Highly Stable Measurements of Springs on an OCMM

Dongmei Ren, Kevin M. Lawton, Steven R. Patterson
University of North Carolina at Charlotte, Charlotte, NC 28223

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Introduction

A lot of 17-7 stainless steel springs has been measured using a View Voyager 12×12 optical coordinate measuring machine (OCMM) in the Metrology Lab of the University of North Carolina at Charlotte for a period of up to three years in order to characterize the dimensional instability [1]. The dimensional drift rates of most of these springs are smaller than 1 nm/day. Measurement of such small dimensional changes requires highly repeatable measurements. In this paper, vision probe influences on measurement repeatability, such as illumination, imaging optics, and edge detection method are discussed. These effects are analyzed, and methods are discussed for minimizing them in order to achieve the repeatability of 0.2 µm.

Uncertainty of the OCMM

The springs being investigated have a U shape with an opening of approximately 6 mm, length of 9 mm and cross section of 0.2 mm×0.9 mm. The opening dimension is measured in order to observe the dimensional variation. The View Voyager 12×12 OCMM was used to measure the springs because of its advantages in non-contact measurements.

To evaluate the underlying measurement uncertainty of the OCMM, a series of measurements of a glass plate artifact were made in which several 10 mm intervals on two perpendicular scales were measured along x and y directions, respectively. The plate was measured under back light illumination, and the pattern was magnified for 20 times by the optical system. Fourteen independent measurements over three weeks showed that the short-term repeatability, estimated by the standard deviation, was 0.05 µm in the x direction and 0.22 µm in the y direction. This test was repeated four times in two years to evaluate the long-term stability. The short-term repeatability values were stable, and no obvious drift of the machine was found. The results are shown in Fig.1.

![Fig.1 Uncertainty of OCMM measurement for x and y directions](image-url)
Because the uncertainty of the OCMM in x direction is much smaller than that in y direction, the opening dimension of the spring is measured along x-axis of the machine. To eliminate the influence of the x-y stage motion errors to the measurement repeatability, it is necessary that springs be measured at approximately the same position on the machine each time.

**Influence of the vision system to measurement**

The complex spring geometry and its imperfect form make the measurement process much more complicated than glass plate measurements. The main factors related to the vision probe that may affect the spring measurement are illumination, magnification of imaging optics and edge detection method. Their interactions with the spring geometry affect the uncertainty of measurements. To investigate the influences of these factors, tests were designed and conducted in which the measurement repeatability was evaluated under different illumination, magnification, focusing methods and edge quality.

The interaction of illumination with the three-dimensional spring geometry is significantly more complicated than that with the thin pattern on the line scale. Both the illumination method and lighting intensity affect measurement repeatability and accuracy. The View Voyager 12×12 provides the backlight, through lens and ring light illuminations. The light control can be set at 0 to 255 intensity levels. To investigate the influence of the illumination, a set of experiments was made in which a spring was measured under backlight and thru lens light respectively at different intensity. The measurement results are shown in Fig. 2. It is shown in this graph that the measurement repeatability under backlight illumination improved with increasing the light intensity. But the repeatability under through light illumination showed less change. Considering the geometry of springs, backlight illumination was used for most of springs. The backlight intensity was set between 180 and 240 in the measurement to create sharp contrast without saturating the image.

![Fig.2 Influence of illumination on measurement repeatability](image)

The magnification of the vision system influences measurements by changing the resolution and the combination of readings from the vision probe and machine scales. The repeatability of measurements using the objectives of magnification 6, 10 and 20 were tested, while other conditions were kept the same. The measurement repeatability values are 0.14, 0.19 and 0.22 µm, respectively. Lower magnification could provide improved repeatability, but it is less sensitive to the dimensional changes due to lower resolution. A magnification of 10 is used to measure the springs in order to achieve the best blend of resolution and repeatability.
The thickness and imperfect edge profile of springs make the lens focus on different planes perpendicular to the optical axis, which leads to low focusing repeatability. The edge shift caused by focusing uncertainty reduces the repeatability of edge position detection. Auto focusing was used and obtained high repeatability for springs with sharp edges. But for most springs a higher repeatability was achieved if a focus position was defined, and the machine was controlled to this position by the measurement program.

Measurement of springs

Based on above analysis and experiments, each spring was measured at a particular position on the x-y stage with its opening aligned with the x-axis. Backlight illumination with proper light intensity and objective lens with magnification of 10 were selected for most of the spring measurements. The rectangular cross sections of springs are typically not aligned to the optical axis of illumination and imaging system due to their rotations about the mean centerlines, which results in two sharpest edges at different planes of focus in backlight images. As the section mean central line lies at approximate midline between the two edges, the distance between midlines of the two spring legs is used as the measurement result. To make the most repeatable measurements, a particular measurement program was written for each spring to achieve repeatable illumination and measurement process.

A larger uncertainty than that of the glass plate measurements occurred in the spring measurements due to the complexity of spring geometry. The average measurement repeatability of fifty-one springs, that have been observed for one year or longer, is 0.23 µm, the standard deviation of which is 0.06 µm. The repeatability data of these springs are shown in Fig. 3. The spring used in the repeatability experiments was measured seventy times during the past three years. The standard deviation of these measurements is 0.20 µm, which is similar to the short-term repeatability. The variation in the repeatability data suggests that the source of the uncertainty may be the particular geometry of the edges of the springs and their interaction with the OCMM. However, with this typical repeatability and sufficient numbers of measurements, the measurement method is able to detect a dimensional variation of 1 nm/day over a period of six months.

Fig.3 Measurement repeatability and the uncertainty of dimension drift

Measurements of the springs show that most of the springs have linear dimensional variations if short period dimensional fluctuations are considered to be results of measurement uncertainties. A least-squares linear model was fit to the data of each spring in order to characterize its
dimensional drift. The linear drift rates of thirty-eight springs that have been measured for one to three years are between -1.35 and 1.18 nm/day with an average of -0.14 nm/day and standard deviation of 0.60 nm/day. The distribution of drift rates is shown in Fig.4. The mean standard uncertainty of the drift rates is 0.19 nm/day. This is at the order of the measurement uncertainty over the period of observation. The uncertainties of dimensional drift rates are also shown in Fig. 3 for comparison. An obvious correlation between the measurement repeatability and uncertainty of the dimensional drift rate was observed. Twenty-five of the thirty-eight springs have shown drift rates significantly larger than their uncertainties.

![Fig.4 Distribution of dimensional drift rate](image)

After a series of fundamental measurements, some of the springs were selected to undergo compression and heating tests, in which the springs were compressed under designed loads or/and heated to designed temperatures in a precision vacuum oven for periods of time. Consistent measurements were made after each test in order to investigate the temperature and force dependent mechanism of the dimensional instability. A steady state linear relationship was observed between the dimensional variation and the test time.

**Conclusion**

Measurements on a lot of 17-7 stainless steel springs have been made using the View Voyager 12×12 OCMM for up to three years. The average measurement repeatability of fifty-one springs, which have been measured for one to three years, is 0.22 micrometer (which does not include the dimensional drift with time) with standard deviation of 0.06 micrometer. An average standard uncertainty of 0.19 nm/day for measurement of linear dimensional drift was achieved. These stable measurements have provided significant information for the analysis of the dimensional instability mechanism of springs. The measurements using optical CMM have proven to be an effective method for the investigating dimensional instability with moderate accuracy.

**Reference**


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