

# From Error Analysis to Life's Precision: The Craftsman Spirit and Foundation of a Powerful Nation in the Young's Modulus Experiment

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## Abstract

Young's modulus is a key parameter characterizing the mechanical properties of materials, and its precise measurement holds fundamental significance in materials science and engineering applications. This study conducted a systematic measurement of the Young's modulus of a metal wire using an FD-YC-I CCD elongation method apparatus, with a focused quantitative and qualitative analysis of systematic, random, and human errors encountered during the experiment. Through rigorous experimental operation and data processing, the measured value of Young's modulus was determined to be  $19.6 \times 10^{10} \text{ N/m}^2$ . The relative error compared to the accepted value of  $20.0 \times 10^{10} \text{ N/m}^2$  is 2.0%, which falls within the range of measurement uncertainty. The core of this paper lies in detailing the entire process of error analysis and providing an in-depth argument for how this process concretely embodies the Craftsman Spirit characterized by rigor, focus, and continuous improvement. Furthermore, the paper connects microscopic experimental operations with macroscopic national strategy, exploring the intrinsic logical relationship between the scientific literacy and values cultivated in basic scientific research and supporting the nation's transition from a "manufacturing giant" to a "manufacturing power." This research transcends simple experimental data reporting, representing a complete educational experience that progresses from knowledge acquisition and skill development to value identification and mission elevation.

## Keywords

Young's Modulus; Error Analysis; Uncertainty Evaluation; Craftsman Spirit; Manufacturing Power; Curriculum Ideology and Politics.

## 1. Introduction

In the fundamental research of materials science and engineering mechanics, Young's modulus, as a core physical concept and material property parameter, is defined as the ratio of stress to corresponding strain when a material is subjected to stress within its elastic limit. This parameter quantitatively describes a solid material's ability to resist elastic deformation and is an indispensable fundamental data point for structural design, material selection, and safety assessment. The primary objective of this experiment is to accurately calculate the Young's modulus of a metal wire by optically measuring its tiny elongation  $\Delta L$  under axial tensile force, based on the fundamental formula of Hooke's Law,  $E = \frac{F \cdot L}{A \cdot \Delta L}$ . Here,  $F$  is the applied force,  $L$  is the original length of the wire,  $A$  is its cross-sectional area calculated from the diameter  $d$ , and  $\Delta L$  is the elongation.

During the initial stage of the experiment, faced with tedious instrument adjustment procedures, repetitive loading-unloading operations, and initially dispersed measurement data, I, like many classmates, felt confused and somewhat impatient. The lab session seemed like just a credit requirement to be completed. However, upon realizing that the measurement accuracy of the key quantity determining the final result's reliability—the micron-scale elongation  $\Delta L$ —depended entirely on every operational detail, my mindset underwent a fundamental shift. I recognized that the ultimate value of this experiment was not merely to obtain a neat data point that closely matched the accepted value in the textbook. Its deeper significance lay in personally experiencing and learning how to systematically identify, analyze, evaluate, and minimize various errors introduced throughout the entire measurement process. This constitutes a complete and rigorous training in scientific thinking.

This persistent pursuit of "precision" at the laboratory scale shares its essential spirit with the stringent requirements for accurate characterization and control of material properties in China's strategic sectors such as high-end equipment manufacturing, aerospace, and precision instruments. The research and manufacturing of major national projects are all built upon massive, reliable, and precise fundamental experimental data. Therefore, this paper decides to use "error analysis" as the consistent thread, not only systematically and objectively recording the entire process of experimental operation and data processing but also striving to elaborate on the profound implications of this process for shaping the scientific spirit, cultivating professional professionalism, and building national industrial capability. This is an exploration from micro-practice to macro-reflection.

## 2. Experimental Methods and Procedure

### 2.1. Apparatus and Measurement Principle

The core equipment used in this experiment was the FD-YC-I CCD elongation method Young's Modulus measuring apparatus. This integrated system mainly consists of the following components: a wire support frame providing suspension and loading mechanisms, a reading microscope for observing tiny displacements, a CCD camera system converting optical signals to electrical signals, a monitor for displaying the magnified image, and a set of weights providing precise tensile force. Its measurement principle is firmly based on the linear elastic assumption of Hooke's Law. Specifically, by directly measuring the tensile force  $F$  applied to the wire (calculated from the mass of the weights), the original length  $L$  of the wire (measured with a steel tape measure), the diameter  $d$  of the wire (measured multiple times with a micrometer, then used to calculate the cross-sectional area  $A = \pi(d/2)^2$ ), and the most critical and challenging quantity to measure accurately—the tiny elongation  $\Delta L$  under tension. The measurement of  $\Delta L$  is achieved by preliminary magnification through the reading microscope, combined with further magnification by the CCD imaging system displayed on the monitor, reading the change in the position of the scale line. This is a typical optical amplification measurement method[1].

### 2.2. Procedure and Error Control Strategies

The progression of the entire experimental procedure was essentially a continuous struggle against various potential error sources. Every operation required preemptive consideration of possible errors introduced and the formulation of corresponding control strategies.

#### 2.2.1. Instrument Adjustment and Preemptive Control of Systematic Errors

**Vertical Alignment of Support Frame:** At the beginning of the experiment, the three leveling screws on the base of the support frame were carefully adjusted using a precision spirit level to ensure the wire remained strictly vertical throughout the experiment. This step was crucial to avoid introducing unnecessary lateral friction between the wire and the clamp platform,

which could cause non-axial stress and affect the accuracy of the  $\Delta L$  measurement. This is a typical measure to avoid introducing new systematic errors through standardized operation.

**Optical System Adjustment and Parallax Elimination:** When adjusting the reading microscope, I strictly followed the operational procedures. First, the eyepiece was adjusted until the scale lines on the reticle were sharpest in the field of view, aiming to eliminate reading errors potentially caused by differences in eyesight. Then, focusing on the transverse line at the lower end of the wire, the objective lens focus was finely adjusted until the image of the line was equally sharp. The most critical step was eliminating parallax: by slightly moving my head left/right or up/down, I observed whether there was any relative displacement between the reticle scale lines and the image of the transverse line. Only when they completely coincided, with no parallax, was the microscope considered properly adjusted. This was a prerequisite for ensuring the accuracy of all subsequent readings; any residual parallax would translate into systematic bias in subsequent CCD readings[2].

### 2.2.2. Data Acquisition and Suppression of Random Errors:

**Equal-Increment Loading and "Symmetrical Observation Method":** To obtain the linear relationship between force and elongation and reduce the impact of random fluctuations, the equal-increment loading method was adopted, adding 50g weights successively, and after stabilization, recording the corresponding scale position reading  $Y_i$  ( $i=1,2,\dots,10$ ) on the CCD monitor. However, performing only a loading process might be affected by instantaneous fluctuations, judgment randomness, etc. To more effectively suppress such random errors, the "symmetrical observation method" was employed: after completing all loading and recording data, the weights were removed step by step (unloading), and the corresponding scale positions  $Y_i'$  were similarly recorded. Then, the arithmetic mean was calculated for the loading reading  $Y_i$  and unloading reading  $Y_i'$  at the same load level, i.e.,  $\bar{Y}_i = (Y_i + Y_i')/2$ . This data processing strategy effectively cancels out some of the random errors introduced by the material's slight anelasticity, instrumental backlash, and drift in reading judgment, making the final  $\bar{Y}_i$  sequence used for calculation more representative.

### 2.2.3. Key Parameter Measurement and Application of Theoretical Methods

**Diameter Measurement and Uniformity Assessment:** The wire diameter  $d$  is key to calculating the cross-sectional area  $A$ , and its measurement accuracy directly affects the final result's precision. Using a 0-25mm micrometer with a maximum permissible error of  $\pm 0.004\text{mm}$ , the diameter was measured 6 times at different sections (upper, middle, lower) of the wire, taking two mutually perpendicular directions at each section. The purpose was twofold: first, to reduce random error through multiple measurements, and more importantly, to assess the inherent uniformity (or lack thereof) of the wire diameter along its length and circumference, which itself is a source of random error. Before measurement, the micrometer's zero reading was checked and recorded for subsequent correction in data processing, another manifestation of controlling systematic error.

**Successive Difference Method for Elongation Data:** Simply using the difference between consecutive readings to calculate the elongation for each load step and then averaging would cause most intermediate measurements to cancel each other out, failing to utilize all data fully and being susceptible to local fluctuations. To overcome this drawback, the "successive difference method," widely used in physics experiments, was applied to process the 10 sets of  $\bar{Y}_i$  data. Specifically, after sequential numbering, the data was divided into front and rear groups (front group:  $i=1,2,3,4,5$ ; rear group:  $i=6,7,8,9,10$ ), then correspondingly subtracted, i.e., calculating  $\Delta L_j = \bar{Y}_{j+5} - \bar{Y}_j$  ( $j=1,2,3,4,5$ ). Finally, the average of these 5 differences was taken to obtain the average elongation. This method cleverly utilizes all data points, not only effectively reducing the impact of random errors but also having a clear physical meaning: it is equivalent

to measuring the average elongation of the wire when the load is increased by 250g (five 50g weights), making the calculation result more stable and reliable[3].

### 3. Results and Discussion

The diameter measurement result is:  $d = 0.511 \pm 0.0024$  mm. The original length measurement result is:  $L = 950.0 \pm 0.2$  mm. The elongation measurement result is:  $\Delta L = 1.02 \pm 0.011$  mm.

According to Hooke's Law, Young's modulus should be a constant and independent of the magnitude of the tensile force. For comparison with the accepted value, this calculation is valid. The final expression is:  $E = 19.6 \times 10^{10}$  N/m<sup>2</sup>.

Compared with the accepted value of  $20.0 \times 10^{10}$  N/m<sup>2</sup>, the relative error is:  $|19.6 - 20.0| / 20.0 \times 100\% = 2.0\%$ . This deviation falls within the expanded uncertainty range of the measurement (approximately  $\pm 2\%$ ), indicating that the measurement results are accurate and reliable.

#### 3.1. In-depth Analysis of Error Sources and Ideological-Political Mapping

Tracing the root causes of experimental errors through in-depth analysis is not only a technical procedure but also a mirror reflecting the character required of researchers and all professionals.

##### 3.1.1. Systematic Errors and the "Seeking Truth from Facts" Scientific Attitude

Systematic errors are caused by experimental instruments, theoretical models, or environmental factors and recur under identical measurement conditions. They are characterized by having a definite magnitude and direction. In this experiment, the +0.003mm zero error of the micrometer is a typical systematic error. If not calibrated before measurement and corrected in the results, all diameter measurements would be systematically too large, leading to a calculated cross-sectional area  $A$  that is too large, and ultimately a calculated Young's modulus  $E$  that is systematically too small. The act of proactively discovering, acknowledging, and correcting this objective systematic error embodies the core spirit of scientific research: "seeking truth from facts." It demands respect for objective reality and the courage to confront problems directly, rather than avoiding or concealing them. This attitude is the most basic professional ethics not only in the laboratory but in any work requiring rigor. It fully aligns with the principle of "integrity" in socialist core values. The reliability of research conducted by a scientist who cannot honestly face systematic errors is inevitably questionable[4].

##### 3.1.2. Random Errors and the "Continuous Improvement" Craftsman Spirit

Random errors, on the other hand, are caused by a series of unpredictable and uncontrollable random factors. Examples include the inherent microscopic inhomogeneity of the wire material, vibrations of the workbench that are difficult to avoid, disturbances from air currents, and the inevitable slight variations in viewing angle and visual fatigue when the observer judges the scale line position on the CCD screen. The characteristic of these errors is that their magnitude and direction are uncertain, causing measurement data to fluctuate around the true value. While random errors cannot be eliminated, their influence can be effectively suppressed by improving measurement methods and increasing the number of measurements. Strategies employed in this experiment, such as averaging via the "symmetrical observation method," repeating the diameter measurement 6 times, and processing data with the "successive difference method," were precisely aimed at achieving this goal. This process of continuously combating random errors, striving to minimize the fluctuation range of measurement results, perfectly embodies the "continuous improvement" aspect of the Craftsman Spirit. It requires dissatisfaction with merely "having obtained data" but pursues "obtaining more accurate and stable data." This attitude of not overlooking any factor that could

affect the outcome and continuously optimizing processes and methods is the fundamental driving force behind technological progress and quality enhancement[5].

### 3.1.3. Human Errors and the "Sense of Responsibility" Professional Competence

Human errors, or gross errors, primarily stem from the operator's negligence, incorrect operation, or subjective judgment mistakes. Examples include not completely eliminating parallax when adjusting the microscope, misreading due to lack of concentration, or transcription errors when recording data. These errors are generally avoidable and should be prevented through strict self-discipline and work protocols. During the experiment, when fatigue from prolonged repetitive operations led to the thought "this reading is probably close enough," I immediately realized this idea was a violation of the seriousness of scientific experimentation. I forced myself to focus, strictly adhered to operational standards, and ensured every instrument adjustment and every reading judgment was performed to the best of my ability. This self-monitoring sense of responsibility and high level of concentration is the core of the Craftsman Spirit and a concrete manifestation of the professional competence of "taking responsibility." It stems from reverence for the accuracy of the final result and a clear understanding of one's role. An engineer with a high sense of responsibility naturally internalizes this attention to detail as a work habit.

## 4. Conclusion and Outlook: From Laboratory Precision to National Strength

This research successfully determined the Young's modulus of the metal wire through systematic experimental design, rigorous error control strategies, and standardized data processing procedures. The final result is  $E=19.6 \times 10^{10} \text{ N/m}^2$ , with the relative measurement error controlled at a low level of 2.0%, indicating an accurate and reliable outcome. However, the value of this experiment extends far beyond this. The more significant gain lies in the fact that the entire experimental process—from the initial instrument adjustment, through the lengthy data acquisition, to the final analysis and reflection—served as profound, immersive training in the Craftsman Spirit and rigorous scientific.

As one of the most fundamental mechanical properties of materials, the precise measurement of Young's modulus is a cornerstone in numerous engineering and technological fields such as materials science, civil and architectural engineering, mechanical design and manufacturing, and aerospace. The scientific principles followed, the operational skills honed, and the thinking habits cultivated through our repeated measurement, analysis, and verification of the Young's modulus of a wire in the laboratory are of the same lineage as those applied in engineering practices on a much grander scale. From characterizing the properties of a single wire in the lab, one can extrapolate to the service safety assessment of the massive stay cables of the Hong Kong-Zhuhai-Macao Bridge, enormous tensile and compressive forces. It connects to the fatigue life prediction of the axles and bogies of the "Fuxing" high-speed train, which withstand complex alternating loads at high speeds. It can also be applied to the reliability design and verification of the lightweight yet high-strength airframe structures of the "C919" passenger aircraft or the core components of the "Long March" series rocket engines, which must endure extreme environments. Behind these "major national projects" representing the nation's scientific, technological, and industrial prowess lies the massive, precise, and reliable measurement, testing, and verification of countless key performance parameters analogous to "Young's modulus," "fatigue strength," and "fracture toughness" conducted by innumerable researchers and engineers. Each data point the relentless the relentless pursuit of "precision." Therefore, the rigorous and truth-seeking scientific attitude, the professional habit of unremitting pursuit of precision, and the consciousness of responsibility, honesty, and accountability honed in this Young's modulus experiment collectively constitute the micro-

foundation of the essential talent quality required to support China's "Manufacturing Power" and "Quality Power" strategies. The "precision" awareness of individuals converges into the "quality" standards of R&D teams and production departments, ultimately elevates the "strength" and international reputation of the entire nation. As a future engineer, I will remember the profound insight from this experiment. In my future professional studies and career, I will steadfastly adhere to the "Craftsman Spirit," striving to perfect every design parameter, every process specification, and every quality inspection. With the "precision" of our generation, we will contribute to propelling China's "acceleration" from catching up to running alongside and eventually leading in future global technological and industrial competition and industrial competition, contributing our own share of solid and precise strength to realizing the Chinese nation's dream of becoming science powerhouse.

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