Application Note: Motion & Sensing 24

Stability Evaluation of Telescope Structure

Truss Integrated Interferometer for Dimensional Deformation Analysis

Paul Vosshage, Markus Maier and Felix Scheinkönig
attocube systems AG, Eglfinger Weg 2, 85540 Haar, Germany

Introduction

One of the critical factors for high-resolution observations of large modern telescopes is their dimensional stability. A telescope, independent of the specific kind, typically consists of a supporting structure and the optical components. Figure 1 shows the design of a Cassegrain-type telescope with precision metering truss to support the primary and secondary mirror. The supporting structure is required to maintain the mirror positions with the proper focus, thus minimizing the optical alignment error. Temperature variations, thermal gradients, and moisture desorption, which are especially critical for space telescopes, can lead to deformations of such structures and therefore to a degradation of the optical performance.

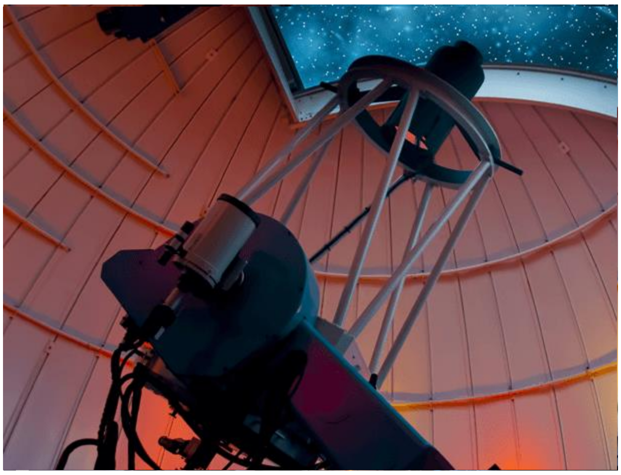

Figure 1: Typical design of a Cassegrain-type telescope with a support truss. At the top of the structure a smaller secondary mirror is attached, focussing the light at the focal point behind the primary mirror at the base of the truss.

There are several complementary techniques to compensate for the structural deformations, such as active thermal control, passive control via low thermal expansion coefficients of the material or correcting the shape and position of the structure with actuators. Crucially, all compensating techniques are based on an accurate evaluation of the dimensional stability of the satellite structure.

To properly account for the deformation of the supporting structure, a reliable system for monitoring the dimensional stability of the truss structure is needed. attocube's Fabry-Pérot interferometers are the perfect choice for this application. As our fiber-based measurement sensor heads are compact and robust, they can be integrate directly into the supporting structure of the telescope (see figure 2, right). This approach has several advantages over a conventional external displacement measuring interferometer (DMI) setup and will be termed as built-in displacement measurement interferometer (BDMI) in the following.

As shown in figure 2 the BDMI concept can be realized without complex alignment apparatus such as multiple optics mounts, which are inherently unstable and prone to damage by handling. This reduces the overall complexity and increases the stability of the mechanical setup. Furthermore, the measurement stability can also be improved with the BDMI, as the beam path is enclosed by the structure, which reduces thermal fluctuation and thereby leads to a more stable measuring environment.

To validate the performance and the expected advantages of the BDMI concept the Japan Aerospace Exploration Agency carried out multiple test measurements and comparisons with conventional techniques, which will be described in the following.[1]

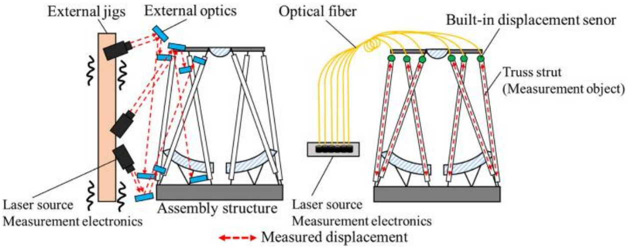

Figure 2: Schematic comparison of the conventional DMI measuring system (left) and the built-in BDMI measuring system based on attocube´s interferomter (right)

Setup

The measurements were performed on two types of truss struts – one made from stainless steel and the other made from a low thermal expansion ceramic (SiAlON). attocube's sensor head was integrated directly into the flange at one end of the respective truss structure for axial displacement measuring (Figure 3, upper left).

The thermal expansion of the stainless-steel strut was measured simultaneously with the BDMI and the conventional external DMI to compare the system functionality against the standard solution. As depicted in Figure 3, the target mirrors of the DMI were attached on each end of the strut and the dimensional change was determined by the difference of the four measurement beams. The measurements took place in a clean room where the specimen temperature was controlled in steps of 5°C from 15°C to 30°C.

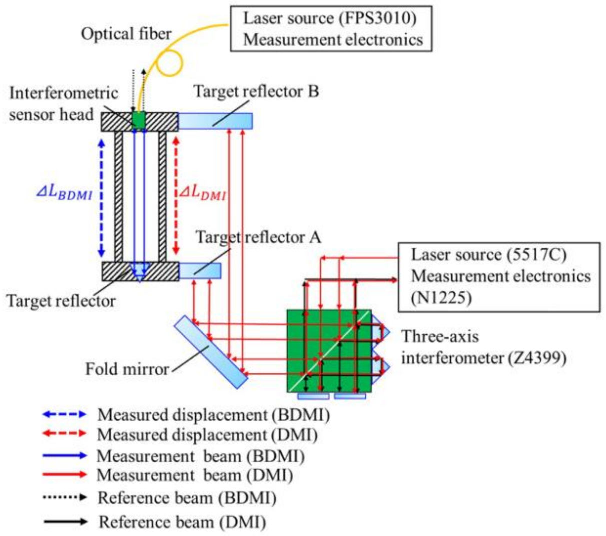

Figure 3: Schematic diagram of the measurement setup for the stainless steel strut, showing the build-in displacement measurement interferometer (BDMI) and the regular displacement measurement interferometer (DMI).

The thermal expansion of the ceramic (SiAlON) strut was measured only with the attocube BDMI and validated by comparison with the CTE of a material sample. The CTE was separately measured with a dilatometer. This confirmed the temperature dependent CTE of the ceramic to be linear between 0°C to 50°C. However, the influence of further strut constituents with non-constant CTE had to be compensated for in order to achieve a more accurate comparison. The BDMI measurement was conducted in a vacuum chamber at less than 2 Pa to further reduce the environmental errors due to air refractive index fluctuation. The temperature was controlled by a heatsink with steps from 0°C to 50°C in increments of 5°C or 10°C.

Measurement Results

The axial displacement of the stainless-steel strut, due to temperature changes, was measured simultaneously with the integrated attocube BDMI and the conventional DMI. The measurements precisely detected the displacement associated with the predefined temperature changes (Figure 4A) and were also compensated for air refractive index fluctuations

The slight temperature fluctuation was caused by the control period of the air conditioning system. When comparing the measurements of the attocube BDMI with the regular DMI in detail (Figure 3B) one can see spike noise in the DMI measurement data, which was caused by air fluctuations in the free beam measurement path. This shows the stability benefits of the truss integration with enclosed displacement sensor.

For the ceramic strut (Figure 3C) the RMS of the difference between the compensated analytical CTE data and the polynomial fit of the attocube BDMI measurements was 145 nm during the wide temperature range from 5 °C to 45 °C and 69 nm during the limited temperature range from 15 °C to 30 °C. Therefore, the CTE based analytical value with compensation matches well with the measured data by the attocube interferometer.

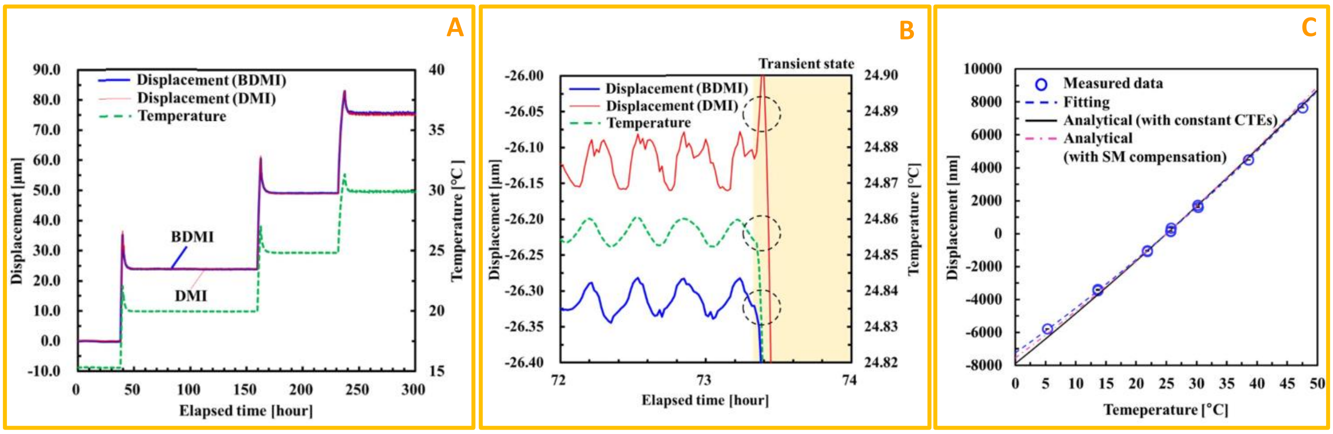

Figure 4: A) Measured thermal expansion and temperature of stainless-steel strut as function of time showing the expected behaviour. B) Comparison of the displacement measured by the BDMI and the DMI during a temperature transition. C) Thermal expansion measured with the BDMI as function of temperature compared to the CTE based analytical data.

Conclusion

By measuring the thermal expansion of two types of truss struts and comparing the results with conventional methods, the attocube interferometer built directly into the supporting structure was verified as a valid analysis tool for monitoring the dimensional stability of a telescope. The integrated interferometer solution showed high precision, equal to that of a conventional displacement measurement interferometer. The integrated setup also provided several advantages including compactness and robustness for facilitated integration, as well as ease of handling and increased measurement stability. This makes the attocube interferometer suitable for continuous stability monitoring of large ground-based telescopes. Furthermore, the compatibility to vacuum and extreme temperatures offers a perfect fit for extensive ground testing of space telescopes.

References

[1] Kazuya Kitamoto et al 2020 Eng. Res. Express 2 045023.