Chapter 28
Analysis and Study of Target Ball Error Accuracy for the Laser Tracker

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Abstract Laser tracker is the mainstream equipment in the field of industrial measurement. The analysis and research of its measurement accuracy have a certain scientific research value and use value. In this paper, the measurement results of the metal and glass target balls at $D = 3730$ mm and $D = 2815$ mm were analyzed and analyzed by combining with the measurement system of the laser tracker. The measurement results of the metal and glass target balls at $D = 2766$ mm and $D = 2727$ mm were analyzed by using three-point support base. It is found that the maximum error of the metal target is 14.2 μm, the 1.5-inch glass target is 5.8 μm, and the 0.5-inch glass target is 9.3 μm at $D = 2727$ mm by using the three-point support base. In the case of removing the positioning error and the base error of the target ball, the three target balls all meet the requirements of use. The closer the target ball is to the laser tracker system, the smaller the error value is. Compared with the base supported by plane, the measurement accuracy of the target ball is improved to some extent when the base supported by triangle is used.

28.1 Introduction

In recent years, with the rapid development of modern three-dimensional space technology, laser tracker has become a high-precision large-size measuring instrument with mature technology, high efficiency and stable performance in industrial measuring system. In some major industries, the 3D high precision measurement

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method represented by the laser tracker gradually replaces the traditional measurement method and is widely used in the installation and detection of large precision equipment [1–4].

28.2 Laser Tracker Measuring System

Laser tracker system (LTS) is a high-precision large-size measurement instrument in industrial measurement system. It integrates laser interferometric ranging technology, photoelectric detection technology, precision machinery technology, computer and control technology, modern numerical calculation theory and other advanced technologies. The space moving target is tracked and the three-dimensional coordinates of the target are measured in real time. It has the characteristics of high precision, high efficiency, real-time tracking and measurement, quick installation and easy operation, etc. and is suitable for real-time measurement of geometric quantities in large-scale space.

28.3 Error Factors Affecting Measurement

The main factors affecting the indication error of the laser tracker measurement system are the indication error of the point length, the double-sided indication error, the distance indication error, the spherical reflection target error and the dynamic velocity error.

The point-to-point length indication error of laser tracker refers to the difference between the indication value and the reference value when the laser tracker measures the point-to-point length of the short ruler. The measurement needs to be made in horizontal, vertical, diagonal and any direction specified by the user [5].

Laser tracker double-sided indication error refers to the difference of the indication value of the laser tracker when the fixed point is tested on both sides and the forward-looking/rear-looking measurement at the same point. This measurement needs to be made at three different points.

The distance indication error of the laser tracker refers to the difference between the indication value of the laser tracker and the reference value when the laser tracker measures the long ruler installed along the measuring axis. The measurement needs to be made on at least four different reference lengths.

Laser tracker spherical reflection target error refers to the spherical reflection target installed in the base point, the laser tracker measured the value of the change. The measurement involves rotating the spherical reflector target four positions about the laser incident axis and four positions about the vertical axis of the laser.

Dynamic indication error refers to the maximum speed when the laser tracker can keep tracking ability when the target moves along the circumference.

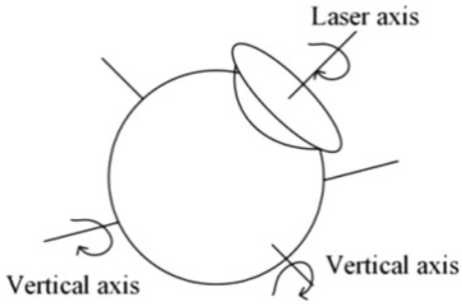

Fig. 28.1 Schematic diagram of spherical reflection target error measurement

28.4 Error Analysis Method of Measuring Target Ball

The reflector of laser tracker generally has cat eye reflector, corner reflector and tool ball reflector and other types. The reflector adopts a spherical structure, embedded in the interior of a hollow cone prism, ranging equivalent reflection center coincides with the center of the ball, in theory, the distance between the prism center and any spherical measuring point is equal to the radius of the ball R. The accuracy of the reflector is very high, each reflector needs to be tested strictly before leaving the factory, and the allowable error is generally (0.01–0.025) mm.

Similar to total station ranging, laser tracker ranging also exists range plus constant and range multiplication constant, which should be corrected. In addition, the error of the center of the ball and the error of the incident angle have a great influence on the measurement of the station construction of multiple laser trackers. This error is not only affected by the error of the prism itself but also affected by the processing error of the base. In order to ensure the measurement accuracy of the laser tracker, it is necessary to test the reflection prism error.

As shown in the figure, the spherical reflection target is installed at the base point (stable and at the same height as the instrument), aligned with the laser incident direction and recorded the value of the laser tracker; rotate four positions around the laser incident to record the laser tracker; swing around two axes perpendicular to the laser axis respectively to record the value of the laser tracker. The measurement results are shown in the Fig. 28.1.

28.5 Example Analysis of Measuring Target Ball Error

In this paper, the 1.5-inch metal target ball, 1.5-inch glass target ball and 0.5-inch glass target ball configured in the laser tracker system are tested at different distances. The measured environmental conditions are: temperature 24.1 °C, air pressure 952.4 hPa, humidity 60.3%RH. The specific test scheme is shown in Table 28.1.

Table 28.1 Test protocol

The serial number	Target ball type	Distance	Type of base support	Number of measurements
1	1.5-inch metal target ball	$D = 3730$ mm	The plane	3
2	1.5-inch metal target ball	$D = 2815$ mm	The plane	3
3	1.5-inch metal target ball	$D = 2766$ mm	Three points	3
4	1.5-inch glass target ball	$D = 3730$ mm	The plane	3
5	1.5-inch glass target ball	$D = 2815$ mm	The plane	3
6	1.5-inch glass target ball	$D = 2766$ mm	Three points	3
7	0.5-inch glass target ball	$D = 2727$ mm	Three points	1

28.5.1 1.5-Inch Metal Target Ball Test

The 1.5-inch metal target ball has the advantage of preventing it from falling and is commonly used in the measurement process. It is necessary to carry out its measurement accuracy. For the 1.5-inch metal target ball, the plane base measurement results are used at the position $D = 3730$ mm and $D = 2815$ mm, respectively, and the three-point support base measurement results are used at the position 2766 mm. It can be seen from the three tables that the maximum measurement error of the metal target ball at $D = 3730$ mm is 15.5 μm, that of the metal target ball at $D = 2815$ mm is 14.4 μm, and that of the metal target ball at $D = 2766$ mm is 14.2 μm. According to the data, the closer the target ball is to the laser tracker system, the smaller the error value is. The datum of the triangular-supported base is a slight improvement over that of the flat-supported base.

The positioning error of the laser tracker measuring system is 15 μm + 6 μm/m, which is about 37, 32 and 31 μm, respectively, when $D = 3730$ mm, $D = 2815$ mm and $D = 2766$ mm. After removing the influence of the positioning error and the base of the target ball, the accuracy error of the target ball in the three places meets the use requirements (Table 28.2).

Figure 28.2 shows the comparison of the three measurement results at $D =$ 2815 mm for a 1.5-inch metal target ball. The image clearly shows the measurement error curve. By comparing the figures, it is found that the error curves of the metal target ball in the laser axis, vertical axis 1 and vertical axis 2 are consistent, and the data fluctuate to some extent. The maximum measurement error of the metal target ball at $D = 2815$ mm is 14.4 μm, and the correction point appears in the laser axis of the second measurement (Tables 28.3 and 28.4).

Table 28.2 Measurement results of 1.5-inch metal target ball $D = 3730$ mm (plane support)

The serial number	Rotation axis	Rotation angle/(°)	X/mm	Y/mm	Z/mm	Distance/μm
1	Laser axis	0	1377.6101	3462.2266	−167.1943	15.5
2		180	1377.6245	3462.2245	−67.1890	
3		90	1377.6125	3462.2243	−167.1908	12.4
4		270	1377.6126	3462.2266	−167.1786	
5	Vertical axis 1	40	377.6111	3462.2257	−167.1972	10.5
6		−40	1377.6105	3462.2245	−167.1868	
7	Vertical axis 2	40	1377.6127	3462.2280	−167.1910	6.1
8		−40	1377.6116	3462.2234	−167.1872	

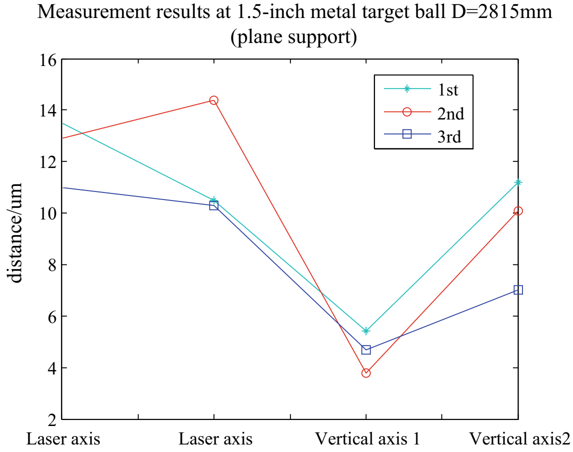

Fig. 28.2 Three measurement results when 1.5 in metal target ball $D =$ 2815 mm (plane support)

Table 28.3 Measurement results of 1.5-inch metal target ball $D = 2815$ mm (plane support)

The serial number	Rotation axis	Rotation angle/(°)	X/mm	Y/mm	Z/mm	Distance/μm
1	Laser axis	0	2070.9713	1898.9193	−173.8509	12.9
2		180	2070.9634	1898.9183	−173.8610	
3		90	2070.9723	1898.9162	−173.8628	14.4
4		270	2070.9634	1898.9207	−173.8525	
5	Vertical axis 1	40	2070.9711	1898.9210	−173.8511	3.8
6		−40	2070.9713	1898.9172	−173.8515	
7	Vertical axis 2	40	2070.9731	1898.9170	−173.8494	10.1
8		−40	2070.9667	1898.9248	−173.8497	

Table 28.4 Measurement results of 1.5-inch metal target ball $D = 2766$ mm (three-point support)

The serial number	Rotation axis	Rotation angle/(°)	X/mm	Y/mm	Z/mm	Distance/μm
1	Laser axis	0	2061.2728	1835.5138	−174.5207	13.3
2		180	2061.2677	1835.5102	−174.5326	
3		90	2061.2770	1835.5066	−174.5307	14.2
4		270	2061.2662	1835.5144	−174.5257	
5	Vertical axis 1	40	2061.2750	1835.5126	−174.5207	3.4
6		−40	2061.2740	1835.5093	−174.5209	
7	Vertical axis 2	40	2061.2735	1835.5107	−174.5211	3.3
8		−40	2061.2758	1835.5127	−174.5224	

28.5.2 1.5-Inch Glass Target Ball Experiment

The advantage of 1.5-inch glass target ball compared with metal target ball is its low price, and it is more commonly used in the measurement process. It is necessary to carry out the measurement accuracy. For the 1.5-inch glass target ball, the plane base measurement results are used at the position $D = 3730$ mm and $D = 2815$ mm, respectively, and the three-point support base measurement results are used at the position 2766 mm. According to the three tables, the maximum measurement error of the metal target ball at $D = 3730$ mm is 11.1 μm, that of the metal target ball at $D = 2815$ mm is 7.0 μm, and that of the metal target ball at $D = 2766$ mm is 5.8 μm. According to the data, the closer the target ball is to the laser tracker system, the smaller the error value is. Compared with the plane-supported base, the data of the triangular-supported base are significantly improved.

The positioning error of the laser tracker measuring system is 15 μm + 6 μm/m, which is about 37 μm, 32 μm and 31 μm, respectively, when $D = 3730$ mm, $D = 2815$ mm and $D = 2766$ mm. After removing the influence of the positioning error and the base of the target ball, the accuracy error of the target ball in the three places also meets the use requirements (Tables 28.5 and 28.6).

28.5.3 0.5" Glass Target Ball Experiment

At a measuring distance of $D = 2727$ mm, the 0.5-inch glass target ball is supported by three points, and the data shown in Table 28.7 show a measurement error of 9.3 μm. A 0.5-inch glass target ball is more difficult to measure than a 1.5-inch target ball due to its relatively small diameter. Through the data, it is found that the measuring accuracy of 0.5-inch glass target ball meets the requirements of use (Table 28.8).

Table 28.5 Measurement results of 1.5-inch glass target ball $D = 3730$ mm (plane support)

The serial number	Rotation axis	Rotation angle/(°)	X/mm	Y/mm	Z/mm	Distance/μm
1	Laser axis	0	1377.6641	3462.2335	−167.2129	3.6
2		180	1377.6664	3462.2321	−167.2153	
3		90	1377.6671	3462.2323	−167.2125	3.3
4		270	1377.6695	3462.2338	−167.2141	
5	Vertical axis 1	40	377.6674	3462.2328	−167.2113	1.8
6		−40	1377.6658	3462.2321	−167.2106	
7	Vertical axis 2	40	1377.6567	3462.2320	−167.2002	11.1
8		−40	1377.6605	3462.2325	−167.2107	

Table 28.6 Measurement results when 1.5-inch glass target ball $D = 2815$ mm (plane support)

The serial number	Rotation axis	Rotation angle/(°)	X/mm	Y/mm	Z/mm	Distance/μm
1	Laser axis	0	2070.9710	1898.9328	−173.8431	1.1
2		180	2070.9713	1898.9321	−173.8439	
3		90	2070.9775	1898.9290	−173.8462	7.0
4		270	2070.9723	1898.9326	−173.8431	
5	Vertical axis 1	40	2070.9709	1898.9318	−173.8462	6.6
6		−40	2070.9714	1898.9322	−173.8397	
7	Vertical axis 2	40	2070.9698	1898.9323	−173.8405	5.0
8		−40	2070.9669	1898.9339	−173.8443	

Table 28.7 Measurement results when 1.5-inch glass target ball $D = 2766$ mm (Three-point support)

The serial number	Rotation axis	Rotation angle/(°)	X/mm	Y/mm	Z/mm	Distance/μm
1	Laser axis	0	2061.2783	1835.5165	−174.5187	5.8
2		180	2061.2752	1835.5164	−174.5237	
3		90	2061.2794	1835.5156	−174.5221	1.6
4		270	2061.2792	1835.5167	−174.5210	
5	Vertical axis 1	40	2061.2785	1835.5159	−174.5188	1.6
6		−40	2061.2772	1835.5160	−174.5179	
7	Vertical axis 2	40	2061.2775	1835.5165	−174.5210	1.3
8		−40	2061.2768	1835.5169	−174.5200	

Table 28.8 Measurement results of 0.5-inch glass target ball $D = 2727$ mm (three-point support)

The serial number	Rotation axis	Rotation angle/(°)	X/mm	Y/mm	Z/mm	Distance/μm
1	Laser axis	0	2048.0392	1792.1104	−187.7215	9.3
2		180	2048.0307	1792.1142	−187.7221	
3		90	2048.0329	1792.1125	−187.7230	6.0
4		270	2048.0302	1792.1120	−187.7176	
5	Vertical axis 1	40	2048.0289	1792.1128	−187.7205	3.5
6		−40	2048.0296	1792.1135	−187.7238	
7	Vertical axis 2	40	2048.0338	1792.1121	−187.7204	7.5
8		−40	2048.0227	1792.1156	−187.7231	

As can be seen from the table, with the change of the attitude of the ball prism, the maximum error of the reflection center of the metal target ball can reach 14.2 μm when the three-point support base is used at the close distance $D = 2766$ mm, and the maximum error of the reflection center of the 1.5-inch glass target ball can reach 5.8 μm when the three-point support base is used at the close distance $D = 2727$ mm. The maximum error caused by the reflection center of the 0.5-inch glass target ball can be 9.3 μm. According to the data, the closer the target ball is to the laser tracker system, the smaller the error value is. Compared with the base supported by plane, the measurement accuracy of the target ball is improved to some extent when the base supported by triangle is used.

28.6 Conclusions

There are many kinds of influence on measurement error of laser tracker system, and the measurement target ball is also a part of the influence on measurement accuracy. The precision of three kinds of commonly used target balls, 1.5-inch metal target ball, 1.5-inch glass target ball and 0.5-inch glass target ball, is analyzed. With the change of the attitude of the ball prism, the maximum error of the reflection center of the 1.5-inch metal target ball is 14.2 μm, and the maximum error of the reflection center of the 1.5-inch glass target ball is 5.8 μm, using the three-point support base at the position of $D = 2766$ mm. The maximum error of the reflection center of the 0.5-inch glass target ball is 9.3 μm when the three-point support base is used at $D = 2727$ mm. In the case of removing the positioning error and the base error of the target ball, the three target balls all meet the requirements of use. The closer the target ball is to the laser tracker system, the smaller the error value is. Compared with the base supported by plane, the measurement accuracy of the target ball is improved to some extent when the base supported by triangle is used. The next step is to develop a tool to further shorten the measurement distance and reduce the impact of the measurement distance on the precision of the target ball.

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