Alignment and arm length measurement of the Swing Arm Profilometer using a laser tracker

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ABSTRACT

Abstract: In this paper, we present the use of the laser tracker to aid the alignment of a Swing Arm Profilometer (SAP) and measure the length of the swinging arm, thus calibrating the operating radius of the SAP. The measurement uncertainty analysis is given. A laser tracker is used to align the SAP to ensure the path of the probe head passes through the rotary axis of the rotary table. By building the coordinate system by laser tracker measurement on the rotary table and measuring the swinging arc of the arm, we can determine whether the swinging path of the probe head passes through the rotary axis of the rotary table and perform the corresponding adjustment if necessary. A laser tracker is also used to measure the arm length, i.e. the length between the probe's ball centre and the rotation axis of the swinging arm. By placing a retroreflector or the tracker ball on the swinging arm and scanning the swinging path of the arm using the laser tracker, we can acquire the data of an arc and fit to determine the length of the probe head center to rotation axis of swinging arm, thus giving accurate SAP calibration data.

Keywords: Alignment, measurement, swing arm profilometer, laser tracker

1. INTRODUCTION

The swing arm profilometer (SAP) in the National Facility for Ultra Precision Surfaces, St Asaph, UK principally comprises a rotary table supporting the surface under test (SUT), a pivoted swinging arm that swings across the SUT, the probe and a counter balance for the arm. The arm pivot bearing provides the arcuate swinging motion of the probe when measuring. The probe is attached to the end of the arm via a joint providing manual tilt adjustment [8]. The SAP is traditionally used for testing large convex or concave optics [3-8].

A laser tracker is essentially an optical coordinate measurement machine. It measures spherical instead of Cartesian coordinates. A laser tracker uses a distance-measuring interferometer (DMI) to measure distance and two angular encoders to measure the rotation angles. Due to its convenience and relatively high accuracy, the use of a laser tracker for aligning and measuring the large optics is applicable [1-2].

In the National Facility for Ultra Precision Surfaces, St Asaph, UK a novel method for measuring large, nominally plano optics with large surface figure errors outside the range of phase-shifting interferometer (tens of microns) with a resolution of 12.5nm using SAP and laser tracker has been developed and reported [9]. The measurement devices are shown in Figure 1. In this paper the detailed alignment method is reported in Section 2. The detailed arm length measurement method, the measurement results and the measurement uncertainty analysis are reported in Section 3. The conclusion is given in Section 4.

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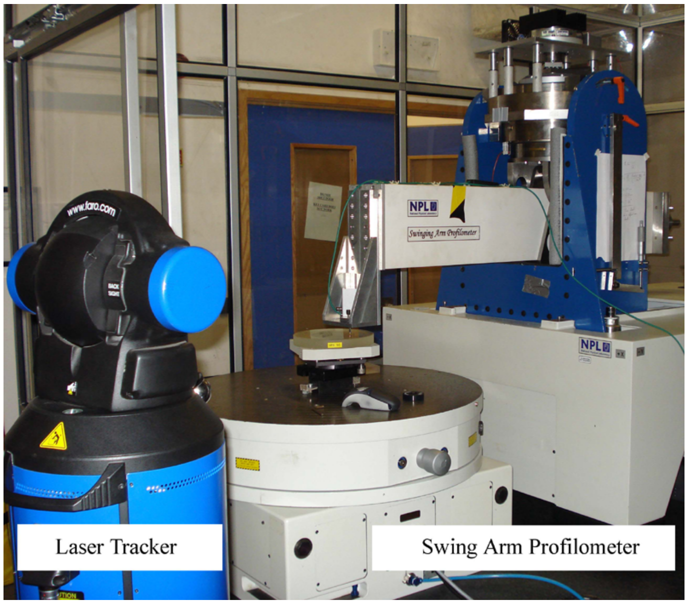

Figure 1: Measurement devices

2. ALIGNMENT

A key technique in aligning the SAP is to ensure the path of the probe head passes through the rotary axis of the rotary table. By building the coordinate system on the rotary table and measuring the swinging arc of the arm using a laser tracker, we can determine whether the swinging path of the probe head passes through the rotary axis of the rotary table and perform the corresponding adjustment if necessary. The alignment is shown in Figure 2.

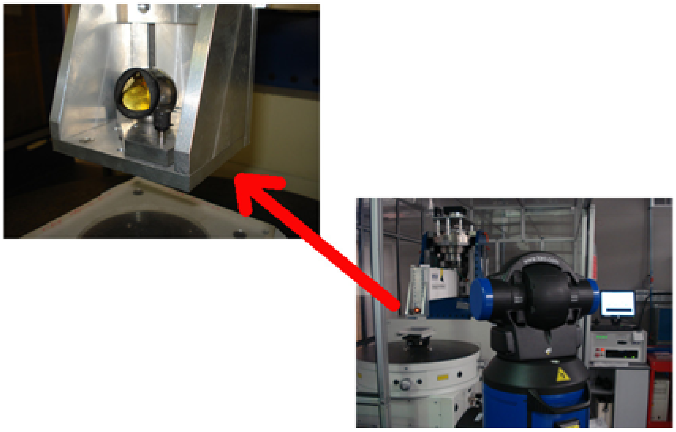
Figure 2: Aligning SAP using laser tracker

During the alignment process, a coordinate system was built. The plane of the surface under test was measured and the surface normal was set as Z axis. A line along the X stage of the SAP was measured and set as X axis. A circle was captured by laser tracker when rotating the rotary table and the center of the circle was set as origin of the coordinates systems. Using the plane, the line and the center point of the circle, a coordinate system was built, which is shown in Figure 3.

The retroreflector was positioned at the mount hole of the SAP probe. The swinging arc was captured by swinging the arm and using the laser tracker to scan the retroreflector, which is shown in Figure 3. By analyzing the swinging arc in the coordinate system, we can determine whether the swinging path of the probe head passes through the rotary axis of the rotary table and perform the corresponding adjustment if necessary.

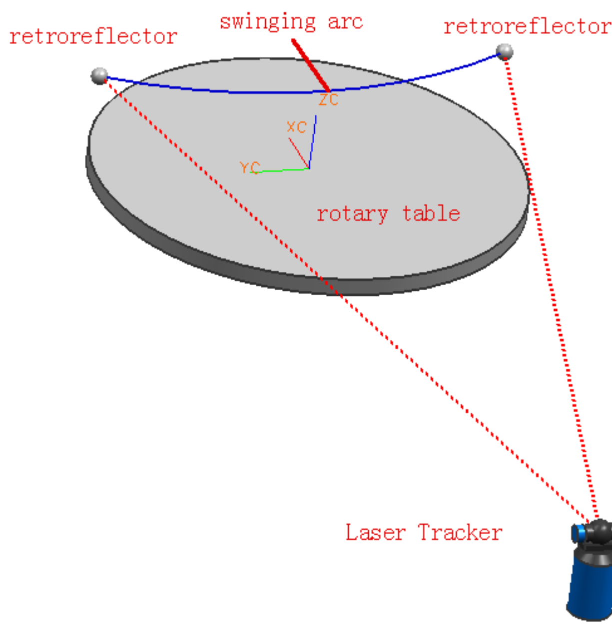

Figure 3: Alignment procedure

After the alignment, a mirror with a straight step is used to test how good the alignment is. By using the SAP to measure the step on the mirror, the mirror surface can be reconstructed.

If the path of the probe head does not pass through the rotary axis of the rotary table, the step looks distorted. As shown in Figure 4. Which means the alignment is not good.

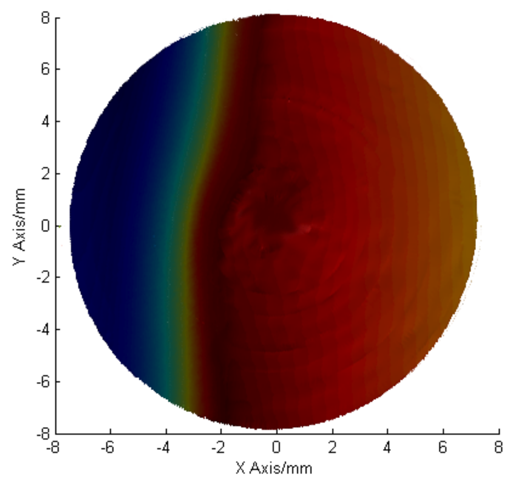

Figure 4: Results of step (not aligned)

If the path of the probe head passes through the rotary axis of the rotary table, the step looks straight. As shown in Figure 5. Which means the alignment is very good.

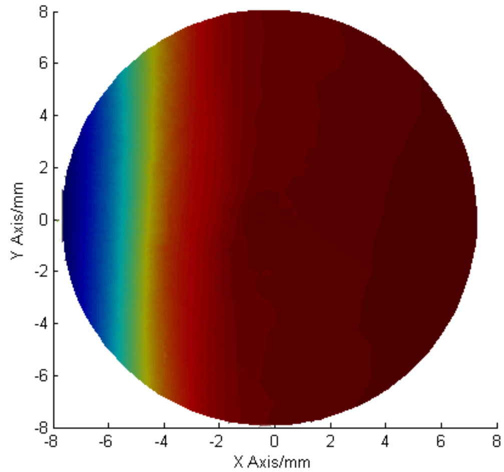

Figure 5: Results of step (well aligned)

3. ARM LENGTH MEASUREMENT

3.1 Measurement procedure

A laser tracker is also used to measure the arm length, i.e. the length between the probe's ball centre and the rotation axis of the swinging arm. By placing the retroreflector at the mount hole of the SAP probe and scanning the swinging path of the arm using the laser tracker, we can acquire the data of an arc and fit to determine the length of the probe head center to rotation axis of swinging arm, thus giving accurate SAP calibration data.

The measurement principle is shown in Figure 6. The swinging arc was captured by swinging the arm and using the laser tracker to scan the retroreflector. The XYZ data of the swinging arc was used to fit a LSQ circle to determine the radius of the circle, which is the arm length.

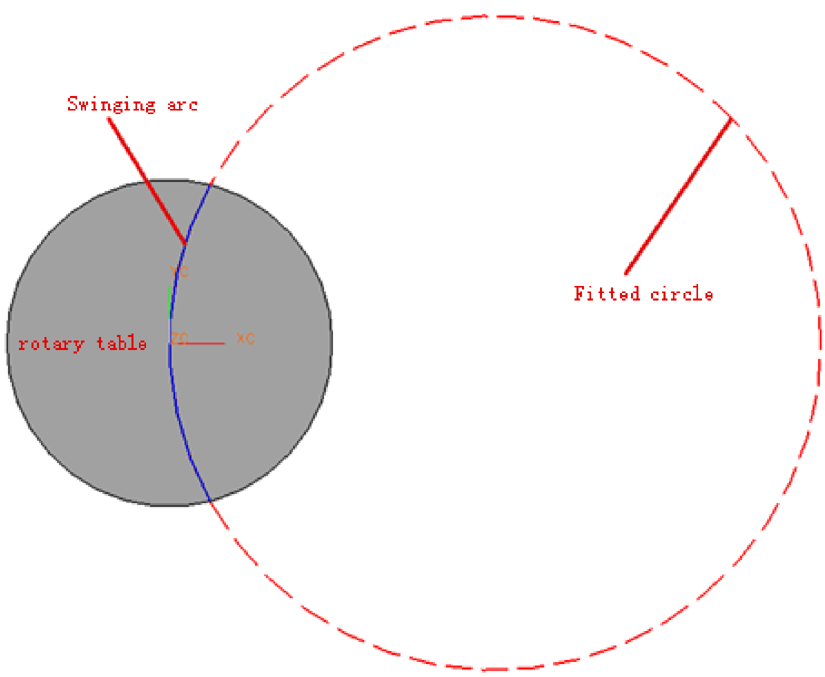

Figure 6: Arm length measurement principle

3.2 Measurement results

Using the measurement technique described in section 3.1, the same swinging arc was measured 10 times. The measurement results are shown in Figure 7.

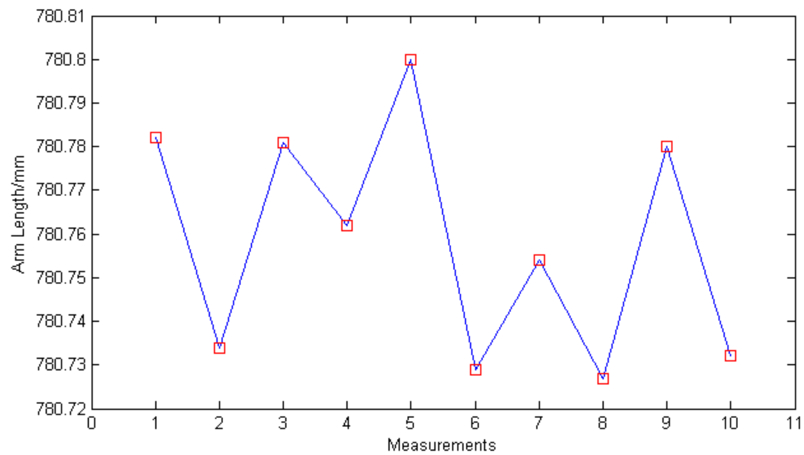

Figure 7: Arm length measurement results

3.3 Measurement uncertainty analysis

The average arm length is

$$\overline{L} = \frac{\sum_{i=1}^{n} L_i}{n} = 780.76mm \tag{1}$$

According to the statistic data, the measurement uncertainty is

$$u_{arm} = \sqrt{\frac{\sum_{i=1}^{n}\left(L_i - \overline{L}\right)^2}{n-1}} = 0.025mm \tag{2}$$

The expanded measurement uncertainty(k=2) is

$$U_{arm} = k \times u_{arm} = 2 \times 0.025 = 0.050mm \tag{3}$$

The arm length is represented as

$$L = (780.76 \pm 0.05)mm \tag{4}$$

4. CONCLUSIONS

We presented the use of the laser tracker to aid the alignment of a Swing Arm Profilometer (SAP) and measure the length of the swinging arm. A laser tracker is used to align the SAP to ensure the path of the probe head passes through the rotary axis of the rotary table. By building the coordinate system by laser tracker measurement on the rotary table and measuring the swinging arc of the arm, we can determine whether the swinging path of the probe head passes through the rotary axis of the rotary table and perform the corresponding adjustment if necessary. A mirror with a straight step is used to test how good the alignment is. A laser tracker is also used to measure the length between the probe's ball centre and the rotation axis of the swinging arm. By placing the tracker ball on the swinging arm and scanning the swinging path of the arm using the laser tracker, we can acquire the data of an arc and fit to determine the length of the probe head center to rotation axis of swinging arm, thus giving accurate SAP calibration data. An experiment was performed to measure the arm length, the result is 780.76mm. The expanded measurement uncertainty of the arm length measurement is 0.05mm.

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