Solid State Phenomena Vol. 164 (2010) pp 91-94
Online available since 2010/Jun/30 at www.scientific.net

doi:10.4028/www.scientific.net/SSP.164.91

Improvement of Precise Angle Control System

Sigitas Šakalinis[a], Dainius Udris[b]

Department of Automation, Vilnius Gediminas Technical University
Naugarduko 41, Vilnius LT-03227, Lithuania

[a]s.sigitas@gmail.com, [b]dainius.udris@el.vgtu.lt

Keywords: positioning accuracy, microstepping, searching optimization.

Abstract. The main task of this research was improvement of precision of positioning drive, installed in a test rig for testing and calibration of the geodetic instruments at Institute of Geodesy of Vilnius Gediminas Technical University. Replacement of a stepper motor and a microstepping controller design increased positioning accuracy up to 0.1″. Vibrations and noise of the test rig were significantly reduced using an optimized control algorithm, where resonating step frequencies were bypassed. Time of scale rotation between measurements (every 30°) reached less than 1.5 min. Methods for further precision improvement were evaluated and this research is currently in progress.

Introduction

The main task of the reported research work was improvement of a positioning drive (Fig. 1), installed in a flat angle calibration machine for testing and calibration of the geodetic instruments at Institute of Geodesy of Vilnius Gediminas Technical University.

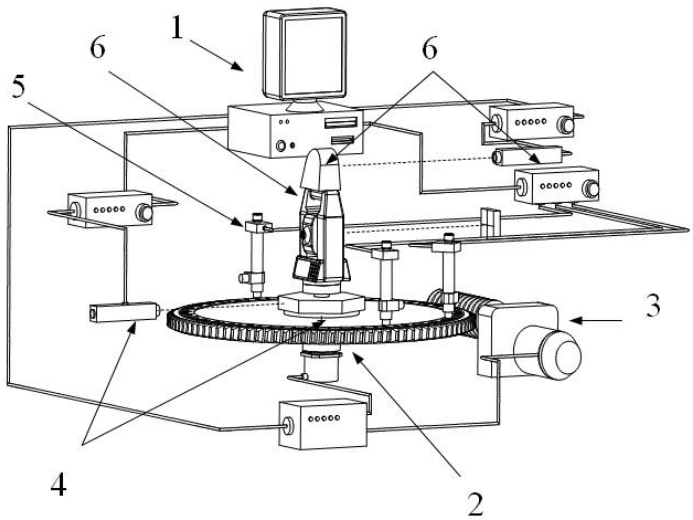

Fig. 1. Precise angle control system

This flat angle calibration and test rig consists of a circular scale, driven by electric drive 3, with precise rotary encoder 2 (model BE198-90000, produced by "Brown&Sharpe-Precizika"), and controlled by a personal computer (PC) 1. Precision of angle measurement is increased by means of twelve-angle polygon, fitted at the centre of the rotary disc, and the photoelectric autocollimator 4, photoelectric microscopes 5, placed on a circular scale, and electronic tacheometer 6 [1]. The rotary scale is positioned by a worm gear, driven by a stepper motor with additional tooth-belt gear. Three problems had to be solved during the modernization:

1. The measurement accuracy of basic equipment was limited to 0.001° by resolution of installed encoder, and the smallest positioning step (limited by the used stepper motor and

gear) was 0.000248°. When autocollimator or microscope is used, the positioning accuracy is not sufficient and should be improved.
2. The circular scale and positioning drive produce a very high level of noise and vibration during rotation and provide insufficient rotation speed, which makes the calibration process uncomfortable.
3. Connection to PC is implemented through RS-232 interface, which has limited transmission speed and is discontinued in new equipment.

Drive Modernization

The circular scale was driven by a 6 phase variable reluctance stepper motor ШД5Д1 with a step value 1.5° in a full step mode, and it was found to be a source generating the highest vibrations and noise. Furthermore, the step accuracy of used motor was insufficient therefore it was impossible to reach a smooth and precise rotation. Consequently, the first decision was to replace this motor with a better one. The required torque was measured for selection of a new motor. The result was found to be in range 0.1-0.15 Nm (measured by STAHLWILLE torsiometer No. 760, provided by UAB "Gitana").
After accuracy measurement, the 2 phase VEXTA PK266-02B hybrid stepper motor in a bipolar 2 phase excitation was selected for further tests. The main parameters of this motor are: step angle – 1.8°; holding torque – 0.88 Nm; motor inertia – $3 \cdot 10^{-6}$ kg·m^2; phase current – 2 A; resistance – 1.8 Ω; inductance – 2.5 mH; starting pulse speed – 1.2 kHz. Accuracy of the selected motor was measured using the rotary encoder A36–F–3600–5V, fixed on the motor shaft, and a digital read out CS 3000 (both produced by "Brown&Sharpe-Precizika"). Angular resolution of used equipment was equal to 0.034°, and the step deflection of the examined motor reached this value only 26 times per revolution (200 steps). It was the best result among the tested motors.
The selected motor was installed on a test rig using a tooth-belt gear with ratio of 1:1.833, and the resulting gear ratio is 1:3960. The circular scale positioning step is 1.64″ in full step mode, and it is not sufficiently accurate to meet the selected task – the microstep mode should be used for motor control.

Microstepping Controller

The stepper motor controller with microstepping was selected to increase positioning accuracy, and several possible solutions were tested.
The first tested controller was based on the *Microchip Application note AN822*, using the modified control firmware for the PIC18F452 microcontroller. 4, 8, 16 and 32 microstep modes were tested with a good positioning accuracy result, but the maximum rotation speed was not enough. Firmware modification was inconclusive and required a microstep number reduction. Consequently application of this controller in this test rig was suspended.
The next tested controller was based on a A3979 microstepping driver from *Allegro Microsystems, Inc*. This controller can produce motor control signals up to 16 microsteps, and the acceptable results were achieved: scale step angle – 0.1″ with a gear ratio of 1:3960 and 16 microsteps, and the maximum stable step frequency 12 500 Hz, so the scale can be rotated to the next measurement position (30°) within 1.5 min. The low internal resistance of used driver and adjustable coil current limit significantly reduced heating of the controller. These values are good enough for daily use, and the new motor with a microstepping controller considerably reduced the noise and vibrations of the test rig.

The Control Algorithm

Examination of modified drive indicated some peculiarities. The noisy vibrations were considerably reduced with a new motor and microstepping controller, but some acoustic noise at the selected pulse frequencies was observed:

1. At rotating counter-clockwise – the resonating noise with a frequency 445 Hz in wide pulse frequency range (from 280 to 12 500 Hz) after 1-2 s of rotation is observable.
2. Rotating clockwise there are several local resonances:
   a) 280 Hz noise in the 280 Hz pulse frequency area;
   b) 165 Hz noise in the 2 550 Hz pulse frequency area;
   c) 280 Hz noise in the 4 700 Hz pulse frequency area.

The calibration process of geodetic equipment does not depend on the rotation direction, measurements should be done every 30° of scale rotation so the noise can be diminished using a couple of simple rules in rotation control:

1. Avoid rotation in counter-clockwise direction at pulse frequencies more than 280 Hz, i.e. use it only for precise adjustment.
2. Avoid rotation in clockwise direction at resonating pulse frequencies, use higher or lower speed.

The control algorithm, based on mentioned circumstances and excluding mechanical stress of the test rig, was created. The pulse frequency increases slowly at the beginning (from 0 to 100 Hz per 0.2 s), then fast (to the 12 500 Hz per 0.5 s). When the encoder output comes close to the necessary point, the rotation speed reduces in reverse order, and accurate adjustment is made in stepping mode – to avoid mechanical springiness.

The first stage of flat angle test rig modification is finished – the necessary accuracy and rotation speed for daily use were achieved, noisy vibrations have been removed.

Further Modification

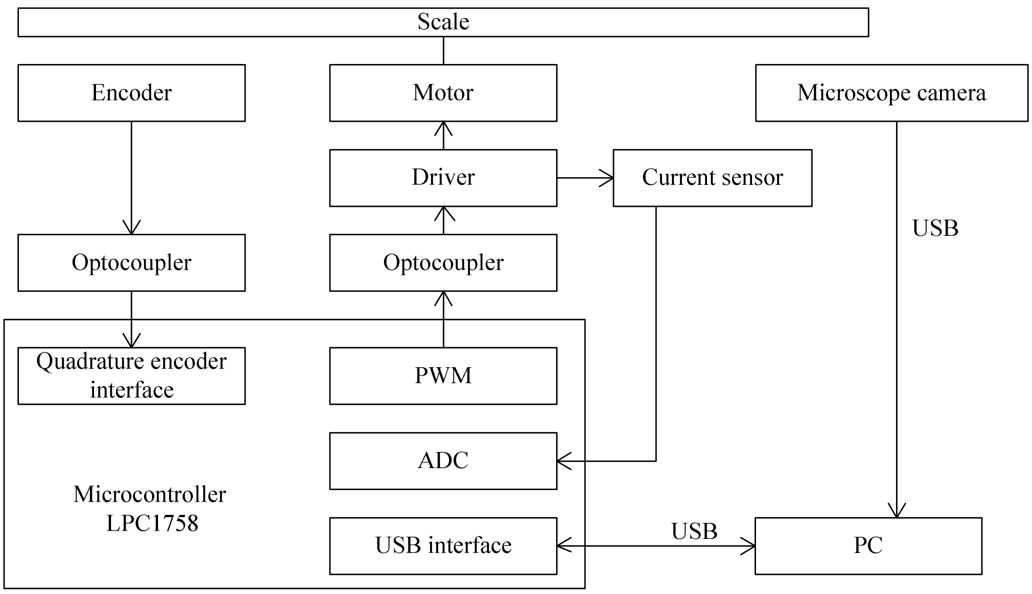

Fig. 2. Functional diagram of modified controller

The next step of test rig modification is implementation of a new interface to the PC and further position accuracy improvement. The highest positioning accuracy is available in correction mode, where currents of stepper motor coils are individually regulated to achieve the right position of scale, supervising it by collimator or microscope. This mode can be implemented using the fast microcontroller and direct search algorithms.

The Cortex M3 core microcontroller LPC1758 from *NXP* was selected for a new control system design after a study of the market. It has a powerful Cortex M3 V2 core for 16/32 bit applications, 100 MHz clock frequency, integrated quadrature encoder interface with pulse quadrupler for position encoder connection, motor-control dedicated 32 bit fast PWM outputs, USB and ETHERNET controllers, 12-bit ADC etc. Mentioned advantages can significantly reduce the complexity of controller and improve system characteristics. Functional diagram of a new controller is presented in Fig. 2.

The algorithm of a new controller can be divided into two stages: rotation to the indicated position and precision. The first stage is based on the aforementioned control algorithm and generates motor control signals in 16 microstep mode. The scale position is calculated from rotary encoder output signals, and there is two way communications with a host PC, implementing a test rig control and measured data visualization. If the mentioned positioning accuracy is enough, the controller will stop the rig in defined position, and reduce the current of motor coils to the safe value, keeping the same current ratio for existing microstep. The precision stage is actuated, when a higher accuracy is needed. At the closest fixed microstep position more accurate current ratio should be found. Due to the existing bias of scale and drive, it is impossible to calculate this ratio, and only the search can be used. The simplex search algorithms can be used for this reason. The mentioned task is close to the search in the specification stage, and the search with a free apex reflection can be used [2, 3]. The aim of the search can be described as a minimum bias between pointed and existing scale position. This bias can be calculated on a host PC, processing signals from microscope cameras. Because the variation of current in precision stage is very small, the current limitation should be maintained, and constrained optimization should be applied. The coil current is proportional to the PWM number, and this is integer, so the best shape is rectangular simplex [2]. The size of simplex depends on requested precision and measurement accuracy. The minimal size depends on PWM step, but can be further increased using additional regulation of power supply.

Summary

Using the 16 microstep mode angular resolution was increased to 0.1″ and noisy vibrations of test rig were significantly reduced. The control sequence was designed eliminating noisy modes of operation. Time of scale rotation between measurements (every 30°) amounted to less than 1.5 min, so duration of test for the full set of instruments can be diminished to 30 min or less.

The new controller with a simplex search implementation, in combination with a PC-based more accurate position measurement equipment - autocollimator or microscope - can be used for further improvement of precision.

References

[1] D. Bručas, V. Giniotis, P. Petroškevičius: *Basic construction of the flat angle calibration test bench for geodetic instruments.* Geodezija ir kartografija, Vol. 32, No. 3 (2006), p. 66-70

[2] A. Dambrauskas: *Methods of Simplex Search.* Vilnius, Technika, (1995), p. 160-165 (in Lithuanian)

[3] A. Dambrauskas, D. Udris: *Research of Simplex Search in Specification Stage*. Elektronika ir elektrotechnika, Kaunas, No.5(54), (2004), p. 47-51 (in Lithuanian)

Mechatronic Systems and Materials: Mechatronic Systems and Robotics

10.4028/www.scientific.net/SSP.164

Improvement of Precise Angle Control System

10.4028/www.scientific.net/SSP.164.91