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Evaluation of Uncertainty in Measurement for Magnification Error of Metallographic Microscope Objective Lens

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Abstract. Propose a method for evaluating the measurement uncertainty of magnification error in metallographic microscope objective lens. Establish a measurement uncertainty evaluation model based on calibration methods and analyse the sources of each uncertainty. Combining measurement examples, this article elaborates on the evaluation of uncertainty in the measurement of magnification error of metallographic microscope objective lens.

Key words: metrology; metallographic microscope; objective lens; magnification error; uncertainty in measurement.

1. Introduction

Metallographic microscope is an optical instrument used to observe and measure the microstructure of metals. A metallographic microscope mainly consists of three parts, namely an optical amplification system, an illumination system, and a mechanical system. The optical amplification system is composed of an eyepiece objective lens. According to the way in which metallographic microscopes observe object images, they can be divided into eyepiece observation and image sensor reception metallographic microscopes [1]. According to the object of use and the complexity of the structure, it is divided into ordinary metallographic microscopy, laboratory metallographic microscopy, and research metallographic microscopy [2]. Many scholars have conducted research on the calibration of magnification error of metallographic microscope objective lens[3-4], but the measurement model used in these studies is different from the measurement model in JJF 1914-2021 "Calibration Specification for Metallographic Microscopes". Due to the fact that the specification does not provide an example for evaluating the measurement uncertainty of magnification error in metallographic microscope objective lens, this article establishes a measurement uncertainty model for magnification error based on the calibration method in specification [1] and evaluates its measurement uncertainty.

2. Calibration method

To achieve the calibration of the indication error of the static level, a calibration device is constructed. The step blocks of different heights are placed on a flat plate. The height range of the upper and lower end faces of the step block is (50~500) mm, and the uncertainty of height measurement U=0.004mm (k=2). The flatness of the upper and lower end faces of the step block is not more than 0.01mm, and the parallelism is not more than 0.02mm. The schematic diagram of the measurement process is shown in Figure 1.

According to JJF 1914-2021 "Calibration Specification for Metallographic Microscopes" [1], when the eyepiece of the metallographic microscope under test is equipped with a reticle, first place the corresponding standard glass line ruler on the workbench, install the calibrated objective lens, focus until the eyepiece target is clear, and make the reticle in the eyepiece parallel to the reticle of the standard glass line ruler. The left end of the reticle in the eyepiece is aligned with the zero reticle of the standard glass line ruler, Read the actual value L of the standard glass line ruler at the tail line of the eyepiece reticle. When the eyepiece of the metallographic microscope under test does not have a graduated scale, place the corresponding standard glass line ruler on the workbench, install the calibrated objective lens, remove the eyepiece, place the magnification meter on the eyepiece cylinder, adjust the image distance of the objective lens, and make the standard glass graduated scale have a clear image on the graduated scale. Use the same method for reading. The magnification error of the objective lens $\Delta\beta$ is calculated by the following equation

$$\Delta\beta = \frac{Cm/\beta - L}{L} \times 100\% \tag{1}$$

Where $\Delta\beta$ is the magnification error of the objective lens, C is the graduation value of the eyepiece ruler, M is the number of grids used for the eyepiece reticle, β is the nominal magnification of the objective lens, L is the actual value of a standard glass line ruler.

3. Evaluation of measurement uncertainty

3.1. Measurement result

Under laboratory environmental conditions, calibrate the magnification error of the metallographic microscope objective lens using the above method. The calibrated metallographic microscope eyepiece is equipped with a graduated scale, with a graduation value of 0.1mm. The nominal magnification of the calibrated objective is 10×。 The measured reticle of the eyepiece uses 100 grids, and the actual length of the corresponding standard glass line ruler is 0.992mm. By substituting equation (1), it can be obtained that 10× Magnification error of objective lens $\Delta\beta$ is 0.8%. The calibration process is shown in Figure 1.

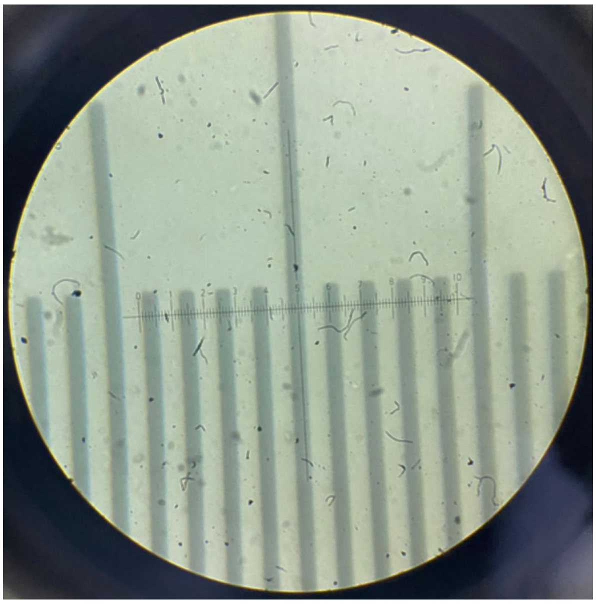

Figure 1. Schematic diagram of the calibration process for magnification error of metallographic microscope objective lens

3.2. Measurement model

The measurement model for the magnification error of the objective lens of a metallographic microscope is shown in equation (1), which can be transformed as follows

$$\Delta\beta = \left(\frac{Cm}{L\beta} - 1\right) \times 100\% \tag{2}$$

In actual measurement, the graduation value C of the eyepiece reticle in equation (2) and the nominal magnification of the objective lens β both are constants, and the actual value L of the standard glass line rule is not correlated with the number of grids m used for the eyepiece reticle. Therefore, the combined standard uncertainty u_c of the magnification error of the metallographic microscope objective lens $u_c(\Delta\beta)$ is as follows[5]

$$u_c^2(\Delta\beta) = c_1^2 u_m^2 + c_2^2 u_L^2 \tag{3}$$

Where um is the standard uncertainty introduced by measuring the number of grids using the eyepiece reticle, and uL is the standard uncertainty introduced by measuring the actual value of the standard glass line ruler, coefficient of sensitivity $c_1 = \frac{C}{L\beta} = 0.010$ and $c_2 = -\frac{Cm}{L^2\beta} = -1.016\text{mm}^{-1}$.

3.3. Sources of standard uncertainty

The standard uncertainty component um introduced by the use of grid number measurement for the eyepiece reticle mainly comes from the indication error of the distance between the reticle lines of the eyepiece reticle. The standard uncertainty component uL introduced in the measurement of the actual value of the standard glass line ruler mainly comes from the measurement repeatability and the measurement uncertainty of the calibration value of the distance between the standard glass line rulers. The sources of standard uncertainty components for measurement results are shown in Table 1.

Table 1. Source and explanation of standard uncertainty components in measurement results

$u_i(x)$	Source of $u_i(x)$	Evaluation method
u_m	Standard uncertainty component introduced by the indication error of the eyepiece reticle	Type B
u_L	Standard uncertainty components introduced in the measurement of actual values of standard glass line rulers	/
u_{L1}	Standard uncertainty components introduced by the measurement repeatability of actual values of standard glass line rulers	Type B
u_{L2}	Standard uncertainty component introduced by the calibration value of the spacing between standard glass line rulers	Type B

3.4. Calculation of standard uncertainty

3.4.1. Calculation of u_m

Due to the fact that the product of the number of cells used in the eyepiece reticle and its graduation value is the actual length, the uncertainty of this standard mainly comes from the indication error of the distance between the reticle lines of the eyepiece reticle. The MPE between any two graduation lines of the eyepiece ruler used for measurement is ±0.005mm, and the graduation value is 0.1mm. Assuming that it satisfies a uniform distribution, the standard uncertainty component u_m is

$$u_m = \frac{0.005\text{mm}}{0.1\text{mm} \times \sqrt{3}} = 0.029 \tag{4}$$

3.4.2. Calculation of u_L

Under the same conditions, select the same standard glass line ruler for 10 repeated measurements of the spacing between the lines. The measurement data are 0.992mm, 0.992mm, 0.992mm, 0.993mm, 0.992mm, 0.991mm, 0.992mm, 0.993mm, 0.992mm, 0.992mm. The calculated standard deviation for a single measurement experiment is 0.0006mm. The standard uncertainty component u_{L1} introduced by measurement repeatability is

$$u_{L1} = 0.00054\text{mm} \tag{5}$$

The calibration value of the spacing between standard glass line rulers was used for measurement, with a measurement uncertainty of U=0.001mm(k=2). Then the standard uncertainty component u_{L2} is

$$u_{L2} = \frac{0.001\text{mm}}{2} = 0.0005\text{mm} \tag{6}$$

Therefore, the standard uncertainty component u_L introduced by the measurement of the actual value of the standard glass line ruler is

$$u_L = \sqrt{u_{L1}^2 + u_{L2}^2} \approx 0.00074\text{mm} \tag{7}$$

3.5. Combined standard uncertainty

The standard uncertainty summary for the calibration of magnification error of metallographic microscope objective lens is shown in Table 2.

Table 2. Source and explanation of standard uncertainty components in measurement results

standard uncertainty	Source of $u_i(x)$	c_i	$u_i(x)$
u_m	Standard uncertainty component introduced by the indication error of the eyepiece reticle	0.010	0.029
u_L	Standard uncertainty components introduced in the measurement of actual values of standard glass line rulers	-1.016mm^{-1}	0.00074mm

Based on the above analysis, according to equation (2), the combined standard uncertainty $u_c(\Delta\beta)$ for the calibration of magnification error of metallographic microscope objective lens can be calculated as follows

$$u_c(\Delta\beta) = \sqrt{c_1^2 u_m^2 + c_2^2 u_L^2} \approx 0.8\% \tag{8}$$

3.6. Expanded uncertainty

Take the inclusion factor k *is 2, the expanded uncertainty of the magnification error calibration of the* metallographic *microscope objective lens is*

$$U = 2ku_c(\Delta\beta) = 2 \times 0.8\% = 1.6\% \tag{9}$$

Obviously, the expanded uncertainty of the magnification error calibration of the metallographic microscope objective lens is less than one-third of the maximum allowable error of the instrument, which is ±5%.

4. Conclusion

Apply the calibration methods and evaluation examples of measurement uncertainty in the standard to achieve the calibration of magnification error of metallographic microscope objectives lens. The expanded uncertainty of the magnification error calibration of the metallographic microscope objective lens is less than one-third of the maximum allowable error of the instrument.

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