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Design of Vickers Hardness Loading Controller

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Abstract: Traditionally Vickers testing needs manual works, as a result, it will induce low precision and automatization. So this paper design a new type of loading controlling system, it is based on single chip computer 89S52, used PZT as the force generator in micro Vickers hardness testing. It primarily includes the designing of hardware, software of collecting data and PZT signals by AD667. This article has given the sketch of electrical circuit and controlling software, it also offers the experiment data. The experiments have showed that using this system can exactly control the loading results, and the average tolerance is less than 0.43 %.

Keywords: Single chip, Vickers hardness, Loading controller.

1. Introduction

Vickers microhardness measurement system is a kind of hardness measurement system widely applied at this time. Through the test using small load and through microscope to observe the indentation, so we can calculate the test materials' Vickers microhardness [1]. Especially suitable for small and thin material samples, nitride, carburizing, spraying surface treatment of specimens, a variety of different plating's surface vickers microhardness test, so micro vickers test in the field of materials science and mechanical electronic industry has a wide range of application at product quality control testing field [2].

Vickers hardness value integrated the advantages of commonly used hardness calibration method (e.g. Brinell & Rockwell). It could Calibrated metal hardness continuously, meanwhile, it doesn't have relationship with test force [3].

Therefore got widely used. Because artificial operation cause the test precision is unstable in traditional vickers microhardness testing process, and repeatable accuracy is low, urge to improve the automation degree of the test, reduce artificial factors of interference, improve the test accuracy [4]. At vickers hardness testing, when indentation diagonal length can use electron microscope to mark. Accuracy of the test is decided by the loading force control precision. In view of this situation, this paper have designed a kind of automatic loading system of vickers microhardness test, with the single chip processor as the core, and using PZT drive as a power generator. Realized a kind of accurate load control, put the depth of the indentation less than 30 um and 9.8 N.

Vickers hardness number:

$$HV = 0.1891 \times F / D^2, \quad (1)$$

where F is the test force/N, D is the indentation diagonal length arithmetic average between D1 and D2.

2. System Principles

This block diagram of Load Control System mechanism is shown in Fig. 1.

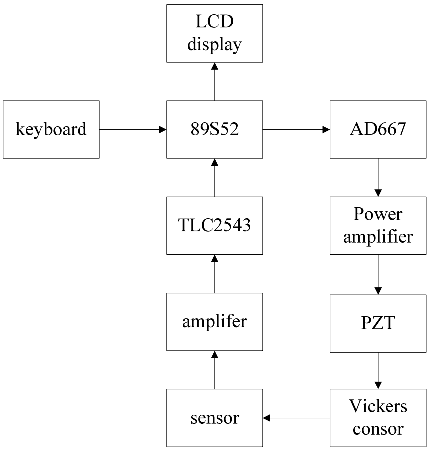


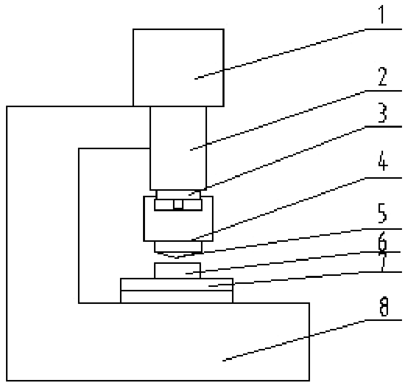
Fig. 1. Principle diagram of the control system.

As can be seen from Fig. 1, type the scheduled loading force from the keyboard and start the test program, DA converter chip AD667 signals control voltage, after power amplified, it drive PZT micro-displacement generator vickers indenter into the specimen surface, elastic deformation occurs on the specimen surface, elastic deformation occurs on the surface of the specimen and generates a elastic force which is opposite to the moving direction of the indenter. The elastic force is equal to the size of Vickers indenter's Pressure, using force sensor for real-time monitoring of elasticity value, get real-time data of pressure force, recorded pressure data and compared with the standard data of RAM memory, and judgment, when the two equal, stop loading and Starting keep load, otherwise continue to load until the two are equal [5]. The whole process under the process sequence control, realize the automation of loading, the load control system can be to communicate with the computer, with electron microscope can complete automatically detect Vickers hardness, and loading system chart is shown in Fig. 2.

3. The Design of the Load Control System

According to the above schematic diagram of mechanism and system function, consisting of the data acquisition, PZT control signal output, keyboard and display above four parts to design the loading system. The keyboard using two lines of four columns of the independent type key Plate, display segment chose the 128 x64 dot matrix LCD displayer. MCU use ATMEL89S52 upscale Microcontroller, it can meet the needs of the software design and doesn't need to enlarge program memory [6].

The following log According to voltage signal acquisition and PZT control two parts to introduce in details.



1. Vidicon, 2. PZT, 3. Sensor, 4. Backstop,
5. Vickers conner, 6. Specimen, 7. Elevator, 8. Base

Fig. 2. Loading system organization diagram.

3.1. The Design of Data Acquisition Part

Data acquisition part chose serial AD TLC2543 as centered components to build. TLC2543 is a 12 serial analog to digital converter, using switch capacitance successive approximation techniques to complete the A/D conversion process. It has these advantages include: In the range of working temperature, the switching time is only 10 us, linearity error lower, programmable MSB or LSB leading, adjustable output data length and serial input, can save MCU I/O resources, it's suitable for the cases of the I/O resource nervous. Therefore, this system adopts the TLC2543, as analog to digital converter, converted model voltage signal of force sensor to a digital signal. As a result of the sensor output voltage in the millivolt level, system adopts 16 times amplification, the maximum in 2.5 V, adopts 2.5 V as reference [7].

For TLC2543, it could use four transport methods to make full 12 resolution of the TLC2543, every conversion and handed can use 12 or 16 clock cycles, this system adopts the transmission sequence 12 clock at eight in the top of the conversion program to write, do not use the piece of select (CS), the reference sequence is shown in Fig. 3.

According to the sequence shown in Fig. 3, this system uses part of the remit Make up the source code is as follows:

```
TLC2543:
SET B  TLCDOU
SETB TLCCS
CLR TLCCS
CLR TLCCLK
TLCLP1:
MOV C, TLCDOU
RLC A
MOV TLCDIN, C
```

```
SETB TLCCLK
CLR TLCCLK
INC R2
CJNE R2, 08H, TLCLP 1
MOV R3, A
TLCLP2:
MOV C, TLCDOU
RLC A
SET B TLCCLK
CLR TLCCLK
IMC R2
CJNE R2, 04 H, TLCLP 2
MOV R4, A
RET
```

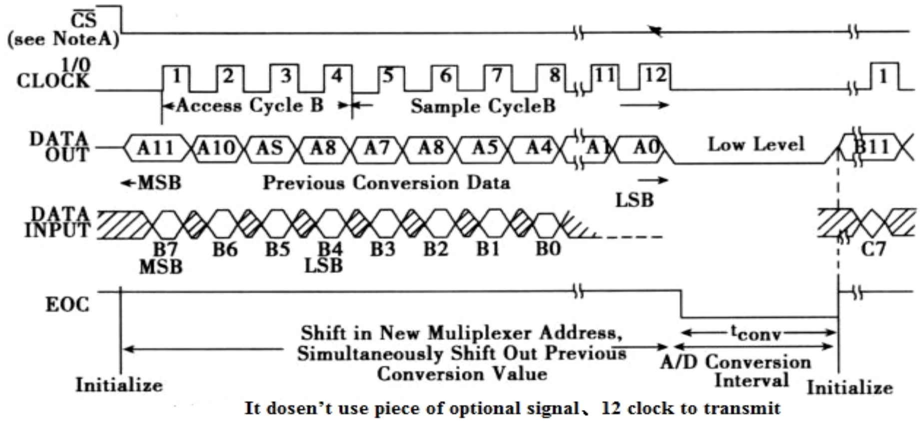


Fig. 3. TLC 2543 timing program diagram.

3.2. Actuator PZT and its Output

This article for PZT is actuators on the hardness tester, and PZT is namely short for piezoelectric ceramics driver (Piezoelectric Translators). It includes PZT voltage amplifier and nanometer micro displacement of the generator.

Hardness instrument developed in this paper the PI in Germany E660-type LVPZT drives as Vickers indentation print head driving devices. E660-LVPZT is a PZT voltage amplifier, and the voltage amplifier is a low voltage of the voltage source, as a low voltage of piezoelectric ceramic actuator amplifier. In the process of work, E660-LVPZT accept 0 to 10 V DC voltage, through internal voltage amplification ratio of 1:10 amplifier, producing 0-100 - V DC voltage, driving within 30 microns nano piezoelectric micro displacement generators of micro displacement, and driving Vickers print head for micro indentation.

The principle of PZT voltage amplifier as shown in Fig. 4.

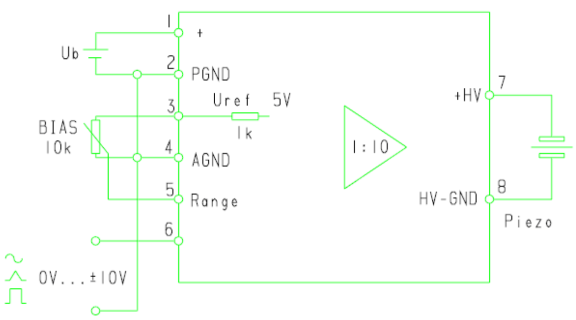


Fig. 4. Amplify circuit of E-660.

Input voltage signal and output displacement of the generator of nano-scale piezoelectric ceramic is a linear relationship.

3.3. Designing of Output Section of PZT Control Signal

The micro-displacement of the generator (PZT) using piezoelectric materials' electricity to create scale effect produce displacement. Therefore, the control signal of output for the system is a voltage signal. After the voltage and power magnify, it produce displacement by driving displacement of the generators. The core of devices control voltage signal using AD667, AD667 which is a D/A conversion device of 12 bit. It has optional range of output voltage and built-in reference voltage reference. In the condition of dual polarity power supply and single polarity 10 V output. The output resolution is 0.0024 V/b. In this design, AD667 adopt double polarity power supply and single polarity output, it works under the state of the double buffer [8].

The hardware connection is shown in Fig. 5 in the system. Under the double buffering method, compile the source code is as follows:

```
AD667:
MOV   A, R0
MOV   DPTR, 3FFEH
MOVX  @DPTR, A
MOV   A, R1
MOV   DPTR, 3FFDH
MOVX  @DPTR, A
MOV   DPTR, 3FFBH
MOVX  @DPTR, A
RET
```

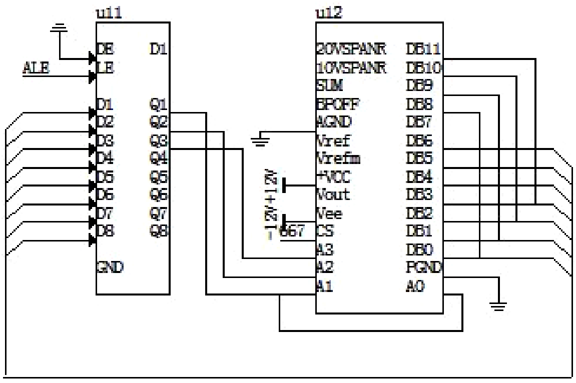


Fig. 5. AD667 hardware connection diagram.

3.4. A Serial Port Interrupt Program

Serial port interrupt program process, please see Fig. 6, after program list enter serial port interrupt, firstly, microcontroller will protect the scene and push it into stack. If this situation want to receive interrupt, microcontroller will receive data until receive completed by byte [9]. Then deal with processing instruction, lastly, Restore the scene and return from interrupt. If ti is Send the interrupt, microcontroller will send data until receive completed by byte, lastly, restore the scene and return to main program [10].

3.5. Design of Control Software

Software program put Data collection, calculation and output control signals and Liquid crystal display (LCD) signal automation come true. Complete the vickers hardness test load control coordinate with each other. The flow chart of control program, please see Fig. 7.

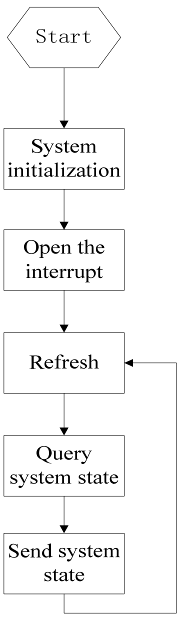


Fig. 6. The process of serial port interrupt program.

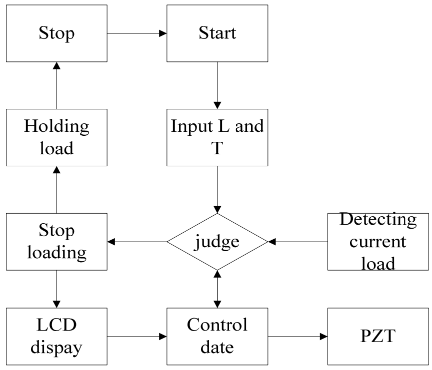


Fig. 7. Flow chart of control program.

After the system startup, the first step is scanning the keyboard, accept keyboard input. It will start the load control program if it input the predetermined loading force L and protect loading time T at the same time [11]. The system constantly collects the force of the current values which compared with predetermined value. If both are equal, then it enter the protection-loading and it will return after the protect loading ended. Otherwise, Current value of loading force doesn't change until the both are equal. LCD always displays the current loading force values. The whole loading process is controlled by program, without human intervention [12].

4. Experimental Analysis

Experimental analysis is to analyze the performance of the system in loading precision control. Analysis of the data is based on the standard voltage sensor voltage data and the corresponding data point sensor which is measured at 10 g, 25 g, 50 g, 100 g, 200 g, 300 g, 500 g, 1000 g eight force.

Table 1. Experimental sample data table voltage.

Sampling point/g	10	25	50	100
Standard values/mV	7.41	9.43	12.74	19.3
Measured value/mV	7.35	9.6	12.87	19.46
Deviation value/mV	-0.06	0.17	0.13	0.16
Deviation ratio/%	-0.8	1.8	1.01	0.82
Average deviation value	0.11 mV			
Average deviation ratio	0.43 %			
Expectancy-deviation value	0.17 mV			
Sampling point/g	200	300	500	1000
Standard values/mV	32.36	45.14	70.64	133.05
Measured value/mV	32.31	45.18	70.84	133.23
Deviation value/mV	0.05	0.04	0.2	0.18
Deviation ratio/%	0.15	0.08	0.28	0.13
Average deviation value	0.11 mV			
Average deviation ratio	0.43 %			
Expectancy-deviation value	0.17 mV			

Analysis data as shown in Table 1. Table 1 standard voltage value is calibrated by higher level precision of the loading system in advance, which can be considered as reference standard data of a prototype test. Sampling point and the actual value of the loading force is a standard voltage data corresponding to each other, which has the following function:

$$f(x_i) = y_i \cdot (1 + \lambda_i), \quad (2)$$

where x_i is the actual loading force value (g); y_i is the sensor voltage standard value; λ_i is the deviation rate.

Because y_i is a fixed value, so as long as control can control the x_i, which is the actual loading force value. At vickers micro hardness tests, we often use limited number of specific force value measurements, such as commonly used 100 g, 200 g, 300 g, 500 g, etc. Therefore, the number of the actual test is limited.

In additional, the specific force value bias voltage sensor collected data after the op-amp amplifier will be in the form of digital quantity deviation is reflected in the AD conversion in the data. According to the principle of the AD conversion in this system:

$$D = U \cdot 2^{12} / 2.5, \quad (3)$$

where D is the conversion of binary data; U is the op-amp output voltage (V).

The value of the digital quantity deviation is:

$$D_p = 16 \cdot (u \cdot 2^{12} / 2.5) \cdot y_i \cdot \lambda_i, \quad (4)$$

As long as compensation in the software the digital quantity deviation can be completely eliminated, that is, to eliminate bias. Then load control precision only associated with the standard values of sensor voltage, which is only related to the calibration precision of the sensor.

Based on the data in Table 1, in the same coordinate system with load. Loading force value data as the abscissa, On the sensor voltage standard theory research data and the measured data of system as the ordinate, then draw map points and connected them by curve. Get the function curve between sensor data and the loading force value, which is known as the reference L - V curves (meet the precision requirement of reference curve) and the actual L - V curve, as shown in Fig. 8.

To make the following definition: of the two curve slope,

$$\varepsilon = \frac{\alpha}{\beta}, \quad (3)$$

where ε of curve fitting and degrees ($0 < \varepsilon$); for the actual L - V Line average slope; β is a standard L-V curves of average slope. ε reflects the fitting degree between the actual load and the standard load. When $\varepsilon = 1$ indicates that the two lines coincide, loaded completely fit. By Table 1 calculated data obtained $\varepsilon = 1.02$, which indicates that the actual load data and reference data is highly fitting, load control scheme is feasible. Meanwhile, which can also be seen in Fig. 6, the two curves substantially coincide, load control still capture higher accuracy in case the deviation is not eliminated, which meet the design requirements.

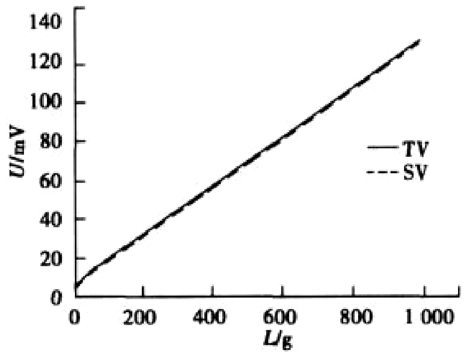


Fig. 8. L/V load curve diagram.

5. Conclusion

Using PZT micro-displacement generator as power generators belongs to the firm innovation in the practical application. Experimental results demonstrate that the control scheme is feasible, loading process is smooth, test results are stable, and precision is controllable.

The load control scheme has high load control precision with average experimental accuracy of about 0.43 %. After eliminating acquisition deviation of sensor by software, system deviation won't be produced and loading precision only depends on the accuracy of sensor calibration.

By the control software different load control modes can be set up according to different materials to be test, and different loading methods can be set on the same kind of test materials, which will make the load results more accurate and help to improve the accuracy of the test.

References

[1]. Huiqi Yang, New metal hardness test, *China Metrology Press*, Beijing, 2006

[2]. Zhihua Yin, The realization of single-chip microcomputer and PC serial port communication, *Data communication of China*, Vol. 6, Issue 1, 2004, pp. 66-69.

[3]. Huimin Li, Jiuyu Hao, Shulong Shi, et al, The development of automatic online test sorting system of the hardness on the Richter scale, *Journal of Scientific Instrument*, Vol. 19, Issue 2, 1998, pp. 135-139.

[4]. Yutai Quan, Xiaosong Zeng, The development of the microcontroller measure-control system of brinell hardness tester, *China Manufacturing Industry Informatization*, Vol. 39, Issue 8, 2003, pp. 401-405.
[5]. Weiliang Yu, The new dynamic and trend of development of hardness testing technology, *Physical Examination: Physical Volume*, Vol. 39, Issue 8, 2003, pp. 401-405.
[6]. Dong Gao, Zhejun Yuan, Ying Yao and et al, The research of material microhardness testing principle under nanoscale, *Aeronautical Manufacturing Technology*, Issue 4, 1998, pp. 16-17.
[7]. Siming Xin, Jianping Hao, Digital principle of Vickers hardness tester, *Journal of Wuhan University: Engineering Science*, Vol. 35, No. 1, 2002, pp. 51-54.
[8]. Xuezhi Zhou, Vickers hardness test under low load, *Precious Metals*, No. 4, 1982, pp. 22-26.
[9]. Huiqi Yang, Bingwei Song, Zhijuan Li, The development of automatic vickers hardness benchmark, *Modern Measurement Test*, No. 5, 1998, pp. 7-13.
[10]. Dewei Han, Metal hardness testing technical manual, *Central South University Press*, Changsha, 2003.
[11]. J. P. Neumann, Determination of true Knoop hardness, *Advanced Materials & Progresses*, No. 1, 2000, pp. 65.
[12]. Cary Dawson, Conversion of Knoop to Rockwell C, *Advanced Materials & Progresses*, No. 9, 1994, pp. 87-88.