Alignment of optical axis parallelism in multi-axis system

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Alignment and testing of optical axis parallelism are the key problems in alignment of a multi-optical axis system. We propose a method which can adjust optical axis parallelism and single-channel wavefront aberration simultaneously in multi-axis imager. Firstly, the imager's installation base surface is adjusted to be perpendicular to the optical axis of the interferometer and remain motionless precisely by using theodolite. Then, according to the measurement principle of wave aberration with interferometer, each channel axis is adjusted to be parallel to the axis of the interferometer. While imaging quality in each channel is measured, alignment on each channel axis parallelism is accomplished. By this method, three-axis parallelism in annular three-channel imager is aligned. The accuracy of axis parallelism is up to 15″, and the imager requirement (30″) is satisfied. Feasibility and precision of this method are verified.

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Optical axis parallelism is a key indicator to ensure the same observation for all channels[1–5], which is vital for target information comparison and retrieval in each channel. But it has always been a key indicator and a difficult one for multi-axis optical system alignment and testing. The common methods include projection target method, pentaprism method, splitting optical path and projection method, large diameter collimator method, and so on. However, these methods require special equipment (poor universality) and rely on human judgment (big subjective factors), which severely limit the adjustment's efficiency and accuracy. To overcome these disadvantages, a method of alignment on optical axis parallelism for multi-axis imager using interferometer and theodolite as auxiliary instruments is proposed. So the method not only has high-precision and good commonality but also achieves the image quality testing and tuning of each channel. In the following, combined with annular three-channel imager, the method is explained in detail.

Annular three-channel imager is a three-channel multi-azimuth filter-type earth limb imager. Its observation mode is shown in Fig. 1. The center wavelengths of three channels filters are 265, 295, and 360 nm, respectively. The detection target of annular three-channel imager is atmospheric scattering spectral radiance at the earth's limb height of 0–60 km. Joint three bands radiances are used for retrieval of vertical distribution information of the gas such as ozone and nitrogen dioxide. Because three bands radiances of the same target are required for the retrieval, three-channel axis parallelism will be guaranteed to detect the same target. The single pixel's field of view (FOV) is 0.033° in annular three-channel imager, corresponding to a spatial resolution of 1.2 km in the limb height. Spectral radiance of the three bands vary violently with limb height, a typical distribution (sun zenith angle is 120°) is shown in Fig. 2. When a channel optical axis is deviated with 0.033°, the corresponding detecting limb height variation is 1.2 km, and the maximum change of detection signal is about 4%. In order to ensure the detection deviation is less than 1%, axis parallelism accuracy of three-channel should be better than 30″. This is a big challenge for axis parallel alignment of annular three-channel imager.

The schematic structural view of annular three-channel imager is shown in Fig. 3. The upper part consists of three spectral channels, the middle part is the installation base plate, and the lower part consists of detectors and electronics system. The schematic view of installation base plate is shown in Fig. 4. The center of installation base plate is benchmark cube prism, which represents instrument installation's mechanical

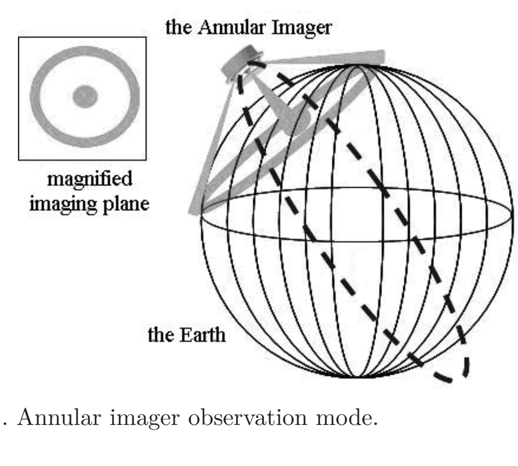

Fig. 1. Annular imager observation mode.

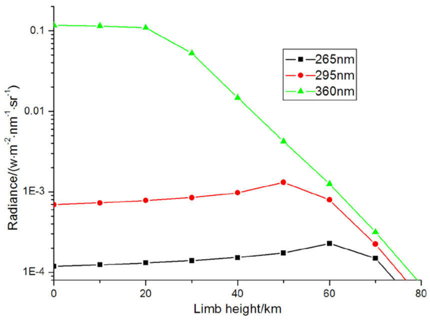

Fig. 2. Spectral radiance distribution with limb height.

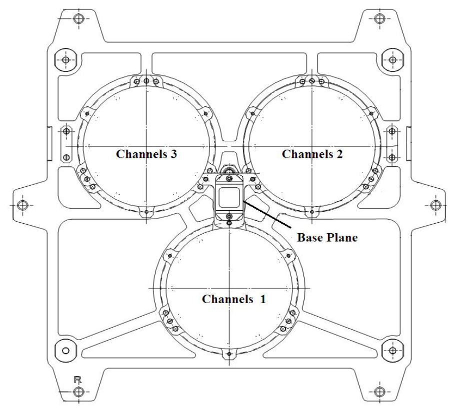

Fig. 4. Schematic view of installation base plate.

coordinate system. The upper surface of the cube prism is reflective base plane, which is perpendicular to optical axis direction of the system. When three channels are installed, optical axis of each channel must be perpendicular to the base plane, and error requirement is less than 30″. To achieve this goal, the base plane must be perpendicular to the optical axis of interferometer and each channel's optical axis must be coaxial with the optical axis of the interferometer.

The adjustment process of base plane perpendicular to the optical axis of interferometer is shown in Fig. 5. First, interferometer, installation base plate, dual-plane mirrors, and theodolite are placed as shown in Fig. 5. Interferometer knob is adjusted to make standard transmission flat (TF) coaxial with interferometer. Plane 1's wavefront aberration of double plane mirrors is measured with interferometer, and tilt of double plane mirrors is adjusted to minimize the number of interference fringes (close to zero). So the optical axis of interferometer is perpendicular to plane 1 of double plane mirrors, and then double plane mirrors is fixed to be stationary. By adjusting the theodolite to make reflected crosshair's image of double plane mirrors move plane 2 move the center of theodolite's FOV. Then the theodolite is fixed to be stationary. Position and tilt of the installation plate are adjusted to make crosshair's image coincide between the base plane and plane 2 in theodolite's image plane. Then the base plane is parallel to plane 2 of double plane mirrors. Because double planes of double plane mirrors (planes 1 and 2) are parallel (error is less than 2″) and profile accuracy is better than $\lambda/20$ at 632.8 nm, the base plane is parallel to plane 1. So the base plane is perpendicular to the optical axis of interferometer.

This adjustment process of channel optical axis coaxial with interferometer is shown in Fig. 6. After the above adjustment requirement, the standard transmission spherical mirror replaces the standard TF and is adjusted to be coaxial with interferometer (in order to cover the full aperture, relative aperture of the spherical mirror must be greater than that of each channel). Then the channel 1's optical–mechanical system is mounted on the installation base plate. The wavefront aberration of the channel 1's optical system is measured with interferometer and plane 1 of double plane mirrors. During the measurement, the number of interference fringes is minimized by adjusting fine-tuning mechanism between channel 1 and the installation base plate. Then the channel 1's optical axis is adjusted to be coaxial with the optical axis of the interferometer. In this process, if the interferogram cannot meet the wavefront aberration requirements of the system, the system is readjusted to release the stress generated in the assembling to meet the requirements according to the conventional computer-aided alignment method.

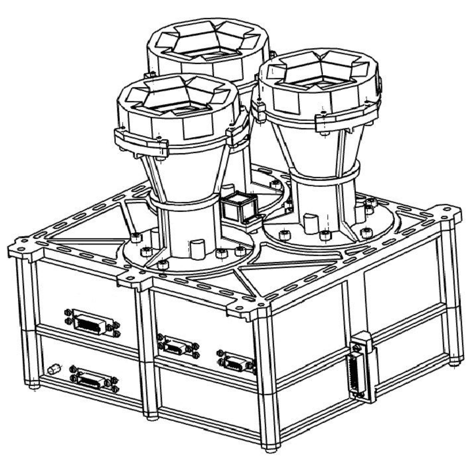

Fig. 3. Schematic view of annular three-channel imager.

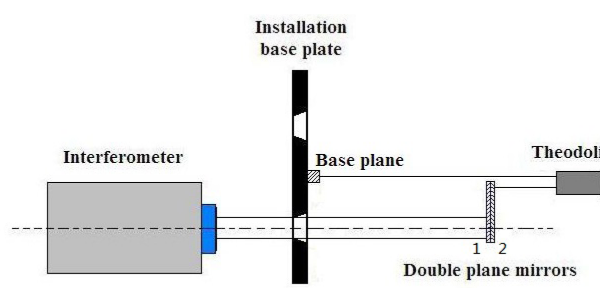

Fig. 5. Schematic view of adjustment base plane perpendicular to the optical axis of interferometer.

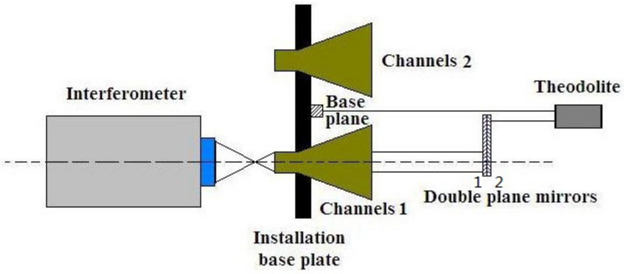

Fig. 6. Schematic view of adjustment channel optical axis coaxial with interferometer.

In the whole alignment process, the crosshair's image coincidence between the base plane and plane 2 is always maintained in the theodolite. While imaging quality in channel 1 is measured, the channel 1's optical axis is guaranteed to be coaxial with the interferometer. So the optical axis of channel 1 is perpendicular to the base plane. Then the alignment of channel 1 is completed.

The alignment of channels 2 and 3 are completed similar to channel 1. Then the alignments of axis parallelism and image quality of the three channels are completed simultaneously. Figure 7 shows the actual alignment process of channel 3 and the final interferogram. The final interferograms of channels 1 and 2 are shown in Figs. 8 and 9. As shown in Figs. 7–9, the numbers of three channels' interference fringes are 3, 3, and 2, respectively. Since the optical system of each channel is composed of a plurality of optical components, much interference is presented in the final interferograms.

In order to analyze the alignment errors of the three channels, it is necessary to calibrate the relationship between the number of interference fringes and the angle of tilt and for this calibration the devices shown in Fig. 5 are used. When the number of the plane 1's interference fringes is minimum, the tilt angle of double plane mirrors is recorded by using theodolite. Then the tilt of double plane mirrors is adjusted slowly, and the number of interference fringes and the angle of tilt are recorded, respectively. The relationship is shown in Fig. 10. By linear fitting, tilt angle corresponding to each stripe is approximately 3.5″. So, relative to the interferometer optical axis, the tilt angles of the three channels' optical axes are 11″, 11″, and 7″, respectively.

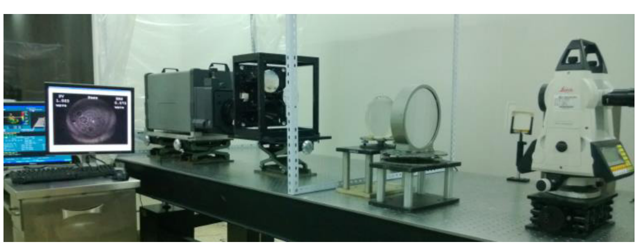

Fig. 7. Actual alignment process of channel 3 and the final interferogram.

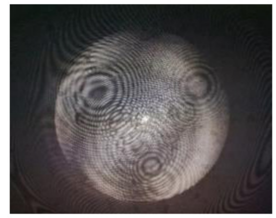

Fig. 8. Final interferogram of channel 1.

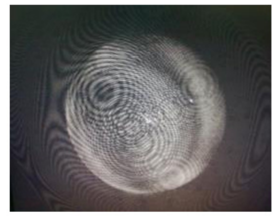

Fig. 9. Final interferogram of channel 2.

The error synthesis is as follows:

a) The coaxial error between standard mirror and interferometer

After many times of measurements, optical axis repeatability error of the standard mirror is 4″.

b) Monitoring error with theodolite

The model number of theodolite is Leica T5100A and the angle measurement accuracy is 0.5″. Alignment repeatability error of crosshair's image is 1″.

c) Parallelism error between planes 1 and 2 of double plane mirrors

The parallelism error is measured using the method given in Ref. [6] and the result is less than 2″.

d) Vertical error between plane 1 and optical axis of interferometer

Based on the quantity of interference fringes of plane 1, the vertical error is 3″.

e) Confocal error between each channel optical system and the standard spherical mirror in interferometer

Combined with adjusting precision and focal length of each channel, the confocal error is about 9″.

f) The coaxial error between each channel's optical axis and interferometer

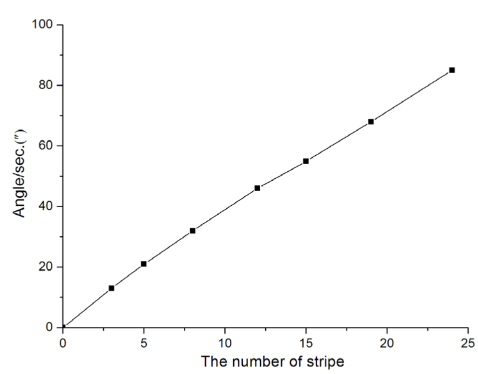

Fig. 10. Relationship between number of interference fringes and angle of tilt.

As shown above, the coaxial errors are 11″, 11″, and 7″, respectively, for three channels.

Synthesizing all the above errors and alignment errors in each channel, the composite alignment errors of three channels are 15″, 15″, and 12.4″, respectively. The given requirement (30″) is satisfied.

In conclusion, in order to solve the problem of alignment and testing of optical axis parallelism in a multi-optical axis system, we present an alignment method of axis parallelism and system wave aberration. The imager installation base surface is adjusted to be perpendicular to the optical axis of the interferometer and remain motionless precisely by using theodolite. Then, according to the measurement principle of wave aberration with interferometer, each channel axis is adjusted to be parallel to the axis of the interferometer. While imaging quality in each channel is measured, alignment on channel axis parallelism is accomplished. By this method, three-axis parallelism in annular three-channel imager is aligned. The accuracy of axis parallelism is up to 15″, and the imager requirement (30″) is satisfied. Feasibility and precision of this method are verified.

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