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Chapter 2: Precision Theory of Instruments

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Outline of Chapter 2

❑ Basic Concepts

 **Lecture 1**

❑ Error sources and properties

 **Lectures 2 & 3**

❑ Analysis and calculation

 **Lecture 4**

❑ Propagation & Accumulation

 **Lecture 5**

❑ Precision Design

 **Lecture 6**

❑ Summary



Lectures Organization

- ❑ Lecture 1: Basic Concepts
- ❑ Lecture 2: Error Sources & Properties of Instr. (Part 1)
- ❑ Lecture 3: Error Sources & Properties of Instr. (Part 2)
- ❑ Lecture 4: Error Analysis and Calculation (Part 1)
- ❑ Lecture 5: Error Analysis and Calculation (Part 2)
- ❑ Lecture 6: Precision Design of Instrument
- ❑ Summary
- ❑ Acknowledgement

Summary of Chapter 2

- ❑ Involved Instruments and Measuring Tools
- ❑ Concepts of Error and Precision Specifications
- ❑ Error Sources of Instr.
- ❑ Error Analysis/Precision Analysis
- ❑ Error Accumulation
- ❑ Precision Design
- ❑ Instrument Error



Involved Instruments and Measuring Tools

- ❑ Laser shadow gauge
- ❑ Universal Involute Measuring Machine (UIMM)
- ❑ Involute measuring system with a circular basis
- ❑ Involute measuring system with a straight line basis
- ❑ 0.001 mm dial indicator
- ❑ Rotating-arm CMM
- ❑ Horizontal-arm CMM
- ❑ Optical Sensitive Lever
- ❑ Michelson laser interferometer
- ❑ Vertical Projection Optimeter
- ❑ Spherometer



Concepts of Error and Precision Specifications (1/2)

❑ Definition of Error

- ✍ True value
- ✍ Error types
- ✍ Error Representations

❑ Precision, Accuracy, Trueness

❑ Precision Specifications of Instr.

- ✍ Static characteristics
- ✍ Dynamic Characteristics



Concepts of Error and Precision Specifications (2/2)

□ Precision Specifications of Instr.

Static characteristics

-  Linearity
-  Indicate error and Repeatability/Reproducibility
-  Sensitivity
-  Resolution/discrimination
-  Stability and zero draft
-  Hysteresis

Dynamic Characteristics

-  Unit impulse response
-  Transfer function
-  Frequency response function



Error Sources of Instr. (1/2)

❑ Principle Errors

- ✍ How to determine the principle errors in the design stage and evaluating stage?
- ✍ How to simplify the mechanism to assure the instrument's precision through compensating for the principle error?

❑ Manufacturing Errors

❑ Running Errors

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Error Sources of Instr. (2/2)

❑ Principle Errors



❑ Manufacturing Errors

❑ Running Errors



Force induced deflection



Stress induced deflection



Measuring force induced deflection



Wear



Clearance and backlash induced error



Thermal induced error



Vibration



Disturbance and environment condition



Error Analysis/Precision Analysis (1/2)

- ❑ Basic concept
- ❑ Steps for Error Analysis and Calculation
 - ✍ Step 1. Determine error sources
 - ✍ Step 2. Analysis influence of each source to accuracy of instrument
 - ✍ Step 3. Precision propagation & accumulation
- ❑ Error independent functional principle (EIFP)
- ❑ Error analysis methods



Error Analysis/Precision Analysis (2/2)

❑ Error analysis methods

 **Differential method**

 **Geometric method**

 **Functional line and instantaneous arm method**

 **Mathematical fitting method**

 **Error analysis method for control systems**

 **Vector Algebra**

 **Coordinate Transformation**

 **Other methods**



Error Accumulation (1/2)

❑ Basic Concepts

- ✍ 在仪器设计完成后，需要估算仪器的总精度，并与设计任务书给出的精度要求相比较，以指导进一步设计，这时需要进行仪器误差的综合计算
- ✍ 在仪器进行技术鉴定时，也需要给出理论上的精度分析与估计，以便做出恰当的评价，这时也需要进行仪器误差的综合计算

❑ Accumulation Methods

- ✍ Accumulation of random errors
- ✍ Accumulation of systematic errors
 - ✍ Accumulation of determinate systematic errors
 - ✍ Accumulation of indeterminate systematic errors

Error Accumulation (2/2)

- ❑ Basic Concepts
- ❑ Accumulation Methods
- ❑ *Case Study*: Error Analysis and Accumulation of Vertical Optimeter

✍ How to classify the determinate/indeterminate systematic errors?

✍ How to adjust the instrument error through adjusting the Lever arm?

Precision Design

❑ Basic Concepts

❑ Determine Precision Specifications of Instr.

✍ 微小误差原理

✍ Mcp检测能力指数法

❑ Error Assignment Methods

✍ Systematic Errors Assignment Methods

✍ Random Errors Assignment Method

✍ 按等作用原则分配

✍ 按加权作用原则分配

✍ 误差调整

❑ Ex: Spherometer Error Assignment and Adjusting



Instrument Error

□ Relationship between

- ✍ Total Measuring Error
- ✍ Instrument Error
- ✍ Measuring Method Errors



The End



Thank you very much for your attention !

