Optical metrology for stability of beam pointing

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Abstract: Single mode optical fiber is commonly used as a light source in complex optical assemblies. A collimation lens can be used to collimate the light. Small displacement, tip, or tilt of fiber with respect to the lens or vice versa induces beam pointing. In this paper an optical metrology is proposed that can measure beam pointing down to ±1μRad.
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1. Introduction

It is common to use single mode optical fiber followed by a collimation lens as a source of collimated light in complex optical assemblies. Optical cement is frequently used to attach different optical mechanical components together. Under temperature and humidity changes, the beam pointing can change which affects the overall system performance.

Position sensing devices are typically used to measure beam pointing in the milliradian range. A lens is needed to transform pointing to position. More sophisticated sensors are needed to measure beam pointing in the microradian range. The absorption of light in surface plasmon resonance prism coating can be used to precisely measure beam pointing [2].

Direct measurement of beam pointing has to be referenced to a mechanical datum (that doesn't change with the variation of environmental conditions). To be able to measure beam pointing down to micro radian level, vibrations, temperature gradients, air turbulences become an issue. The proposed setup is capable of measuring beam pointing down to micro radian level and is of minimum sensitivity to environmental conditions using on the shelf components.

2. Measurement setup

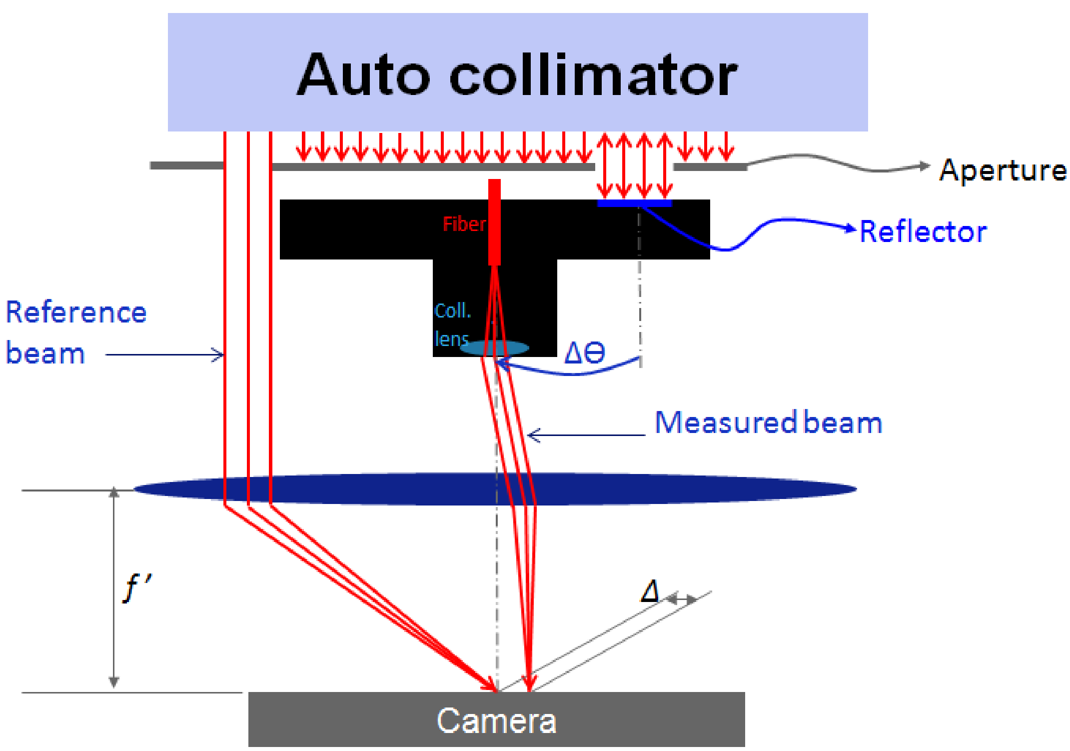

Fig. 1. Measurement setup.

Measurement setup is shown in Fig. 1. Input Fiber Assembly (IFA) comprises a single mode optical fiber that is placed at the focal point of a collimation lens. IFA is the only element that is taken out and in the setup. Other elements remain static to the setup.

The test setup is designed to be self-referencing. The Auto Collimator (AC) is tilt-aligned to the back-reflection of the reflector on the IFA. This ensures that the AC light (i.e. reference beam) that reaches the camera has a fixed pointing relationship to IFA flange mechanical datum. Thus, any drift or pointing error of the light delivered through the fiber to the camera (i.e. measured beam) is a change in the relationship of the fiber optical system to the IFA flange mechanical datum. Consequently, IFA can be removed and subjected to temperature, humidity, and shock testing, knowing that upon return to the test stand the baseline is preserved by the self-referencing nature of the metrology. Thus, obtaining robust insight into the changes that may have occurred due to cycling of environmental conditions.

Both reference and measured beams travels through the same optics and are subjected to same possible measurement conditions: e.g. temperature gradients, vibrations, air turbulences, etc. Therefore measurement conditions instabilities don't contribute to the measurement accuracy.

The spot displacement Δ at the camera has a linear dependence on beam pointing error $\Delta\theta$.

$$\Delta = \theta_o + f\,'\Delta\theta \tag{1}$$

where θ_o is the nominal tilt of the reflector surface with respect to the flange mechanical datum, θ_o is few milliradians to enable enough separation of reference and measured beam spots on the camera. $f\,'$ is the focal imaging lens. Choosing $f\,'$= 500 mm, and assuming camera pixel is 5X5μm^2, this sets the theoretical resolution to be 1 μRad.

3. Measurement capability

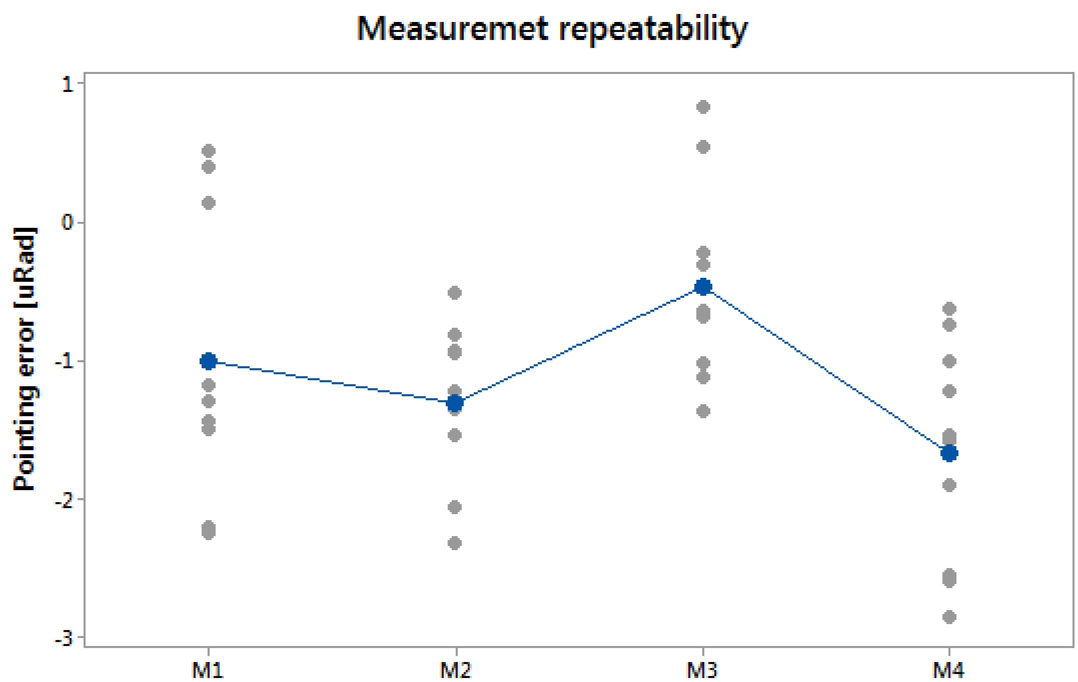

Fig. 2. Repeatability is less than 1 μRad.

The function of this setup is to qualify the variation of beam pointing after subjecting IFA to environmental conditions. Therefore, measurement repeatability is the main quality metric. Measurement repeatability is evaluated by measuring the beam pointing relative to flange mechanical datum. 4 measurements are made. IFA is completely taken off the setup and placed back between measurements. In each measurement, 10 images of spots on the camera are taken separated by 1 minute. Each image is an average of 10 frames. Figure 2 shows that the measurement repeatability is less than 1 μRad. It also shows the presence of noise in the measurement in the order of 4 μRad. This noise is attributed to AC mount and expected to be minimized by using another AC mount.

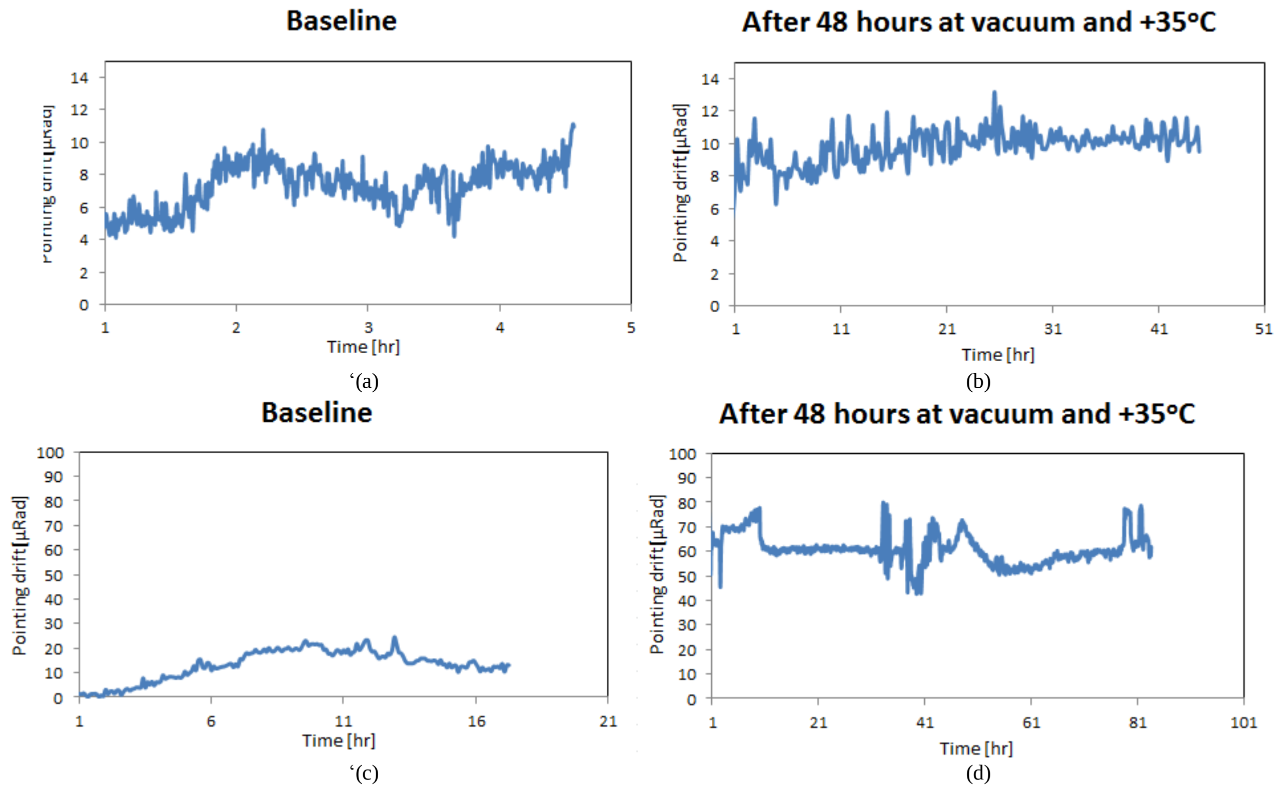

Fig. 3. Comparing the drift of beam pointing of IFA1 (a) before and (b) after placing in vacuum at +35°C for 48 hours to IFA2 (c) before and (d) after placing in vacuum at +35°C for 48 hours shows that IFA1 is more stable than IFA2 .

Proposed metrology can be used as well to measure the drift of beam pointing over time. Figure 3 shows a comparison between two different designs of IFA drift over time. IFA1 is clearly more stable than IFA2. Placing IFA1, 2 in vacuum at +35°C for 48 hours causes IFA2 to drift by about 60 µRad.

4. Summary and conclusions

An optical metrology is proposed that is capable of measuring beam pointing down to ± 1 µRad. Repeatability has been characterized. Metrology is used to assess stability and drift of different designs.

5. References

[1] ME Hansen, RA Wilklow, “Beam characterization monitor for sensing pointing or angle of an optical beam,” US patent 8013999, 2011.