Study on on-Line Measurement and Controlling System of the Foundation Trench-Leveling Machine

J G Yi, H Y Jiang, Y Z Xing, J Chen and J T Liu
Mechanical and electronic Engineering College, Hebei Agricultural University, Boding City, Hebei Province, China

E-mail: yijinggang2000@yahoo.com, yjg@heinfo.net

Abstract. Research the system software and hardware composing, the control mode, the on-line measurement and control principle based on the laser receiver and the inclination sensor as the signal source. After the laser receiver accepts the laser signal, the laser signal is carried through the light filter treatment so as to reduce the sunlight interference, and then amplified and modulated, last transmitted to the control unit. The inclination sensor adapts XWQJ02-01S, measure the slope angle the x and y verticality direction. The error adjusting range is $f_{0.05^\circ}$. The separate time treatment avoids simultaneously adjusting the laser and inclination signal to each other interfere. The on-line measurement and control system realizes the parts to work on the plane that parallels with the datum plane of the laser beam scan. The trench-leveling machine must retain $f_{0.05^\circ}$ with the datum plane. Adapting the least square method to fit the linear curve, the movement trend of the work parts on the work plane is judged through the slope number. The test result shows that thought the combination measurement and control of the laser and slope angle the leveling precision are $\pm 5\text{mm}/100$. Its can satisfy with the construction criterion request.

1. Introduction
Foundation trench-leveling is the important work procedure in the construction of foundation. Because of the foundation area expanse the trench-leveling machine adapts the laser to ever and again control and measure in order to ensure parallelism error below $\pm 10\text{mm}/100\text{m}$. The laser beam scan forms the datum plane. The trench-leveling machine work part always works in the parallel plane with the datum plane through the inclination sensor and the control system. Many factors influences trench-leveling operation sash as the trench-leveling libation, terrene odds and cutter wear etc. So the work parts have the trend to deviate the work plane. The on-line control and measurement system must always estimate the deviation trend. Before exceeding the error the system adjusts the work part to level.

2. Systematic hardware
2.1. Hardware construction
The system hardware mainly includes laser emitter, Position sensitive detector(PSD), laser receiver, inclination sensor and controller. The system hardware structure sees figure1. The laser signal source is a semiconductor laser emitter the model number of which is JP3 [1]. Position sensitive detector is one-dimensional sensor the model number of which is 2DPSD [2]. The laser receiver accepts the laser
beam signal, and then transmits the location error signal to the controller which of the model number is AT89C51. The height adjusting range of laser receiver is 20mm. The effective semi diameter of receiving is 150mm, and the effective angle is $360^\circ$. Two-axle inclination sensor adapts XWQJ02-01S.

2.2. Filter treatment
The disturbing signal of natural light is stronger more than the laser signal. So the light signal must carry through the lithe filter treatment. Because the laser transitivity of 635nm wave is strong, the laser receiver adapts the big bandwidth filter chip. Considering the slope incidence of laser, the central wave of filter chip is 670nm. When the slope incidence angle of laser beam is $45^\circ$, the central wave changes from 670nm to 600 and the peak value transitivity reduce a percentage of 10. So the half bandwidth of filter chip is 100nm [3].

2.3. Laser receiver
The laser receiver is an important composing portion in the laser measurement and control system. When the system works the laser receiver scans the light beam to form the leveling datum plane above working plane. The laser receiver always receives the laser beam signal of faintness frequency. After treating, the deviation error signal is transmitted to the controller. The Position sensitive detector transforms the faintness laser signal to the faintness analog signal. After the amplitude modulation, the head amplifier of low-noise, the rectifier circuit, the pulse forming amplifier, the controller exports the control signal to the control system.

When the controller, which adapts the microprocessor unit and the built-in system, receives the location deviation error, the controller judges the deviation position of work part opposition laser beam datum plane, and then gives the corresponding control signal to adjust the work parts [4,5].

2.4. Slope angle data sampling
The inclination angle collects the slope numeric value of x, y direction, exports the mill voltage. After the amplifier enlarges the mill voltage, the amplifying voltage exports the frequency transformer. Last after the photo isolator the controller reads the pulse data. After the upper treatment the disturbing signal is effectively restrained [6,7].

3. System software
The controller has three output channels. According to the highness and low of deviation location the controller respectively exports the control signal to No1 synchronous motor, No2 synchronous motor and No3 synchronous motor. Based on laser scan location, inclination angle, different location

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**Figure 1.** Hardware of measure and control system.
deviation and inclination signal the controller exports the control signal according to the setting control rule. The program flow chart sees figure2.

4. Work process
Laser receiver receives the benchmark laser beam that is emitted by the laser emitter. The controller judges the excursion benchmark direction of the trench-leveling machine, and controls the permanent-magnet synchronous motor by the time measure to drive the execution parts to up and down adjust the machine locality in Z direction [8].

Inclination sensor measures the x and y direction inclination angle on x, y plane. When the inclination deviates 0.1 degree from the balance location, the controller controls permanent-magnet synchronous motor by time measure to drive the execution parts to adjust x and y direction inclination angle in order to level the machine work parts. The x and y direction control sees figure3.

![Figure 2. The program flow.](image)

![Figure 3. Principle of operation](image)

Laser combines with inclination sensor to detect and time measure control. Permanent magnet synchronous motor drives the deflection swing crane and adjusts the machine to keep the work parts level through controlling its positive and negative turn. Adjustment algorithm:

X direction: \( H_x = \pm \frac{1}{2} [h_2(t) + h_3(t)] \)

Y direction: \( H_y = \pm h_1(t) \)

Z direction: \( H_z = \pm \frac{1}{2} [h_2(t) + h_3(t) + h_1(t)] \)

\[ h_1(t) = \left[ t_0(t) + \frac{t}{60} p \right] \cos \alpha(t) \]

Equation: \( H_x, H_y, H_z \) are the height variable of x,y,z direction
$h(t)$ is the height function of time variable (unit:mm)

$l_0$ is the support length of adjustment wheel (unit:mm)

$\alpha(t)$ is the angle function of adjustment wheel (unit: degree)

5. On-line measurement and control principle

In order to prevent the laser signal and the slope angle signal from bringing the disturbing signal the adjustment range of slope angle is set to ±0.05°. Because the trench distance length the trench-leveling machine easily deviates the work plane. So the height position of trench-leveling machine must be measured and controlled all the time, adjusted in time. The Position sensitive detector of one-dimensional always collects the location signal of height direction every one second, and then transmits the signal to SCM to treat.

The frondose method is that PSD output signal is collected every 2 second, and the sampling position has ten points. The data software treats the sampled data, and then the sampled data is fitted through the linear equation. And then the linear equation is analyzed according to the minimal binary multiplication. One terminal of x and y direction is set to zero, another terminal judges the movement trend of z direction along y height which is changed in time by adjusting the back wheel. The positive and negative of x coordinate denotes the movement trend. The positive indicates the upper deviation; the negative indicates the down deviation.

5.1. Date processing

It’s easy to judge the linear equation because of its simple form and graph. Fitting with linear equation makes the experiment date process simple and convenient, we can judge the date trend accurately by fitting expression.

Suppose linear equation:

$$Z=a+by$$

From the least square method, we know the coefficient a and b of the linear equation when the deviation quadratic sum is least. B is the slope of the linear equation, a is the intercept of the linear equation.

$$S(a,b) = \sum_{i=1}^{n}(y_i - a - bx_i)^2$$

$$b = \frac{\sum_{i=1}^{n}y_ix_i - \sum_{i=1}^{n}x_i\sum_{i=1}^{n}(y_i/n)}{\sum_{i=1}^{n}x_i^2 - (\sum_{i=1}^{n}x_i)^2/n}$$

$$a = \frac{1}{n}(\sum_{i=1}^{n}y_i - b\sum_{i=1}^{n}x_i)$$

For example, Take a standard plane as the beginning, after the trench-leveling machine works, y direction linearity highly z actual value sees table1.

| Point | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  | 10 |
|-------|----|----|----|----|----|----|----|----|----|----|
| y     | 0.00 | 50.00 | 100.00 | 150.00 | 200.00 | 250.00 | 300.00 | 350.00 | 400.00 | 450.00 |
| z     | 2.10 | 3.20 | 3.60 | 4.30 | 5.20 | 5.60 | 6.00 | 6.80 | 6.20 | 6.50 |

Data linear treatment, adopting the data of table1, the z of the linear fitting equation: $z = 2.719 + 0.01y$. The fitting curve sees figure4. The control system bases on the positive slope number to hoist the back wheel. The adjusting distance is 2.719mm.
5.2. Trench-leveling effect analysis
After selecting the original foundation and datum plane, artificially leveling a datum plane the trench-leveling machine levels the foundation. The sampling area is 50m×50m, the sampling point has ten and the sampling interval is set to 50mm. The sampling data see table 2. The relief map after leveling test see figure 5.

Table2. Leveling test sampling data (unit:mm).

| Hij | j=1 | j=2 | j=3 | j=4 | j=5 | j=6 | j=7 | j=8 | j=9 | j=10 | j=11 |
|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-------|------|
| i=1 | 14.5| 1.0 | 13.1| 15.0| 13.5| 14.9| 13.2| 14.5| 14.0| 14.5  | 13.0 |
| i=2 | 12.0| 13.0| 9.5 | 14.5| 13.2| 13.0| 14.0| 15.0| 14.9| 15.0  | 10.0 |
| i=3 | 13.0| 15.0| 12.0| 15.0| 14.0| 12.0| 14.9| 13.0| 15.0| 15.1  | 11.0 |
| i=4 | 15.1| 14.0| 9.8 | 14.5| 13.0| 9.0 | 12.0| 13.2| 13.0| 14.0  | 14.5 |
| i=5 | 13.0| 11.0| 11.0| 13.0| 11.5| 11.0| 12.3| 15.1| 14.2| 14.5  | 13.0 |
| i=6 | 13.5| 12.5| 11.0| 12.5| 12.0| 10.0| 12.0| 11.0| 10.0| 12.0  | 10.0 |
| i=7 | 11.1| 12.0| 9.5 | 15.1| 13.0| 9.8 | 10.0| 9.0 | 7.5 | 9.5   | 15.0 |
| i=8 | 14.0| 10.0| 8.0 | 13.5| 13.5| 12.0| 15.0| 8.0 | 10. | 12.1  | 7.5  |
| i=9 | 12.1| 13.2| 9.5 | 13.0| 12.0| 10. | 13.0| 12.5| 11.0| 13.0  | 15.0 |
| i=10| 13.0| 11.0| 10.0| 11.0| 11.5| 9.5 | 14.1| 14.2| 13.2| 15.1  | 11.2 |
| i=11| 11.0| 10.0| 7.2 | 9.8 | 10.0| 7.1 | 15.0| 13.2| 12.2| 13.0  | 10.0 |

6. Conclusion
Adapting the combination measurement and control of the laser and slope angle, the separate time treatment and the height position priority avoids simultaneously adjusting the laser and inclination signal to each other interfere. The linear curve is always fitted through the least square method. The deviation trend of the trench-leveling is judged through the slope number of the linear curve, and then adjusted in time to prevent beyond the error. The test result shows that the precision of the trench-leveling surface can reach ±3mm and the leveling precision is ±5mm/100m. Its can satisfy with the construction criterion request.

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