Dun-Yuan Wang, Yong-Ping Zhang, Li-Mei Yao, Xian-Feng Xu and Jian-Guo Li

Detection System of Temperatures and Displacements for CNC Machine Tool Based On Lab VIEW

Abstract: The paper introduces a PXI system for detecting the temperature and displacement of CNC machine tool. The hardware of the system composes of high-performance embedded controller NI PXIe-8840, 9-slot chassis NI PXIe-1078 in which each slot accepts PXI Express module and X Series Data Acquisition Module NI PXIe-6341. Lab VIEW (Laboratory Virtual Instrument Engineering Workbench) software is used to process the acquired data from the digital potentiometer temperature sensor and grating displacement sensor according to CNC performance requirements. The developed system can be used to measure temperature, displacement, speed and acceleration accurately.

Keywords: Lab VIEW, digital potentiometer, grating, data acquisition

1 Introduction

Temperature and displacement are important test indicators of CNC machine tool, because the change in temperature during processing can lead to work piece's thermal deformation and the inaccuracy of the position may affect the accuracy of the work piece directly. In order to complete the test efficiently and flexibly, the NI virtual instrument technology is used. It consists of three components: the graphical programming software-Lab VIEW, modular I/O hardware and software hardware platform for integration. Lab VIEW is the most important part of NI virtual instrument technology, because communication function of GPIB, VXI, RS-232, RS-485 protocol hardware and data acquisition card is integrated and the function of in-

Dun-Yuan Wang, School of Electronic and Control Engineering, Chang'an University, Xian 710064, China. Email: 1213836557@qq.com
Yong-Ping Zhang, School of Electronic and Information Engineering, Ningbo University of Technology, Ningbo 315211, China. Email: ypz@nbut.edu.cn
Li-Mei Yao, GOLDCARD HIGH – TECHCO...LTD, Hangzhou 310018, China. Email: 1621674790@qq.com
Xian-Feng Xu, School of Electronic and Control Engineering, Chang'an University, Xian 710064, China. Email: 3110259@qq.com
Jian-Guo Li, School of Electronic and Control Engineering, Chang'an University, Xian 710064, China. Email: 603757352@qq.com

DOI 10.1515/9783110540048-052 © 2017 Dun-Yuan Wang et al, published by De Gruyter. This work is licensed under the Creative Commons Attribution-NonCommercial-NoDerivs 3.0 License.
strument panel control design, data analysis, instrument drive, I/O interface communication [1] can be achieved. The paper introduces a way to develop your own virtual instruments.

2 Temperature Detection

2.1 Uj33d-3 Digital Potentiometer

UJ33D-3 digital potentiometer uses advanced digital intelligent technology and traditional crafts, as shown in Fig.1. It can be used to read eight kinds of thermocouples’ (K, E, J, S, T, B, R, and N) temperature values corresponding to the output or measured voltage value. Its DC voltage and current input/output range is 0-4999.0mv and 0-19.999mA.

Fig. 1: UJ33D-3 digital potentiometer

RS-232 standard interface is used to communicate with the computer. RS232 parallel cable is unable to communicate with this device but RS232 cross cable can transmit data. The PC can be used to send commands to control the device’s mode of data transmission, for example: the instrument can send data continuously to the PC by sending C or c. Its communication protocol is that baud rate is 9600 and data frame mode is 9 bits including 8 data bits and 1 stop bit without parity-proof bit.
Before using the device, it needs to be zeroed (set voltage function selector switch to “zero”, and adjust the “zero potentiometer” so that the digital display is zero). In the 20mV and 50mV range, it needs to be preheated 5 to 10 min so that the displayed voltage remains stable. In addition, as shown in Fig. 2, by using four-terminal output mode, it can eliminate the voltage drop error generated by measuring wire when outputs small signal voltage. It can adjust the voltage to get the desired value through the coarse and fine adjustment. After setting the voltage value and thermocouple type, it can read the corresponding temperature value by opening the temperature read-only button up. The maximum test temperature is at 1700 °C and the temperature value will flash when the temperature value is out of range.
The main technical indicators as shown in Table 1:

Tab. 1: The main technical indicators of UJ33D-3 digital potentiometer

<table>
<thead>
<tr>
<th>Graduation</th>
<th>Range</th>
<th>Basic error permissible limit</th>
<th>Resolution</th>
<th>Rated load</th>
</tr>
</thead>
<tbody>
<tr>
<td>2V</td>
<td>0~1999.9mV</td>
<td>±(0.04%Ux+200μV)</td>
<td>100μV</td>
<td>2mA</td>
</tr>
<tr>
<td>200mV</td>
<td>0~199.99mV</td>
<td>±(0.04%Ux+20μV)</td>
<td>10μV</td>
<td>2mA</td>
</tr>
<tr>
<td>20mV</td>
<td>0~19.999mV</td>
<td>±(0.04%Ux+2μV)</td>
<td>1μV</td>
<td>2mA</td>
</tr>
<tr>
<td>2V×2.5</td>
<td>2000.0~4999.0mV</td>
<td>±(0.04%Ux+500μV)</td>
<td>300μV</td>
<td>2mA</td>
</tr>
<tr>
<td>200mV×2.5</td>
<td>200.0~499.90mV</td>
<td>±(0.04%Ux+50μV)</td>
<td>30μV</td>
<td>2mA</td>
</tr>
<tr>
<td>20mV×2.5</td>
<td>20.000~49.990mV</td>
<td>±(0.04%Ux+5μV)</td>
<td>3μV</td>
<td>2mA</td>
</tr>
<tr>
<td>(K)</td>
<td>0~1230.0°C</td>
<td>±(0.1%Tx+0.2°C)</td>
<td>0.1°C</td>
<td></td>
</tr>
<tr>
<td>(E)</td>
<td>0~660.0°C</td>
<td>±(0.1%Tx+0.2°C)</td>
<td>0.1°C</td>
<td></td>
</tr>
<tr>
<td>(J)</td>
<td>0~860.0°C</td>
<td>±(0.1%Tx+0.2°C)</td>
<td>0.1°C</td>
<td></td>
</tr>
<tr>
<td>(S)</td>
<td>0~1768.0°C</td>
<td>±(0.1%Tx+1°C)</td>
<td>0.5°C</td>
<td></td>
</tr>
<tr>
<td>(T)</td>
<td>0~380.0°C</td>
<td>±(0.1%Tx+0.2°C)</td>
<td>0.1°C</td>
<td></td>
</tr>
<tr>
<td>(B)</td>
<td>300.0~1600.0°C</td>
<td>±(0.1%Tx+1°C)</td>
<td>0.5°C</td>
<td></td>
</tr>
<tr>
<td>(R)</td>
<td>0~1600.0°C</td>
<td>±(0.1%Tx+1°C)</td>
<td>0.5°C</td>
<td></td>
</tr>
<tr>
<td>(N)</td>
<td>0~1300.0°C</td>
<td>±(0.1%Tx+0.4°C)</td>
<td>0.2°C</td>
<td></td>
</tr>
</tbody>
</table>

2.2 Test Plan

Use RS232 cross cable connect the digital potentiometer to the NI PXIe-8840’s IOIOI interface properly. According to the type of temperature sensors, digital potentiometer in turn applies 0.1V, 0.25V, 0.5V, 0.75V and V out voltage values to the input port of temperature detection system under test. According to (1), LabVIEW can be used to calculate the temperature of each test point indication error and determine whether this value is qualified by comparing with the allowable error. The maximum temperature indication error of all test points is taken as the measured value of the temperature indication accuracy of the system.

\[
(T_c - T_s) / T_s. \tag{1}
\]

\(V_c\) — The temperature-sensor output signal value of the corresponding actual maximum used temperature, expressed in mV.

\(T_c\) — The corresponding temperature value read from the display unit of the system under test, expressed in °C.
\( T_s \) — The corresponding temperature value read from the display unit of the test system, expressed in °C.

### 2.3 Create the VI

After setting up the front panel, and call the function in the program block and connect the function with the input/output control according to the implemented function. As shown in Fig.4: initialize the serial port by using VISA Configure Serial Port VI[1], and connect the serial terminal of function with the corresponding serial input control; Enable Termination Char prepares the serial device to recognize Termination char; The role of Termination char is able to stop read operation when the Termination char is read from the serial device where the Termination char is set to the hexadecimal number 0xD for carriage return; Set the Message Based Settings: Send End Enable property (where the END flag is sent at the end of each write operation) through the Property Node; SARL End Out property: termination mode for serial transmission; Termination Char property: serial terminator to send; Call the For loop structure to connect the test number control to the count (N) terminal; Add a “Test: value change” event to the Event Structure and enable the test to start when you click the test control; VISA Flush I/O Buffer Function flushes the specified I/O buffer; VISA Write Function writes the command to the device specified by the VISA resource name; VISA Read Function reads the specified number of bytes from the device or interface specified by VISA resource name and returns the data in read buffer [1], and displays the read string on the digital potentiometer-display control and convert it to a numeric output via the Fractional/Exponential String To Number Function to a graphical display control; Call the functions of Numeric Function according to the test requirements logically; Case structure determine whether the results are qualified; Convert data to strings by using Number To Decimal String Function and Number To Fractional String Function, then the string will be displayed in the test table control through Build Array Function, and create a test table’s local variable to save the last test data, then create the invoke node of the test table’s reinitialize to default to clear the test table at the next test; Establish your own Word template: by entering title name and adding corresponding bookmarks in the new Word, generate the test Word that has the title name entered in the document, and select the inserted table to add the bookmark to save the data in the table, finally save the Word as a template file type, then double click on MS Office Report Express VI, and when the dialog box appears, enter the Word template path and select the custom report for Word from the Template Drop-down list box, and click OK to load the Word template into the function; VISA Close Function closes the device specified by VISA resource name; Simple Error Handler VI displays an error when an error occurs[1]; “Return to optional test main interface: value change” event structure realizes returning to the
‘Test interface’ when you click on return to optional main interface control, and make the test interface VI keep run and the front panel open; While Loop structure repeats the subroutine block; Flat Sequence Structure is executed in the order from left to right, and after the completion of each frame, the data is transferred to the next frame.

Fig. 3: Temperature control front panel
3 Displacement Detection

3.1 SINO KA-300 Grating

SINO KA-300 grating is a high precision displacement detection device formed by the light source, (1) scale grating, (2) cable, (3) indicating grating, (4) secure connection plate, photoelectric detection devices and other components. The scale grating and the indicating grating are installed on the machine’s moving parts and fixed parts respectively. Its output is a square wave signal and there are three square wave signals: A phase, B phase, Z phase (A phase and B phase have the same cycle and the phase difference of 90°. A phase ahead of B phase represents the positive displacement; A phase lag B phase represents the negative displacement. Z signal can be used as a calibration signal to eliminate cumulative errors). The scale grating produces a count pulse when it moves a grid distance so grating can measure the relative displacement of the scale grating and the indicator grating by measuring the count pulses. Technical parameters of SINO KA-300 grating are resolution: 5μm (0.005 mm), grating pitch: 0.02mm, grating grid line: 50 lines/mm, reaction rate: 120 m/min (0.005 mm), operating temperature: 0–45 °C, storage temperature: −20–
70 °C, supply voltage: DC 5V ±5 %, 80 mA; cable length: 3.0m (can be extended), Main ruler’s length: 1020 mm.

### 3.2 Test Plan

Use the SHC68-68-EPM Shielded cable to connect the 68-pin terminal block TBX-68 to the data acquisition equipment NI PXIe-6341. Then connect the grating to TBX-68 according to the pin number of the counter in NI PXIe-6341, as shown in Table 2:

<table>
<thead>
<tr>
<th>Grating pin</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
</tr>
</thead>
<tbody>
<tr>
<td>signal</td>
<td>Empty</td>
<td>0V</td>
<td>Empty</td>
<td>Empty</td>
<td>Empty</td>
<td>A</td>
<td>+5V</td>
<td>B</td>
<td>Z</td>
</tr>
<tr>
<td>Wiring color</td>
<td>Black</td>
<td>White</td>
<td>Orange</td>
<td>Red</td>
<td>Green</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Counter pin</td>
<td>9</td>
<td>42</td>
<td>8</td>
<td>46</td>
<td>41</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Tab. 2: The wiring method**

The grating is mounted on a displacement measuring apparatus; the digital input port of the system accepts the grating’s output pulse and displacement curves will be displayed on the display unit after the system calculating the number of pulse. Performance requirements: measurement accuracy ≤0.01mm; measuring range (0-1000) mm. Based on the displacement and measured time during the displacement measurement, the linear velocity and acceleration of the related mechanical equipment are calculated. Curve reflects the dynamic response process of results. Speed detection performance requirements: accuracy ≤0.1 %; measuring range (0–500) mm/s. Acceleration detection performance requirements: accuracy ≤1 %.

The grating drive device is installed on the displacement detection test device, and the grating drive device is connected with the tested control system properly. The motor drives moving parts toward the predetermined position in a straight line, and if the maximum displacement distance of the controlled moving parts is L(mm), the moving parts will be controlled to move $L_S (L_S$ may be 0.1 L, 0.3 L, 0.5 L, 0.7 L, 0.9 L)which is measured by the grating again. Each detection point will be tested 10 times, and the average of the absolute value of each detection point difference is calculated according to (2). The maximum difference among all detection points is used as the position detection accuracy index.

$$L_P = \frac{\sum_{n=1}^{10} (|L_{CN} - L_{S1}|)}{10}$$  \hspace{1cm} (2)

In the equation: $L_P$—the average of the absolute values of the difference in each detection point, expressed in mm;

$L_{CN}$—The position value read from the system under test, expressed in mm;
Detection System of Temperatures and Tool Based On Lab VIEW

$L_{s1}$—The moving distance measured by the grating of moving parts, expressed in mm.

### 3.3 Create the VI

Create a Lab VIEW VI library under the test plan. First of all, create input and output controls that can control the test in the front panel, as shown in Fig. 5: The counter control specifies the physical channel for task, because the NI PXIe-6341 data acquisition equipment is used in the third slot of the PXI chassis and counter 1 is used to count, so select PXI1Slot3/ctr1 in its drop-down list; A,B,Z input terminal controls specify the terminals of the A,B,Z signals, and select the corresponding pin in the drop-down list by looking at the pin number of the NI PXIe-6341; Z index enable Boolean control specifies whether to use the z signal; The cycle time(ms) control sets the time interval between two adjacent samples; The Displacement data control shows the amount of displacement; Digital Trigger Source control specifies the clock to be used for triggering, using 20MHz time base, where the trigger is a rising edge; The Start measurement button controls whether the measurement starts; Return to optional test main interface button controls whether to return to the Test interface VI; The Displacement waveform chart shows the displacement and displacement curve.

![Fig. 5: Displacement Online test front panel](image)
Call the function in the program block and connect the function with the input/output control according to the implemented function after setting up the front panel. As shown in Fig. 6: DAQmx Create Virtual Channel VI creates a virtual channel for data acquisition tasks, and the virtual channel includes a set of attribute settings, the name to assign, physical channel, input connection, type of signal measurement and scaling information. Where the physical channel is a terminal or pin of hardware device for measuring and generating an analog signal or digital signal [2], and the signal measurement type uses the counter input-signal-position-linear encoder. The decoding type specifies how to count and parse the pulses generated by the encoder on signal A and signal B. The initial position is the position of the grating when you begin the measurement; Connect grating output signal to the corresponding receiver of the virtual channel counter through DAQmx channel property node; DAQmx triggered property node sets the digital trigger source and trigger type for the virtual channel; DAQmx Start Task VI makes the task start the measurement. DAQmx Read VI reads samples from the user-specified task or virtual channel, and read type selection is counter-single channel-single sample-DBL; The read data is multiplied by the pitch to obtain the displacement [2]; The current time will be displayed on the waveform chart X-axis after displacement being processed into dynamic data by Merge Signals. DAQmx Stop Task VI returns the task to the state the task was in before the DAQmx Start Task VI ran; DAQmx Clear Task VI clears the task; Simple Error Handler VI displays an error when an error occurs[4]; “Start measurement: value change” event branch and “Return to optional test main interface: value change” event branch can’t be placed within an
event structure, then edit the “Start measurement: value change” event structures: uncheck “lock panel (defer processing of user action) until the event case completes”.

**Fig. 7**: Velocity Acceleration online test front panel

**Fig. 8**: Velocity Acceleration online test program
As shown in Fig.7 and Fig.8: subtract the displacement from the next two acquired acquisitions from the shift register and then divide by the time interval to get the velocity[5]; The time domain Math Express VI is used to derive the acceleration.

**Fig. 9:** Position accuracy detection front panel

**Fig. 10:** Position accuracy detection program
As shown in Fig.9 and Fig.10: The feedback node is used to save the last run data and achieve the accumulation of displacement data; The case structure is used to determine whether the number of test points in each test point reaches 10, and calculate the average of the absolute value of each detection point’s difference if the number reaches 10; The results will be displayed in the waveform chart and test table, and will generate Word document after the end of the measurement.

4 Conclusion

It is found that the data can be collected quickly and accurately by NI hardware and the data can be processed to meet the accuracy requirements through LabVIEW software. Because LabVIEW provides powerful functions library and the Express VI (based on configuration, no need to program), so you can write a program easily and quickly. Programs with the same functionality can be reused in different VIs, such as the program that counts grating’s pulse of displacement, velocity, acceleration detection program[6]. If you change the hardware connection mode, just change the corresponding terminals on the front panel’s input controls without changing your program. In addition, you can change the number of measurement as needed. LabVIEW provides modification function, so you can beautify your interface.

References
