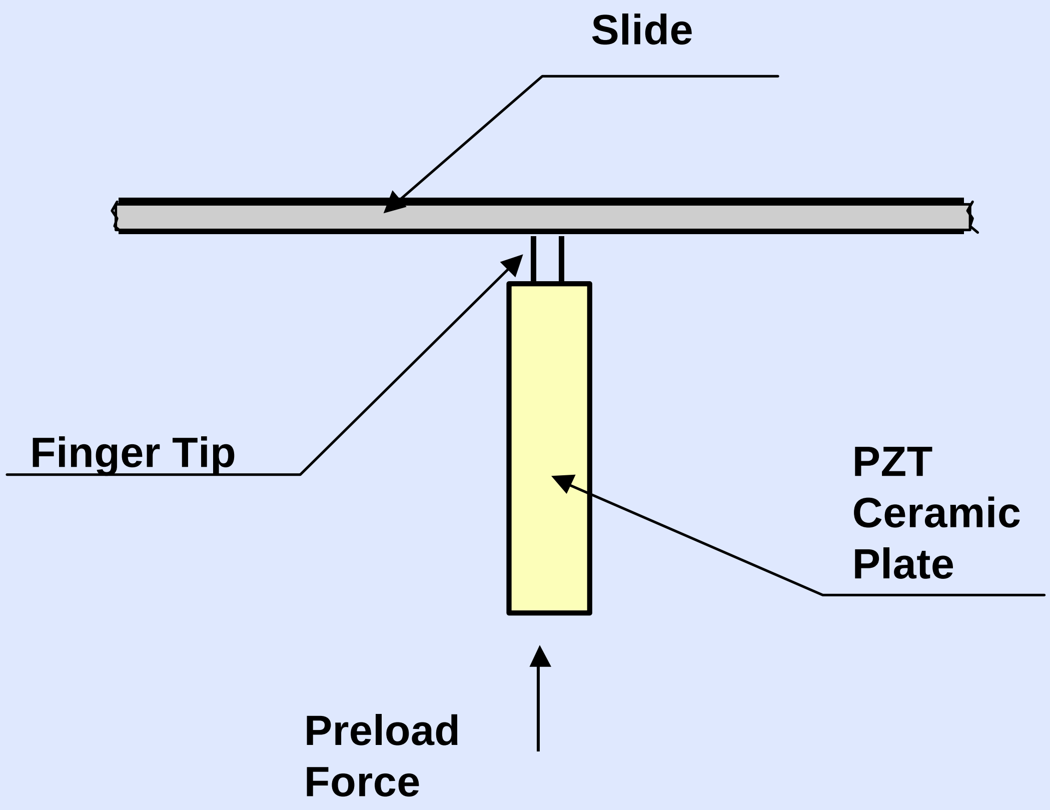



**Simultaneous excitation of both modes**

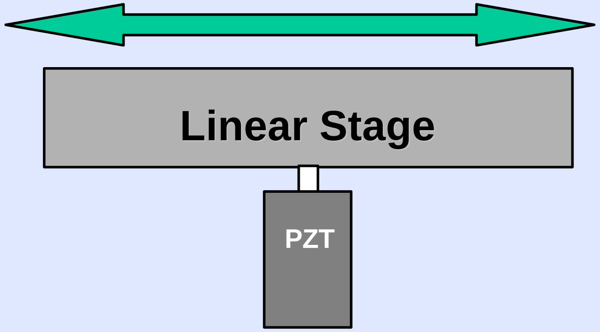


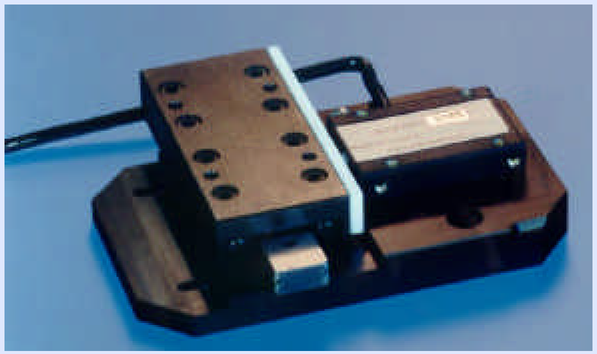

**creates motion at the edge of motor fingertip**

# Basic Structure: Stationary

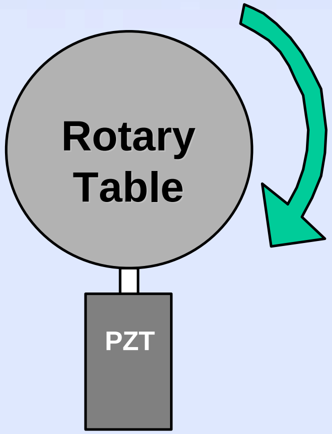


# Nanomotion Motor Basics



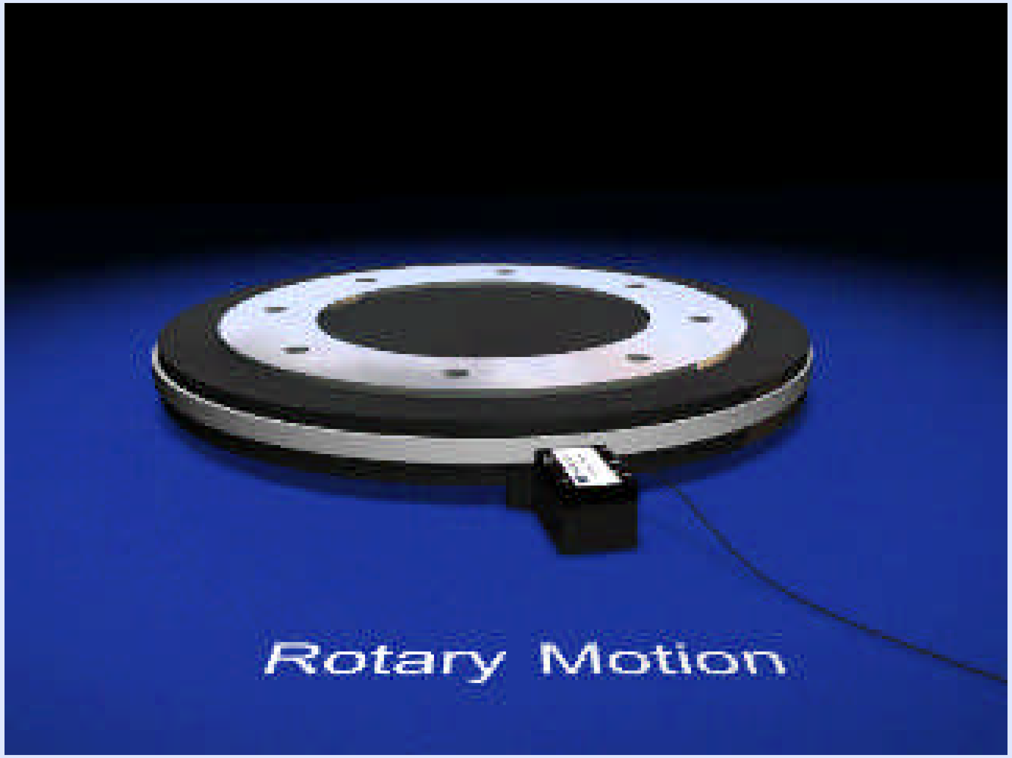
Linear Motion




Rotary Motion

# Linear Motion

# Rotary Motion

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# Nanomotion Technology Highlights (1)

Wide dynamic speed range
(1mm - 250 mm/sec)

Nanometer resolution
(5nm and better)

High linear force
(5N per element)

Zero settling time

Unlimited travel

Inherent Power Off break

Compact size

No moving parts

Fast response

Operates inside clean
environments

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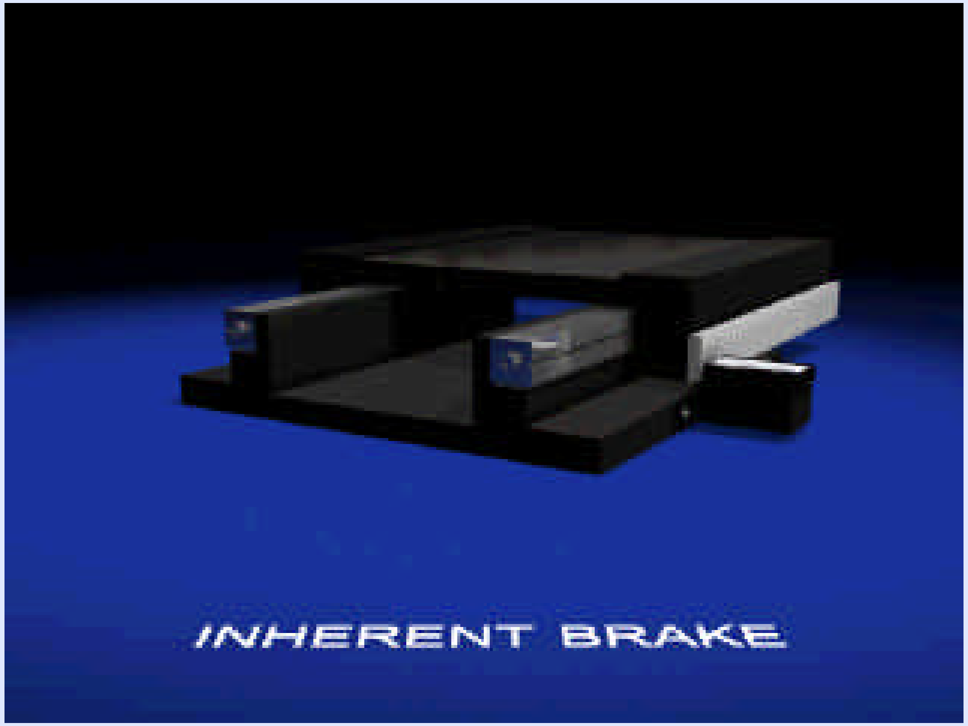
# Inherent Brake



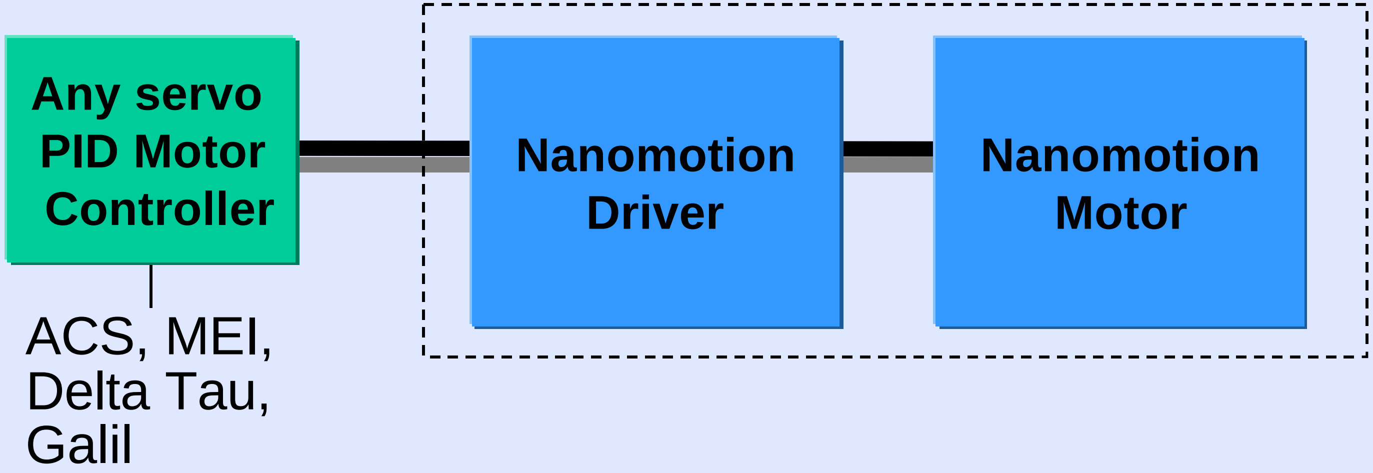
# Nanomotion Technology Highlights (2)

- **Operates inside the actual vacuum environment**
- **Ultra-high vacuum compatibility ($10^{-10}$ torr)**
- **Totally non-magnetic, enables operation in proximity with E beam equipment**
- **Compact size, helps reduce size and complexity of vacuum chambers**

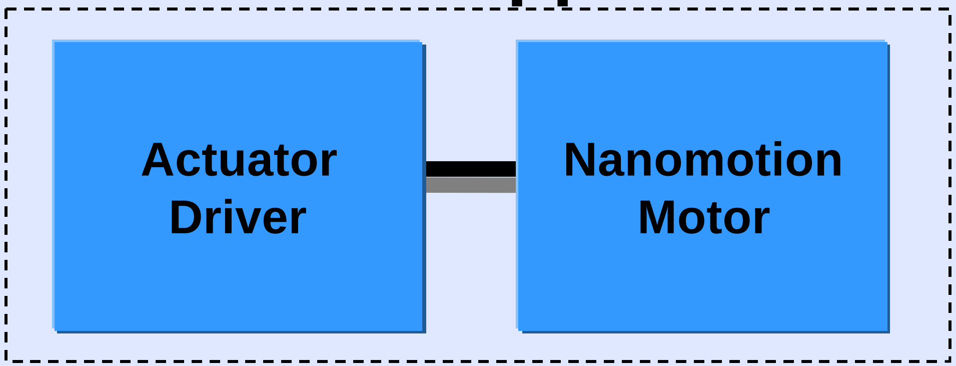
**No feed-through connections**

# Easy to Implement

## High Precision Applications

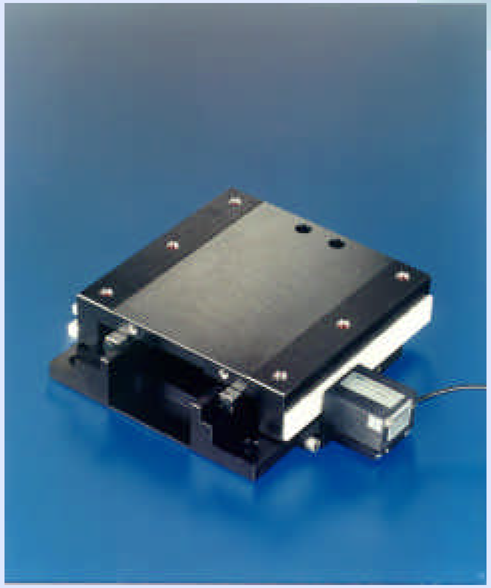



## Actuation Applications



# Typical Applications

- Rotary and linear
- Precision Motion Systems (x,y,z,t)
- Microscopy
- Printers and Plotters
- Scanners
- Vacuum Applications
  - Motorization in vacuum chambers
  - E Beam writers
  - SEM, TEM systems
  - CD measurements



# Spherical Motion

# Application Specific Motors (ASM)

- **Motors are available in different sizes**
- **Nanomotion can "tailor" a motor to meet your requirements:**
  - Size
  - Force
  - Speed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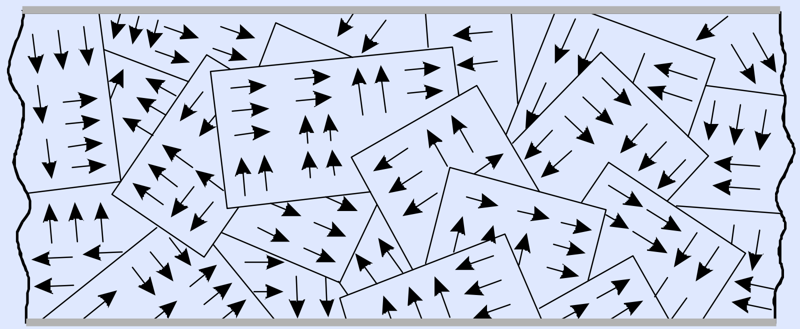
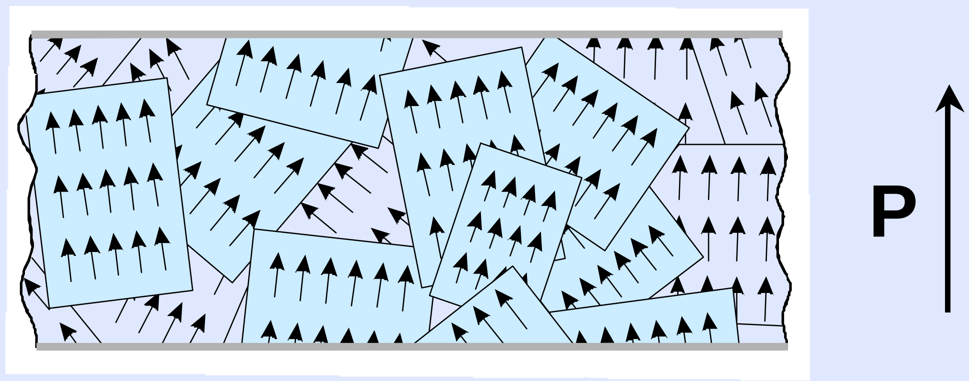
# Theory of Operation

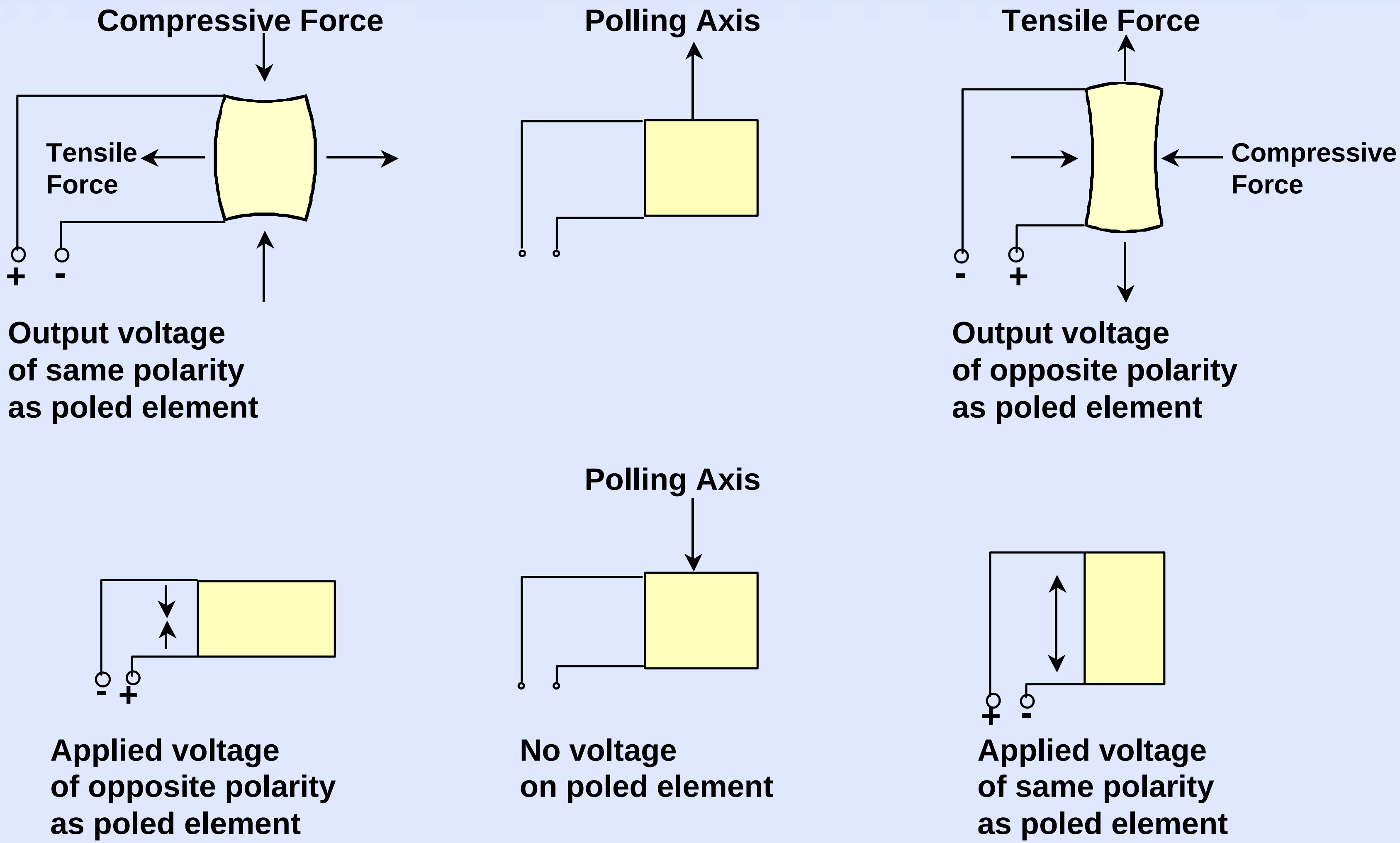
Unpoled element



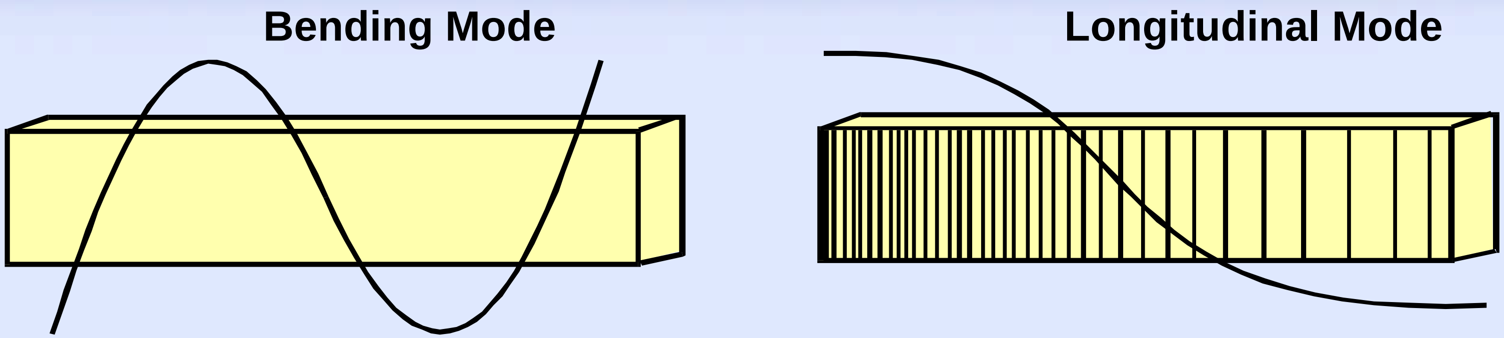
Poled element



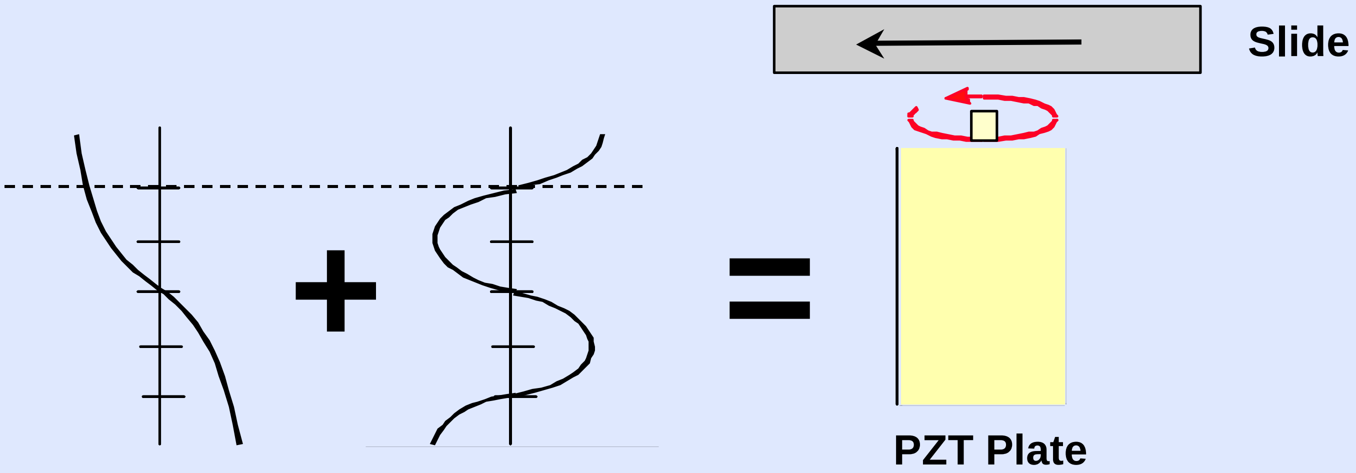
# Direct and Reverse Piezo Effect



# Nanomotion Motor Basics (1)
# The Reverse Piezoelectric Effect

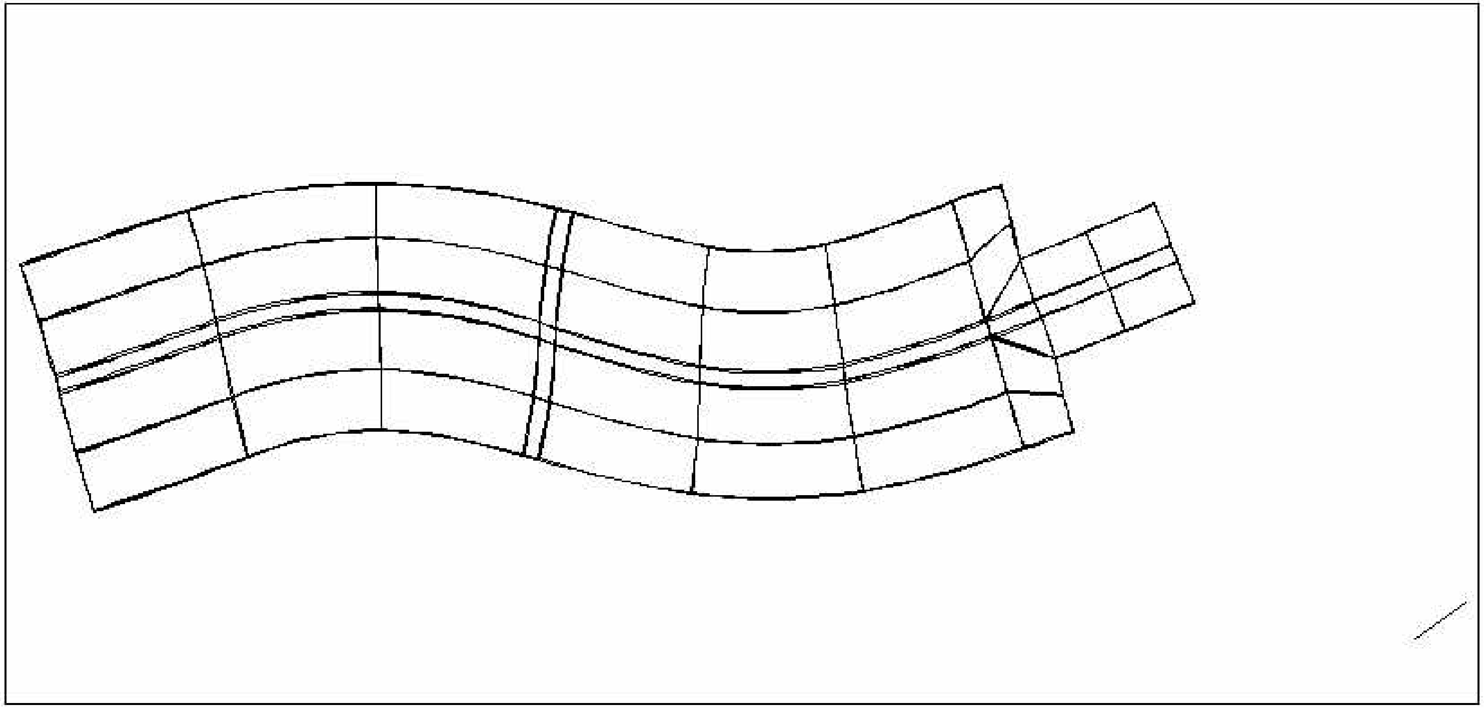



**Simultaneous excitation of both modes**

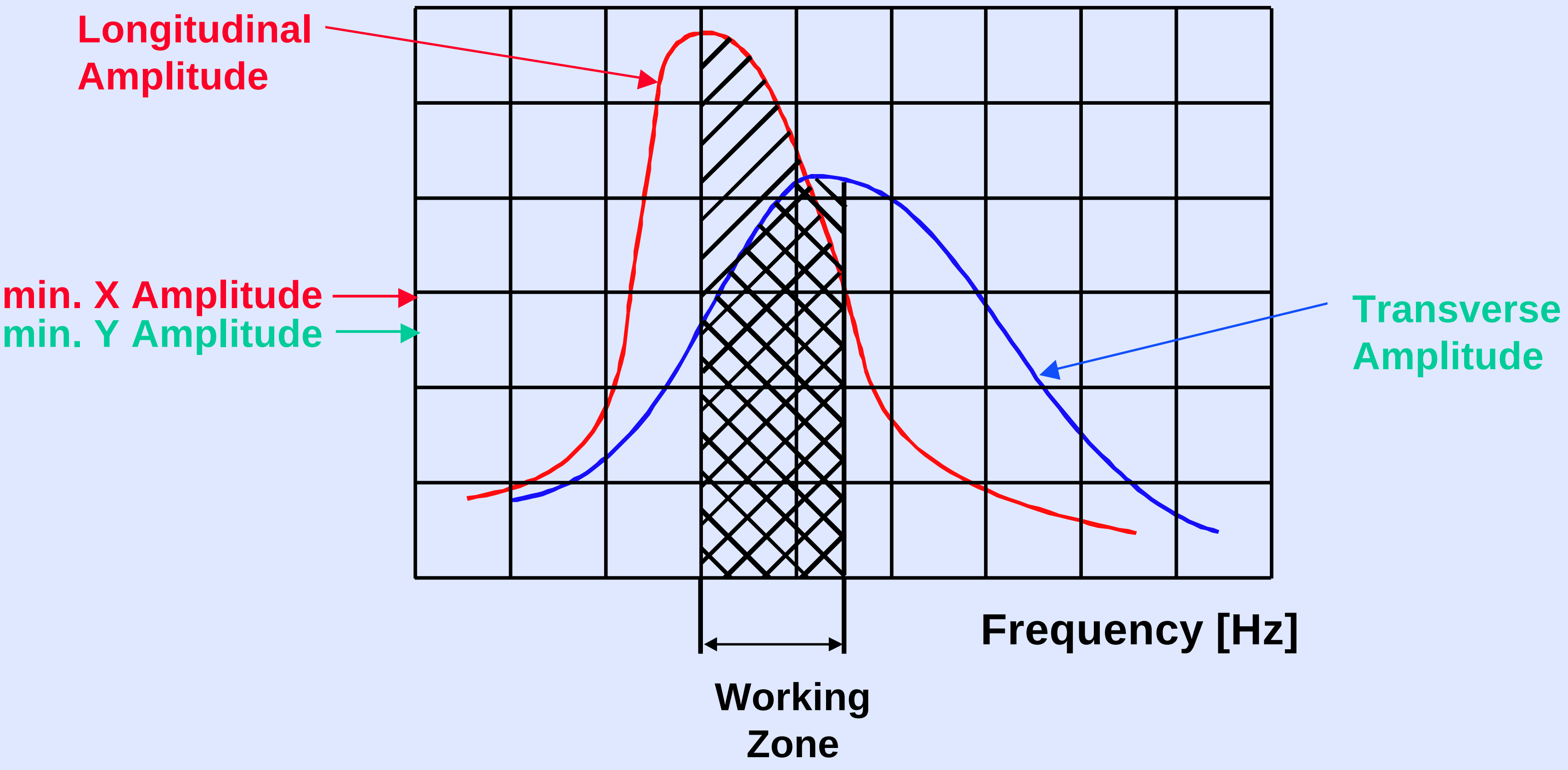



**creates motion at the edge of motor fingertip**

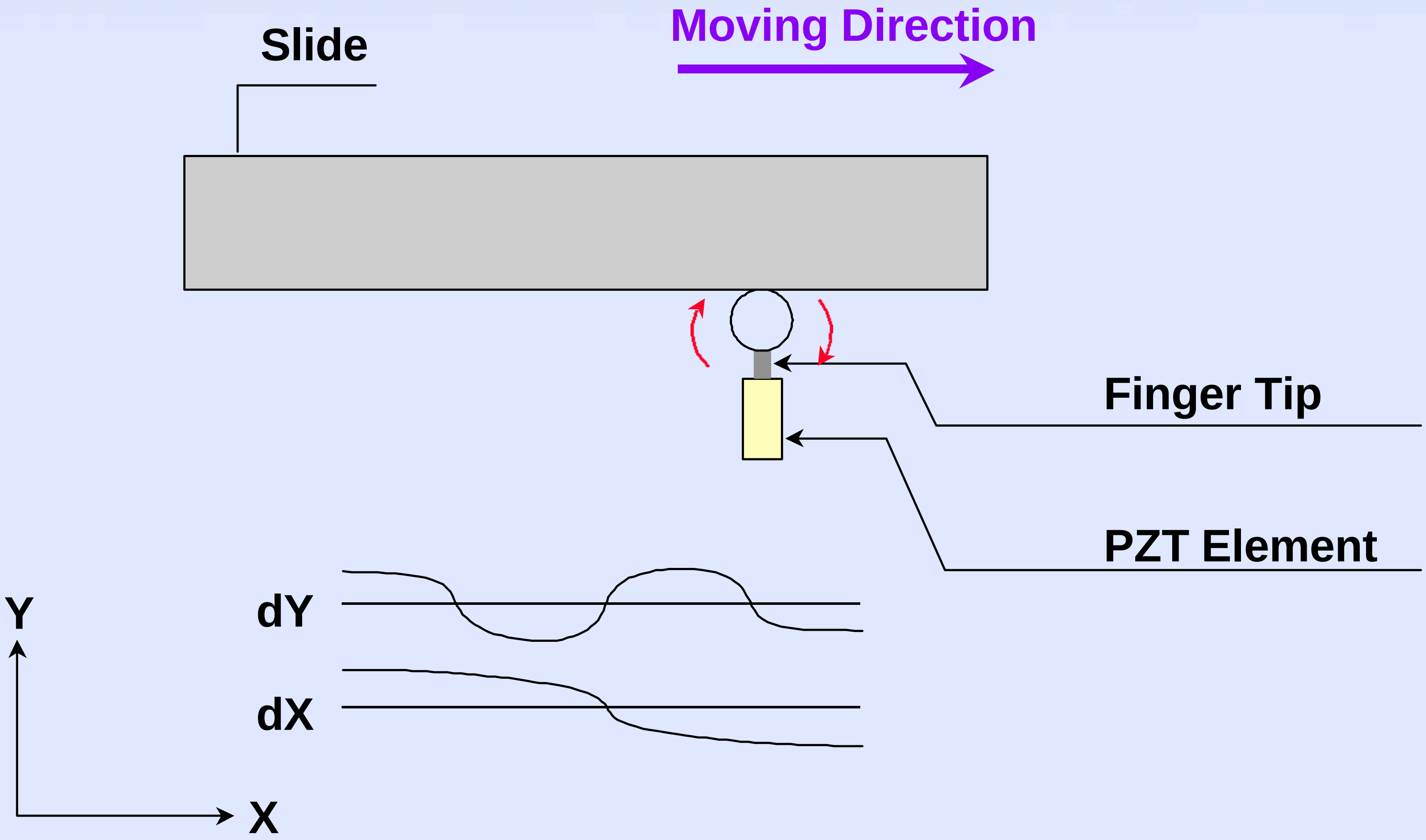
# Oscillating Element



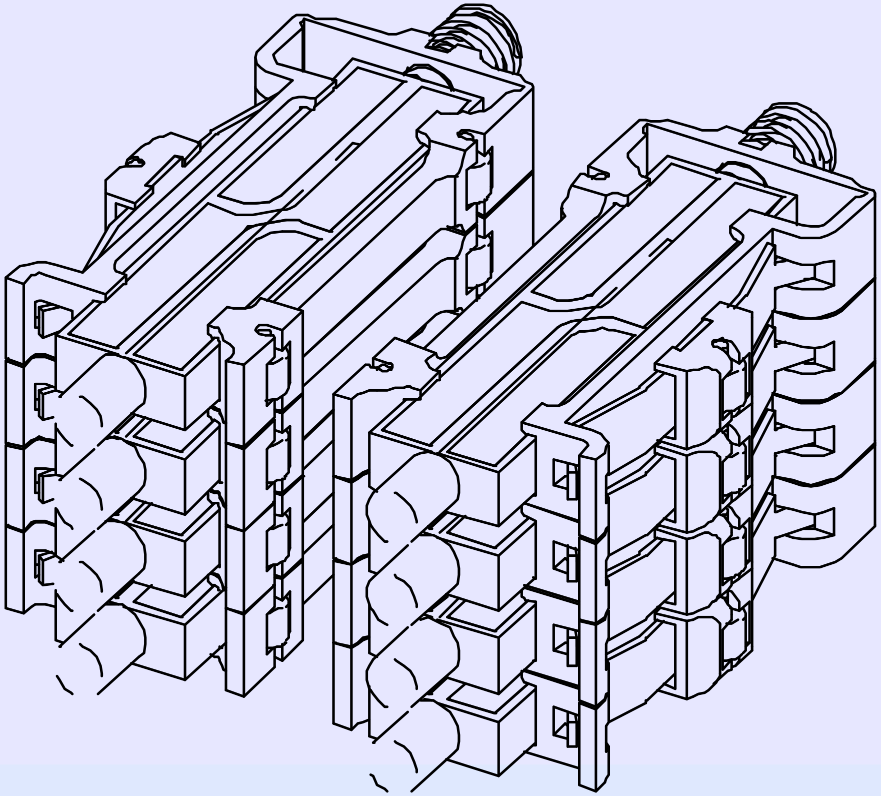
# Robust Concept



# Linear Motion



# Motor Assembly



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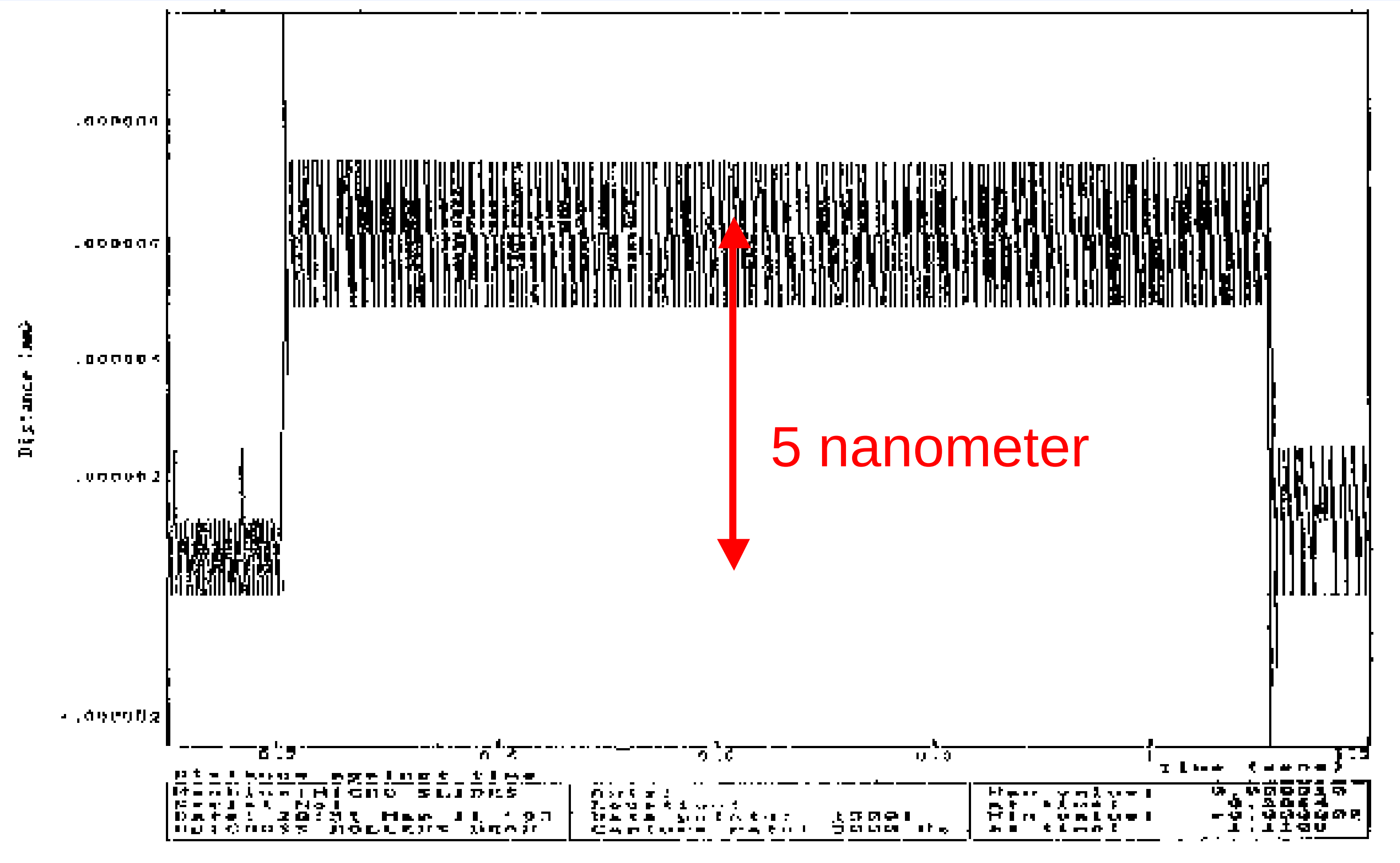
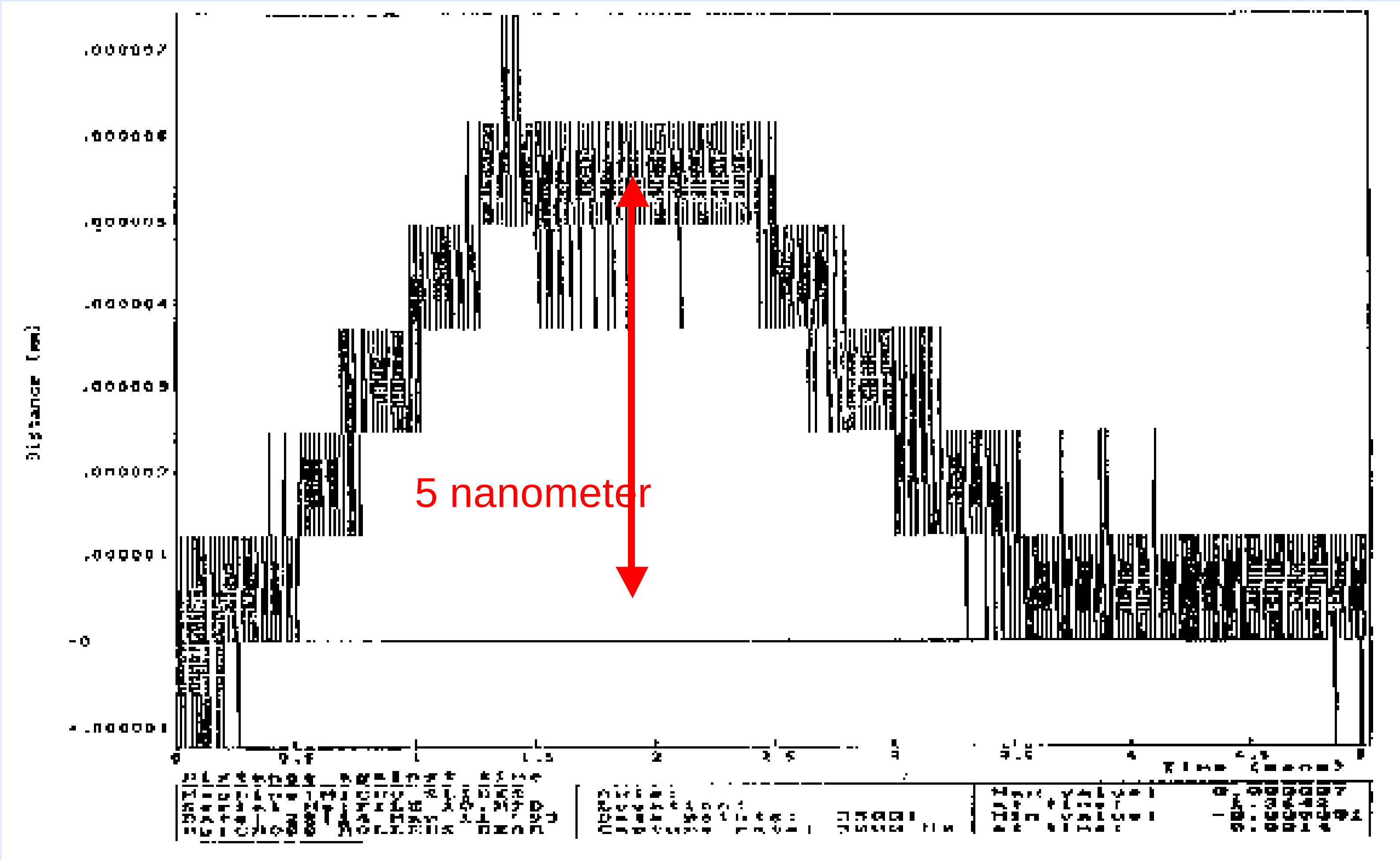
# NM Motor – Minimal Step
## 5 nanometer



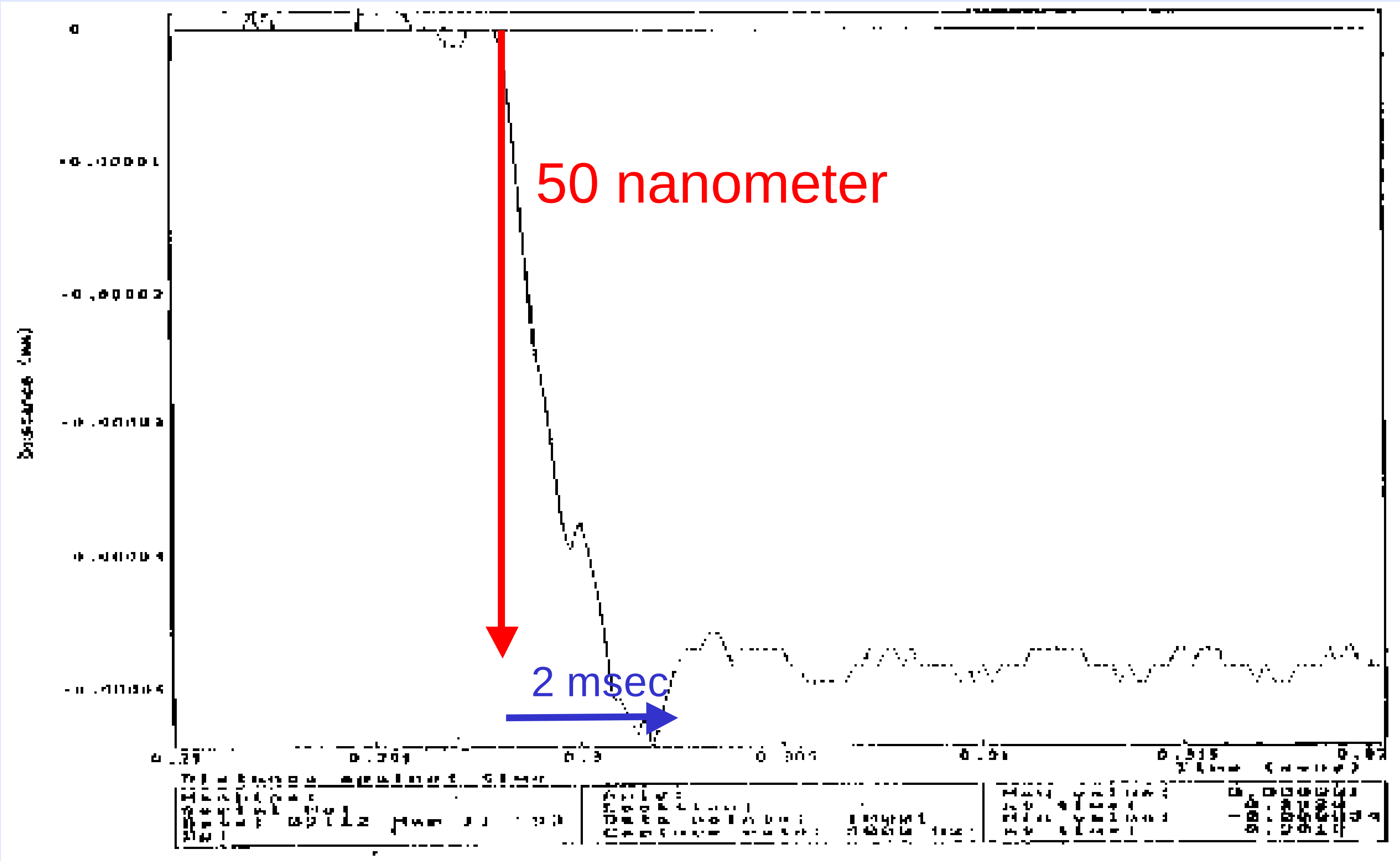

Interferometer resolution = 1 nanometer

# NM Motor
## Sub nanometer Resolution Mode



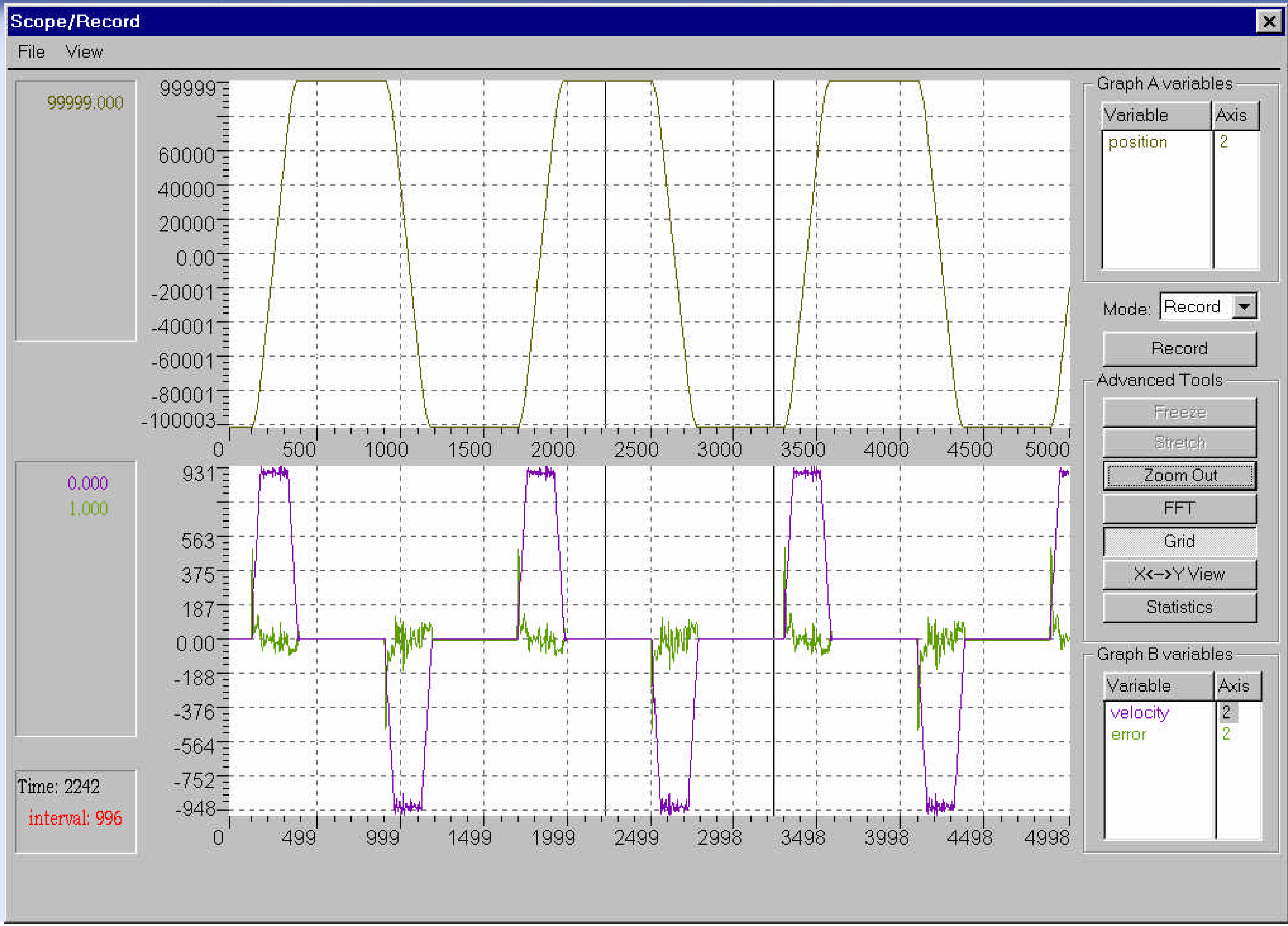
# NM Motor

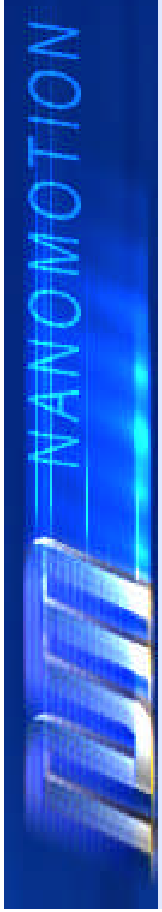
## Fast Response Time



# NM Closed Loop Operation

## Encoder Resolution 100 Nanometer



# HR-8 Specifications
# 8- Element Motor

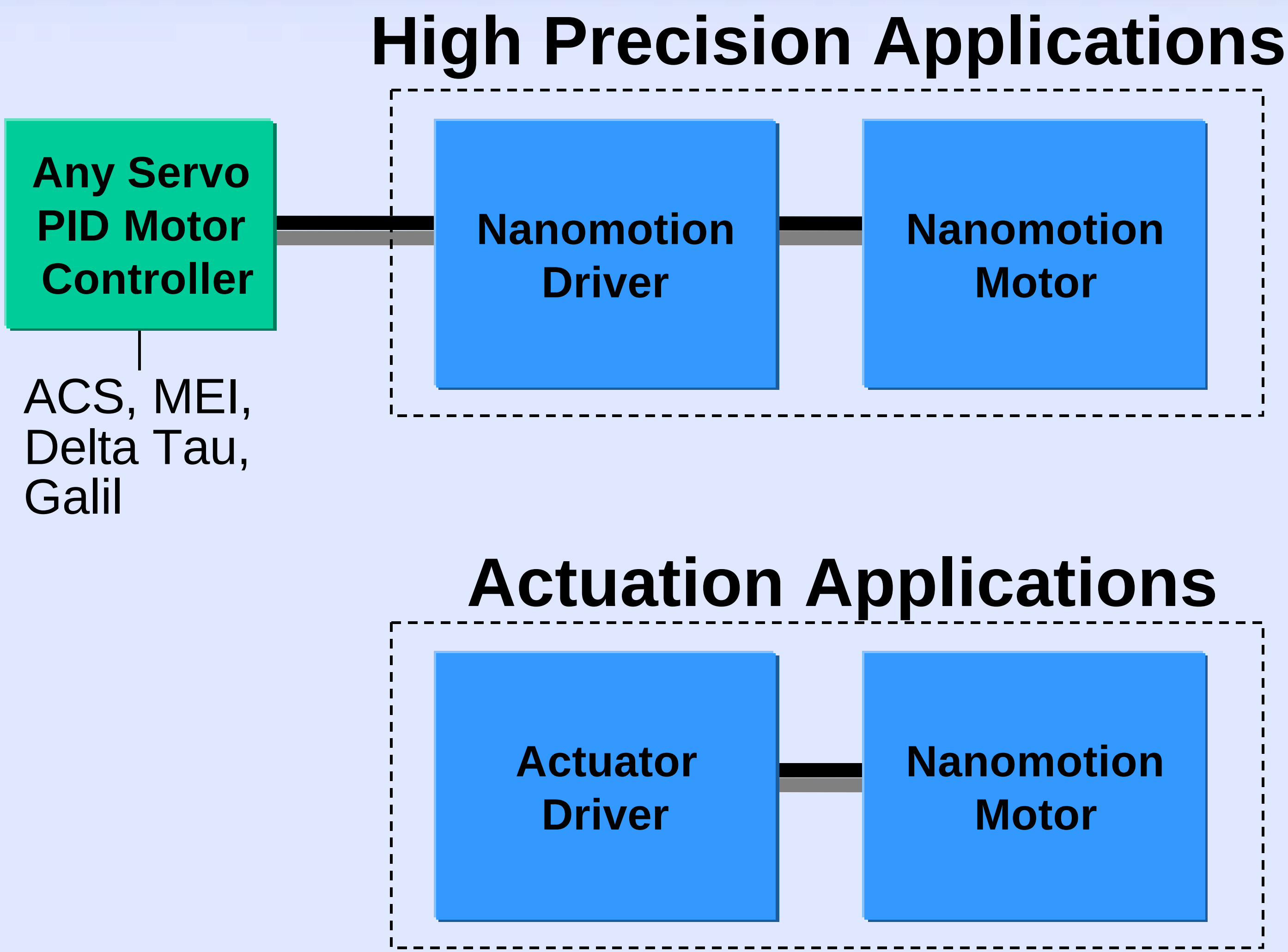
| | |
|---|---|
| Force | 40N |
| Max Speed | 260 mm/sec |
| Resolution | 5 nanometer |
| Settling Time | 4 msec (1 lb. load) |
| Size | 23 X 46 X 41 mm |
| Weight | 103 gr |

# Motor Interface

**Control**

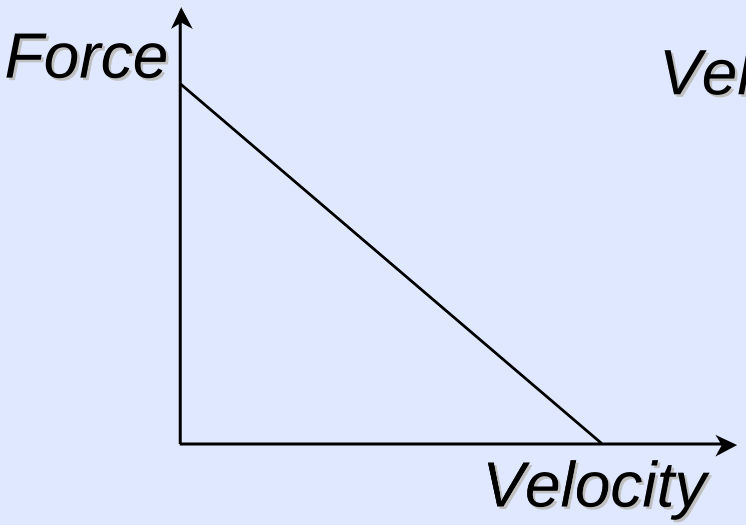
**Motor Installation**

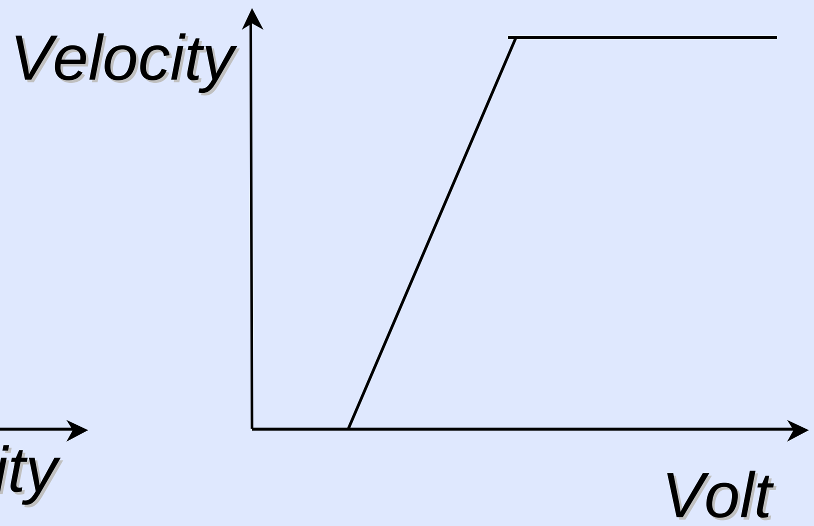
# Control


High Precision Applications
Any Servo PID Motor Controller
Nanomotion Driver
Nanomotion Motor
ACS, MEI, Delta Tau, Galil
Actuation Applications
Actuator Driver
Nanomotion Motor

# Selecting a Motor Model

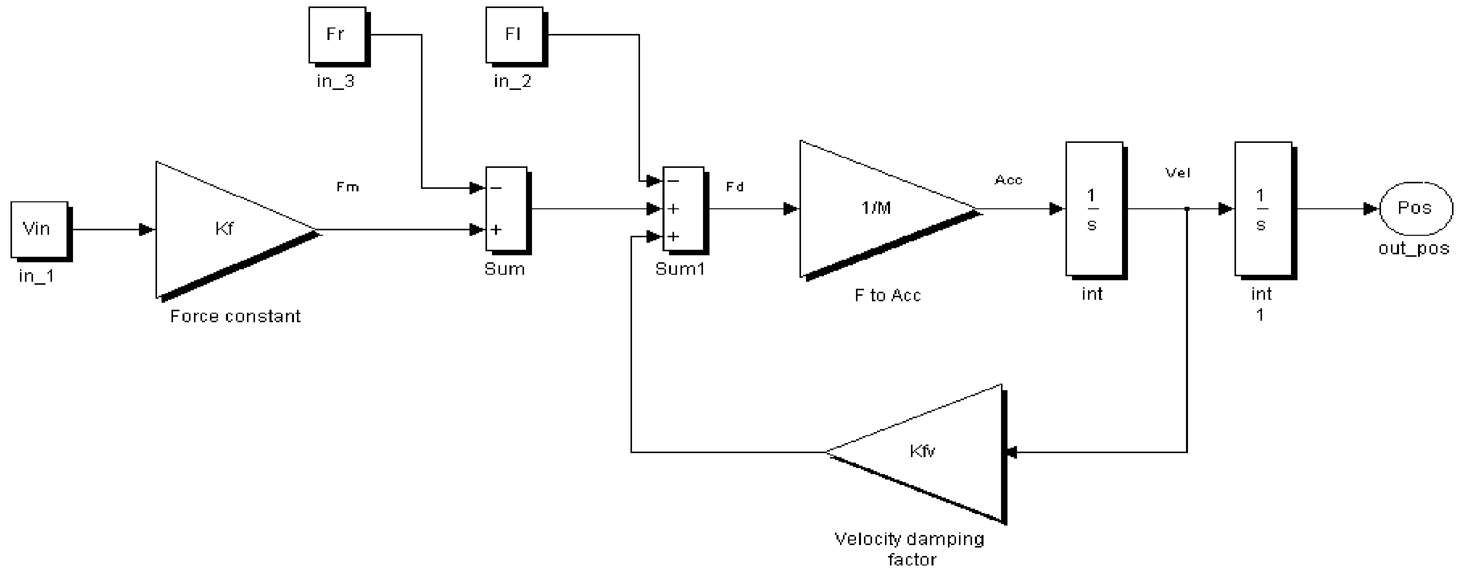
**Linear behavior of Force to Velocity and Velocity to Input Voltage**




**Nanomotion motor model is correlated to a DC linear motor with friction, driven by a voltage power amplifier.**

# Model for HR Series Motors



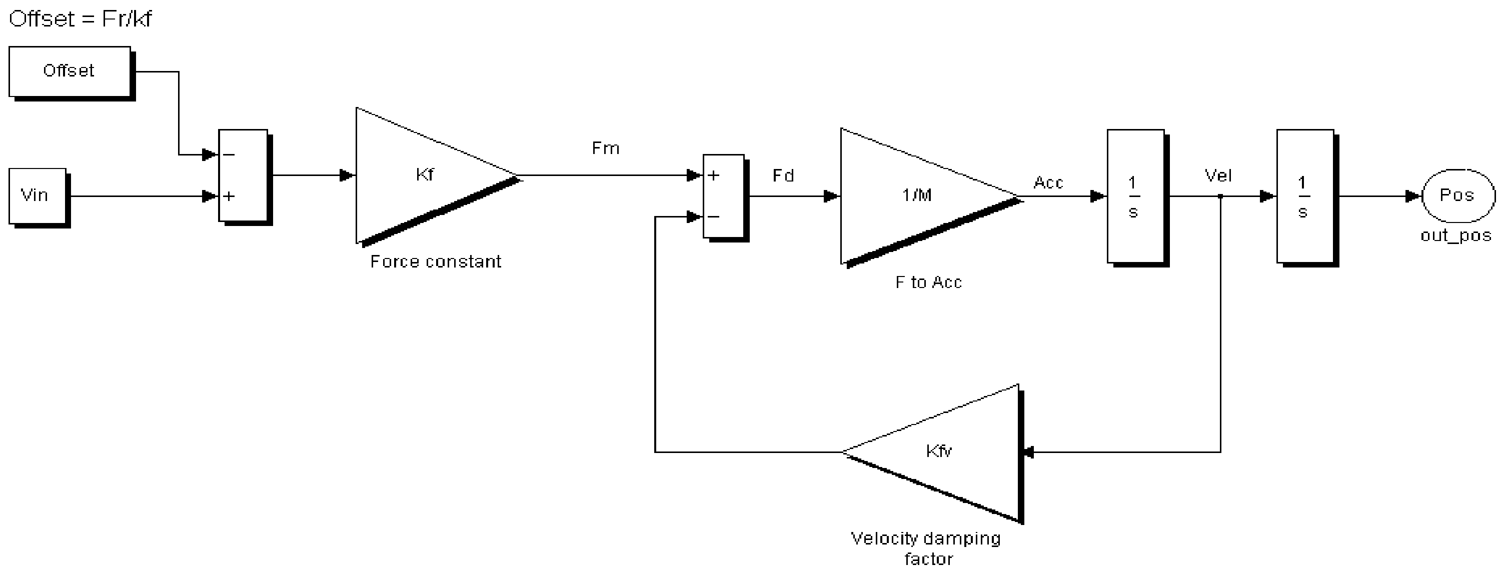
# Nanomotion Motor Implementation Model

Where:

| | |
|---|---|
| Vin = voltage command to the power amplifier range 10 (volts) | [V] |
| Fm = motor force (Newton's) | [N] |
| Kf = force constant | [N/V] |
| Fr = motor friction | [N] |
| Fl = load force | [N] |
| Fd = dynamic force | [N] |
| M = total moving mass | [Kg] |
| Acc = acceleration | [m/sec$^2$] |
| Vel = velocity | [m/sec] |
| Pos = position | [m] |
| Kfv = velocity damping factor | [N/m/sec] |

The basis for this model is as follows: Movement caused by the Nanomotion motor is based on friction between the finger tip and the ceramic slide. The set up is preloaded to assure that there is a Normal force to maintain the friction.

# Equivalent Model for HR Series Motors

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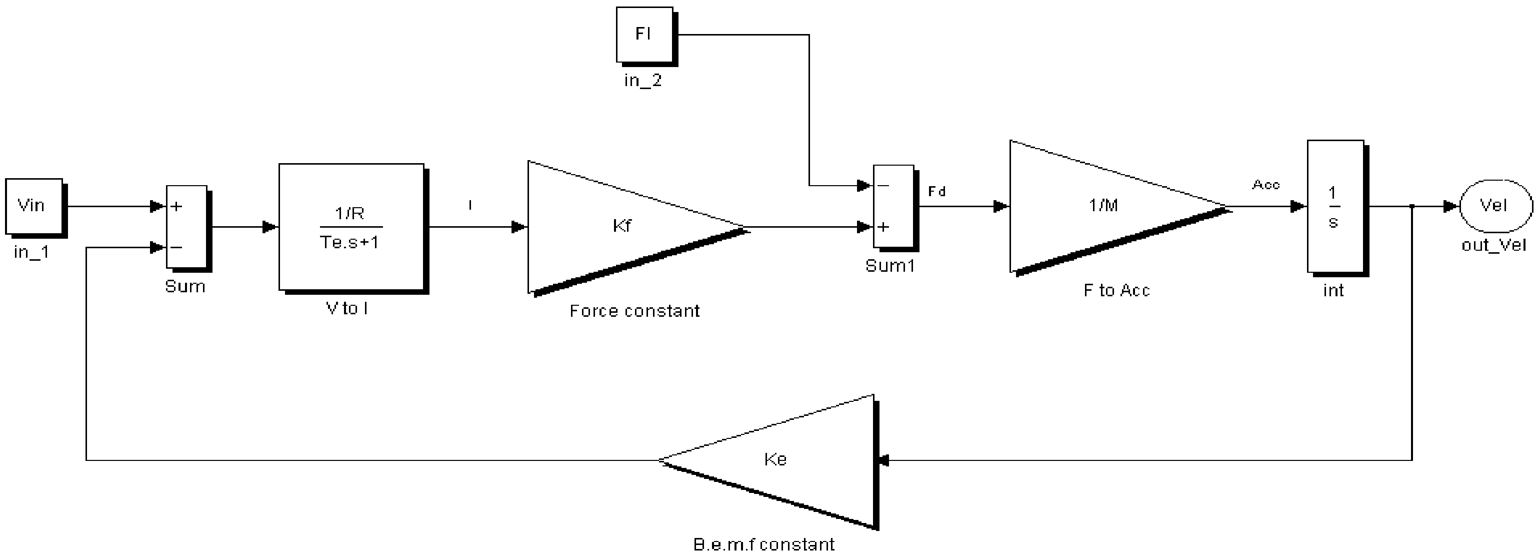
# DC Linear Motor Model




DC Linear Motor Model

# DC Linear Motor Model Considerations

Symbols:

V = input voltage [V]

Vel = output velocity [m/sec]

R = motor resistance [r]

L = motor inductance [H]

$\tau_e$ = motor electrical time constant [sec]

$K_f$ = force constant [N/A]

m = total moving mass [Kg m]

$K_e$ = back EMF constant [V / (m/sec)]

S = Laplace variable

where

$\tau_{em}$ = electro mechanic time constant

$\tau_{em} = mR/K_eK_f = m\,(R/K_e^2)$

(as in mKS, $K_f = K_e$)

$F_d$ = disturbance force [N] (friction and load)

Neglecting $\tau_e$ and $F_d$, it is easy to show that

$vel = v/Ke[1 - e^{-(t/\tau em)}]$

The electro mechanic time constant is related to the motor open loop bandwidth as follows: $B = 1/2\pi\tau_{em}$ [Hz]

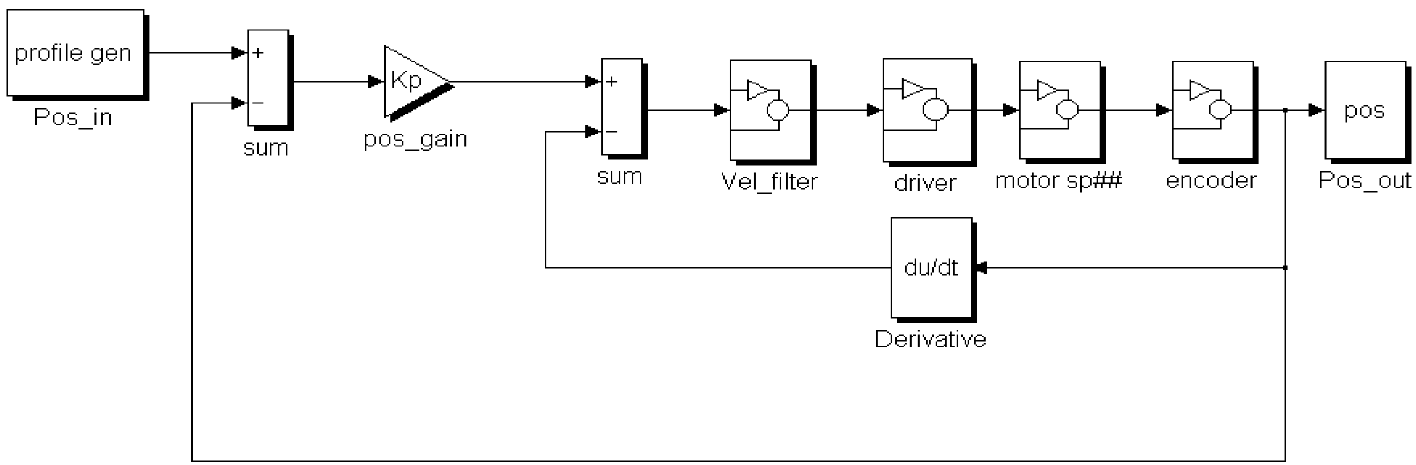
# The Nanomotion Control Model

The Nanomotion control model uses Position Loop over Velocity Loop.

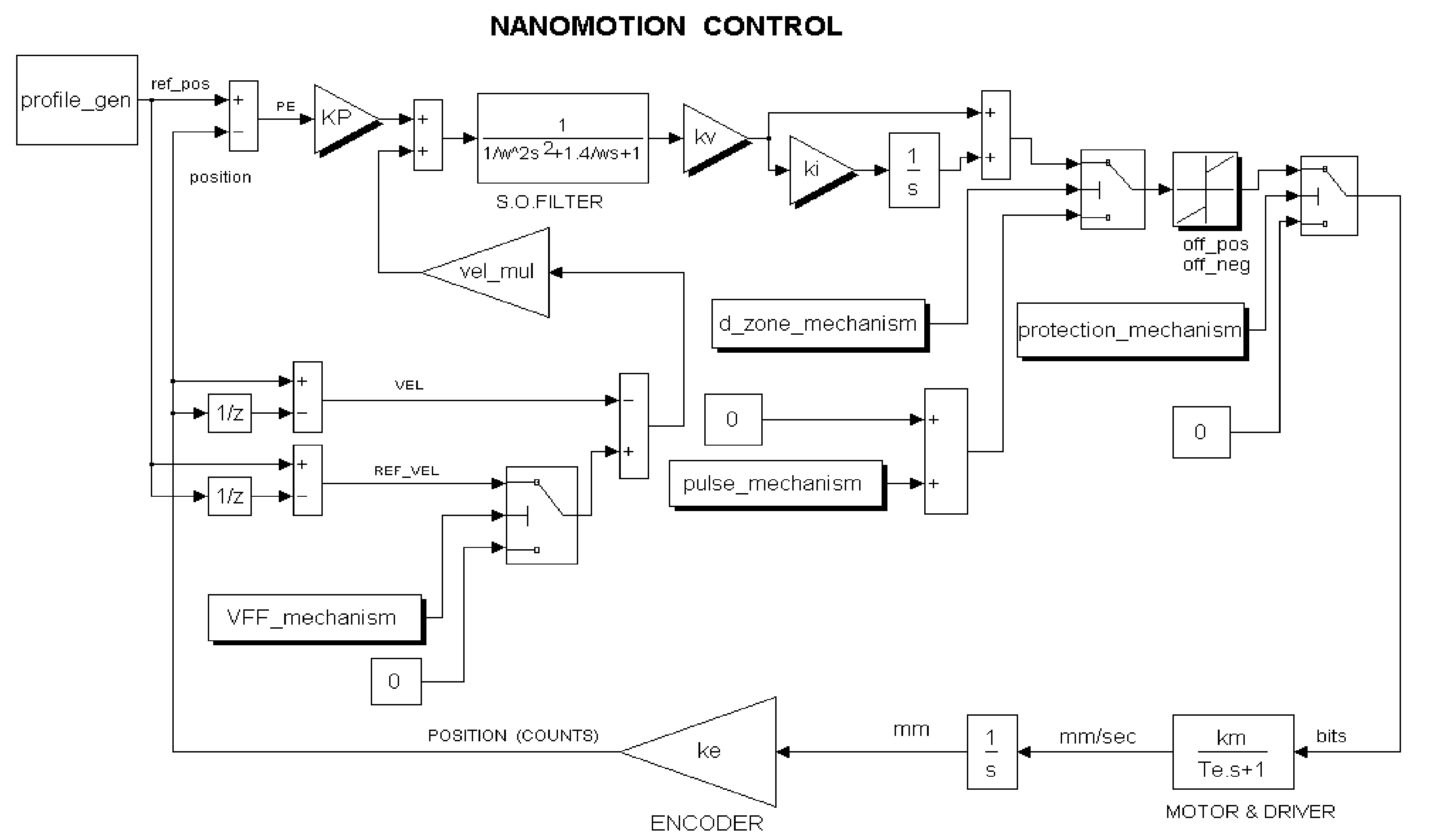
Velocity Loop - equivalent to DI

Position Loop - equivalent to P

# Simplified Position Control Model for Nanomotion Motors



# Comprehensive Velocity-Position Control Model



# Nanomotion Control Advantages

Optimized control method for motor characteristics

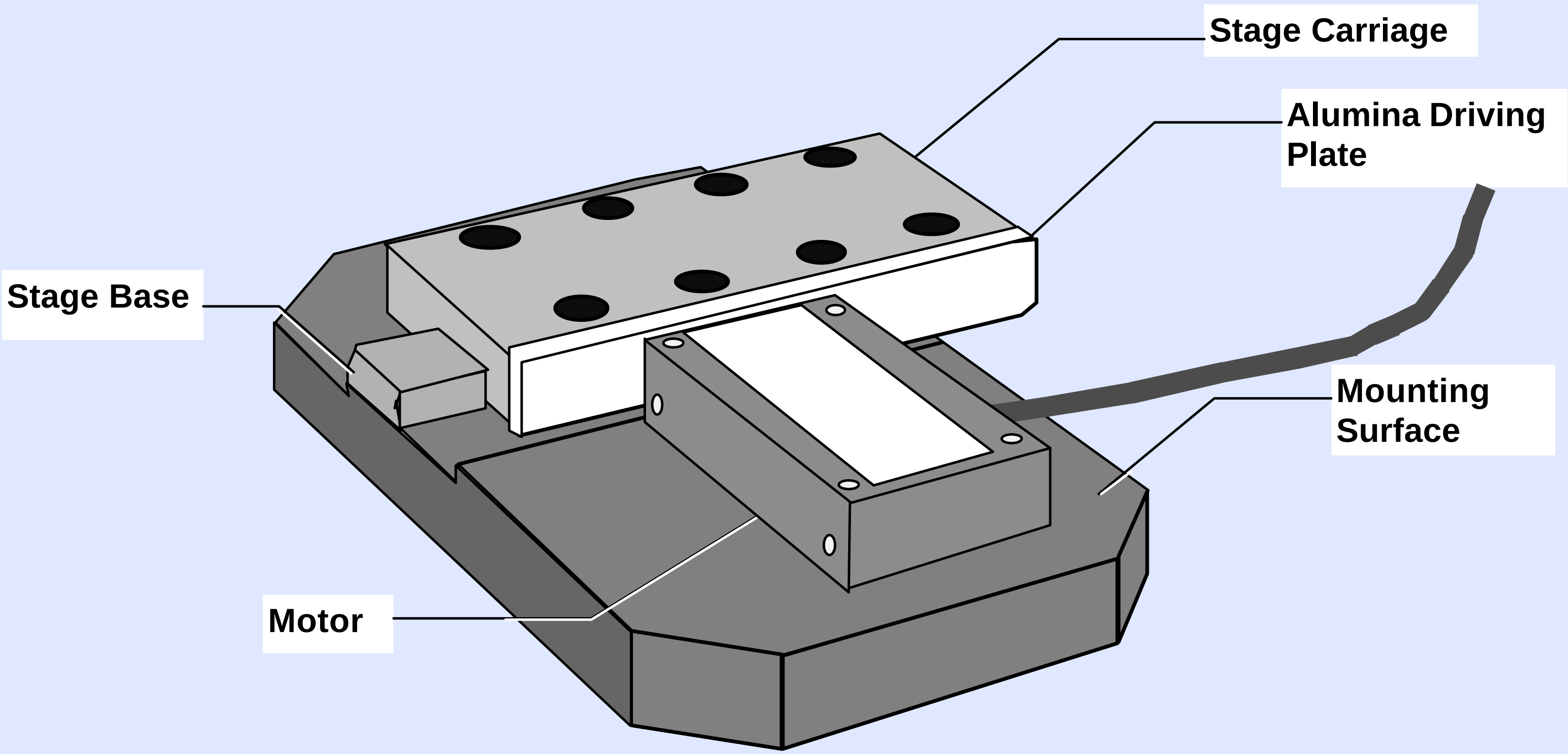
High resolution (5 nm)

Extremely short settling time (few msec)

Easily tuned by setting Kfv, Kf, Vff

Tunable second-order filter for ultra-smooth operation

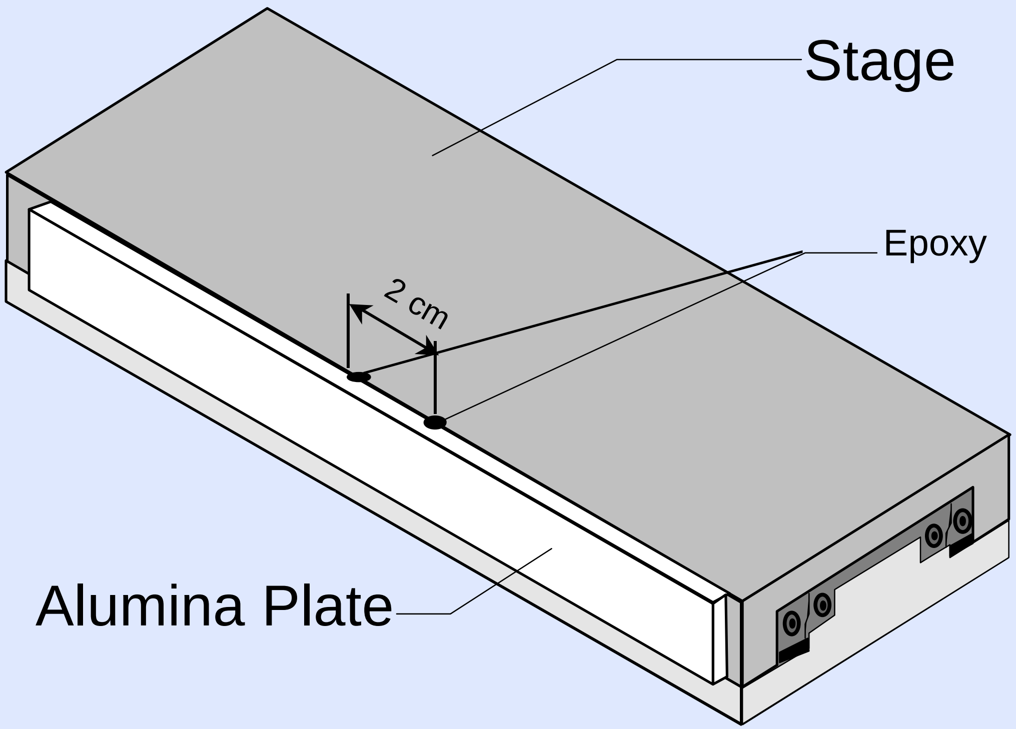
# Motor Interface:
## Mounting



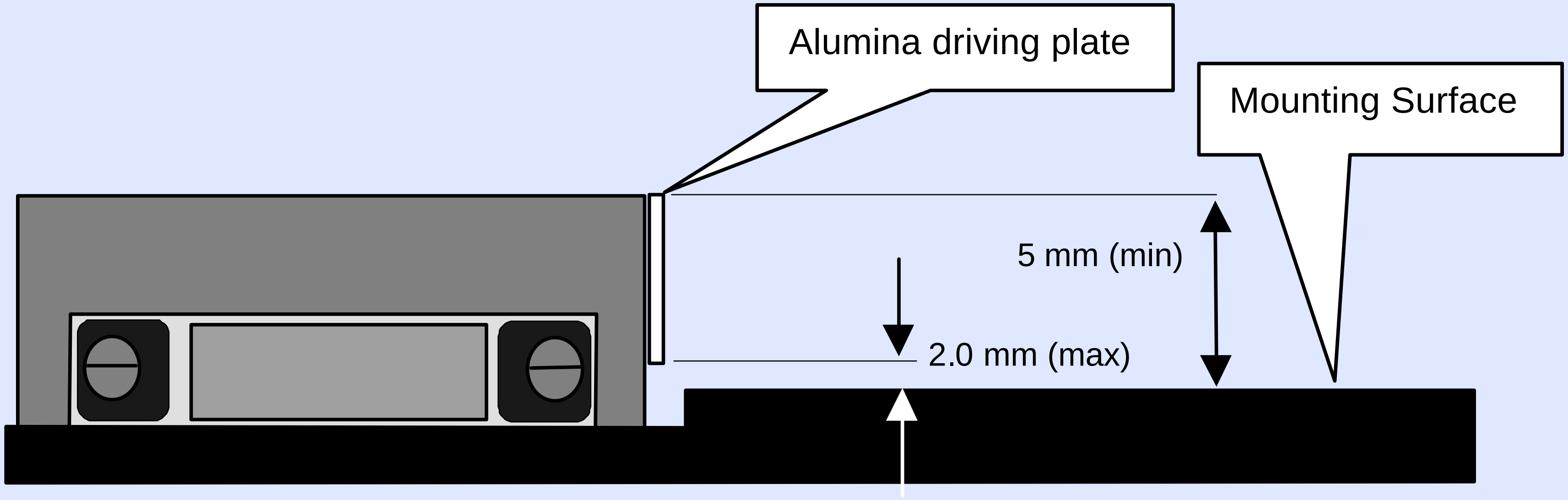
# Motor Interface

## Bonding the Driving Plate

The Alumina Driving Plate interfaces between the motor finger tip and the stage, providing the required friction and extended product life.

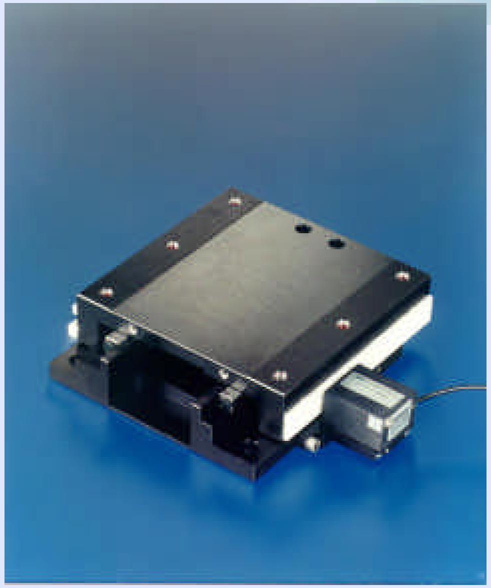


# Motor Interface
## Alumina Driving Plate Position



# Nanomotion Technology Highlights (1)

- Wide dynamic velocity range (1um - 250 mm/sec)
- Nanometer resolution (5nm)
- High linear force (5N per element)
- “Zero” settling time
- Unlimited travel
- Inherent “Power Off” break
- Compact Size
- No moving parts
- Fast response



# Nanomotion Technology Highlights (2)

- Operates inside the actual vacuum environment
- Ultra-high vacuum compatibility (10E-10 torr)
- Totally non-magnetic, enables operation in proximity with E beam equipment
- Compact size, helps reduce size and complexity of vacuum chambers

No feed-through connections

# Product Positioning

| Market Segment | High Precision OEMs | Vacuum Applications | Actuators OEMs | Textile Selectors | Textile Needle | HDD Positive Latch | HDD-HSA CD-Sledge | Cameras | Automobile Mirrors, Door Locks |
|---|---|---|---|---|---|---|---|---|---|
| Advantages | | | | | | | | | |
| Compact | 7 | 9 | 10 | 10 | 10 | 10 | 9 | 9 | 10 |
| Light | 8 | 8 | 9 | 8 | 8 | 8 | 9 | 9 | 7 |
| High Resolution | 10 | 10 | 2 | 7 | 8 | 2 | 10 | 7 | 2 |
| Vacuum Compatible | 0 | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Wide Dynamic Range of Speed | 7 | 8 | 0 | 0 | 0 | 0 | 3 | 3 | 6 |
| Simplicity in Linear Motion | 7 | 7 | 8 | 9 | 9 | 2 | 8 | 8 | 9 |
| Braking Feature | 6 | 10 | 9 | 9 | 8 | 9 | 5 | 8 | 10 |
| Fast Response | 8 | 8 | 8 | 9 | 10 | 10 | 10 | 8 | 2 |
| Long Travel | 8 | 9 | 10 | 0 | 2 | 2 | 2 | 2 | 4 |

# Competitive Analysis (1)

- **Traditional PZT Actuator**
  - (–) Travel Limitations
  - (+) High Resolution
  - (+) High Frequency
  - (+) Open Loop Operation
- **Ultrasonic Traveling Wave**
  - (–) Low Speed
  - (–) Low Force
  - (–) Mainly Rotary Operation
  - (–) Expensive
  - (–) Large Dimensions
  - (–) Short Lifetime

(+) Advantage
(–) Disadvantage

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# Competitive Analysis (2)

- **Vacuum Applications:**

  Magnetic Motors:

  (–) Motors require feed through connection

  (–) No Inherent Brake

- **Precision Applications:**

  Magnetic Motors:

  (–) Slow Response Time

  (–) High Velocity Ripple at Low Speed

  (–) Low Stiffness

  (+) High Force

  (–) No inherent brake

(+) Advantage
(–) Disadvantage

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# Competitive Analysis (3)

- **Actuators:**

  Minimotor and Gear:

  (–) Trade Off:  Speed - Resolution

  (–) Large Dimensions

  (–) High Price at high volume

  (–) Backlash

  Miniature Stepper Motors:

  (–) Trade off:  Speed - Resolution

  (–) Large Dimensions

(+) Advantage
(–) Disadvantage

# Competitive Analysis (4)

- **Actuators (continued)**

  Electromagnets:

  (–) Reliability

  (–) High Current

  (–) No Inherent Brake

  (–) Dimensions

  (–) Response Time

  Memory Shape:

  (–) High Current

  (–) Response Time

  (–) Flexibility

(+) Advantage
(–) Disadvantage

# Motor Comparison

| Characteristc | Nanomotion Motors | Stepper | DC Motor |
|---|---|---|---|
| Control | Closed Loop | Open Loop | Closed Loop |
| Dynamic Range of Velocity | Excellent | Small | Large |
| Resolution | High | Medium | Medium |
| Compactness | Compact | Bulky | Bulky |
| Velocity Ripple | Excellent | Poor | Good |
| Non Energized Stiffness | High | Medium | Zero |
| Magnetic Field | No | Yes | Yes |
| Settling Time | Good | Good | Poor |
| Vacuum Compatibility | Excellent | Limited | Limited |

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# Actual Customer Applications (1)

- Linear stage for CD master machine (air bearing)
- XY stages for Stepper machine (air bearing)
- 42” linear optical bench slide for newspaper plotter (air bearing)
- 7 axes stage for SEM (vacuum)
- Single axis slide for STM (vacuum)
- XY stages for microscope
- Rotary tables

# Actual Customer Applications (2)

Micro-manipulator for

biomedical microscope

Dispenser

Inspection machines in production lines

Laser milling machines

# ASMs
# Application Specific Motors (1)

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**Miniature Actuators:**

HDD:

- Positive Latch
- Front Door (removable disk)
- Disk Insert/eject (removable disk)

CD:

- CD Insert/Eject

Cameras:

- Shutter

# ASMs
# Application Specific Motors (2)

Automotive:

- Mirrors
- Door Locks

Optical Systems:

- Mirror Adjustment
- Lens Adjustment
- Laser Adjustment
- Adjustment Fixtures
- Prism Rotation

# ASMs
# Application Specific Motors (3)

- **Miniature Motors:**

  HDD:

  - H.S.A. Actuator
  - Micro-manipulator

  CD: Sledge Actuator

  Cameras: Focusing and Zooming

  Automotive

  - Lamp Actuators
  - Dashboard Indicators