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The Designing Acceleration of Driving Motor of Theodolite in the Tracking System

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Abstract: In this study, the laser tracking system was introduced. In order to capture the target in a finite area, the laser tracking system was first given a moving speed in the horizontal direction to make that the target and laser tracking system were stillness in horizontal orientation relatively. The scanning pattern was raster scanning. The smallest acceleration of the driving motor of the theodolite must be $8.5°/s^2$ in order to make the target to be still on the area of pointing beam spot in the course of acquisition and tracking. When the numerical value of eccentricity that the target departed from the center of laser beam spot was bigger than a planning one, the motor compensated the eccentricity and pointed the target again. The driving motor of theodolite compensated the eccentricity by an acceleration, uniform motion and speed-down process. The minimum demanding acceleration was $5.72°/s^2$. So the acceleration of the motor of laser tracking system was $8.5°/s^2$.

Keywords: Acceleration, acquisition, motor, scanning, tracking

INTRODUCTION

The laser tracking system was the base of the optical communication. There was a breakthrough on the research of laser tracking cooperative target. It was successful in laser communication between two satellites of GEO and LEO in the project of SILEX by EPA (Zu *et al*., 2003; Laurent and Duchmann, 1991; Duchmann and Planche, 1991). The background experiment of laser tracking cooperative target was usually done between two mountains, two valleys, two cars or between the fire balloon in the stratosphere and the ground (Kamugisha *et al*., 2006; Prasada *et al*., 2004; Vilcheck *et al*., 2004). The laser tracking cooperative target experiment was done by using the laser beam to illuminate the retro reflector setting on the cooperative target. The echo that reflected from the retro-reflector was used to detect the position and distance of the target (Lucy *et al*., 1966). In the study of Zu *et al*. (2003), Laurent and Duchmann (1991), Duchmann and Planche (1991), Kamugisha *et al*. (2006), Prasada *et al*. (2004), Vilcheck *et al*. (2004), Ortiz *et al*. (2001), Lucy *et al*. (1966) and Zeng *et al*. (2005), the tracking process and precision were researched in the simulating experiment. But the limited value and design requirement of the motor's acceleration in the tracking system has not been researched. This study researched the characteristic of the acceleration of the tracking motor in the laser tracking uncooperative target system. The limited acceleration value of the driving motor was given. The research on the acceleration of driving motor of theodolite was important for the development of the laser tracking system.

THE INTRODUCE OF LASER TRACKING UNCOOPERATIVE TARGET SYSTEM BY ACTIVE ILLUMINATION

From Fig. 1, the laser tracking system tracked the target between two satellites. The secondary satellite that rotated by the main satellite was scanned, captured and tracked by laser tracking system that was set on the main satellite in order to complete laser communication. The illuminating laser that set on the

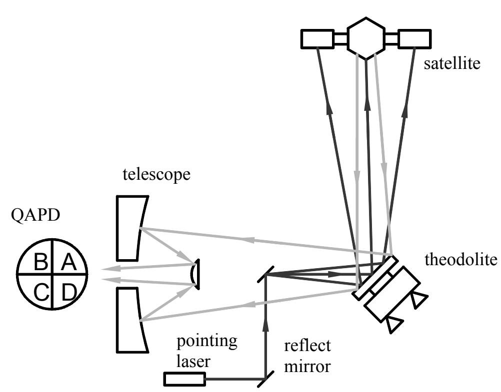

Fig. 1: The laser tracking system

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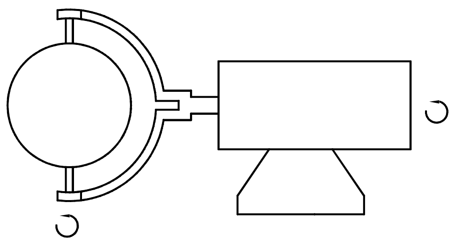

Fig. 2: Configuration of the theodolite

main satellite illuminated the secondary satellite by the reflection mirror that set on the theodolite. The reflecting echo from the secondary satellite target was received by the telescope that set on the tracking system. And the reflection mirror that set on the theodolite made the illuminating laser to track the secondary satellite target. From Fig. 2, the theodolite can rotate in the directions of pitch and azimuth. The reflection mirror that set on the theodolite guided the laser beam to scan, capture and track the secondary satellite target. The receiving telescope that was coaxial with the axis of the illuminating laser beam received the echo that was reflected from the diffuse reflection target satellite surface and the range and position of the secondary satellite were measured. The 2 satellite were working on the same orbit and the speed of secondary satellite that rotated by the main satellite was bigger. In order to capture the secondary satellite in a finite area, the scanning equipment was first given a moving speed in horizontal direction that was same as the speed of secondary satellite turning around the scanning system, so the secondary satellite and tracking system were stillness in horizontal orientation relatively. We can track the secondary satellite target.

THE DRIVING MOTOR IN THE CLOSED LOOP CONTROL SYSTEM

From the Fig. 3, the stop signal was sent to the control computer, when the Quadrant Silicon Avalanche Photodiodes (QAPD) detected the echo that reflected from the target. The driving motor slowed down and stopped, when it received the stop instruction. The position error that the target was in the illuminating laser beam spot was obtained by the QAPD. The error signal was amplified and separated by the amplifier of the QAPD. The A/D transform and digital signal processing computed the position error and sent the adjusting instruction to the driving motor. The motor transformed into pointing state by a process of accelerating, uniform motion and speed-down. The coder sent the feedback signal that from the motor to the control compute in a sampling frequency. When the QAPD detected an eccentricity error, the control computer made the driving motor to compensate the error and made the illuminating laser to point the target. The control system received the position error signal that from the QAPD repeatedly and the motor compensated the error. It was in tracking state after pointing. The sampling frequency of the QAPD was equal to the one of the scanning (Zeng *et al*., 2005).

THE REQUIREMENT OF THE ACCELERATION OF DRIVING MOTOR IN LASER TRACKING PROCESS

The requirement acceleration of the motor was high. When the laser tracking system met the target in laser scanning, the control system sent the stop instruction to the driving motor. The motor stopped after a deceleration process because of the inertia (Fig. 4). At this time, the system turned to capture state from scanning state. Because the target was rotating with the tracking system in the level, the raster scanning style along the vertical direction was used to scan. The scanning laser along the vertical direction stopped after moving a vertical distance because of the inertia. In order to make the laser beam spot to be on the target, the moving distance of the laser beam that the beam moving in the time of motor from starting to stop to completely stop must be smaller than the difference between the beam spot diameter and the target diameter. The α was the motor's acceleration, the t was the time that from the motor receives the stop instruction to completely stop. The θ was the divergence angle of the laser beam. ΘR was the scanning beam diameter, the d was the target diameter, the f was the scanning frequency. $I_0 = 1/3\ \theta R$ was the scanning interval that between the every scanning beam spot. The R was the distance between the laser tracking system and the target. $1/2\ \alpha t^2 = \theta R - d$ was the moving distance of the laser beam that the beam moved in the time of motor from the motor received the stop instruction to completely stop. The v_0 was the scanning speed. $v_0 = I_0 f$ the motor's acceleration was:

$$a = \frac{I_0^{\ 2}}{2(\theta R - d)} f^2 = \frac{\theta^2 R^2}{18(\theta R - d)} f^2 \tag{1}$$

We can draw a figure about the demanding acceleration that affected by scanning frequency and

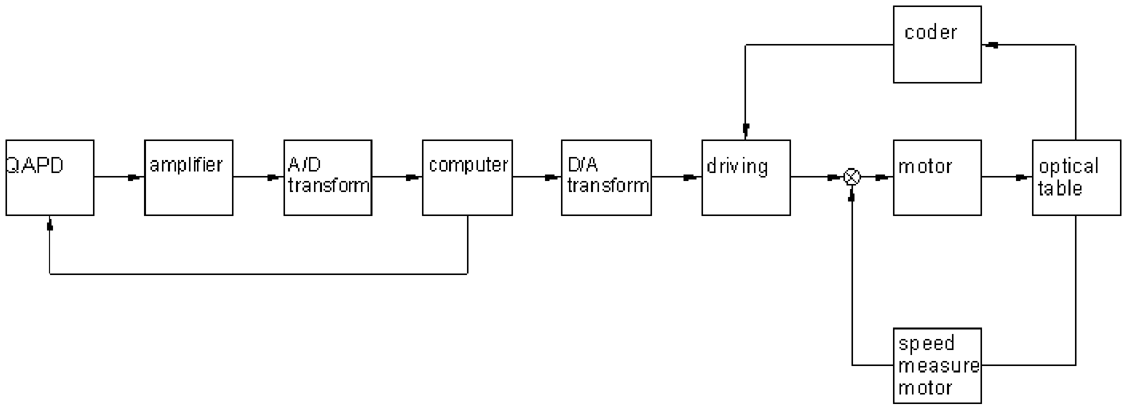

Fig. 3: The system flowchart of feedback and controlling

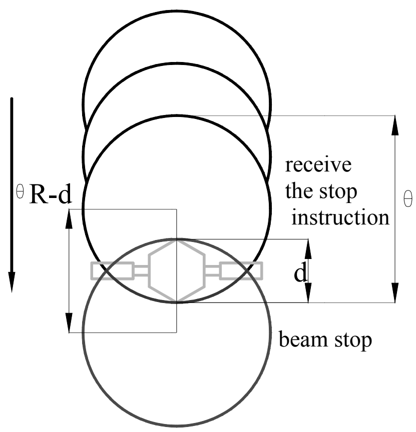

Fig. 4: The distance of the laser beam moving in the course of tracking

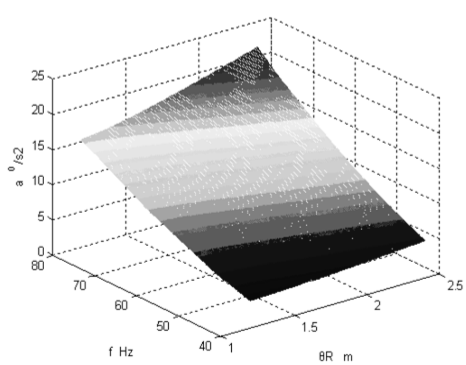

Fig. 5: The demanding acceleration that affected by scanning frequency and beam diameter

beam diameter by the expression (1). From the Fig. 5, when the diameter of the scanning beam spot decreased by the laser beam divergence and the detecting distance between the tracking system and the target became bigger and the scanning interval that was 1/3 of the beam spot diameter became bigger too. The motor's acceleration became bigger when the laser beam spot moved a distance that was from receiving instruction to completely stop (the target was always in the laser beam spot). At same time, the scanning frequency increased, the using time that the laser beam spot using in moving a scanning interval became smaller, the scanning speed increased. The motor's acceleration became 4 times as the before one, when the beam spot diameter increased twice or the scanning frequency increased twice. In the laser tracking system, the detecting distance R was 3000 m, the scanning frequency was 50 Hz, the divergence of the illuminating laser beam was 0.8 mrad, the target diameter was 0.56 m and the scanning interval was 1/3 of the laser beam spot diameter. The rate of laser every beam spot overlaps was 2/3. The minimum motor's acceleration that computed was 8.5°/s.

THE REQUIREMENT OF THE ACCELERATION OF DRIVING MOTOR IN COMPENSATING PROCESS

The QAPD can detect the eccentricity that the target in the laser beam spot and send the adjusting instruction, when the target departed from the center of the laser beam. It was shown in the Fig. 6. The eccentricity was $= \delta_1 + \delta_2$. At this time, the tracking system pointed the target again. The driving motor compensated the eccentricity in a scanning period and minimized the eccentricity error. The eccentricity became lower after several compensating periods after that the AQPD couldn't find this eccentricity error and

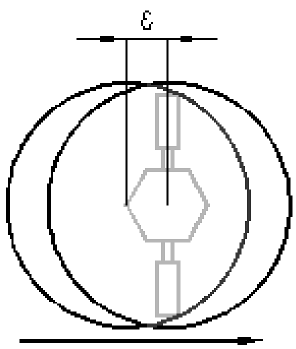

Fig. 6: The satellite left the center of the laser beam

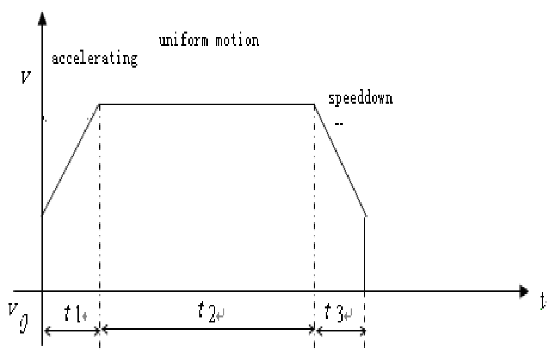

Fig. 7: The changing of speed of the motor

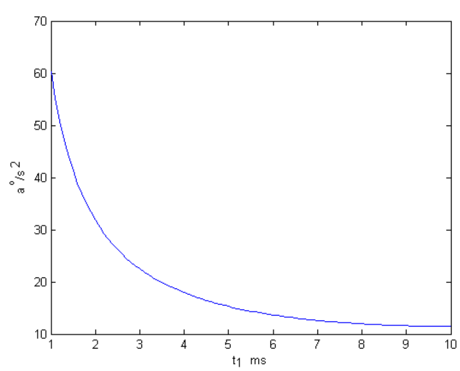

Fig. 8: The changing of acceleration of the motor as the changing of the accelerating time

the tracking system changed into tracking state. The output error of the QAPD was δ_1. It was the minimum value that the QAPD can find and send the error signal to the system. The detecting error of the QAPD was δ_2. The total eccentricity error that the target departs from the center of the laser beam spot was $\delta_1+\delta_2$.

In order to make the target to be in the laser beam spot, the driving motor compensated the eccentricity error and let the laser beam to point the target again. In a compensating period, the compensating error of driving motor was δ, the precision of motor was δ_3, the real compensating error was $\delta-\delta_3$, $\delta-\delta_3\leq\delta_1+\delta_2$. The motor changed into pointing state by an accelerating, uniform motion and speed-down process.

The accelerating time was t_1, uniform motion time was t_2, deceleration time was t_3, $t_1 = t_3$. It was shown in the Fig. 7. The acceleration of motor was α:

$$(\frac{1}{2}at_1^2 + at_1t_2 + \frac{1}{2}at_3^2 = \delta - \delta_3)$$

$$a = \frac{\delta - \delta_3}{t_1(t - t_1)} \tag{2}$$

From the Fig. 8, the motor acceleration became smaller, when the accelerating time became bigger. If δ_1 = 50 μrαd, δ_2 = 10 μrαd, δ_3 = 10 μrαd, δ = 20 μrαd, t_1 = 1/2 t, the maximum acceleration was $\alpha = \frac{\delta-\delta_3}{t_1(t-t_1)}$ = 5.72°/s.

The acceleration of motor was 8.5°/s^2.

CONCLUTION

In this study, the system of laser pointing, acquisition and tracking was introduced. In order to capture the target in a finite area, the scanning system was first given a moving speed in horizontal direction that was same as the speed of the target turning around the scanning system, so the target and tracking system were stillness in horizontal orientation relatively. The scanning pattern was step scanning. The smallest acceleration of the driving motor of the theodolite must be 8.5°/s^2, so the satellite may still on the area of pointing beam spot in the course of acquisition and tracking. The illuminating laser beam spot was still on the target in the time from the motor received the stop instruction to completely stop. If the target departed from the center of the laser beam spot a distance and the numerical value of eccentricity was bigger than a planning one, the motor compensated the eccentricity and pointed the target again. The demanding acceleration was 5.72°/s^2. So the acceleration of the motor of laser system was 8.5°/s^2.

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