Outline

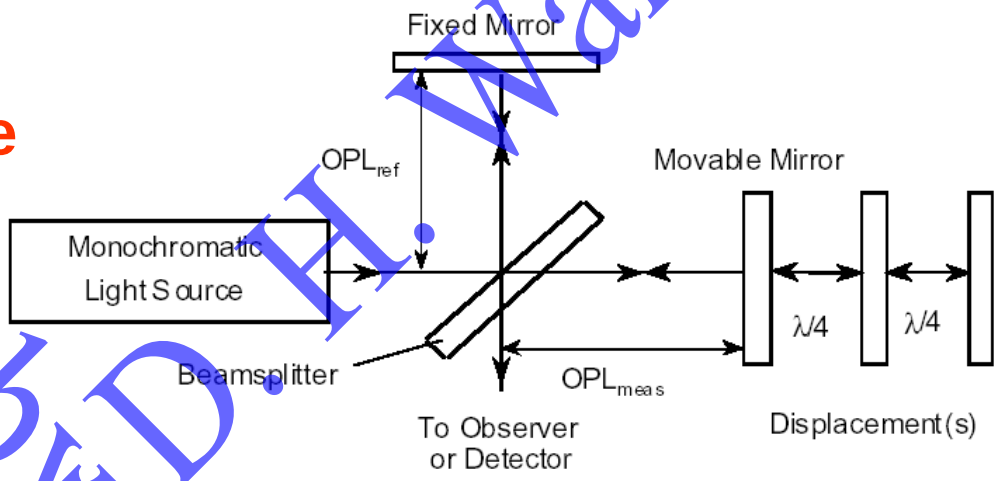
- Basic concept
- Min {Deformation due to Force}
  - Ex: 1 m Laser Interference Length Measuring Machine
    - Major Applications of Light Interference
  - Ex: Optoelectronic Waveform Comparative Length Measuring Machine
- Min {Deformation due to Thermal Expansion}
  - Ex: Dynamic Measuring Machine for Screws
  - Ex: Pressure Transducer

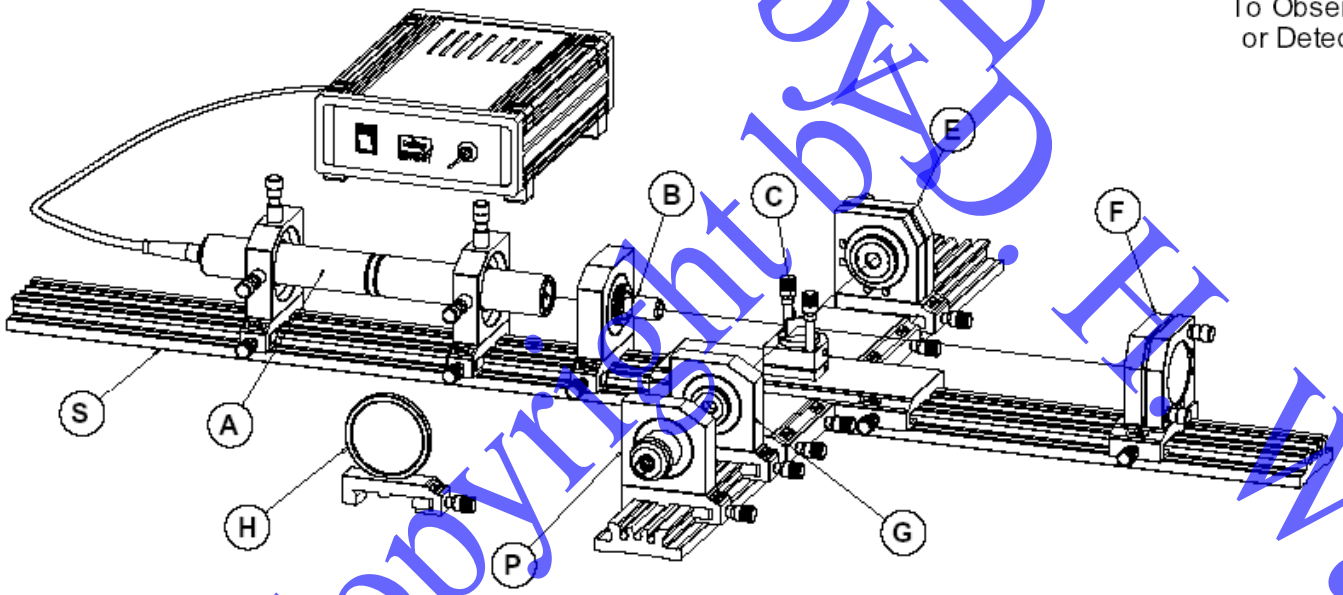
变形最小原则

- 定义
  - 应尽量避免在仪器工作过程中因受力变化或因温度变化而引起的仪器结构变形或仪器状态和参数的变化，并使之对仪器精度的影响最小
- 示例
  - **Min {Deformation due to Force}**
  - **Min {Deformation due to Thermal Expansion}**

1 m Laser Interference Length Measuring Machine

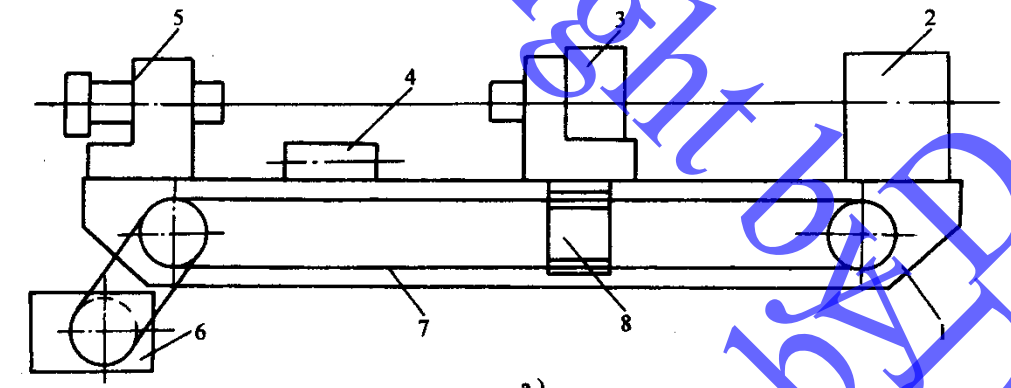
Set-up of the Michelson Interferometer showing the modules

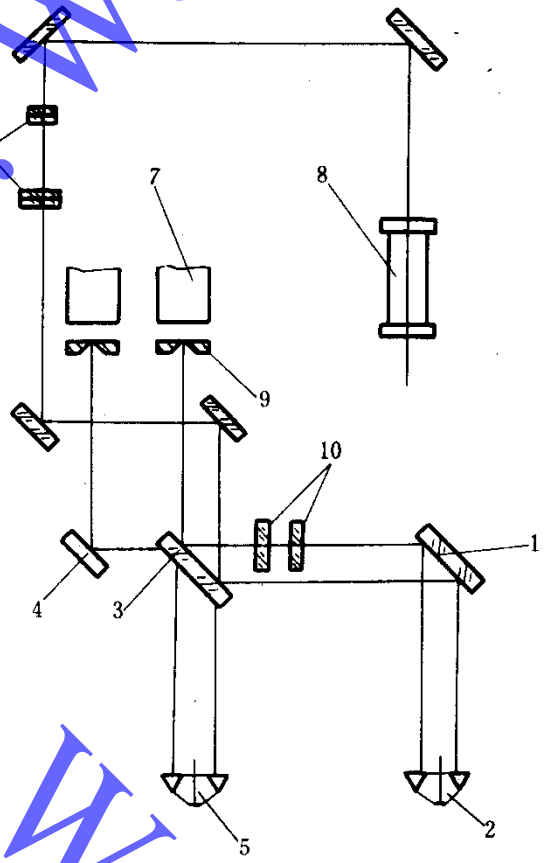




1 m Laser Interference Length Measuring Machine

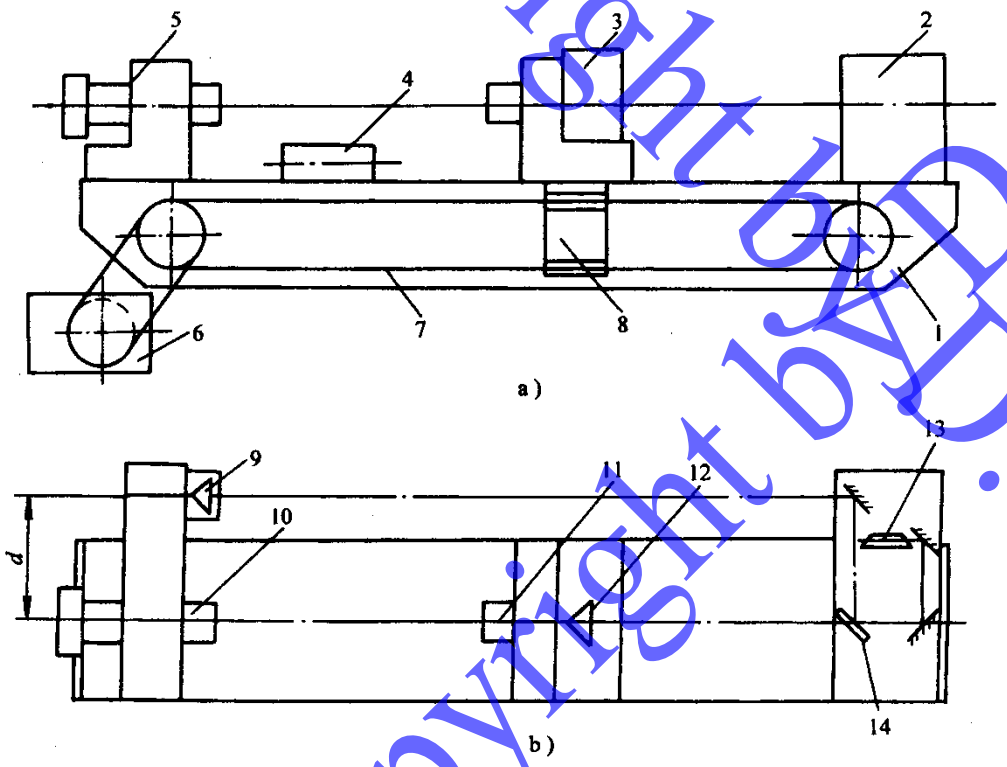
❒ Principle & Structural Properties





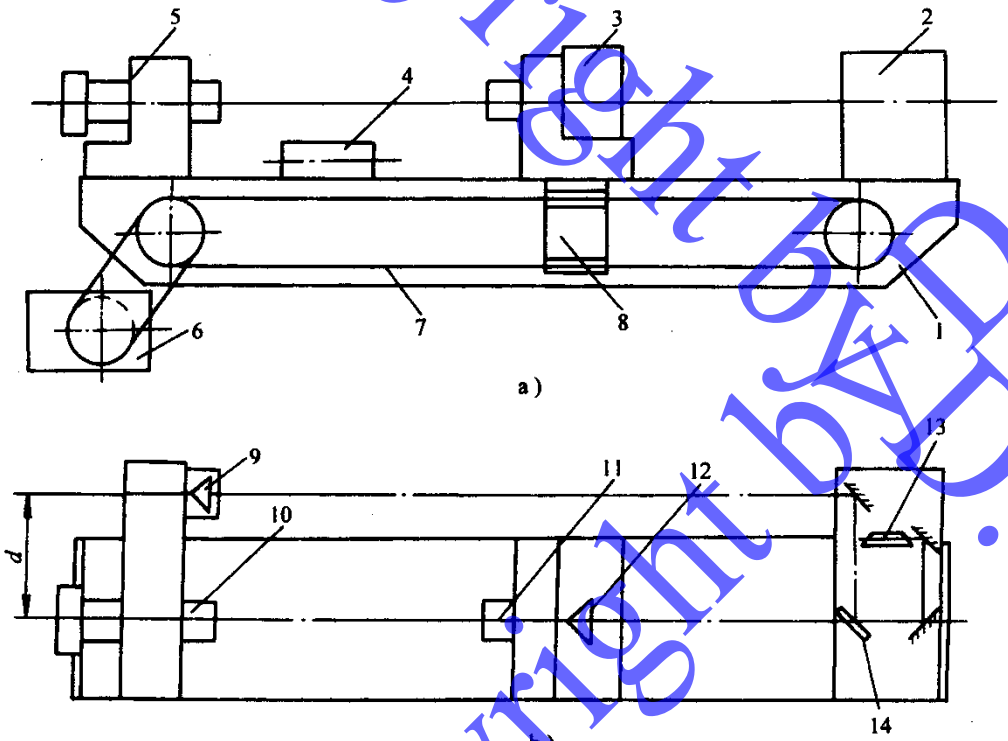
1 m Laser Interference Length Measuring Machine

❒ Operation

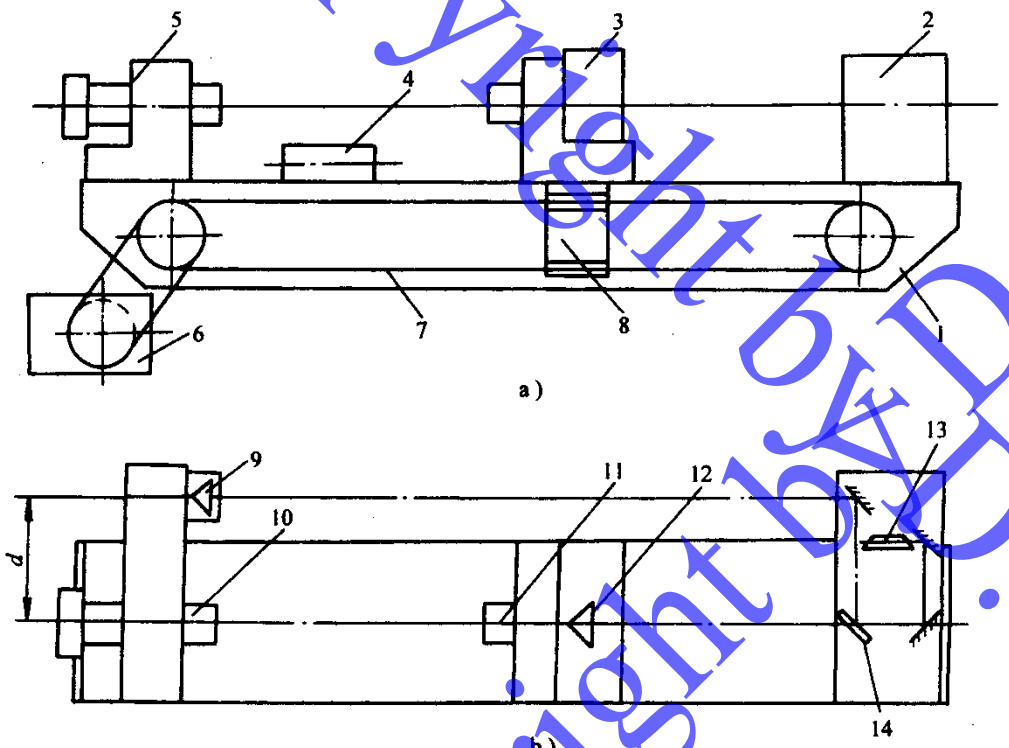


1 m Laser Interference Length Measuring Machine

❒ **Force induced deformation and its influence**



1 m Laser Interference Length Measuring Machine



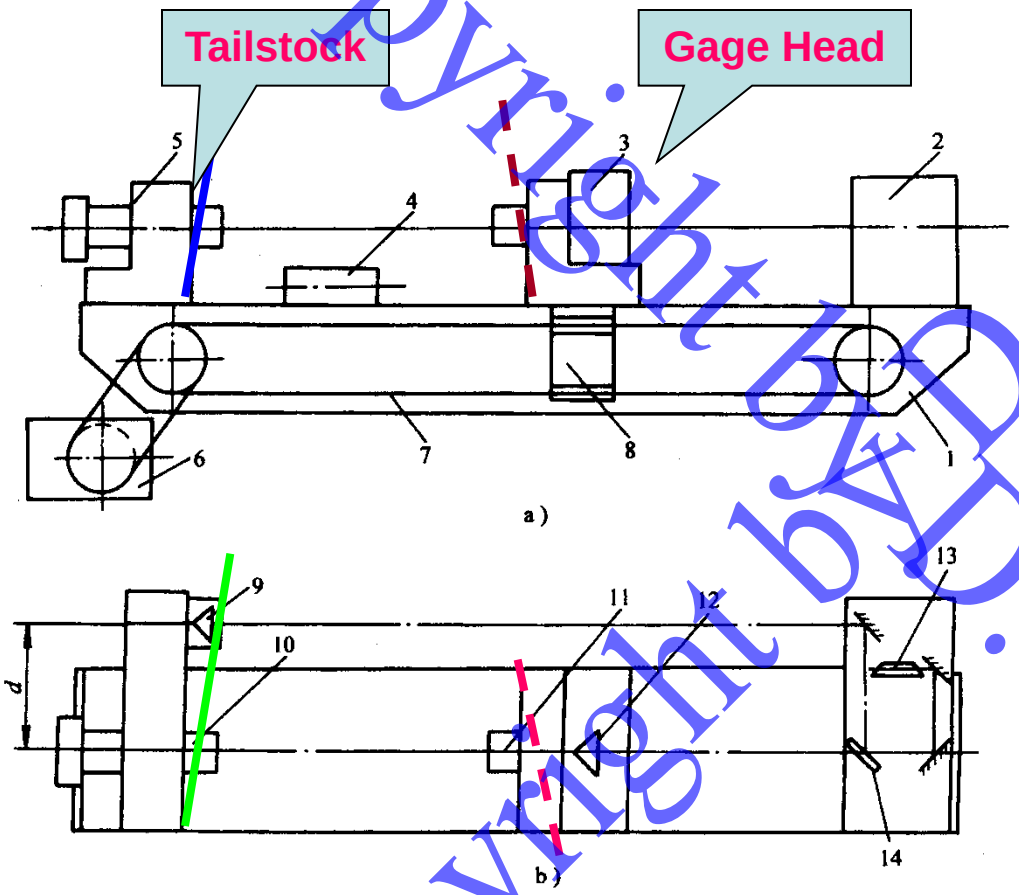
- 在测量位置上，尾座轴线相对于导轨面在垂直平面内发生**5”**倾斜角的零位变化，尾座中心高为 **200 mm**，此时引起的零位变动量

$$\Delta = 5 \times \frac{1}{2 \times 10^5} \times 200 \times 10^3 \ \mu m$$

$$= 5 \ \mu m$$

- **How to eliminate the force induced deformation through design?**

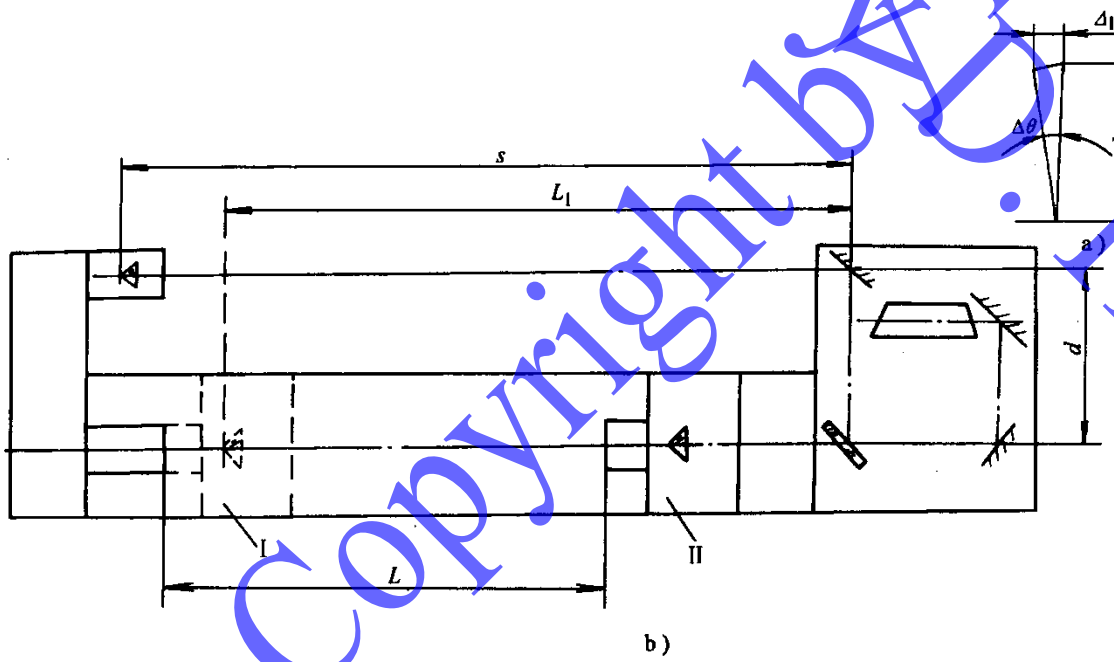
1 m Laser Interference Length Measuring Machine



- 底座因重力变形变化而引起的误差
  - 尾座5因变形变化在垂直平面内有倾角
  - 尾座在水平面内产生摆角
  - 测量头架在垂直平面内产生倾斜
  - 测量头架在水平面内产生摆角

1 m Laser Interference Length Measuring Machine

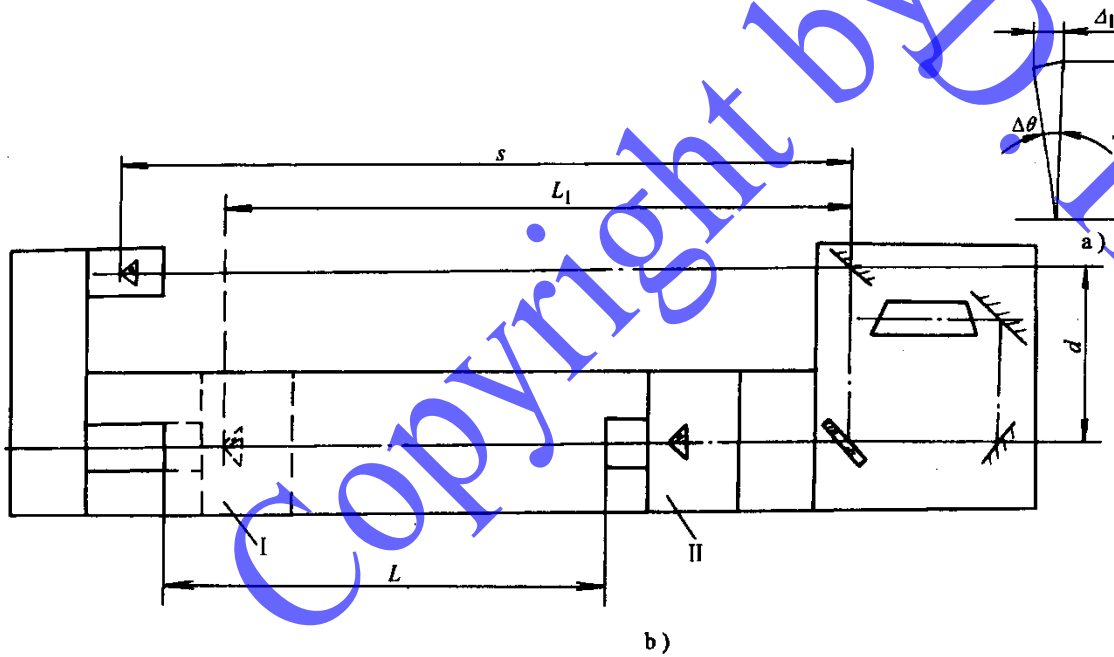
- 尾座5因变形变化在垂直平面内有倾角（位置Ⅰ）
  - 测量光路中由测量角隅棱镜到分光镜之间的距离为 ***L1***
  - 参考光路由固定角隅棱镜到分光镜之间的距离为 ***s+d***
  - 两路相干光束的光程差为 $\delta_1 = 2n\left[(s+d) - L_1\right]$



1 m Laser Interference Length Measuring Machine

- 尾座5因变形变化在垂直平面内有倾角（位置I I）
  - 测量光束由测量角隅棱镜到分光镜之间的距离 $(L_1+\Delta_1-L)$
  - 参考光束由固定角隅棱镜到分光镜的距离 $[(s+d)+\Delta_1]$
  - 测量时两路相干光束的光程差为

$$\delta_2=2n[(s+d)+\Delta_1]-2n(L_1+\Delta_1-L)=2n[(s+d)-L_1+L]$$



条件：

① 固定角隅棱镜与尾座固结在一起；

② 固定角隅棱镜的锥顶安放在尾杆10的轴线离底座导轨面等高的同一平面内；

1 m Laser Interference Length Measuring Machine

- 尾座5因变形变化在垂直平面内有倾角
  - 测量时和对零时两个光程差的变化量为

$$\delta_1 = 2n\left[(s+d) - L_1\right]$$

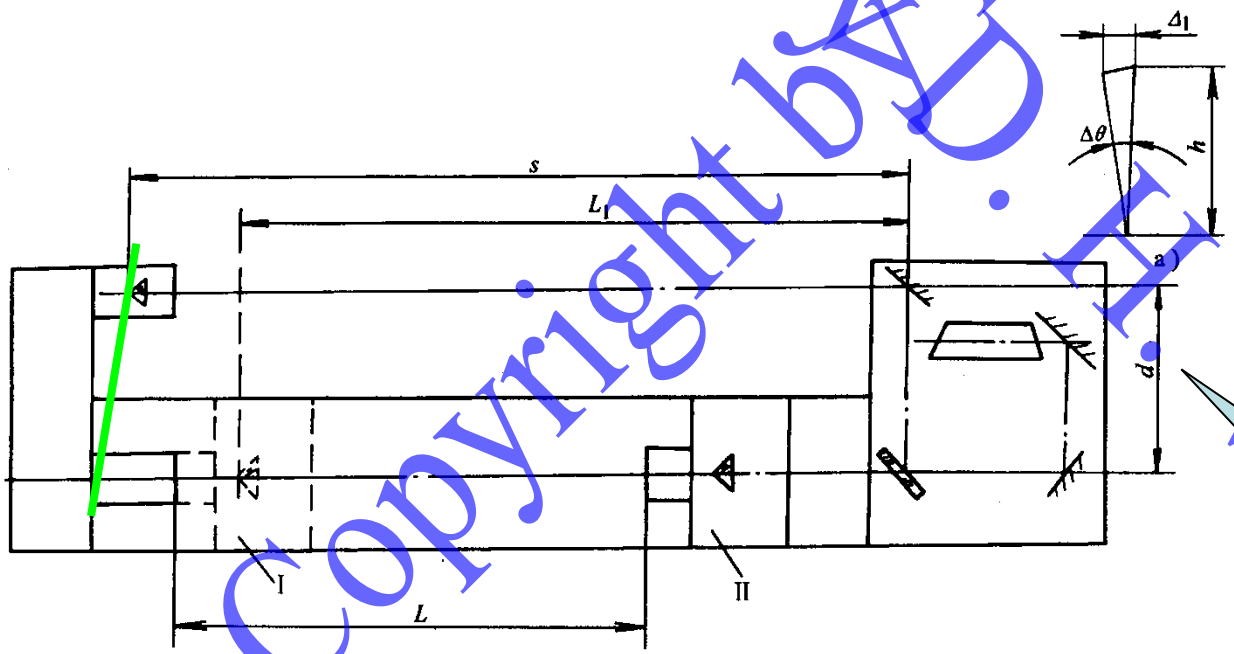
$$\delta_2 = 2n\left[(s+d) + \Delta_1\right] - 2n\left(L_1 + \Delta_1 - L\right) = 2n\left[(s+d) - L_1 + L\right]$$

$$\delta = \delta_2 - \delta_1 = 2nL$$

  - 光程差的变化的正好正比于被测长度L，也即尾杆的零位变动量已由参考镜的零位变动量所补偿。
  - 前提条件
    - ① 固定角隅棱镜9与尾座5固结在一起；
    - ② 固定角隅棱镜的锥顶安放在尾杆10的轴线离底座导轨面等高的同一平面内；

1 m Laser Interference Length Measuring Machine

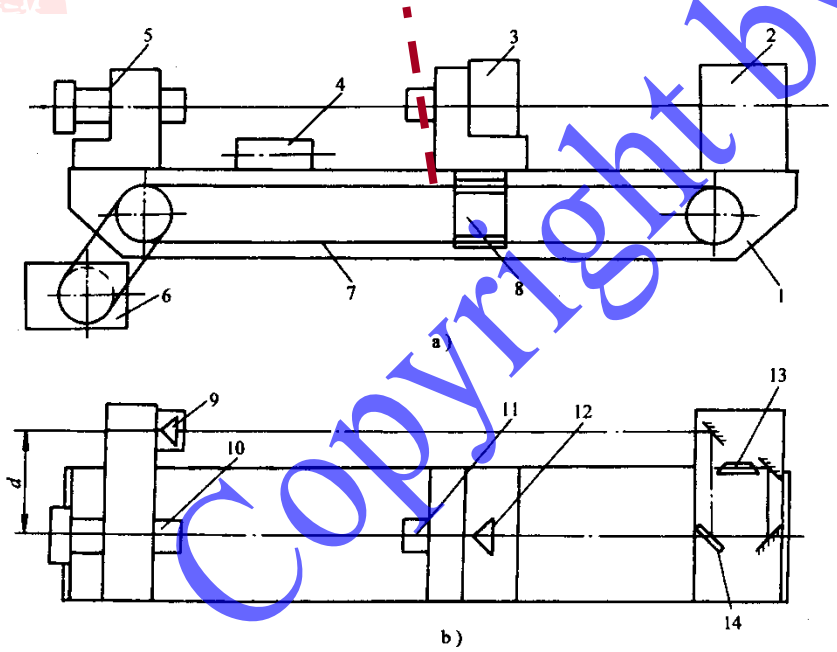
- 尾座在水平面内产生摆角
  - 因不符合阿贝原则，故误差不能补偿，满足总体布局的第④项条件可以减小该误差。
  - 条件：④ 尽可能减小固定角隅棱镜9和尾杆10在水平面内的距离***d***



Abbe Offset

1 m Laser Interference Length Measuring Machine

- 测量头架在垂直平面内产生倾斜
  - 由于总体布局满足第③项内容，符合阿贝原则，只引起二次方微小误差，可以忽略。
  - 条件：③可动角隅棱镜12的锥顶位于测量主轴11的轴心线上(以便符合阿贝原则)；



1 m Laser Interference Length Measuring Machine

- 测量头架在水平面内产生摆角
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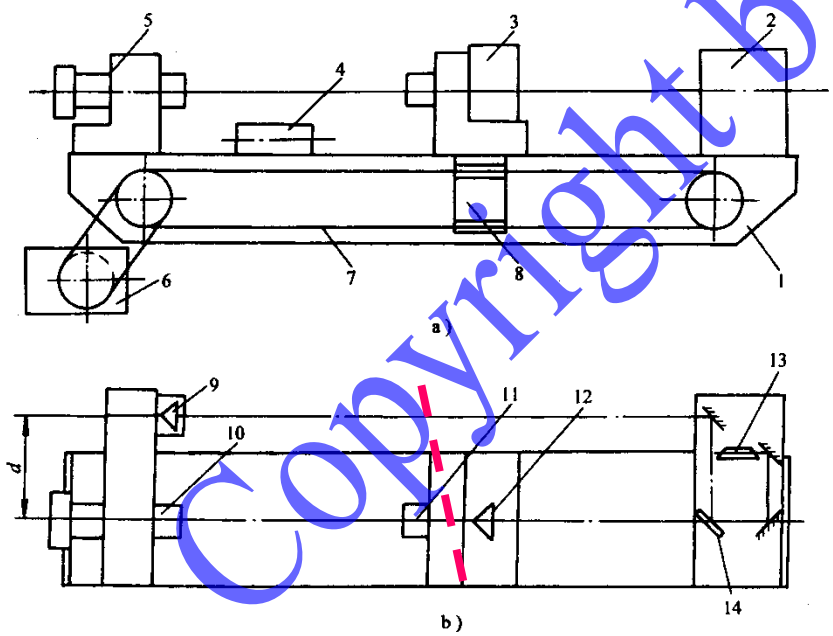

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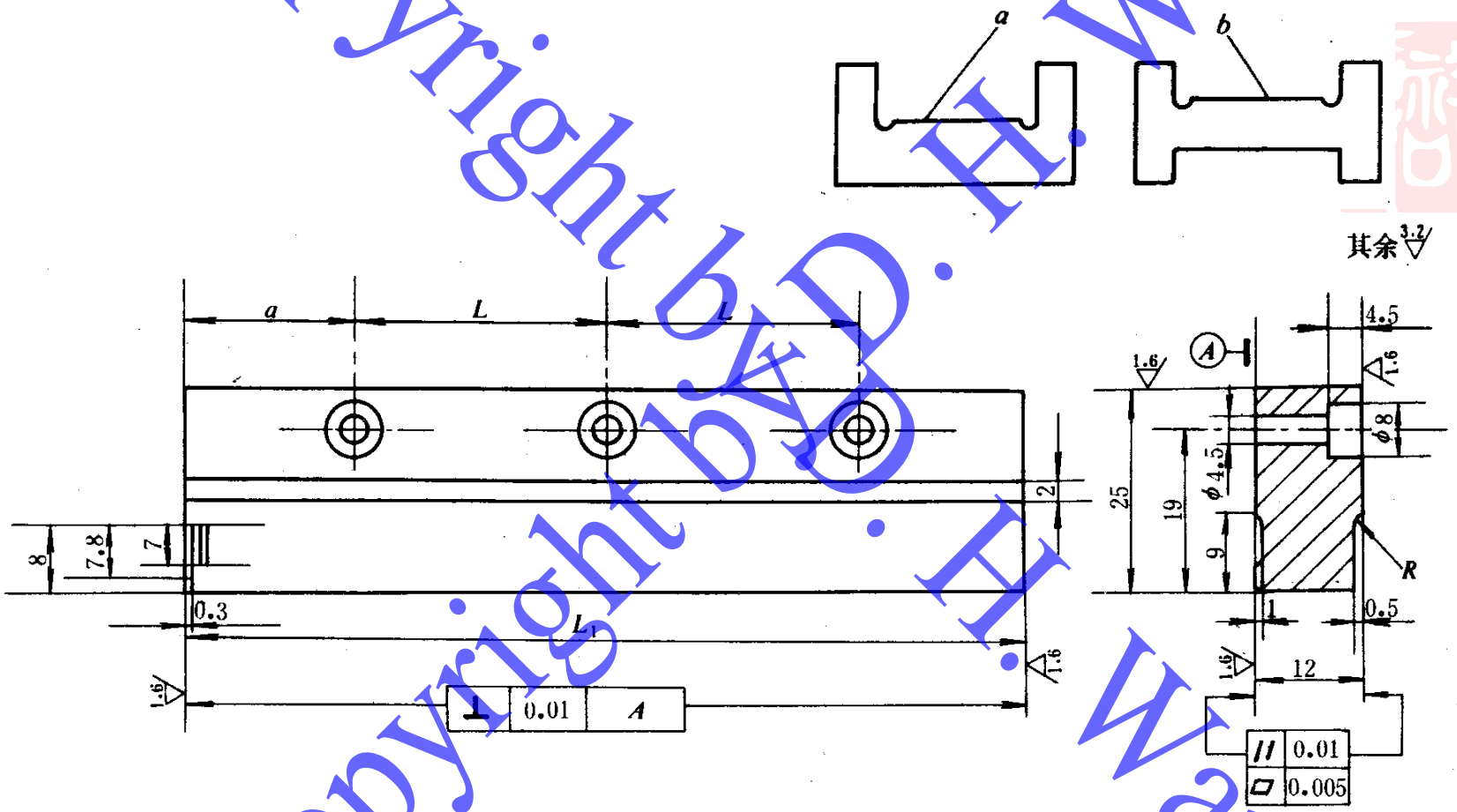
Major Applications of Light Interference

- The physical phenomenon of light interference is utilized in dimensional metrology for different purposes, the major applications are as follows
  - Length Measurement
  - *Distance Measuring Interferometer (DMI)*
  - Form Trueness Measurements
  - Surface Texture Measurement
- Refer to MCID 3 Interferometers

Francis T. Farago, *Handbook of Dimensional Measurement*, Industrial Press Inc. 1982

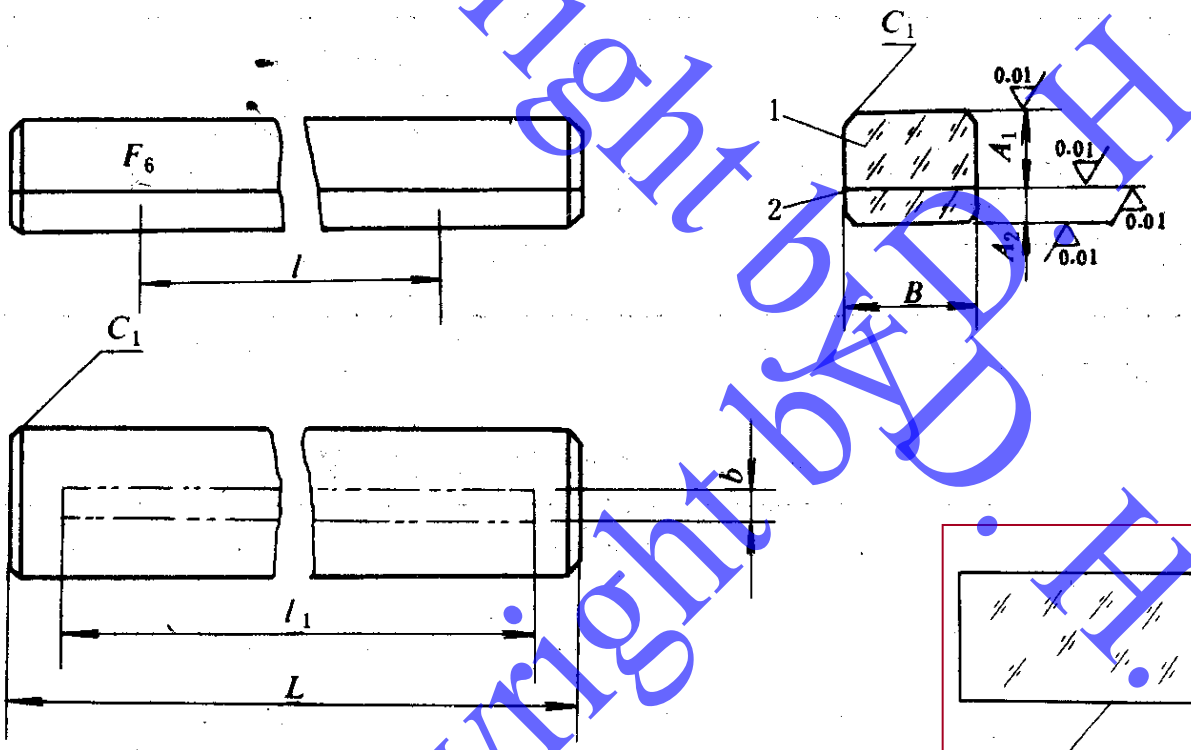
Optoelectronic Measuring Machine for Line Scales

- Line scales: Metal line scales



Optoelectronic Measuring Machine for Line Scales

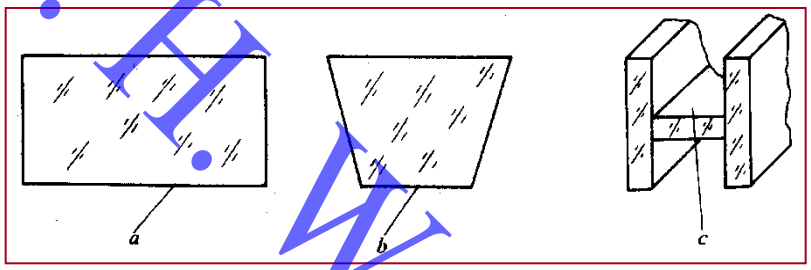
❒ **Line scales: Glass line scales**



1-线纹尺

2-保护尺

l-白塞尔支点标记



Question?

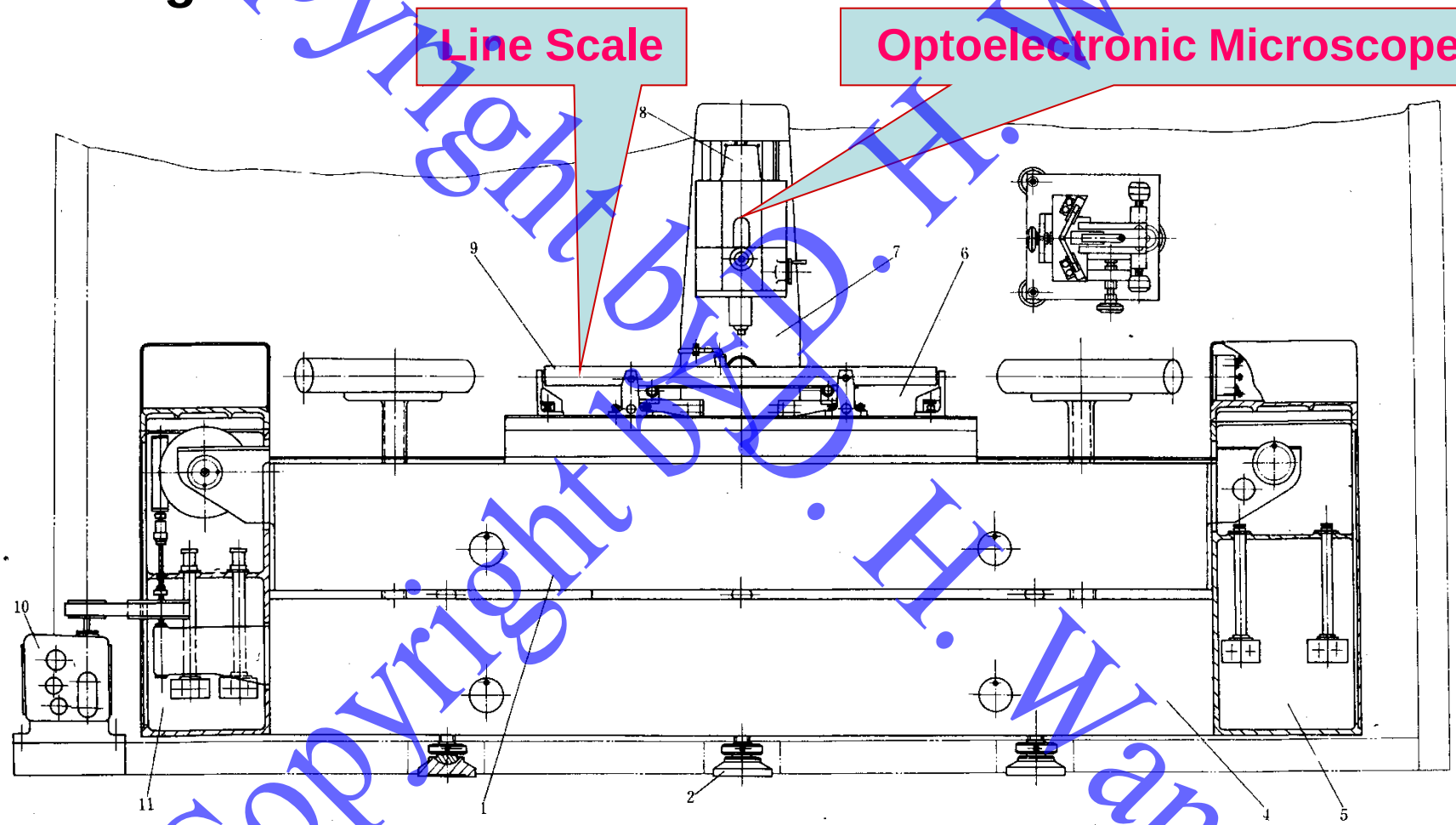
- How to measure the errors of the line scales dynamically?

Optoelectronic Measuring Machine for Line Scales

- Components
  - 标准量系统
  - 瞄准系统
  - 精密机械系统
  - 伺服控制系统
  - 。。。

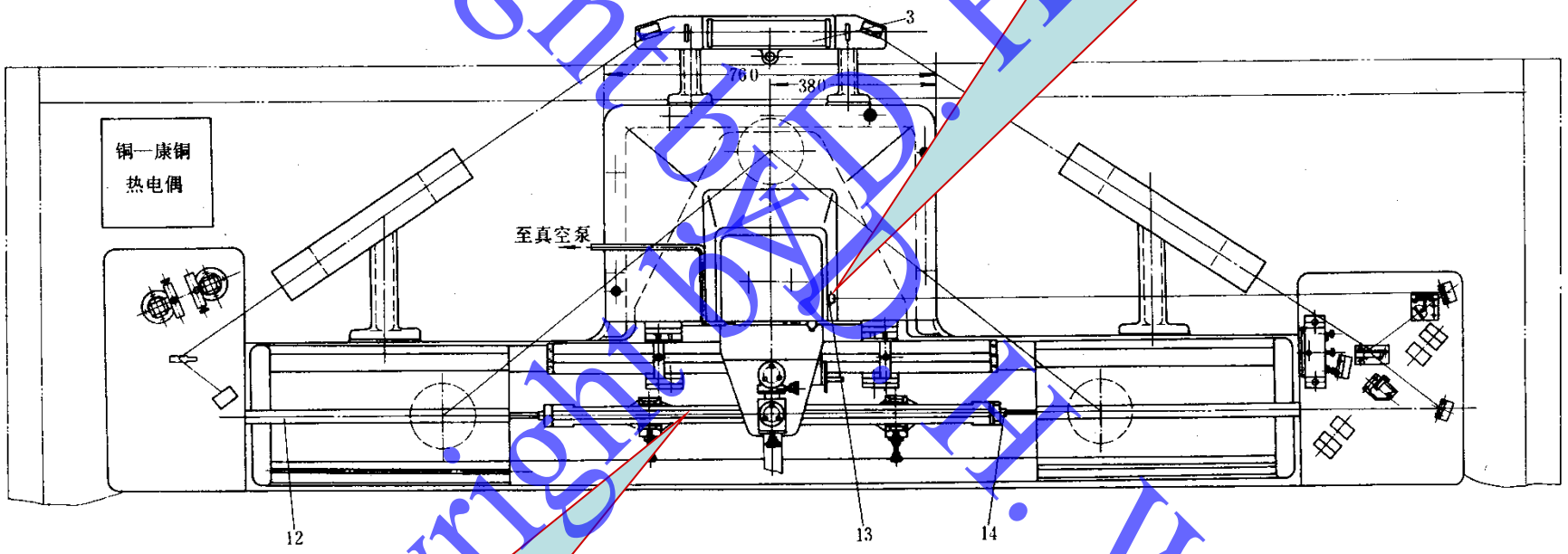
Optoelectronic Measuring Machine for Line Scales

❒ Configuration

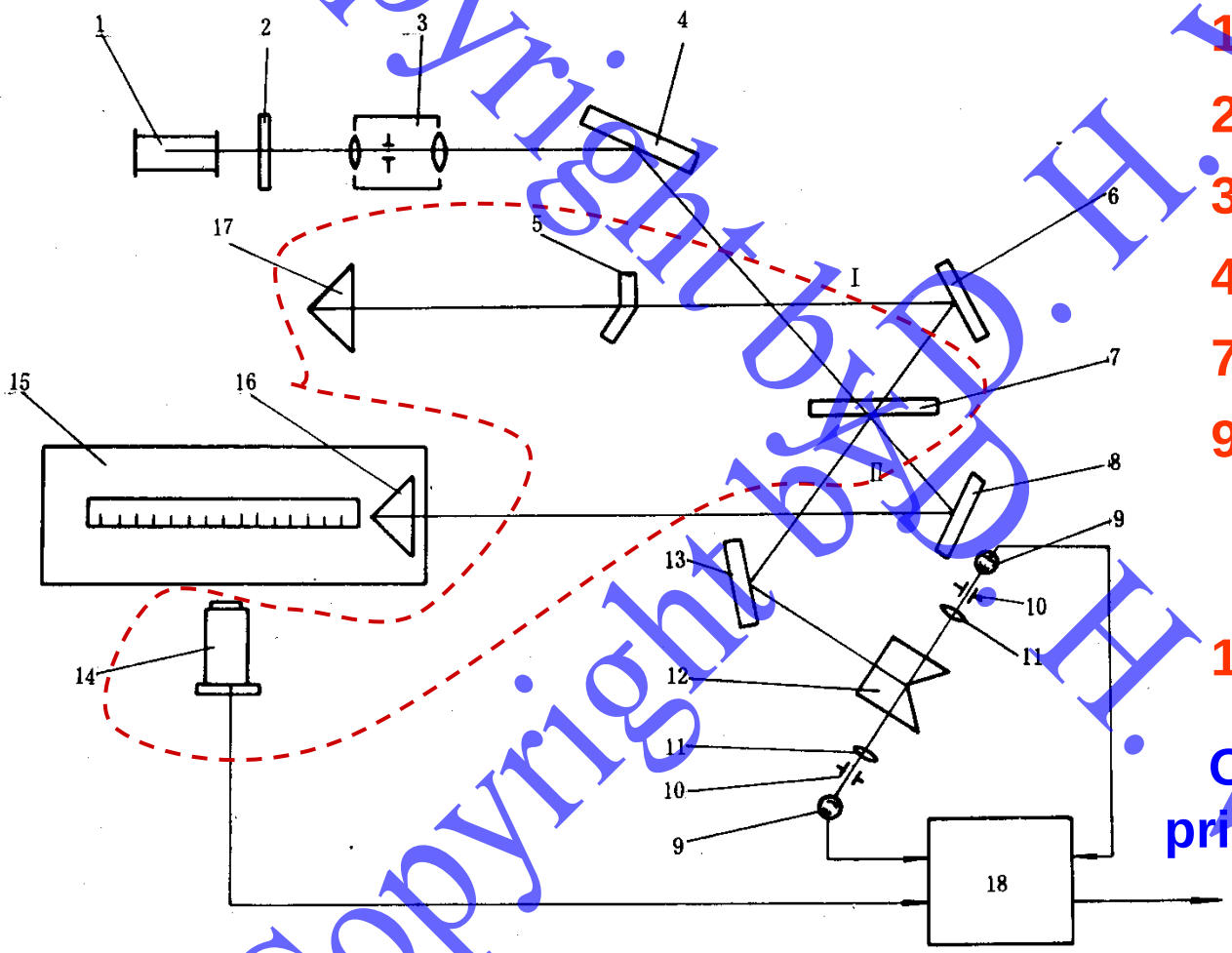


Optoelectronic Measuring Machine for Line Scales

❒ Configuration



Optoelectronic Measuring Machine for Line Scales



1-Laser tube

2-Quarter waveplate

3-Beam Expander

4,6,8,13-Mirror

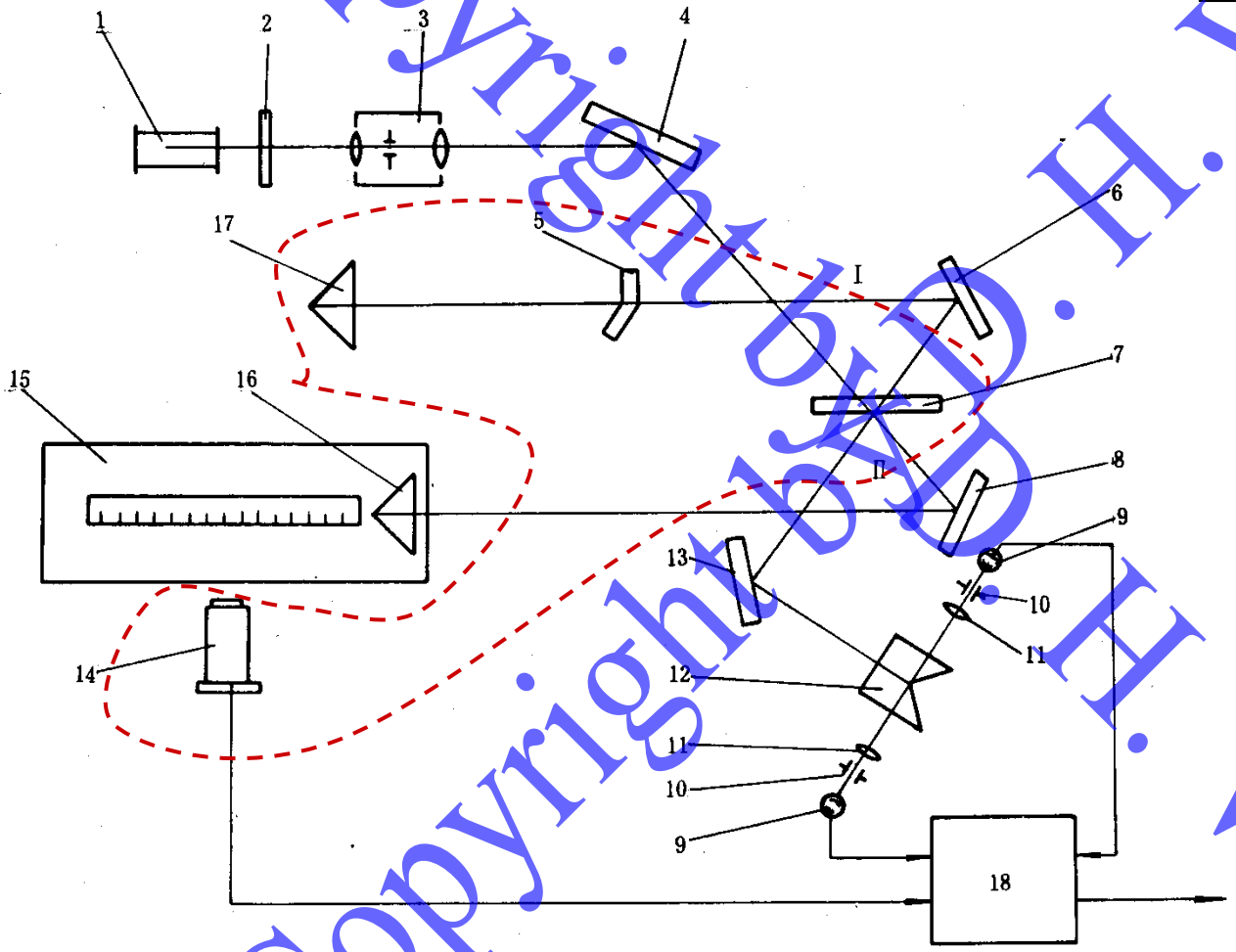
7-Beam splitter

9-PMT (Photomultiplier Tube)

12-Prism

Operating principle of principal interferometer (type: HYQ029)

Optoelectronic Measuring Machine for Line Scales



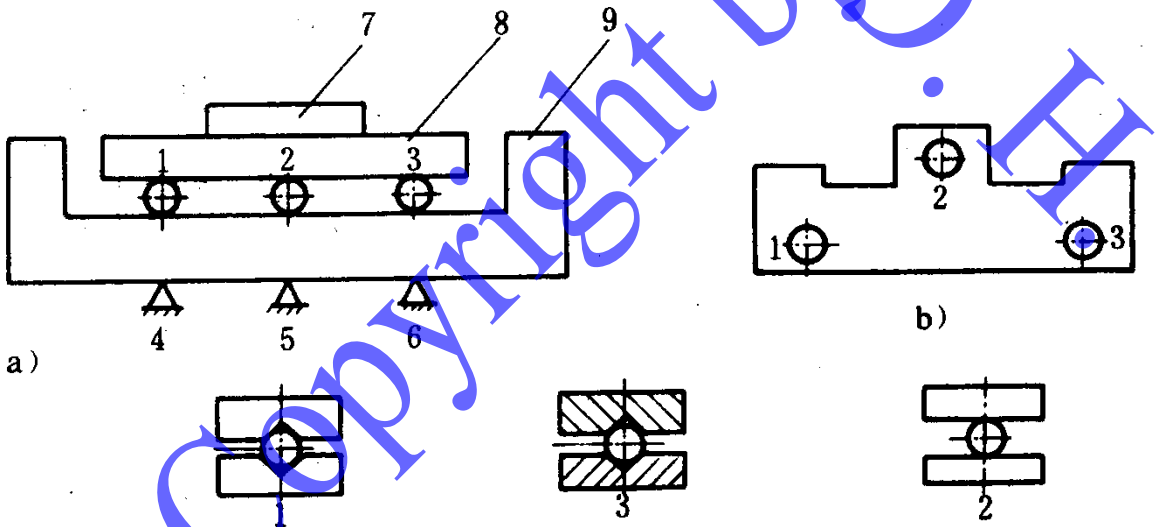
- 要求

在光电光波比长仪中，光电显微镜、固定参考镜和干涉系统的分光镜三者之间的相对位置，要求严格保持不变

Optoelectronic Measuring Machine for Line Scales

❒ Characteristics of Mechanical Structure

- 采用了工作台、床身、基座三层结构的形式
- 布局上把光电显微镜、固定参考镜和干涉系统的分光镜三者都装在与基座相连的构件上
- 既能自动定位，又无附加内应力，在有些资料中，把它称之为无附加内应力的自动定位设计

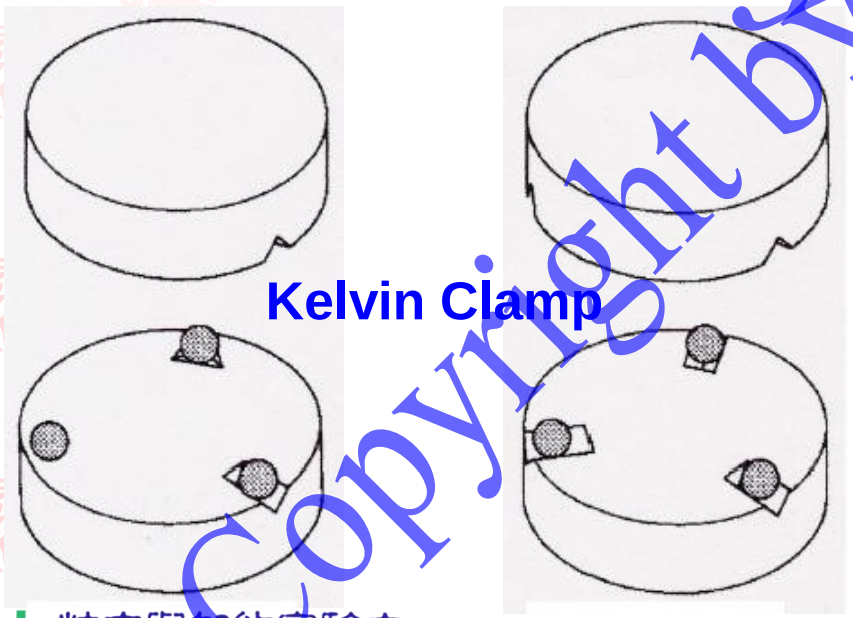


Exact Constraint (Kinematic) Design

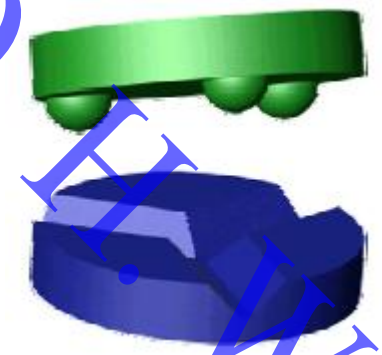
- Exact Constraint
  - Number of constraint points = DOF to be constrained
- These constraints must be independent!!!
- Assuming couplings have rigid bodies, equations can be written to describe movements
- Design is deterministic, saves design and development
- KCs (Kinematic Coupling) provide repeatability on the order of parts' surface finish

Kinematic Coupling Design

- KNOW what is happening in the system
- Manage forces and deflections
- Minimize stored energy in the coupling
- Know when “Kinematic Design” should be used
- Know when “Elastic Averaging” should be used

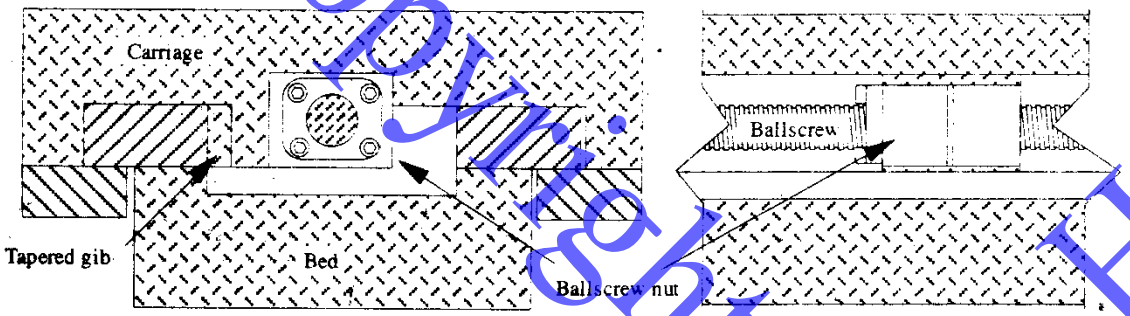


Kelvin Clamp



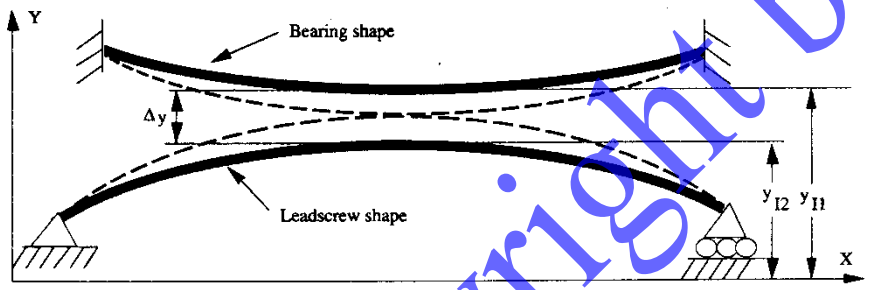
Boyes Clamp

Optoelectronic Measuring Machine for Line Scales

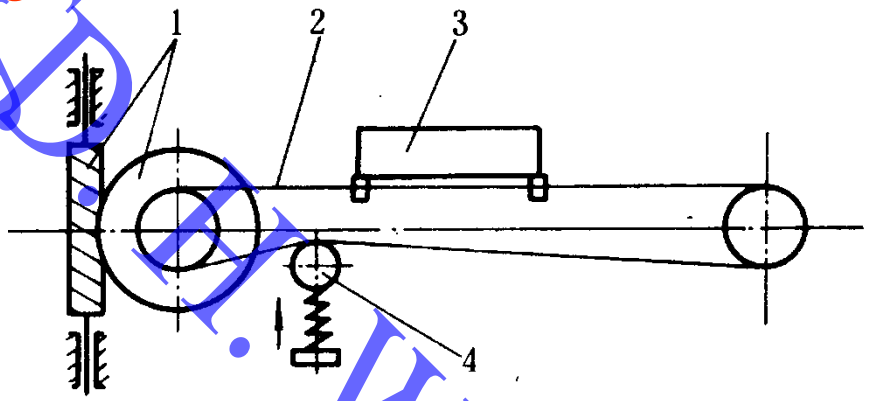


Alexander H. Slocum, *Precision Machine Design*, Prentice Hall, Inc., 1992

Schematic of a ballscrew–driven machine-tool carriage with sliding contact bearings



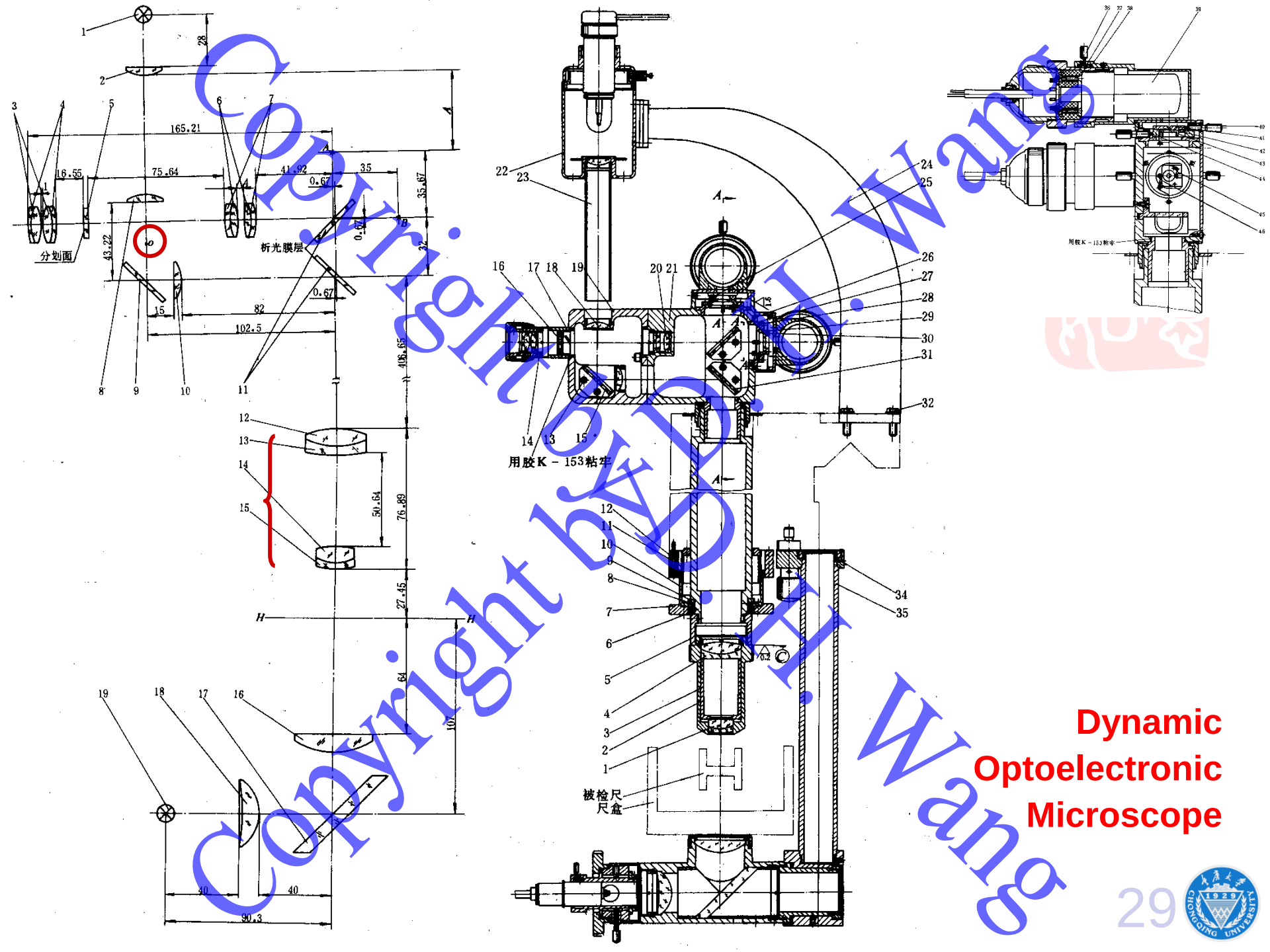
Example of coupling geometry between a linear bearing and a leadscrew.



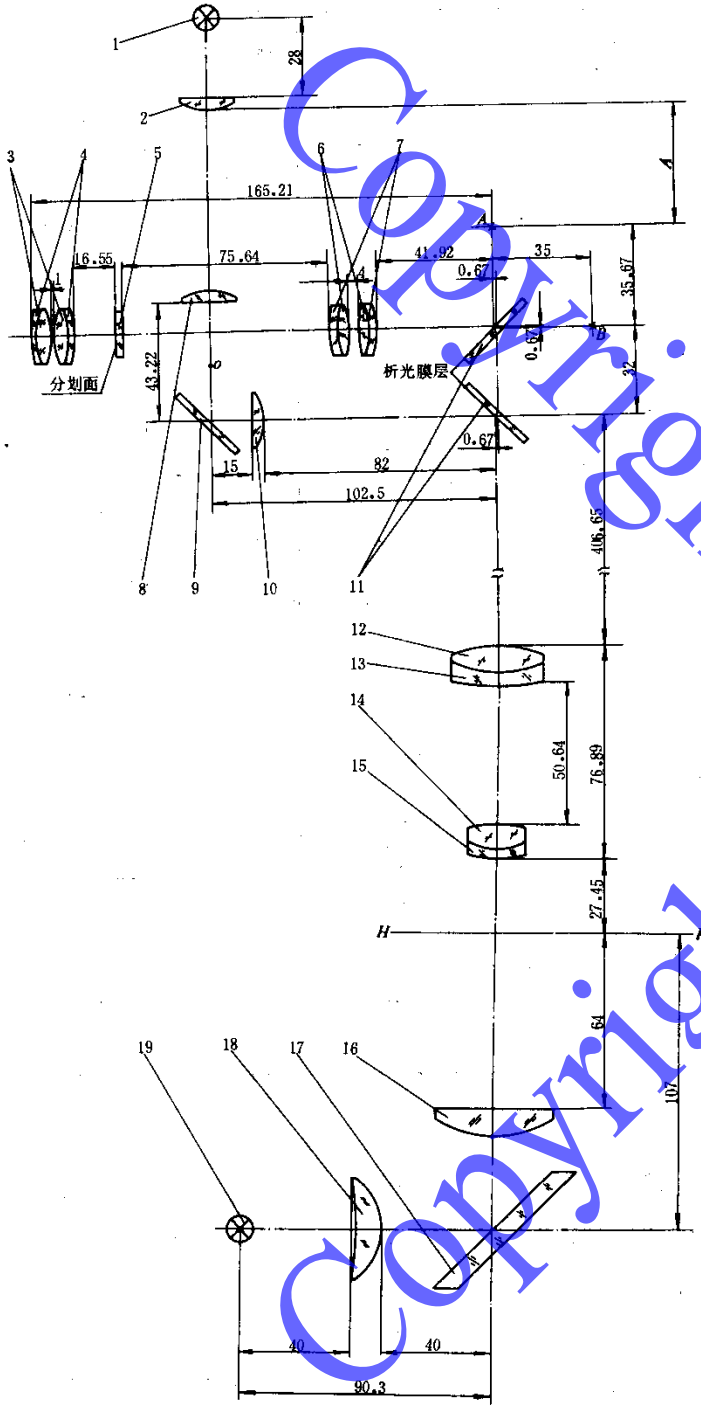
Metal belt drive

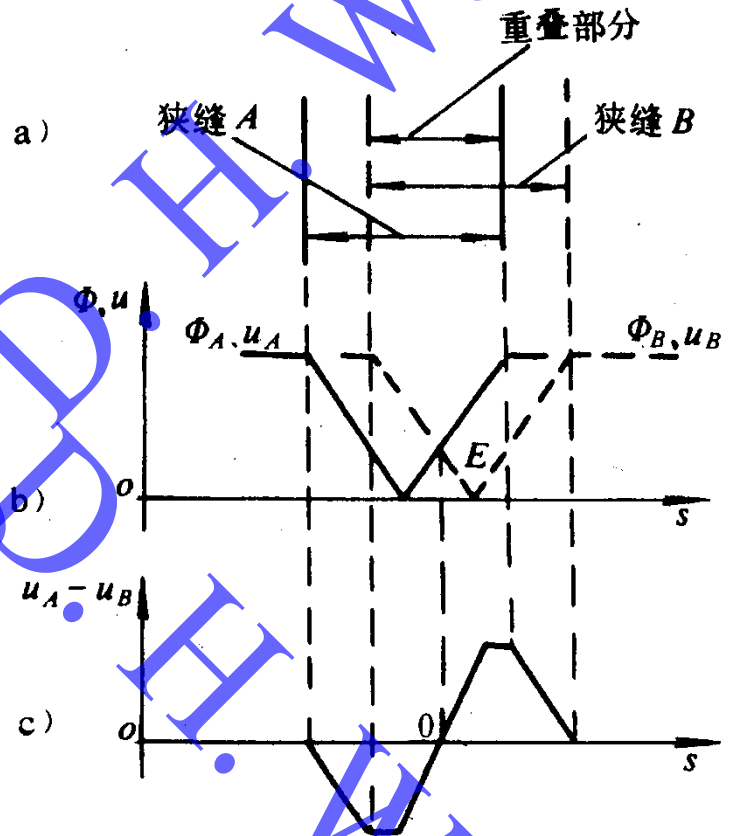
Dynamic Optoelectronic Microscope

- 动态光电显微镜用于被检尺在连续运动状态下进行瞄准



Dynamic Optoelectronic Microscope





Dynamic Optoelectronic Microscope

（光度式双管差动光电显微镜）

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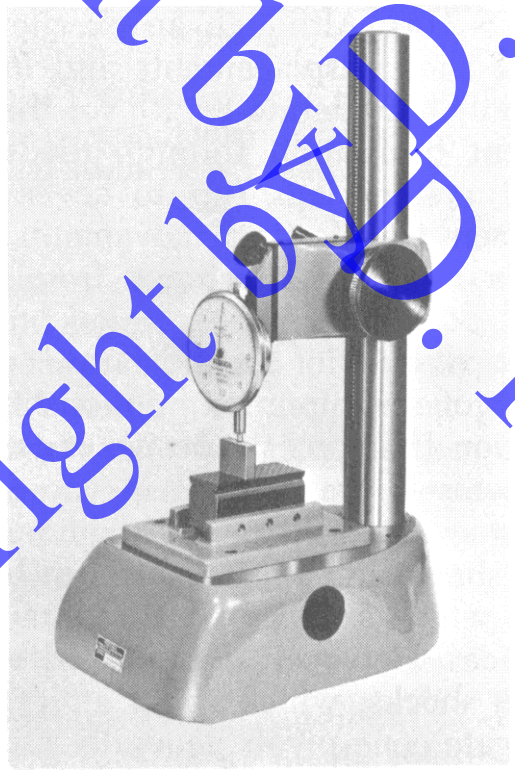
JRL: http://www.pilab.coe.cqu.edu.cn/

Question?

- How to design a measuring machine to check dial indicators (Automatic Measuring Machine for Dial Indicator) according to the working principle of checking line scales?

Dial Indicators



Comparator stand with dial indicator, adjustable support arm, and work-staging platen mounted on the plate

The End

Thank you very much for your attention !

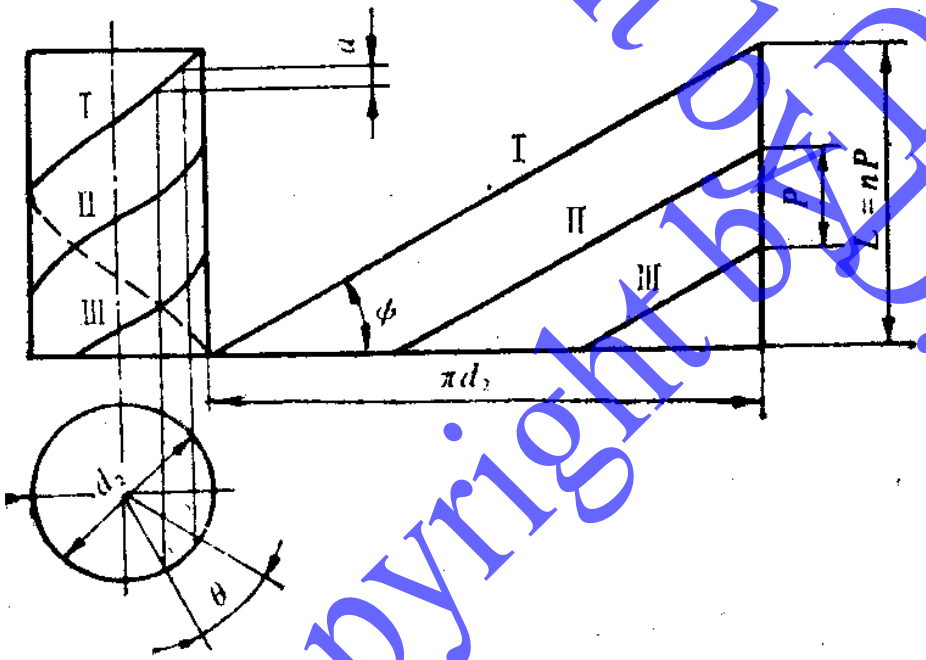
E-mail: dhwang@cqu.edu.cn
URL: http://www.pilab.coe.cqu.edu.cn/

Minimize Deformation due to Thermal Expansion

- Design strategies to minimize deformation due to Thermal Expansion
  - Reduce sensitivity
  - Manage heat sources
  - Control machine environment
  - Compensate for measured deviations
- Ex: Dynamic Measuring Machine for Screws

Dynamic Measuring Machine for Screws

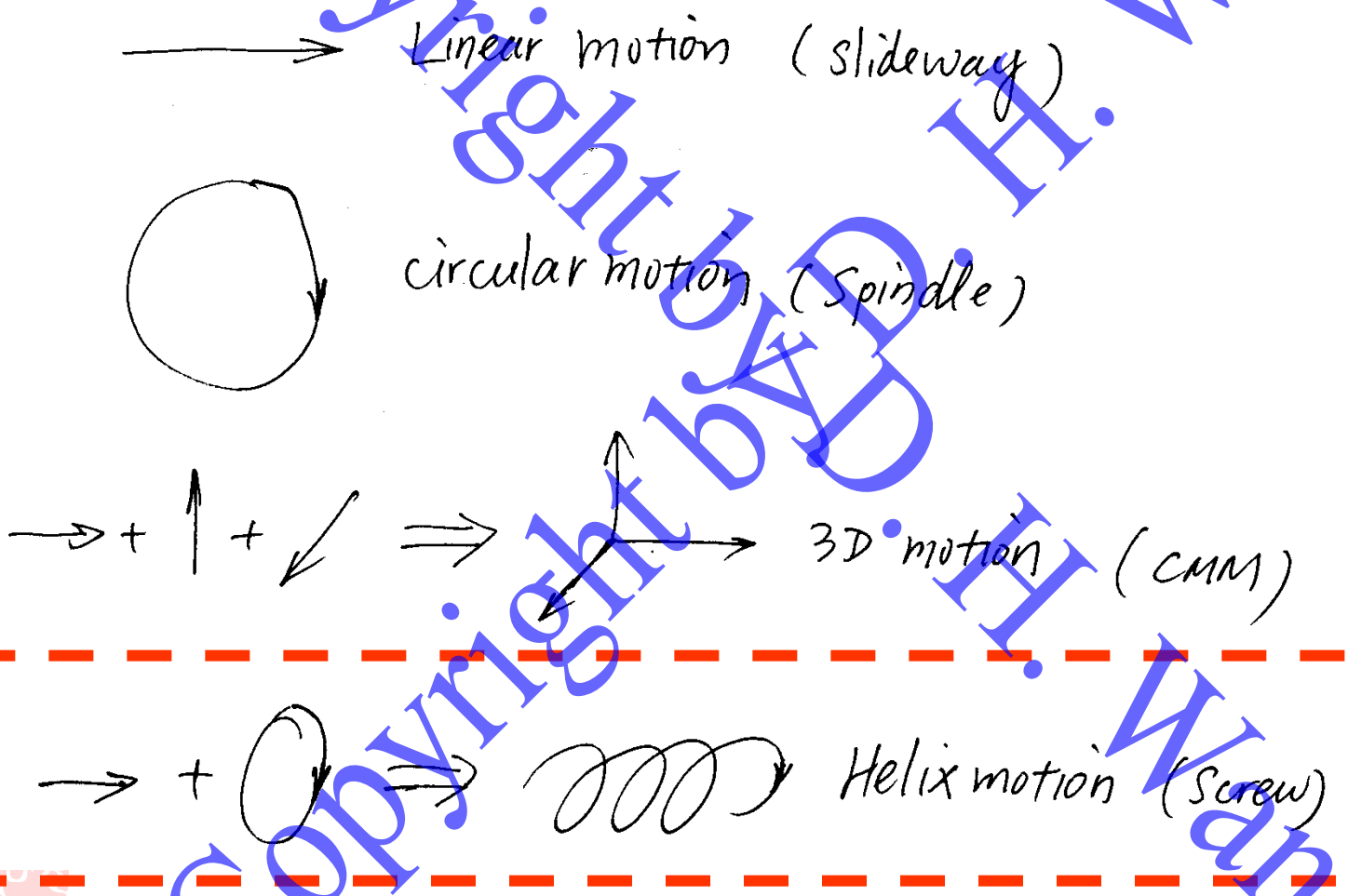
- Helix motion
  - Lead
  - Pitch



$$\frac{L}{2\pi} = \frac{a}{\theta}$$

Dynamic Measuring Machine for Screws

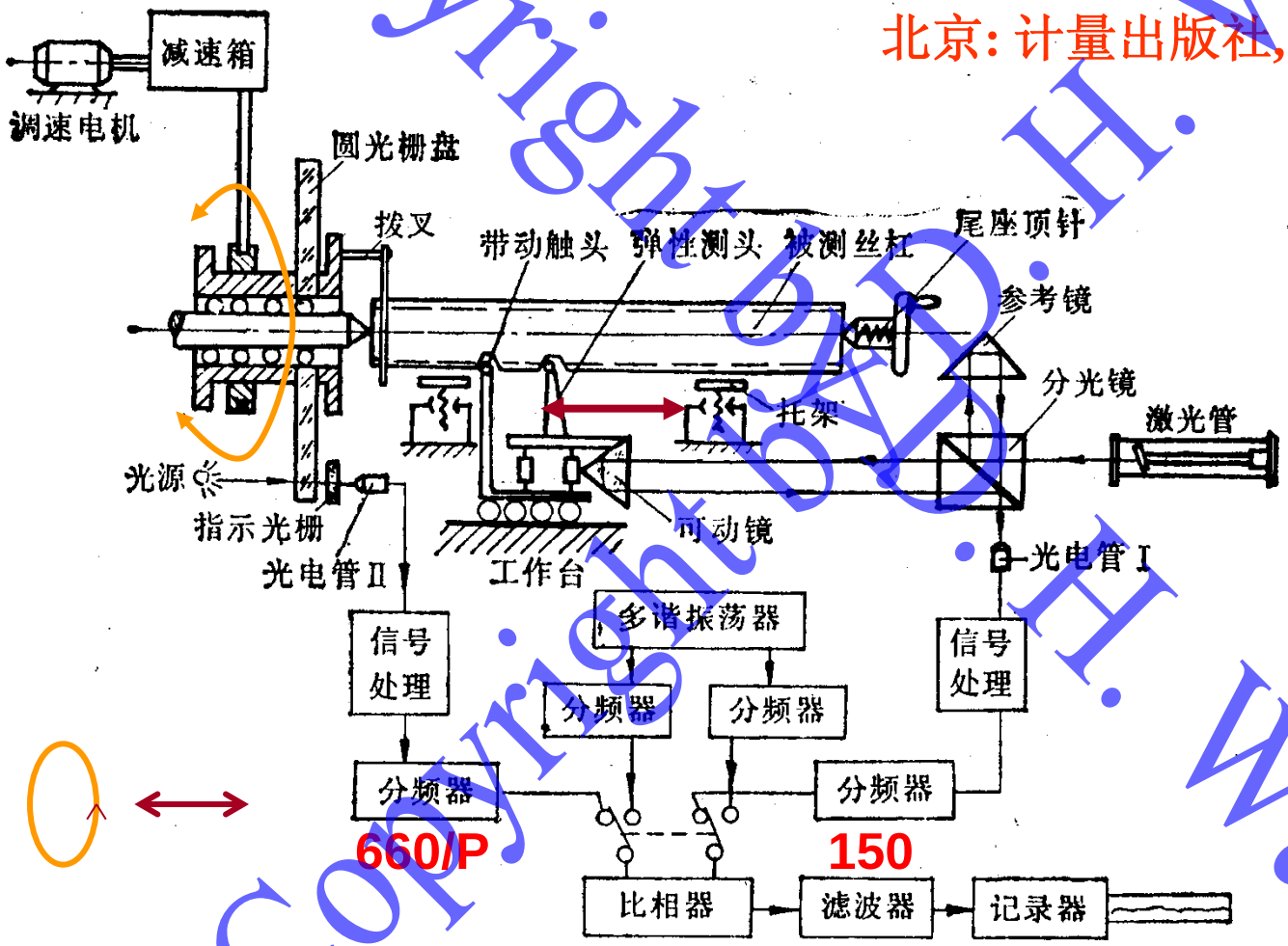
❒ Helix motion



Dynamic Measuring Machine for Screws

❒ Working principle

李柱, *互换性与测量技术基础(下册)*, 北京: 计量出版社, 1985



$$\frac{L}{2\pi} = \frac{a}{\theta}$$

Dynamic Measuring Machine for Screws

- **Wavelength of the He-Ni Laser**

$$\lambda = 0.6328198 \pm 1 \times 10^{-7}\,\mu m$$

- **Pulse number from the photo-detector in 1 mm**

$$N = \frac{1000}{\lambda/2} = \frac{2000}{0.6328198} \approx 3160.457 \approx 13906 \times \frac{5}{22}$$

$$\frac{PN}{150} = \frac{P}{150} \times \frac{13906 \times 5}{22} = \frac{6953}{330} P \approx 21.07P$$

P—螺距

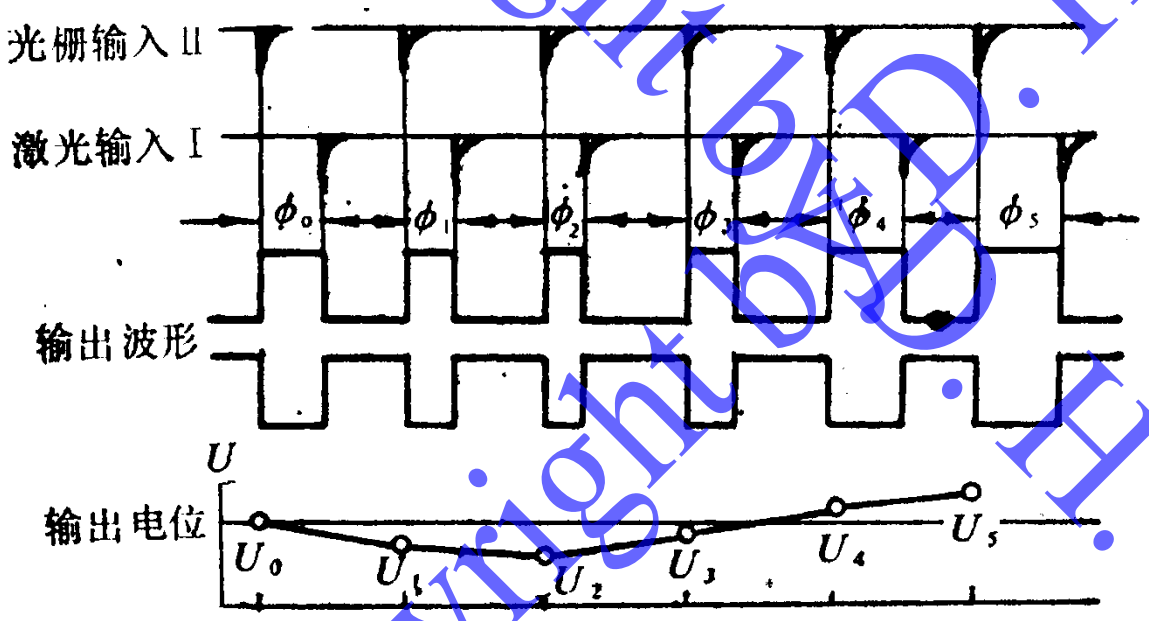
- **Pulse number from the circular grating sensor**

$$\frac{13906}{660/P} = \frac{6953}{330} P \approx 21.07P$$

$$\frac{L}{2\pi} = \frac{a}{\theta}$$

Dynamic Measuring Machine for Screws

- Working principle of the phase-detector of Dynamic Measuring Machine for Screw



Dynamic Measuring Machine for Screws

- **Assumption**
  - The temperature does not change within a whole measurement process.
  - The error induced by the temperature is linearly proportional to the measured length.
- **Method**
  - According to the measured temperature and humidity, the compensated error is determined.
  - The error is compensated through increasing/decreasing the number of the counting pulses in the two legs.

Dynamic Measuring Machine for Screws

❒ **Error compensated** $\Delta L = 5\ \mu\text{m/m}$

$$N_1 = \frac{\Delta L}{\frac{\lambda}{2}} = \frac{5\ \mu\text{m}}{\frac{\lambda}{2}}$$

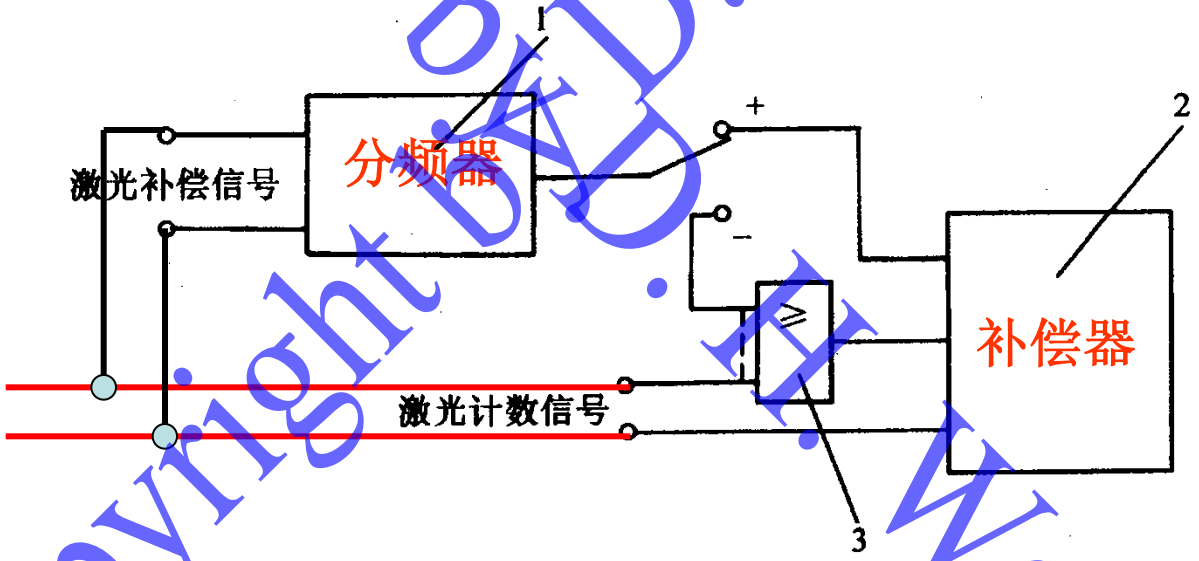
$$M_1 = \frac{10^6\ \mu\text{m}}{\frac{\lambda}{2}}$$

$$\frac{M_1}{N_1} = 2 \times 10^5$$

Dynamic Measuring Machine for Screws

❒ **Schematic of temperature error compensating system**

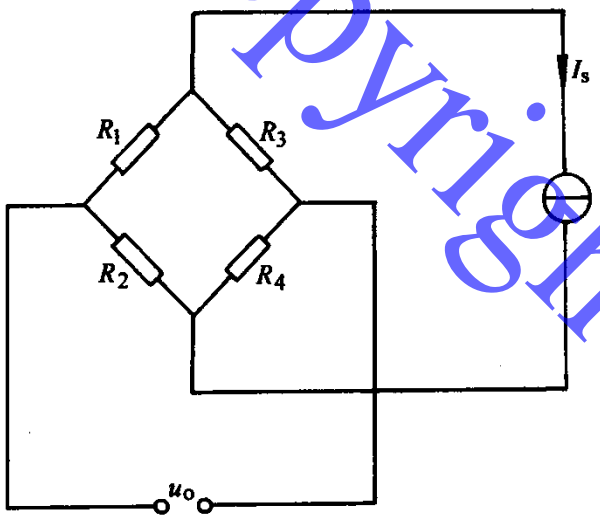
$$\frac{M_1}{N_1} = \frac{10^6}{\Delta L}$$

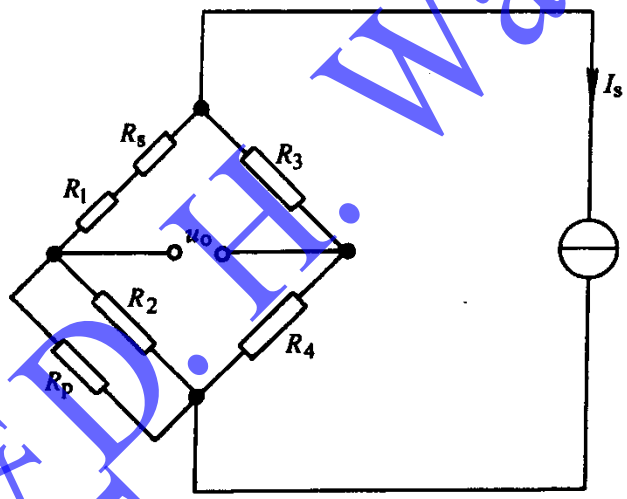


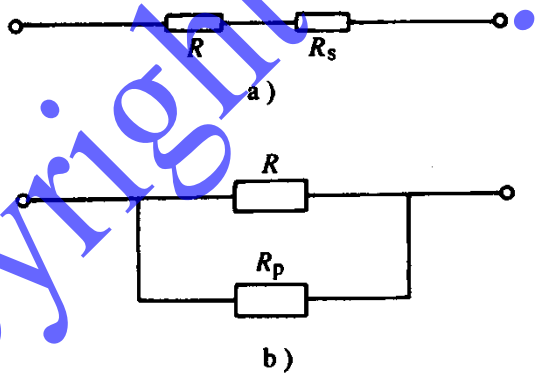
Question?

- 怎样采用脉冲计数的原理（代替分频比相原理）设计激光丝杆动态测量仪的信号处理系统？
  - 要求：绘制详细电路原理图，给出相应的文字说明。

Si-diffused Pressure Transducers







The End

Thank you very much for your attention !

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