Lecture 6. Micro-Displacement Mechanism

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Outline

- Introduction
- Flexures
- Microactuators
- Common Micro-Displacement Mechanisms
- Design Strategies of Precision Micro-Displacement Stages
- Acknowledgement

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Introduction

- LODTM: Large Optics Diamond Turning Machine
- Advantages of LODTM
  - Produce complex geometries
  - Achieve high accuracy and repeatability
  - Produce mirror finish surface
- Precision of LODTM
  - Radial: 28 nm (280Å)
  - Surface finish: 4.3 nm (42Å)
  - Analogy: 280Å is ~ 3500 times smaller than diameter of human hair

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Introduction

❒ **Principle of Common Micro-displacement Mechanisms**

✐ **Flexures + Micro-actuators**

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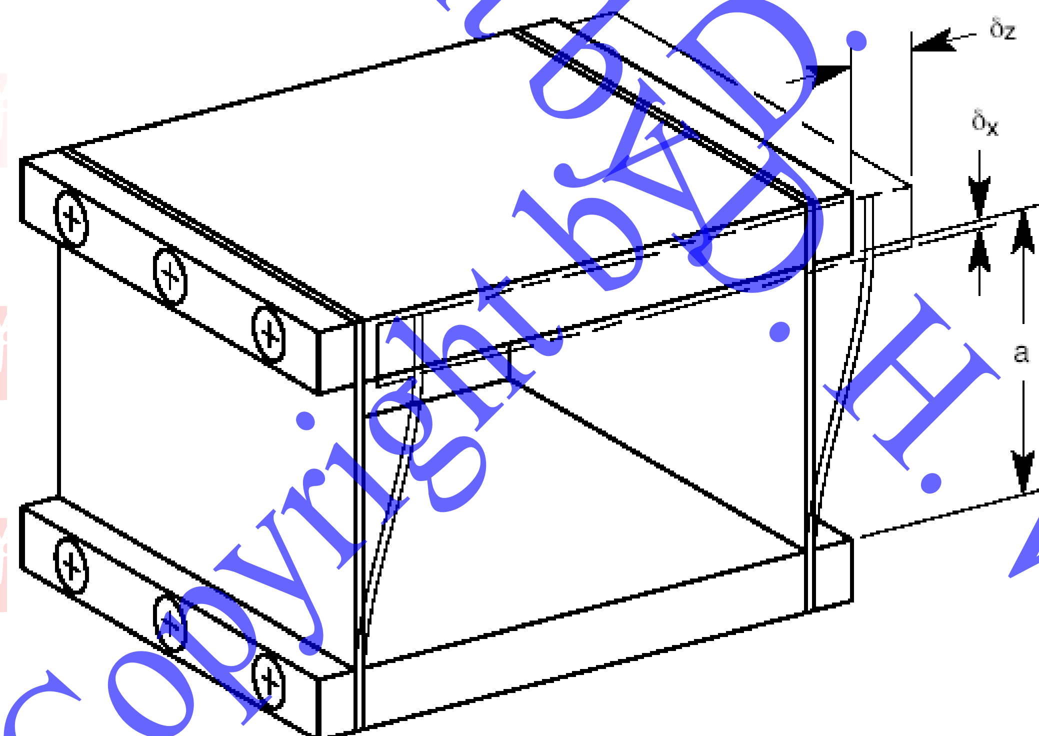
Flexures

- Blade flexures
  - Parallel Blades
  - Cross Blades
  - Axial Blades
- Flexible hinges
  - Single Axis
  - Double Axis

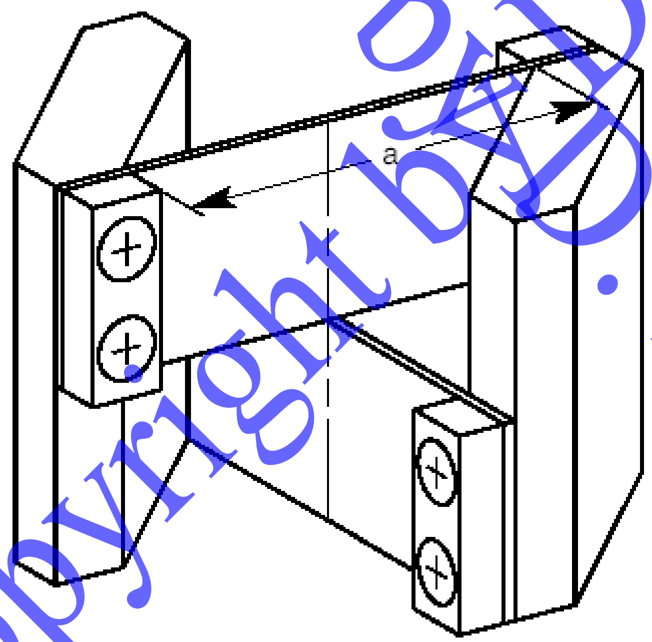
Blade Flexures: Parallel Blades

- Two parallel blades allow one translational degree of freedom and constrain all others. This example shows bolted construction but monolithic designs are also common.



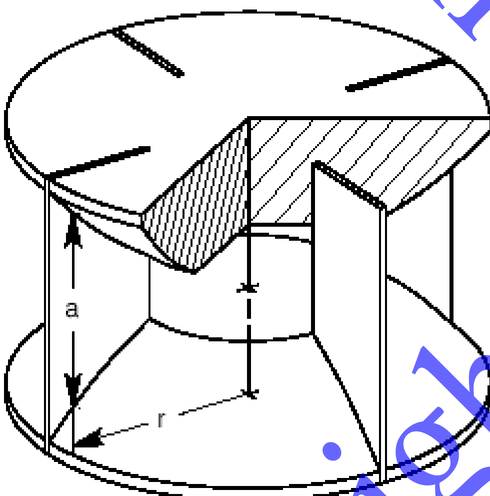
Blade Flexures: Cross Blades

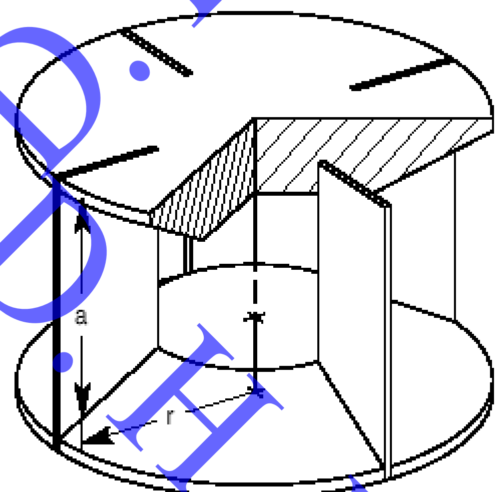
- Two cross blades allow one rotational degree of freedom and constrain all others. This example shows bolted construction but brazed connections are common in commercial products.



Blade Flexures: Axial Blades

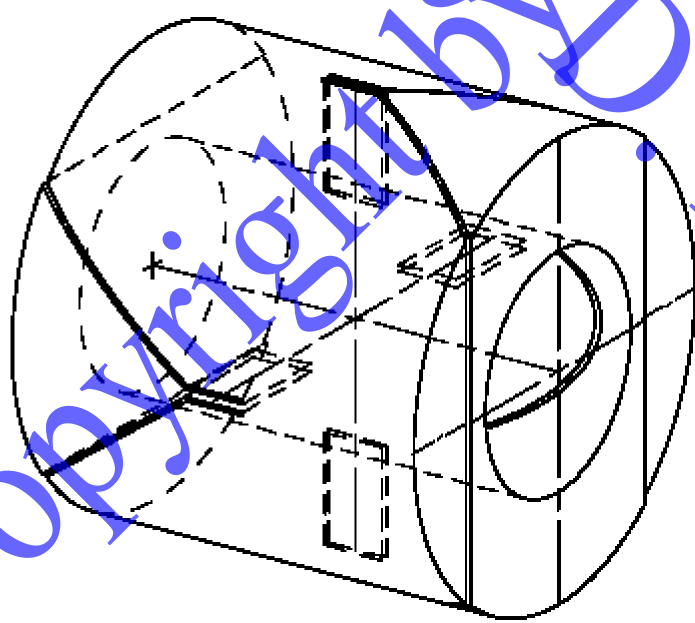
❒ **Axial blades allow one rotational degree of freedom and constrain all others. The shape of the flanges is important to the behavior of the flexure.**





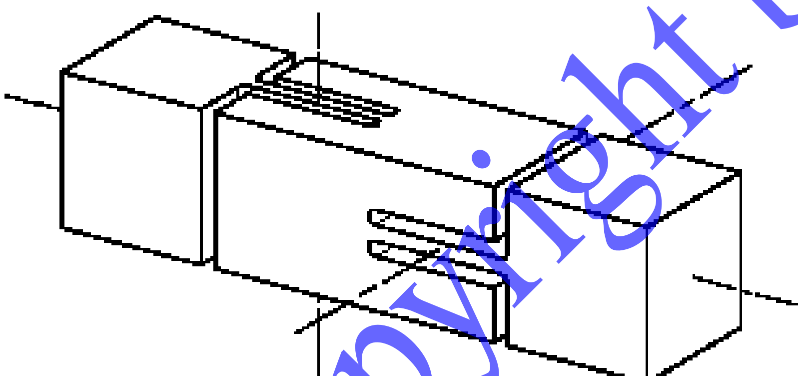
Blade Flexures: Axial Blades

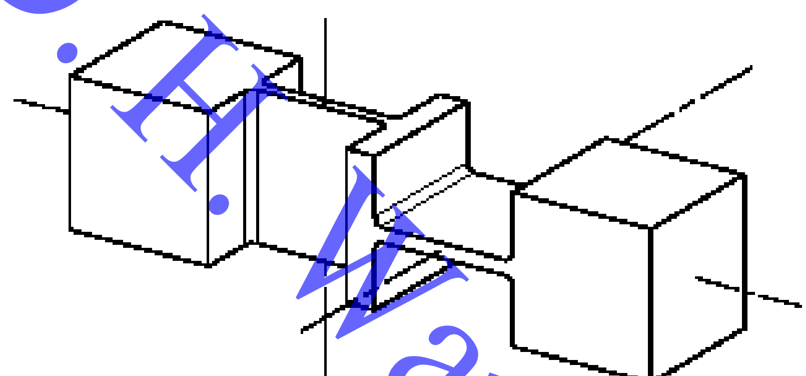
- The ball-screw flexure for the NIF precision actuator requires two rotational degrees of freedom, a primary constraint against translation along the screw, and secondary constraints for the remaining degrees of freedom. Note, some hidden lines were removed to better show the main features.



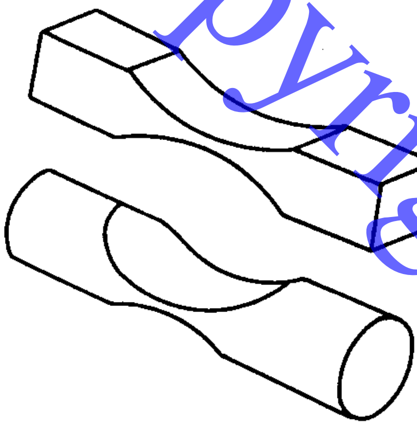
Blade Flexures: Axial Blades

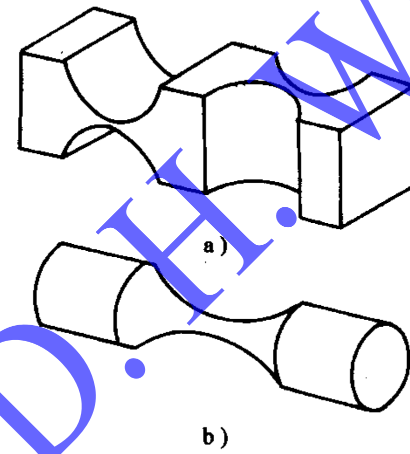
- The design in (a) allows the minimum spacing of blades and maintains good axial stiffness. In addition, the gaps may be controlled to provide over-flexion protection. In order for the design in (b) to have good axial stiffness, the junction between blades would have to be lengthened.

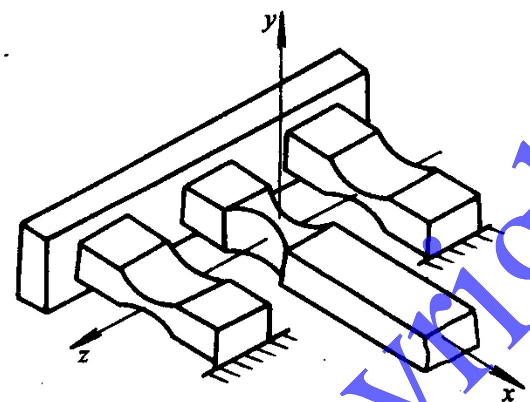


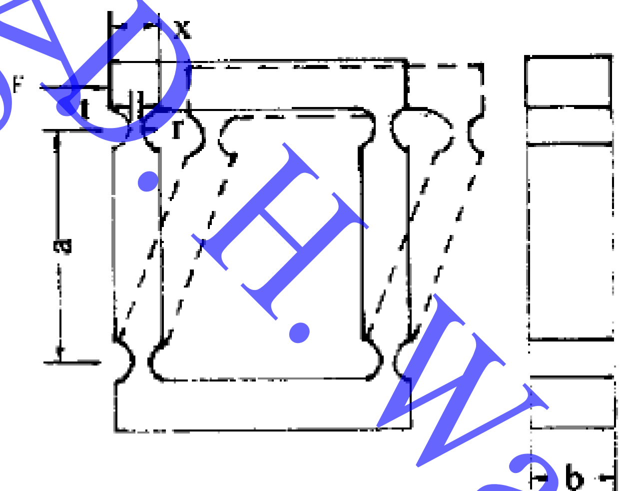


Flexible Hinges: Configuration

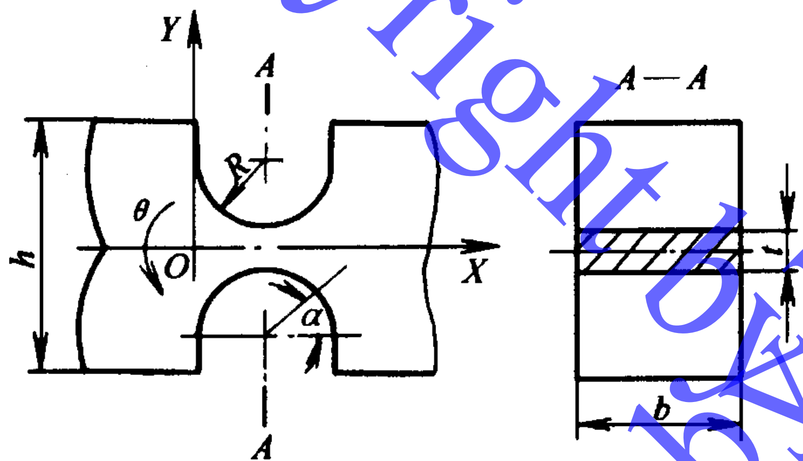








Flexible Hinges: Design



$$\frac{1}{\rho}=\frac{M_z(x)}{EJ(x)}$$

$$\frac{1}{\rho}=\frac{\frac{d^2y}{dx^2}}{\left[1+\left(\frac{dy}{dx}\right)^2\right]^{3/2}}$$

$dy/dx \leqslant 1$

$$\frac{1}{\rho}\approx\frac{d^2y}{dx^2}$$

$$\theta=\sum_{i=1}^{n}\Delta\theta_i \qquad y=\sum_{i=1}^{n}\Delta y_i$$

$$\frac{1}{\rho}\approx\frac{d^2y}{dx^2}=\frac{M_z(x)}{EJ(x)}$$

Flexible Hinges: Design

$\mathrm{d}y/\mathrm{d}x = \tan\theta$ → $\theta \approx \mathrm{d}y/\mathrm{d}x$

$$\theta = \frac{\mathrm{d}y}{\mathrm{d}x} = \int \frac{\mathrm{d}^2 y}{\mathrm{d}x^2}\mathrm{d}x = \int \frac{M_Z(x)}{EJ(x)}\mathrm{d}x$$

$$\theta = \int_0^{\pi} \frac{12MR\sin\alpha}{Eb(2R+t-2R\sin\alpha)^2}\mathrm{d}\alpha$$

表 4-5 柔性铰链转角刚度 （单位：mm・kg/rad）

R/mm \ t/mm	1.0	1.5	2.0	2.5	3.0
1.0	0.081Eb	0.24Eb	0.52Eb	0.94Eb	1.6Eb
1.5	0.063Eb	0.18Eb	0.39Eb	0.70 Eb	1.2 Eb
2.0	0.053Eb	0.15Eb	0.32Eb	0.58Eb	0.94Eb
2.5	0.047Eb	0.13Eb	0.28Eb	0.50Eb	0.91Eb
3.0	0.043Eb	0.12Eb	0.25Eb	0.45Eb	0.73Eb

Micro-Actuators

- Piezo Actuators
- Electrostriction Actuators
- Electromagnetic Actuators
- Magnetostriction Actuators

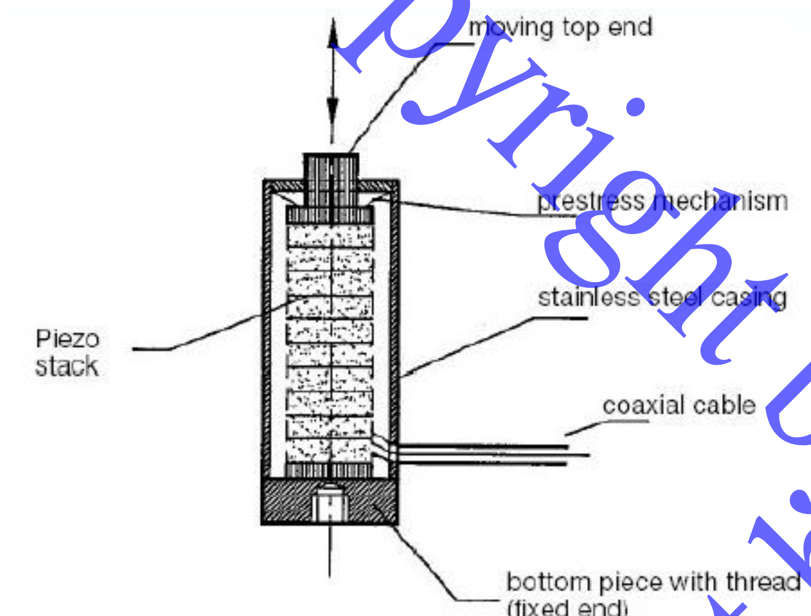
Piezo Actuators

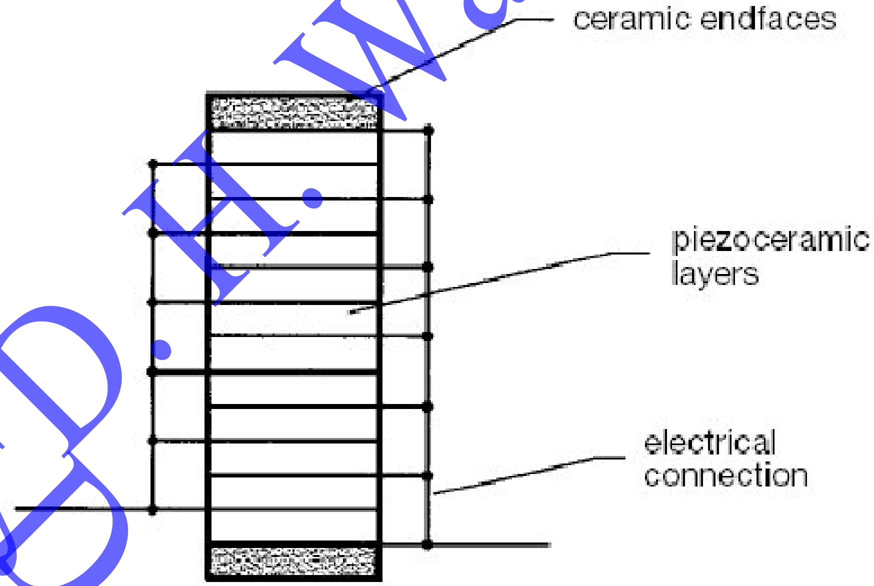
- Piezo Effects
- 压电材料: 具有压电效应和电致伸缩效应的材料。
  - 常用压电材料是压电陶瓷，尤其是以锆酸铅和钛酸铅组成的固溶体使用更为普遍，以**Pb**(铅)、**Zr** (锆)、**Ti**(钛)这三种元素符号的第一个字母组成**PZT**来代表。
  - 逆压电效应仅在无对称中心晶体中才有，而电致伸缩效应则所有压电材料都有。
  - 在一般的压电材料中，电致伸缩系数比压电系数大，在自然状态没有电的极化现象。
- 压电晶体: 利用逆压电效应工作的电介质材料，如**PZT**；
- 电致伸缩材料: 利用电致伸缩效应工作的电介质材料，如**PMN**(铌镁酸铅)和**La**：**PZT**

Piezo Actuators

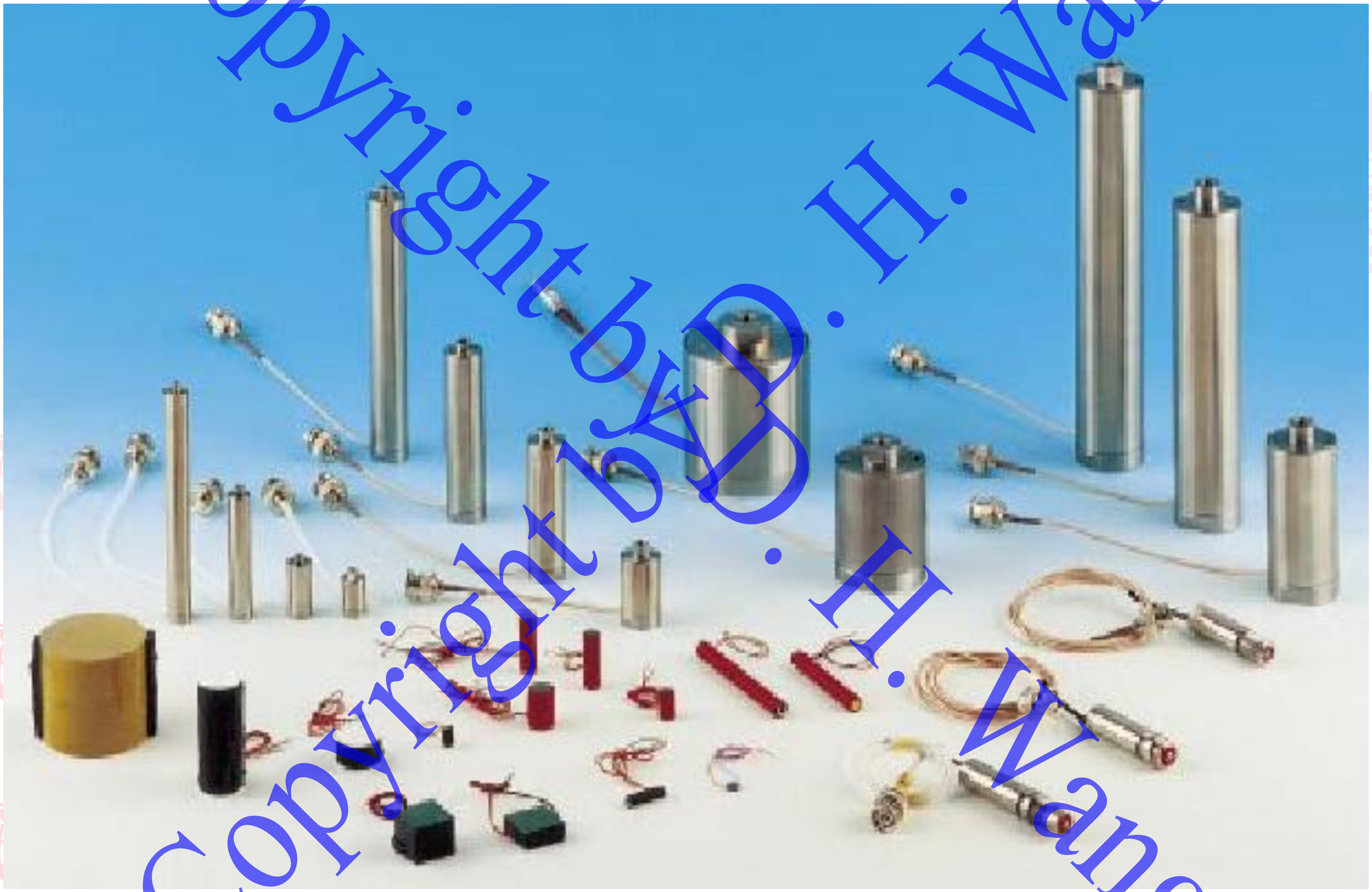
- DEFINITION: An actuator that uses piezoelectric material.
- DESCRIPTION: Piezoelectric actuators are classified into the single-plate, bimorph, and stacked types, and the popular material is lead zirconate titanate (PZT).
- The features are:
  - Quick response,
  - Great output force per volume,
  - Ease of miniaturization because of simple structure,
  - Narrow displacement range for easier micro-displacement control
  - High efficiency of energy conversion.
- Piezoelectric actuators are used for the actuators for micromachines, such as ultrasonic motor, micro-displacement stage, fan, pump, and speaker.

Piezo Actuators

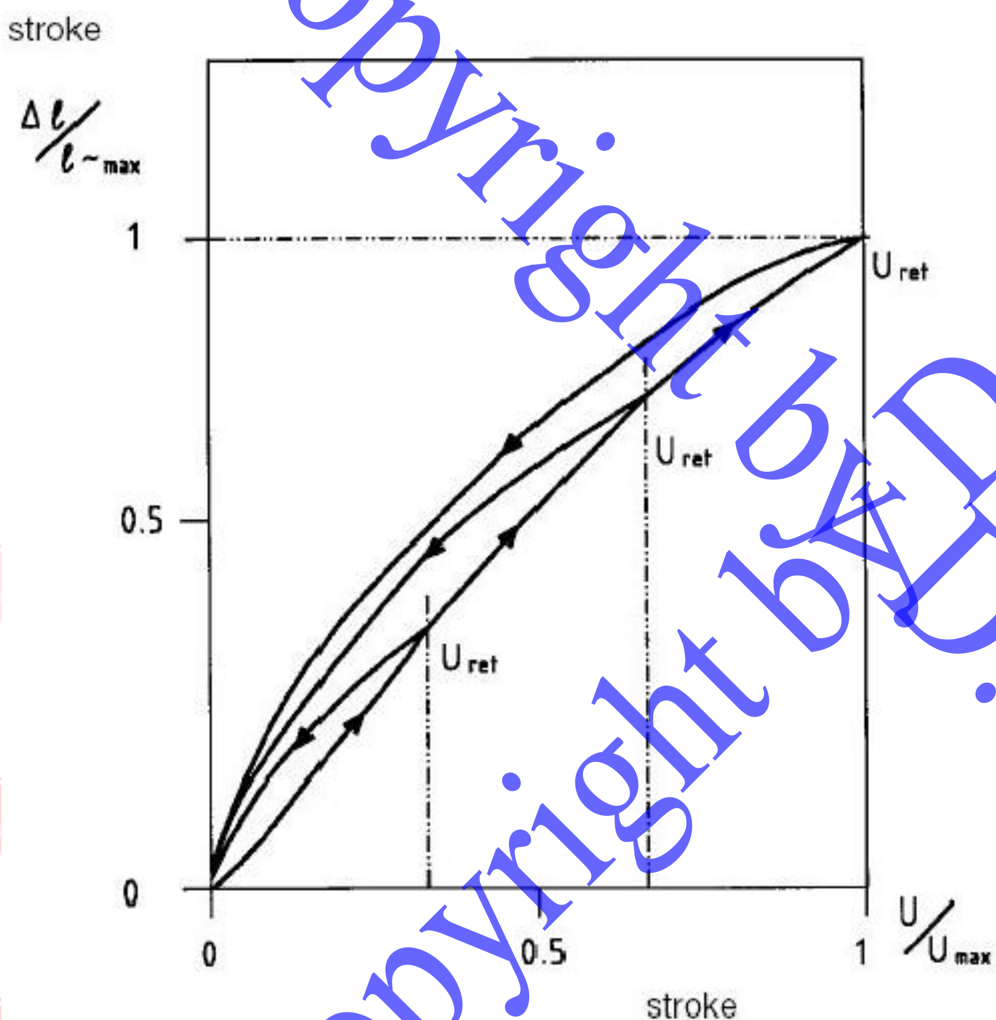




Piezo Actuators



Piezo Actuators



$$S = dE$$

Electrostriction Actuators

❒ DEFINITION

- The generation of strain in a dielectric material induced by an electric field.

❒ DESCRIPTION

- The model of crystal lattice of cations and anions bonded with one another by springs is often well applied to ceramics.
- If an electric field is applied to a material that is not conductive, the cations in the material are attracted in the direction of the electric field whereas the anions are attracted in the opposite direction, with this inducing a stress to deform the crystal lattice.
- The strain induced by the electric field is classified into two by the property of the inter-ionic springs determined by the crystalline structure.

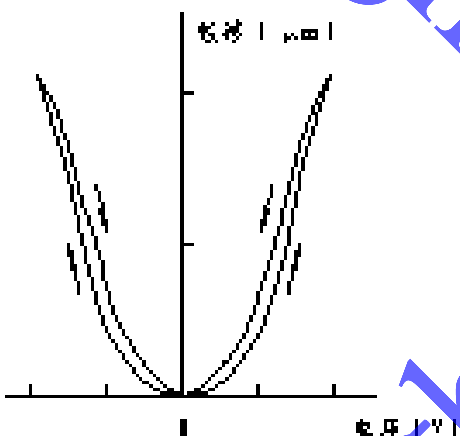
Electrostriction Actuators

❒ DESCRIPTION

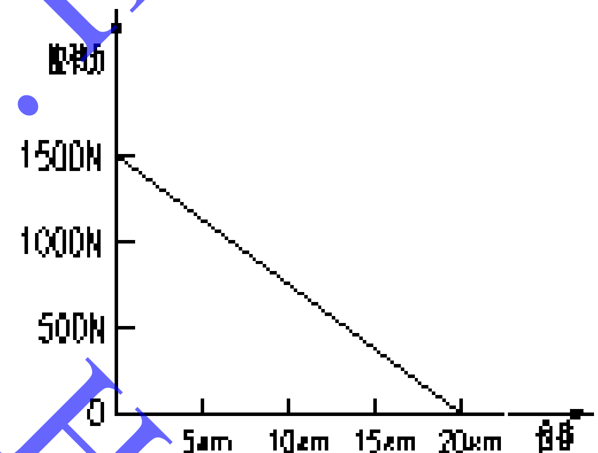
- In a symmetric crystal, much part of extension and contraction is cancelled between neighboring springs so that the whole crystal shows little strain.
- Although, to be accurate, the anharmonicity of the springs causes a strain that is proportional to the square of the electric field strength. This is known as the electrostrictive strain effect.
- Whereas an asymmetric crystal shows a strain that is proportional to the electric field strength, which is called the reverse piezoelectric effect.

❐ Electrostriction Effect

$$S = ME^2$$



电压——位移曲线图



阻挡力——位移曲线图

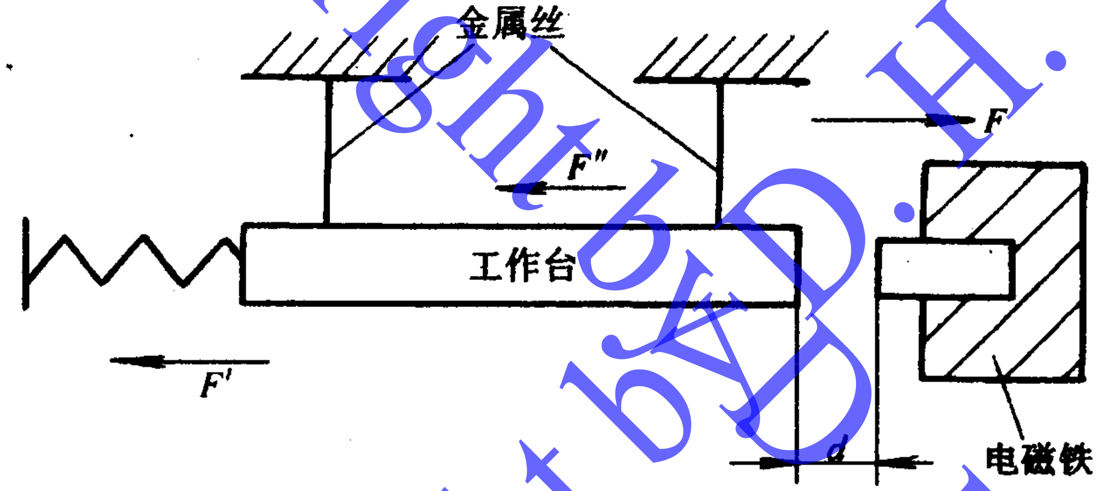
Electromagnetic Actuators

- DEFINITION
  - An actuator that uses electromagnetic force.
- DESCRIPTION
  - Magnet and coil winding are the major element for micro-electromagnetic actuators.
  - For sub-milimeter or smaller magnetic rotors for micro-electromagnetic devices, thin film magnets fabricated by sputtering are useful.
  - High-energy products and larger thickness are needed for the thin film magnets in order to raise the power of the devices.
  - …

❐ DESCRIPTION

- …
- On the other hand, research into devices based on electromagnetic force focuses on those with plane structures such as axial gap types, because it is difficult to wind the coil around the cylindrical stator used for radial gap type microdevices.
- With regard to efficiency, radial gap types have an advantage, but an appropriate process for winding the coil around the cylindrical stator must be developed.

Electromagnetic Actuators



Magnetostriction Actuators

- **DEFINITION**
  - The generation of strain induced by a magnetic field.
- **DESCRIPTION**
  - The magnetostrictive effect is that the strain of a ferromagnetic material is produced by rotation of the magnetizing direction of each magnetic domain in the material in the direction of the magnetic field.
  - Recently it was discovered that alloys of iron and rare-earth metals (Sm, Tb, Dy, Ho, Er, Tm, and so on) exert intense magnetostriction of about 100 to 1,000 times greater than that generated by conventional Co-Fe-Ni alloy magnetostrictive materials, and since then these alloys have been drawing attention as supermagnetostrictive materials.

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Magnetostriction Actuators

❒ DESCRIPTION

- A magnetostrictive actuator utilizing magnetostrictive effect is driven by external magnetic field. Therefore a magnetic circuit is necessary, but the advantage of the actuator is that it can be driven by wireless. Super-magnetostrictive actuators have been applied on an experimental basis to a wireless robot and a robot that moves through pipes.
- This effect can also be refered as Joule effect.

Common Micro-Displacement Mechanisms

- Flexure Hinges + Piezo-Actuators
- Parallel Blades + Piezo-Actuators
- Rolling Element Bearings + Piezo-Actuator
- Parallel Blades + Stepper Motor
- 位移缩小机构
- Parallel Blades + Electromagnetic-Actuator
- Aerostatic Bearings + Stepper Motor

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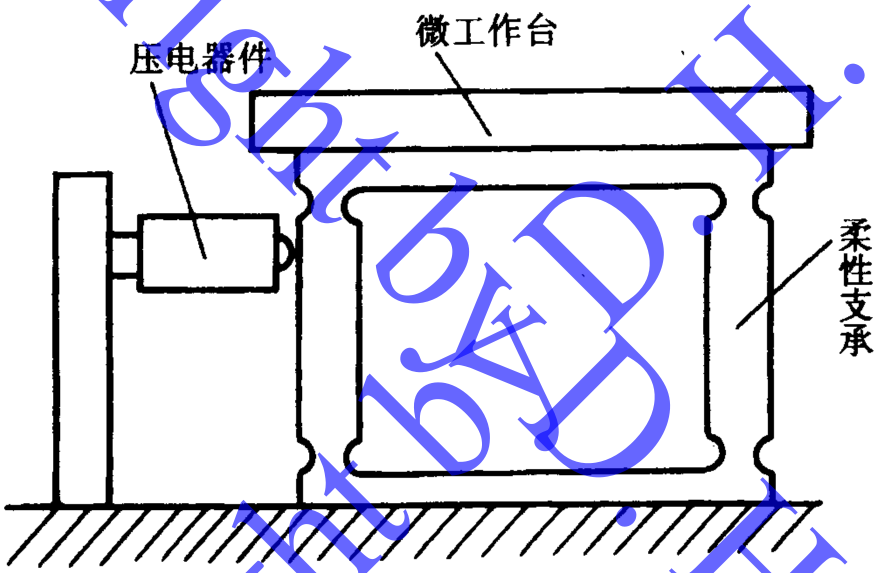
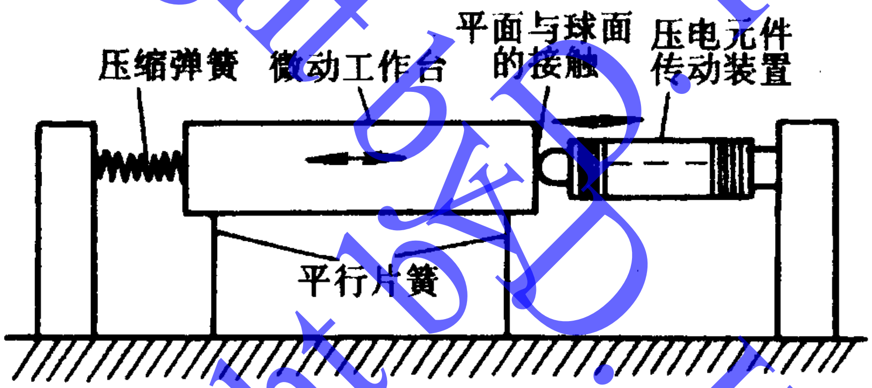
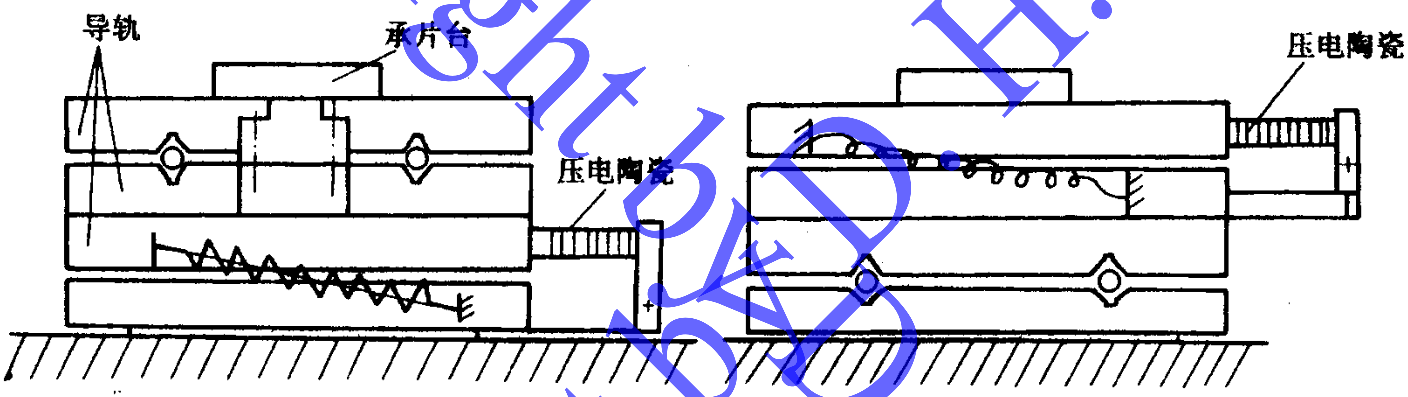
Flexure Hinges + Piezo-Actuators



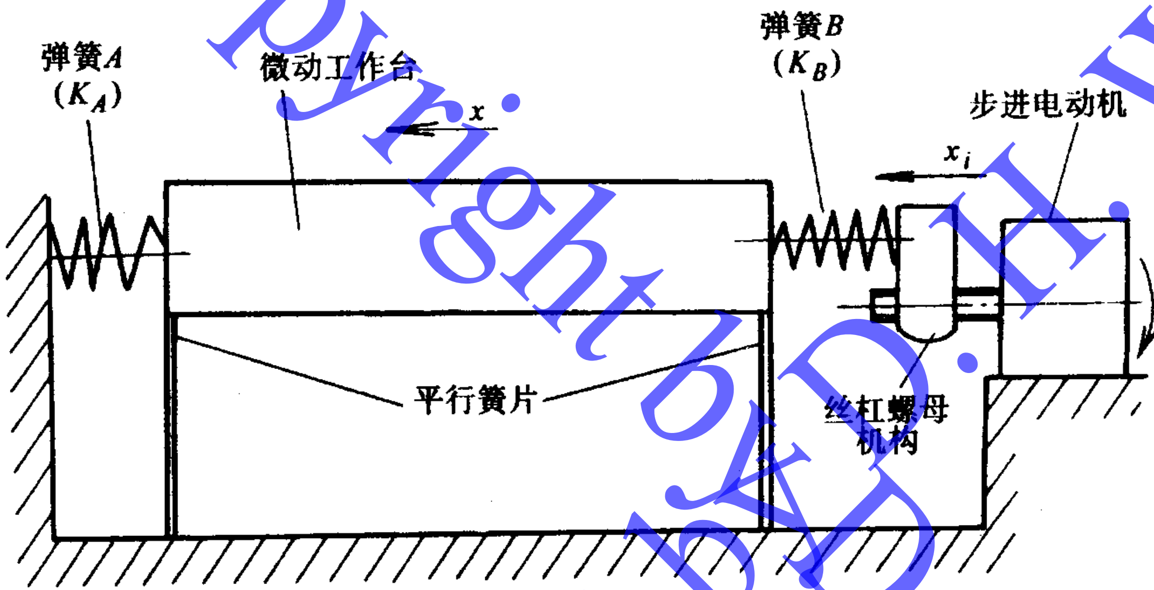
Parallel Blades + Piezo-Actuators



Rolling Element Bearings + Piezo-Actuator

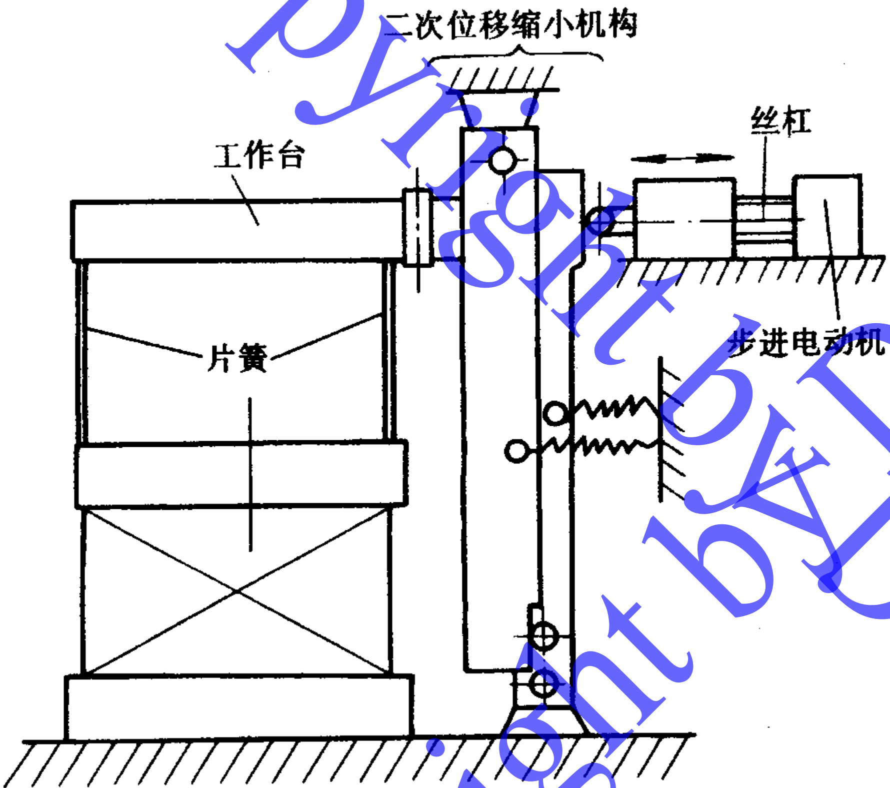


Parallel Blades + Stepper Motor

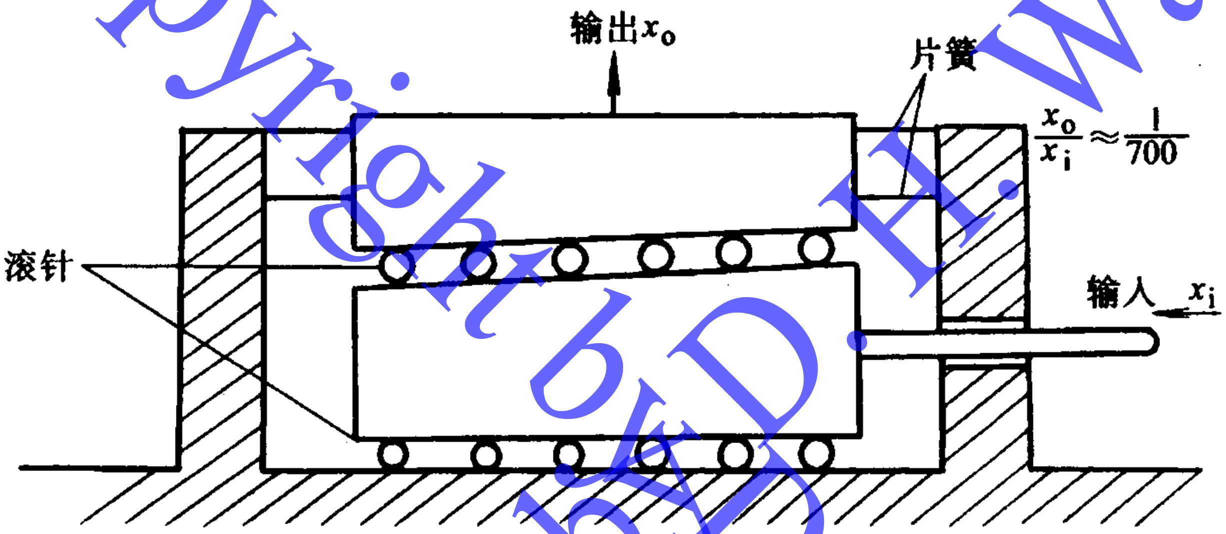


$$x = x_i \frac{K_B}{K_A + K_B}$$

Parallel Blades + Stepper Motor

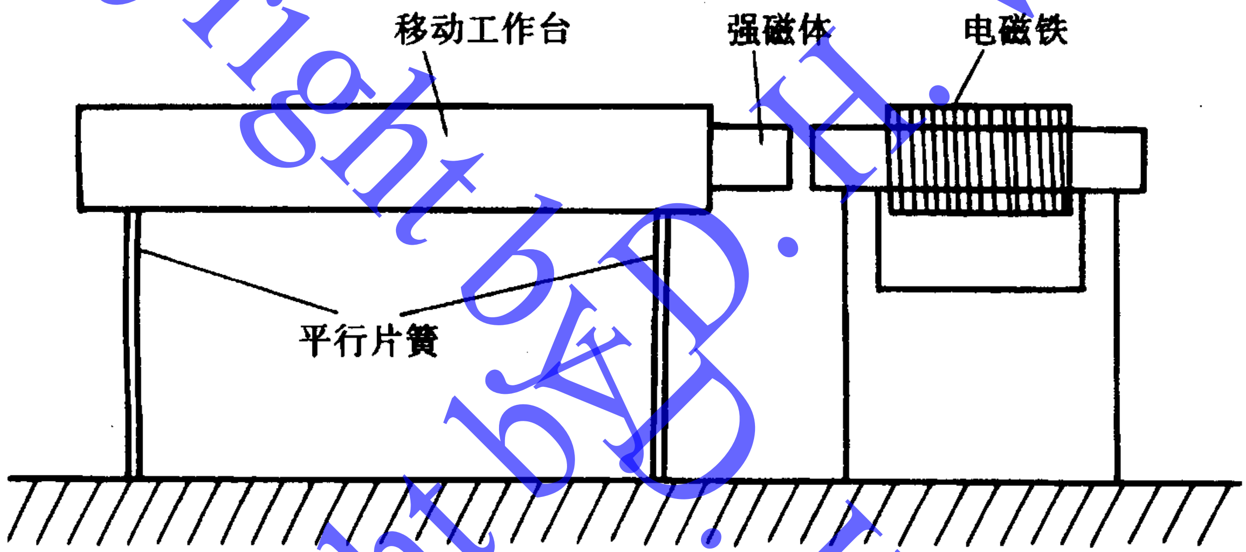


位移缩小机构

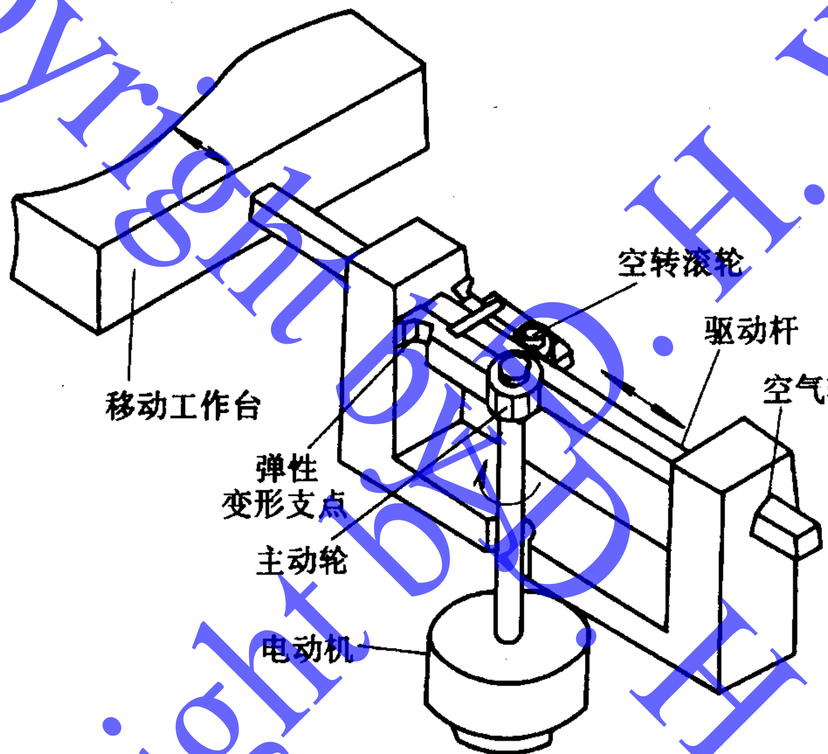


$$x = x_i \tan\theta$$

Parallel Blades + Electromagnetic-Actuator



Aerostatic Bearings + Stepper Motor



Design Strategies of Micro-Displacement Stages

- ❒ Design requirements
- ❒ Key problems
  - Configurations of guides
  - Driven modes

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Acknowledgement

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