The application of ultramicroscope with high precision in light and small laser communication system for micro-nano satellite

Tie Chi\textsuperscript{1,2}, Xiaoming Li\textsuperscript{1}, Lixin Meng\textsuperscript{1} and Lizhong Zhang\textsuperscript{1}\textsuperscript{*}

\textsuperscript{1} Electro Mechanic Engineering College, Changchun University of Science and Technology, Changchun, JiLin, 130022, China
\textsuperscript{2} Technology School, Jilin Business and Technology College, Changchun, JiLin, 130507 China

*Corresponding author’s e-mail: chi122333@163.com

Abstract: With the rapid development of space laser communication technology, it is possible to realize mass data transmission between satellites in low orbit. Micro-nano satellite is the first choice of low orbit communication satellite because of its lightweight, small size and low cost. Laser scanning technology is a kind of technology that can accurately control the direction of laser beam. It has been widely used in the field of space laser communication. In this paper, after analyzing the technical requirements of the scanning mirror with APT system for micro-satellite, a kind of miniature scanning mirror is selected to realize the accurate pointing of the beam.

1. Introduction
Since the 21st century, many "cube" satellite was launched into space, including a certain number of low orbit satellite laser communication[1]. On low orbit of the space, such micro-satellites are cheaper to build and launch, not only are they not limited by the power and size for cubesats, but they also solve the problem of mass data transferring between satellites[2]. The large amount of data transmission between satellite and ground is completed by high-power and large/medium-sized laser communication satellites, which greatly reduces the difficulty in the design and development of light and small laser communication systems for micro-nano satellites.

![Schematic diagram of space laser communication link](image-url)
No matter which kind of link laser communication, their common characteristic is communication distance, narrow communication beam. Especially in space applications, the volume, weight and power consumption of the payload are very strict. However, the design and manufacture of micro-nano satellites of space laser communication have the following characteristics: lightweight, small-size, low-cost, short development period, generally placed in low orbit, easy launch, strong survivability, no influence of atmospheric channel, and more importantly, the influence is lower in low-frequency disturbance and high-frequency vibration to the platform. It is difficult in integration of modules and technical difficulty, but it just meets the technical requirements of long-distance laser communication.

In micro-nano laser communication satellite, light and small laser communication system is the core part. In terms of functions, the space laser communication system is composed of the laser communication transmitting and receiving subsystems and the beam capture, alignment and tracking (APT) subsystem [3]. However, due to the smaller field angle of transmitting and receiving in micro-nano laser communication satellite, the beam alignment and acquisition between satellites is a key technology [4]. Laser scanning technology is a kind of technology that can accurately control the direction of laser beam. It has been widely used in the fields of optoelectronic medicine, laser processing, space laser communication, lidar, remote sensing and measurement. In this paper, a high-precision scanning galvanometer is adopted to realize the accurate pointing of beacon light in APT system.

2. Technical conditions of APT system for scanning galvanometer

2.1 Load capacity of scanning galvanometer
The diameter of optical reflection lens in common galvanometer on load is very small, and the thickness of the reflector is better than a certain thickness, the stability of the heavier load can produce all kinds of disturbance torque, at the same time, the system resonance frequency and bandwidth control can not meet the required width, but the lens of micro scanning galvanometer is very small, its load capacity can bear completely and meet the technical requirements [5].

2.2 Beam control accuracy of scanning galvanometer
No matter at home or abroad, laser communication systems have designed high-bandwidth accurate tracking systems to achieve accurate beam alignment and effectively suppress platform disturbance. In general, the closed-loop bandwidth of the accurate tracking system is improved, which will make most of the frequency band of platform jitter contained in the effective bandwidth of the system, thus achieving the purpose of suppressing interference and improving accuracy.

2.3 The bandwidth requirements of the galvanometer
(1) Two-dimensional fast galvanometer servo platform is preferred.
(2) The load directly affects the resonant frequency of the galvanometer system. Under the condition that the beam diameter and beam quality are allowed, the diameter and thickness of the optical reflection lens should be minimized to improve the closed-loop bandwidth of the system.
(3) Interface control mode: the control interface mode of the system is also a major factor affecting the servo bandwidth of the system. This system uses the standard SPI interface and can drive and control the galvanometer by entering a simple serial command.

2.4 Scope of control of beam by scanning galvanometer
APT system coarse beacon light receiving system has a relatively large field of view angle design, which is to receive coarse signals in a large range. The field of view angle design of scanning galvanometer for accurate tracking field of view is relatively small, and the size of beam control range of scanning galvanometer is related to the size of accurate tracking field of view, and also related to the magnification of the system.
3. Our Scanning galvanometer selection

The two-dimensional scanning galvanometer chose by us is piezoelectric ceramic micro galvanometer (Table 1), it belongs to the New Scale Technologies, this scanning galvanometer can integrated micro piezoelectric motor, precision guidance system, displacement sensors and microprocessor to a compact space, in this space, beam control and mirror positioning system can constitute a complete beam control system. The module has an extremely small size (diameter <12mm) and contains the world's smallest piezoelectric motor and IC drive in a compact space, which can provide higher power and reliability, and its precision is ten times higher than that of electromagnetic motors. The built-in absolute displacement sensor enables the angular resolution of the rotating table to reach 0.025° without the need for an external controller. This module integrates the PID controller onto the circuit board, and drives the controller simply by inputting simple serial commands through the standard SPI interface [6].

![Figure 3. New Scale Technologies scanning galvanometer [6]](image)

| Parameter name          | Parameter value         |
|-------------------------|-------------------------|
| Rotation range          | +/-20deg                |
| Speed                   | >1100deg/sec            |
| Acceleration            | >1,000,000deg/sec       |
| Stall torque(min)       | 0.04N-mm                |
| Holding torque(min)     | 0.08N-mm                |
| Mass                    | 3g                      |
| Inertia                 | 350g-mm²                |
| Recommended step frequency | Up to 100hz            |
Resolution (encoder resolution) 0.025 deg (440 urad)
Repeatability +/-0.05 deg (880 urad)
Accuracy 0.25 deg (4400 urad)
Maximum closed-loop step & settle times 0.99 g-mm² inertial load
0.5 deg 9ms
5 deg 14ms
20 deg 21ms
Resolution <0.0057 deg (<100 urad)

4. Pointing accuracy of the scanning galvanometer
The errors affecting the pointing accuracy are as follows:
1) execution error of two-dimensional rapid galvanometer: the resolution of the galvanometer is 0.05 mrad and the accuracy is 4.4 mrad. Considering the magnification factor of the telescopic system, the control angle error of the corresponding viewing axis is σ₁.
2) the influence of CCD camera resolution and noise is uniformly classified as σ₂.
3) since the satellite platform is small, non-airborne and no atmospheric disturbance [7], only the satellite-borne platform is used to control the error σ₃.
4) the apparent axis deviation of APT system in satellite-borne platform is σ₄.
5) the nonlinear distortion error of the two-dimension scanning galvanometer is σ₅.
The total error \( \sigma = \sqrt{\sigma_1^2 + \sigma_2^2 + \sigma_3^2 + \sigma_4^2 + \sigma_5^2} \approx 8 \text{ mrad.} \)

5. Conclusion
If the height of the low-space orbit is 500 km from the ground, about 100 satellites are distributed in the low-orbit, which are loaded with the APT system of this kind scanning galvanometer, and the communication distance of each satellite is between 50 and 80 km, at this height and distance, the uncertainty of the APT system in micro-nano satellite is 27 mrad [8], and the capture uncertainty region is about three times to the algorithm error, so in theory, this type of scanning galvanometer can meet technical requirements for laser communication systems in micro-nano satellites.

References
[1] Jiang HL, Tong SF, Zhang LZ, Song L, Wang XM, Li HZ. (2010) The Technologies and Systems of Space Laser Communication. National Defense Industry Press, Beijing.
[2] Morio T, Tetsuharu F, Dimitar RK. (2015) Current status of research and development on space laser communications technologies and future plans in NICT [C]. In: 2015 IEEE International Conference on Space Optical Systems and Applications (ICSOS), New Orleans, LA, USA. 1-5.
[3] Hu Z, Jiang HL, Tong SF, Song ZX. (2011) Research on ATP System Technology of Laser Communication Terminal in Space. Acta Armamentarii. 32(6).
[4] Yu SY, Zhou BK. (2016) Satellite optical communication aiming acquisition and tracking technology. 6(3).4.
[5] Yi JC, Hamid H, Gerry GO. (2012) Feasibility of infrared Earth tracking for deep-space optical communications. Optics Letters. 1(1).
[6] New Scal. (2016) Aunion-M3-RS_Rotary_Smart_Stages_AU-M3-RS. http://www.auniontech.com.
[7] Ma XP, Sun JF, Zhi YN. (2013) Research of DPSK Modulation and Self-Differential Homodyne Coherent Detection Technology to Overcome Atmospheric Turbulence Effect in the Satellite-to-Ground Laser Communication. Optical fiber and optical communication. 33(7).
[8] Zhao X.(2012)The APT Initial Capture and Error Analysis of SpaceLaser Communication. Master's thesis. 40.