Gravity Effect Evaluation for TMA Telescope based on CMM Measurement

Kun-Huan Wu, Shenq-Tsong Chang, Yu-Chuan Lin, Po-Ming Lin, Yu Hsiang Lin, Chun-Chieh Lien

Taiwan Instrument Research Institute, National Applied Research Laboratories.
20 R&D Road VI, Hsinchu Science Park, Hsinchu 30076, Taiwan.
Email: rirawu@narlabs.org.tw ; stc@tiri.narl.org.tw ; yclin@tiri.narl.org.tw; poming@tiri.narl.org.tw ;
lingln@tiri.narl.org.tw ; rogerlien@narlabs.org.tw

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Abstract: In order to evaluate the gravity effect of the three-mirror anastigmat (TMA) telescope with the aspherical primary and secondary mirrors. A ground-measuring method and an algorithm are presented to demonstrate how to predict the gravity effect for a TMA space telescope under zero gravity. For the TMA space telescope, one can change the gravity acceleration from +1 gravity to −1 gravity by rotating the telescope upside down, which is difficult for larger optical space telescopes. In this article, we introduce and develop a new approach to get zero gravity results by measuring the wave-fronts of mirror under +/- gravity acceleration by a coordinate measurement machine (CMM).It based on the direction of optical axis and the reference points on the barrel instead of on the attitude indicator of the primary and secondary mirrors.

Our findings might be valuable in understanding the relationship between the results of change in attitude and repeated cycles of testing for comparison about the gravity effect by CMM. A coordinate transformation, a measurement process, and gravity effect evaluation for the TMA telescope were established in present study. Meanwhile, this approach is worth trying as a pathfinder test for a prototype design of future space telescopes.

1. INTRODEUTION

Gravity keeps things together. It is a force that attracts matter towards it. Anything with mass creates gravity, but the amount of gravity is proportional to the amount of mass. Therefore, to estimate the attitude of a telescope in the Space, it is necessary to flip the telescope 180 degrees on the ground to measure the effect of gravity on the optical system.

There are only few research methods and devices to measure the Gravity Effect (GE), such as non-contact laser interferometer (Interferometer). Although traditional method could report GE, it is not clear what their tests and verifies are if the diameter of mirrors are greater than or equal to 300 mm. Interferometer could not measur the wave front errors (WFE), decenter, and tilt at the same time.

Several studies have examined the Gravity Effect. Heinisch J,et al. (2006) described the optical lens assembly and adjustment is an important key technologies [9].S.T. Chang et al.(2012) made some studies of the GE about three-mirror anastigmat (TMA) optical system, that is one of the most important specifications for spherical optics by the coordinate measurement machine (CMM) at TIRI [1] [2] [3] [4]. The measurement also has to consider whether the mechanical axis of the lens are coincide with the optical axis by the CMM. Po-Han Huang et al.(2015) improved the accuracy of each mirror assembly adjustment to optical axis, to took mirrors attitude adjustment, adjust the optical system installations and meet the design requirements [6] [7].

In order to understand the gravity effect of the TMA optical system assembled with the lens barrel and the relationship between the aspherical primary mirror and the secondary mirror, the TMA plan developed a lens center measurement based on the optical axis direction and a part of the reference point. Coordinate transfer methods and measurement procedures and procedures were established for the TMA system, and relevant measurement data were obtained using the CMM.

In this study, the coordinate transfer expectation caused the measurement points to be consistent before and after the flip, thus avoiding the error caused by the true sphericity. This paper examined the TMA gravity effect with the CMM. In order to obtain more accurate optimization results, we traced the pertinent parts, measurement results of CMM and the environment temperature. Our findings might be valuable in understanding the relationship between the results of change in attitude and repeated cycles of testing for comparison about the GE by CMM automatic measuring system.

2. METHOD

2-1 PURPOSE AND EXPERIMENTAL DESIGN

To evaluate the gravitational effects of the TMA telescope, the aspherical primary and secondary mirrors, we recommend a ground-based measurement method and algorithm to demonstrate how to predict the effects of the gravity effect of the TMA space telescope under zero gravity. For the TMA telescope, the gravitational acceleration could be changed from +1G gravity to -1G gravity by turning the telescope upside down, which is difficult for larger optical telescopes. An interferomter and a laser tracker have been applied to measure the radius of curvature of a spherical mirror, but these methods physically contact on the TMA system, it is evitable that the contacts may make scratches on the mirrors during measurement. To avoid scratches on the mirrors,, experiment of contact probing on a BK7 plate has been performed with a mechanical probe whose spring constant is 0.6 N/mm. The measurement was done by point-contact without probe sliding on the sample surface. No scratches by this measurement have been found through the aid of microscope. We started contribution of the TMA system by CMM in years, and completed it by ST Chang et al. (2012). The measurement applies the coordinate measuring machine (CMM),Brown & Sharpe Global Image 9128 in this study.

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u=1.7 + l /1000 (μm) (1)

,where l is the measurement distance in mm. In this paper, 5 balls and 2 planes are used as references, we introduce and develop a new method for analyzing the zero-gravity mirror wavefront error CMM measurement under +/-1G gravity acceleration. It is based on the direction of the optical axis and the point on the lens barrel, rather than the attitude indicators of the primary and secondary mirrors. The contents of items 9, 10 and 11 of the procedure in Figure 1 are the innovative methods developed primarily for this study.

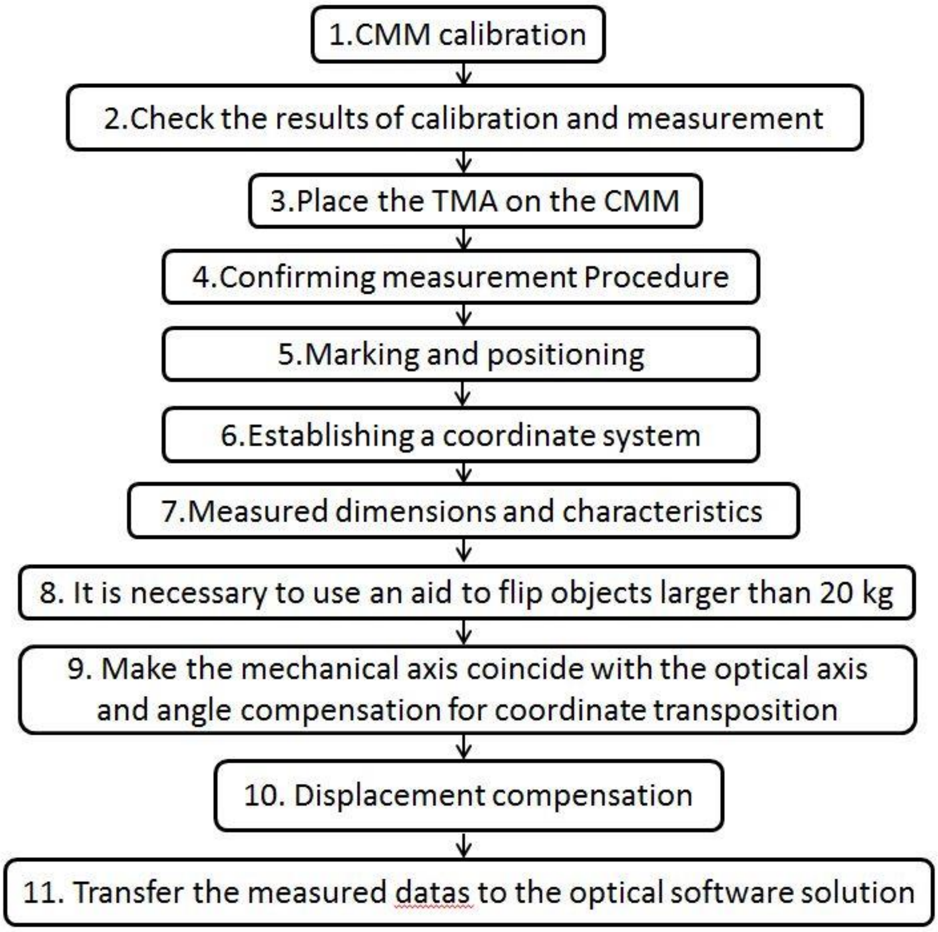


Fig1. Optical system using CMM for +/-1G gravity test main measurement and analysis architecture and procedure

2-2 DESIGN PRINCIPLE: CONVERSION COORDINATES, OPTICAL ANALYSIS CONCEPTS, PURPOSES AND STEPS

Because the TMA designs is a symmetrical structure, the coordinate conversion of the positive and negative (+/-1G) gravity test does not require the same individual coordinate pre-measurement as the previous primary and secondary mirrors, and does not need to have a specific relationship with the CMM and optical coordinates.

2-2-1 THE PURPOSE OF CMM MEASUREMENT COORDINATE CONVERSION

Taking the benchmark ball spherical as an example, unless the 100 % guaranteed true sphericity, even if the reference ball a little moves or rotations, theoretically, the CMM measurement results (excluding the movement amount) may not be completely consistent. The reason was that the same CMM measurement program, before and after the measurement is different point on the ball, the true sphericity of the reference ball naturally affects the CMM measured spherical coordinates. Therefore, it is necessary to know the movement of the reference ball (the amount of movement along the three axes) and the rotation (the rotation angle around the three axes), and restore the CMM touch point to the same position before the change.

Usually a CMM test object (system) needed a fixed set of reference coordinates. There were several ways to establish a reference coordinate, one of which is to select three points that are not in a straight line (actually the spherical coordinates) to form a constant angle coordinate. This reference coordinate (three reference spheres) will move or rotate with the system under test. In the "Exploring the TMA's attitude change under gravity +/- 1G image" program, the TMA's main mirror fixture (M1 mount) and the fixed system main board (it named main plate) were quite stable, while the secondary mirror (M2) passes through a long The lens barrel is attached to the main plate and might be affected by gravity. The three reference glass spheres constituting the reference coordinates were adhered to the main plate, and the attitude changes of the two stainless steel reference steel balls on the secondary mirror (M2) with respect to the reference coordinates are respectively measured under the action of +1G or -1G gravity. In the middle of the +1G and -1G measurements, the TMA must be flipped 180 degrees, and the three reference steel balls that establish the reference coordinates move and rotate together. It is expected that the difference between the two attitude changes is extremely small, so it is required to be consistent before and after the reference coordinates, and the spherical center coordinates of the measurement reference ball must consider above the conditions described.

2-2-2 Coordinate conversion

The coordinate transformation included coordinate translation and coordinate rotation. In Cartesian coordinates, the coordinate movement was relatively simple, that translated along the x, y, and z axes, and the result was independent of the order. The coordinate rotation was complicated, and the coordinate conversion results were related to the order of rotation around x, y, and z. coordinate rotation was described by mathematically (Rotation Matrix).

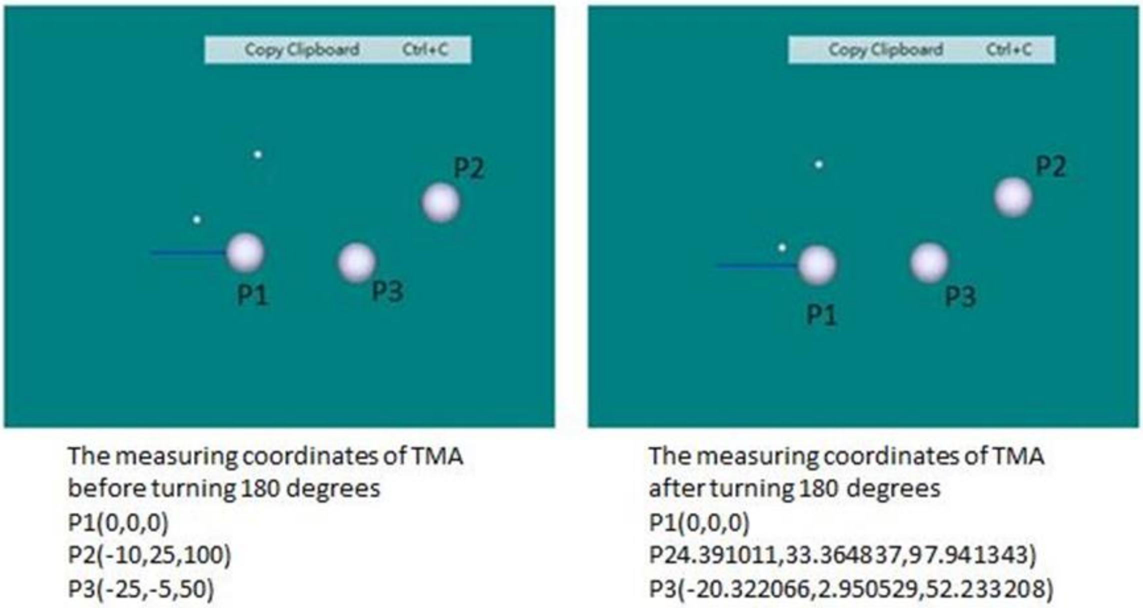
2-2-3 Using Zemax for CMM measurement simulation

(1) Centers of P1, P2, and P3 form the TMA reference coordinates, and P1 is the coordinate origin (rotation center).

(2) Before rotating the object under test (rotation vector), the P2 coordinate is S0, assuming rotation around the x

(Rpx), y (Rpy), and z (Rpz) axes, and the coordinates should be S1, S2, and S3. After rotation (Rp=RpzRpyRpx), the CMM measures P2 and P3, and the P2 coordinate is S3.

(3)Rotating the coordinates in the reverse order of the same angle as above 3-2, perform CMM program coordinate conversion (Alignment),and the P2 and P3 would be returned to the same coordinate values (S2, S1 and S0) before rotating the object to be tested. CMM program coordinate conversion. Rc = RcxRcyRcz.



The simulate CMM test rotation of object with Zemax: conceptual diagram as shown in Fig. 2.

2-2-4 Software and hardware system

The software used in this paper is Zemax, and the measurement results could be analyzed by Zemax program to obtain optical surface parameters such as radius of curvature or conic constant, eccentricity or tilt.

The hardware is a contact CMM (which hardware includes PC-DMIS software), which the probe contacts the workpiece and senses three directions via the probe, and transmits the signal to detector by contact, and at the same time, the displacement measurement system (such as the optical meter) of the three axes is triggered, and the measurement coordinates (X, Y, Z) of the workpiece are calculated through a data processor or a computer, and the dimensional accuracy and geometric precision are obtained by calculation and integration. The CMM of TIRI is Brown & Sharpe Global Image 9128. The accuracy is 1.7 + l 1000 (mm), where l is the measured distance in mm. In this study, four spherical optical surfaces were used as a reference. These optical surfaces are calibrated by the National Physical Laboratory (NPL) through interferometry. These surfaces were used as transfer standards and the data is listed in Table 1. The uncertainty is 0.0055% and the confidence is 95%.

3. RESULTS AND DISCUSSION

As shown in Figure 3, the measurement results indicate: M2 mount is the secondary fixture, S is the sphere, and P is the center of the sphere after the flip. In order to confirm the results of flipping which it flips before and after 180 degrees, coincidence error (mm) is designed to help determine the coincidence of the coordinates after the flip; if the Coincidence error is 0, it means that the coordinates before and after the flip are completely consistent; if it is not 0, there is error in results. The actual error is shown in Table 1.

The P1 is the center of the first reference sphere and is declared as the reference in the CMM program. Therefore, the x, y, and z spheres are (0,0,0) before and after the flip, and (+1G)-(-1G) is 0.The P2 and P3 are the marks of the second and third reference balls, the SPHL is the steel ball on the left side of the secondary mirror, the SPHR is the steel ball on the right side of the secondary mirror, and the PLN is the face of the secondary mirror mount (the purpose is to observe the angle of tilts).

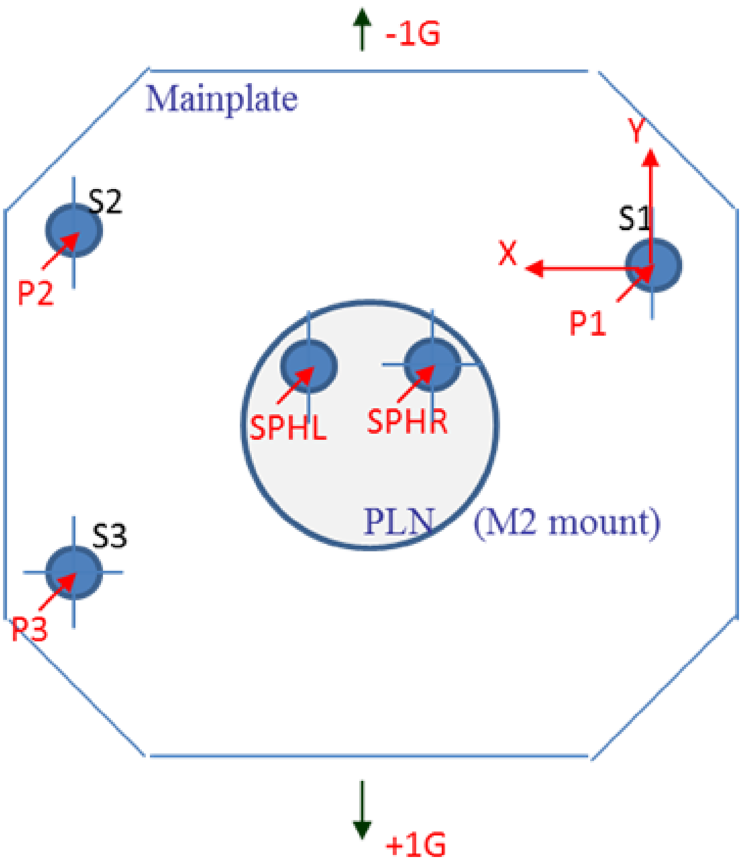


Fig.3 The marking instructions of measurement

Table1.The effect and error of secondary mirror under +/- gravity acceleration

Coincidence error(mm)				0.0165
		+1G	-1G	(+1G) - (-1G)
P1(mm)	x	-0.0004	-0.0134	0.0130
	y	-0.0004	0.0019	-0.0023
	z	0.0005	0.0002	0.0003
P2(mm)	x	817.7956	817.8025	-0.0069
	y	-4.0246	-4.0232	-0.0014
	z	0.1758	0.1755	0.0003
P3(mm)	x	817.5630	817.5690	-0.0060
	y	-301.8487	-301.8523	0.0036
	z	29.1268	29.1270	-0.0002
SPHL(mm)	x	423.0438	423.0647	-0.0209
	y	-224.1146	-223.9221	-0.1925
	z	-866.4545	-866.4679	0.0133
SPHR(mm)	x	392.9764	392.9938	-0.0174
	y	-224.1776	-224.0113	-0.1663
	z	-866.5361	-866.5407	0.0047
PLN(dir. Cosine)	L	0.00043190	0.00044476	-0.00001286
	M	-0.09679773	-0.09664678	-0.00015095
	N	-0.99530400	-0.99531866	0.00001466

Results are calculated by the data by more than 10 successive measurements and listed in table 1. From the results of Table 1. the reference spheres represent the primary, secondary mirrors and their planes as shown. This optical system might have structural rigidity problems. From the CMM measurement repeatability could be ≤ 1 μm, the measurement error was actually very small, indicating that the continued amount was also to obtain little difference data. It was found that that discrepancy and difference between direct CMM and CMM spherometry was low and negligible. The long lens barrel of the entire TMA had a cantilever effect, and it could be found from Fig.4. that a small downcast displacement.(It is exaggerated representation of displacement un Fig4.).After the solution, the amount of the head was calculated to be 25 μm. About 0.8 arc seconds, the diagram was exaggerated. The results of this experiment could achieve the research purpose for this research and support the idea of innovation. (inversing vector measurement and optimization solution).

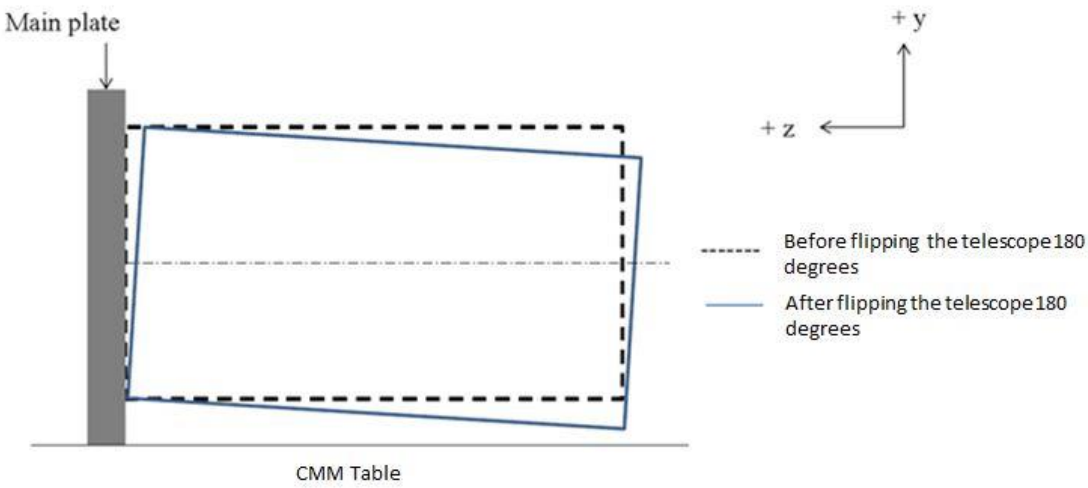


Fig.4 The schematic of downcast lens barrel

4. CONCLUSION

To improve the progress and efficiency of the project, the flatness of the Main plate and the roundness of the reference ball should be required at the design stage, or a standard plane or lens with a large enough area to represent the main plate as a vertical reference to the optical axis. It might not need to be a lot of times at each stage or measurement cycle. (This report used a multi-measurement method to make the measurement accuracy converge. It was quite time-consuming. In the main mirror measurement reference section, confirmed that the program setting that was correct; confirming that the coordinate point of each measurement point was the same position. It took at least 6 hours. If you encounter power failure or the machine is shut down, you would have to recalibrate and re-measure.) According to the program , you could complete all the measurement processes in this study. The innovative method developed mainly in this study which is to obtain the result from the optimization of the optical software Zemax after the actual measurement by CMM. Our findings might help to understand the relationship between the results of the attitude change and the repeat test cycle in order to compare the gravity effects of the CMM. This study established the coordinate transformation, measurement process and gravity effect evaluation of the TMA telescope. At the same time, this method was worth trying to test as a prototype for future space telescopes. Our findings might be valuable in understanding the relationship between the results of change in attitude and repeated cycles of testing for comparison about the gravity effect by CMM. A coordinate transformation, a measurement process, and gravity effect evaluation for the TMA telescope were established in present study. Meanwhile, this approach is worth trying as a pathfinder test for a prototype design of future space telescopes. Adding the temperature compensation in the future will be better. It applies the CMM embedded algorithm that calculates the effect of the temperature by CMM which considers the coefficient of expansion(CTE).

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