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Online Cutting Temperature Measurement System Based Thermocouple

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Abstract

In order to measure cutter temperature, the on-line thermocouple temperature measurement system was proposed. In this system, temperature sensing element thermocouple was welded in the flank face close to the cutting edge with double bare wires welding way. With this method, this system has advantages of a single point temperature measurement and no effect on cutter temperature distribution. For a higher sampling rate, two AD were used to sample alternately; and for the convenient signal transmission when the cutter is rotating at high speed, wireless transmission was adopted to transmit thermocouple output signal and cold side temperature signal to the host computer. After temperature compensation to the cold side, the compensated temperature will be real-time displayed, stored and played back. System measurement range is 0 ~ 1300 °C, and the measurement uncertainty is 0.58%. For 8000rpm rotational speed of XH714D machine, experimental results show that the system can measure cutter temperature online, and has advantages of low cost and great practicability.

***Keywords**: Cutter Temperature, Thermocouple, Wireless Transmission, Alternate Sample*

1. Introduction

Cutting is one of the basic machinery manufacturing and processing methods. During cutting process, cutting heat and cutting temperature will impact tool life and wear directly, and also affect the processing quality and surface quality of the work piece. Therefore, cutting heat is an important aspect in cutting research, and the online temperature measurement is also crucial. The research of online temperature measurement is important for monitoring temperature changes and ensuring process safety and process quality [1, 2].

Currently, the cutting process on-line measurement methods include natural thermocouple, artificial thermocouple method, semi-artificial thermocouple method and solar thermal radiation method. At present, thermocouple temperature line cutting measure is the most mature and practical method, but this method still exist difficulties of installation and signal extraction. Natural thermocouple method is mainly to measure the average temperature of cutting area, and cannot measure the designated point temperature; artificial and semi-artificial thermocouple method can be used to designated point, but these method need punch holes in the cutter to lay thermocouple, which can change temperature field [3]. In addition, the thermocouple method requires special processing, even transform spindle structure to lead output signal to outside for processing [4-6], which is difficult to achieve with the increasingly high spindle speed. Although signal lead-out problem does not exist in solar thermal radiation non-contact method, it still be affected by the processing environment and

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not practical. Furthermore, it often measures the average temperature, rather than the specified point temperature [7-9].

The system uses mature and practical thermocouple temperature measurement method to measure cutting temperature online; in this system, fusion welding method is used to fix thermocouple junction in the blade surface, which can measure single-point temperature without affecting the distribution of tool surface temperature; and for solving signal extraction problem, wireless transmission is used to extract thermocouple signal to the host computer.

2. System Components and Working Principle

In this paper, thermocouple temperature measurement method was used to detect measurement cutting temperature online, the block diagram is shown in Figure 1.

From this Figure, we can see the bare wires of thermocouple were welded to the blade surface next to cutting edge, and the thermocouple change the point temperature into the output potentials; Thermocouple was placed in the analog to digital conversion module within tool holder through a coolant hole, thermocouple output potential and cold junction temperature were sampled by analog to digital conversion module and converted to digital values to the microprocessor; microprocessor control conversion module for sampling and analog-digital conversion, and send the digital signal output from analog-digital converter module to the wireless transmitter module, and control the transmitter module to transmit; transmitter module, AP and receiver module form a wireless network, then the host computer system control wireless receiver module to receives data, compensate cold junction temperature, get the measured point temperature, and has functions of real-time data display, data storage and data playback.

2. Keys of System Design

2.1. Thermocouple Mounting

Use the capacitive welder to fusion-weld the bare-wire couple of thermocouple at the back cutter which is adjacent to the cutting edge. The instant discharge of the capacitive welder generates high temperature and consequently fuses thermocouple junction and the cutter surface as one, which achieves the temperature measurement of a single point on the cutter surface and hardly influences the temperature distribution of the cutter surface. Since the thermocouple junction and the measured cutter surface are fused as one, the temperature of the thermocouple junction is the temperature of measured point and therefore, there is no delay between the temperature of the thermocouple junction and the measured point. In addition, the use of thermocouples with very thin bare wires and the capacitive welder can make the measuring position extremely close to the cutter blade, which is very important for the study of temperature field of the cutter due to the fact that the highest temperature area is around the blade , but not exactly at the blade. The weld of the thermocouple and the back of the cutter is shown in Figure 2. For the thermocouple, we select a K-type thermocouple wire of which the model number is TT-K-36-SLE. The diameter of the core is 0.127mm and the measuring accuracy is 0.4%.

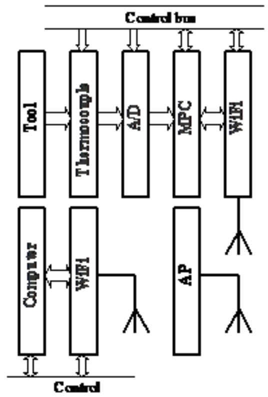


Figure 1. Block Diagram of System

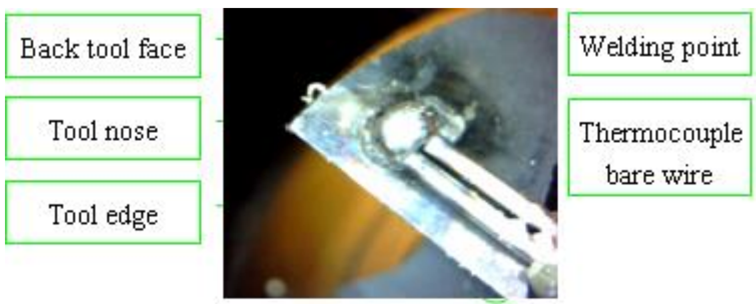


Figure 2. Welding Photograph of Thermocouple and Tool Flank

2.2. The Scheme of the Analog-Digital Conversion

Some factors need to be taken into consideration when designing a sampling module, which are: 1. the space available is small; 2. the revolving speed of the principal axis is high. For the former factor, the ADC needs to have small size and low power consumption. We can achieve the low power consumption by powering the ADC with low-power batteries and meanwhile, the battery also has a small size. As for the latter factor, we take 20,000 rps as our upper limit of the revolving speed and 20 sampling points per revolution as our lower limit. Therefore, we can obtain at least 400,000 sampling points per minute. After considering the factors like size, power consumption, accuracy, response time, cost and reliability, we decide to choose ADS1018 which is a ultra-small, low-power, SPI™-compatible, 12-bit, Analog-to-Digital Converter and temperature sensor with internal reference. The size of ADS1018 is 2mm × 1.5mm × 0.4mm and the consumption of this ADC in a consecutive working circuit is merely 150μA. Furthermore, the analog-digital conversion error of ADS1018 is below 0.05% and the error of the temperature measurement is less than 1 ℃.

However, the maximum sampling frequency of ADS1018 is only 3,300sps, which cannot meet the demand. Thus, we utilize two ADS1018 to sample alternatively. Two identical sampling circuits work simultaneously. One circuit samples at the rising edge of the clock and the sampling points are 1, 3, 5, 7, 9…. The other samples at the falling edge and the sampling points are 2, 4, 6, 8, 10…. In this way, the sampling frequency is two times of that with a single ADS1018. With this scheme, we can sample 396,000 data per minute, which meets the demand without the decrease of the sampling accuracy and the increase of the cost.

2.3. The Circuit of the Analog-Digital Conversion

According to the analog-digital conversion scheme, we design an analog-digital conversion circuit, which is shown in Figure 3. First, the temperature of the measured point on the cutter is converted by the thermocouple into the potential difference of the electric potentials U_1 and U_2 (Point 1 and 2 in Figure 3), which is denoted by $U_{12}=U_1-U_2$. Then, with RC network, this potential difference becomes the potential difference $U_{AIN0-AIN1}$ between the two input ports AIN0 and AIN1 of ADS1018 and finally is converted as a digital value by the two ADS1018 alternatively.

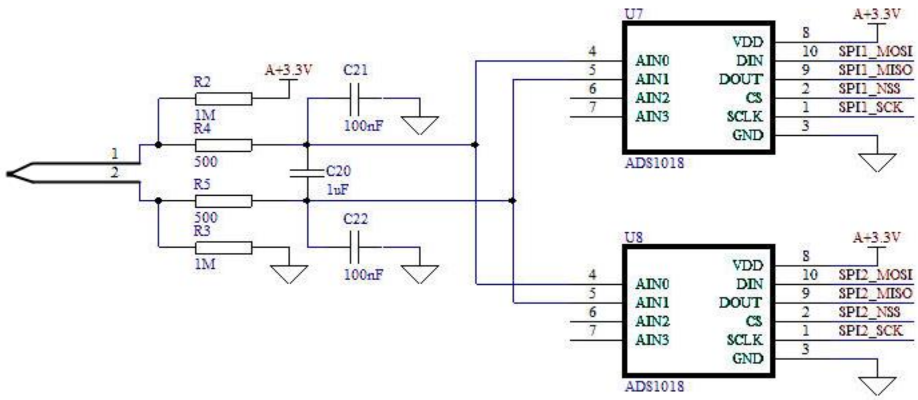


Figure 3. The Circuit of the Analog-Digital Conversion

2.4. The Hardware of the Slave Computer

According to the system block diagram shown in Figure 1, the slave computer consists of the analog-digital module, the microprocessor and the WiFi transmission module. The wiring connections among the three parts are shown in Figure 4. Under the condition of meeting all the technical indicators, we particularly focus on the size and the power consumption of the device. First of all, we choose the small size, low power consumption and low cost STM8 as our microprocessor. This chip has QFN packaging and the size of it is 5mm × 5mm × 1mm. Besides, the data transmission rate of STM8 can reach 8 Mbit/s and the working current of it is less than 150 mA.

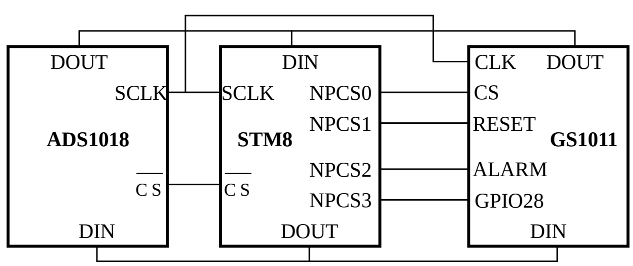


Figure 4. Connection Figure between the Analog to Digital Conversion Module, Microprocessor and WiFi Transmitter Module

As for the WiFi transmission module, we choose the ultra-low power consumption chip GS1011 which uses 2 32-bit ARM7 processors and is integrated with RF transmitter, on-chip Flash and on-chip SRAM. Also, it supports IEEE82.11 RF communication, MAC/physical layer protocol and application process. The size of GS1011 is 10mm × 10mm × 0.85mm and the communication rate of it may reach 11 Mbit/s. Meanwhile, the current of GS1011 under transmission status is under 250 mA. The thermocouple welded on the back of the cutter goes through the hole of the cooling liquid and connects to the slave computer circuit, which is shown in Figure 5.

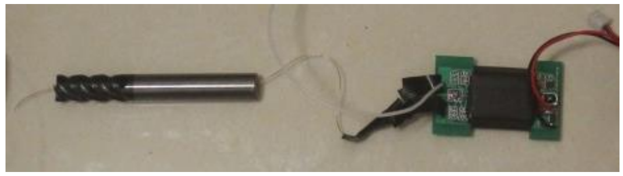


Figure 5. The Photo of Thermocouple Connect to Guest Through one Tool Coolant Hole

2.5. Thermocouple Cold Junction Compensation

Through a reverse lookup of the thermocouple voltage indexing table, the host computer change the value of the received ADS1018 temperature sensor into a corresponding electric potential U_{T0}.Then it received ADS1018 thermocouple output potential values together and then we get the thermocouple output potential measurements $U_{12C}=U_{12}+U_0$. Then the same thermocouple voltage indexing table to get the temperature value T measured point of cold forging tools compensated by the forward lookup.

Due to interval of thermocouple indexing Table is small, a potential produces approximately each 1 ℃to. To save storage space and running time of the microprocessor, 16-32 interval value from the same thermocouple indexing table were selected in the measuring range, other values between two adjacent values used to obtain by a simple linear approximation. Moreover, the obtained temperature values are close of the accuracy of table.

2.6. Systematic Uncertainty

According to the circuit of Figure 3, the input of ADS1018 is assumed ideal case. The input impedance is infinite. According to the parameters of capacitance and resistance of the figure to obtain thermocouple output potential difference, and convert it to ADS1018 input terminals of a potential difference exists a sub uncertainty about 0.07%. When estimating the signal frequency is 250KHz. Because the ADS1018 analog-to-digital conversion error is less than 0.05%, the uncertainty of its sub is 0.05%. Because thermocouple indexing tables exist error of 0.4%, By the time the indexing table is determined by the temperature of the corresponding potential, it presences of sub-0.4% uncertainty. And the ADS1018 presences of measurement error of 1 ℃, then again there is an analysis uncertainty (1÷1300)≈0.08%. After the thermocouple cold junction compensation, it needs to according to U12C to obtain the temperature of cold-junction compensation use the indexing table. Also due to the presence of indexing table of error of 0.4%, and then In turn generates a breakdown of Uncertainty 0.4%. Based on the above, the overall uncertainty of system as follows：

$$\sqrt{(0.07\%)^2+(0.05\%)^2+(0.40\%)^2+(0.08\%)^2+(0.40\%)^2}=0.58\%$$

3. System program

The system program includes a microprocessor program and PC program two parts, the former includes data acquisition, data process and data sending. This part is mainly to complete reading and controlling of two ADS1018, read cold junction compensation data and control wireless transmission module transmits data. The latter includes a wireless data receiver, real-time data display, data recording and broadcasting and data playback. PC program use LabVIEW graphical programming language. It has some advantages that include fast response, friendly interface, and can be run independently. Wireless data reception and real-time procedure screenshot shown in Figure 6. After UDP port reading data, it is called by subsequent module. After the thermocouple data cold junction compensation, the temperature measurement curves are Real-time displayed. Data storage and playback program screenshot shown in Figure 7. The temperature measurement is saved as a text file for subsequent analysis and processing. When data playback, select the file path and file firstly, and then reading.

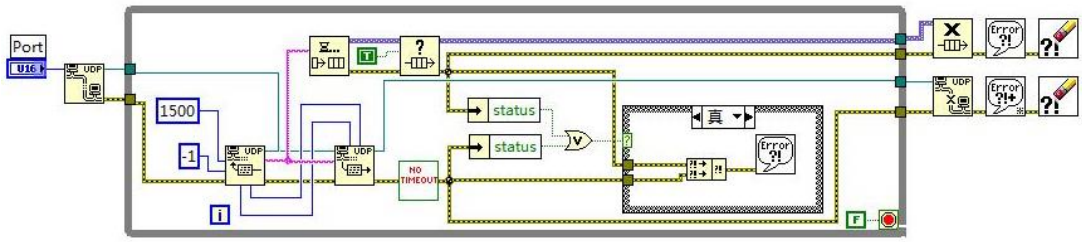


Figure 6. The Screenshot of Wireless Data Reception and Real-time Display Program

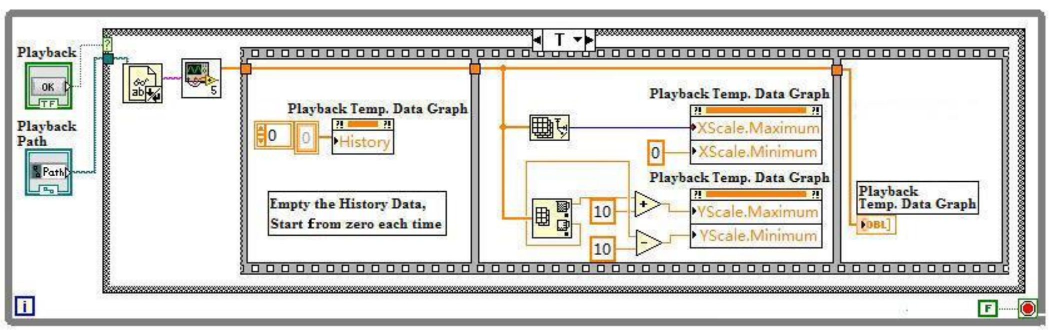


Figure 7. The Screenshot of Data Storage and Data Replay Program

4. Experiment Results

This paper uses the measurement system to test and experiment, the experiment system is shown in Figure 8. We use eight times repeated test on the XH714D machine tool (the maximum revolving speed is 8000rpm) and get eight data documents of the cutting temperature. One group of data which is about the measurement curve of the replay temperature is shown in Figure 9. The horizontal coordinate represents the sampling point sequence of equal interval; the vertical coordinate represents the measurement value of the temperature.

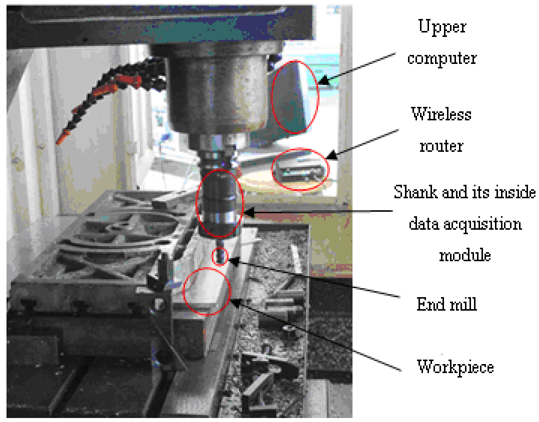
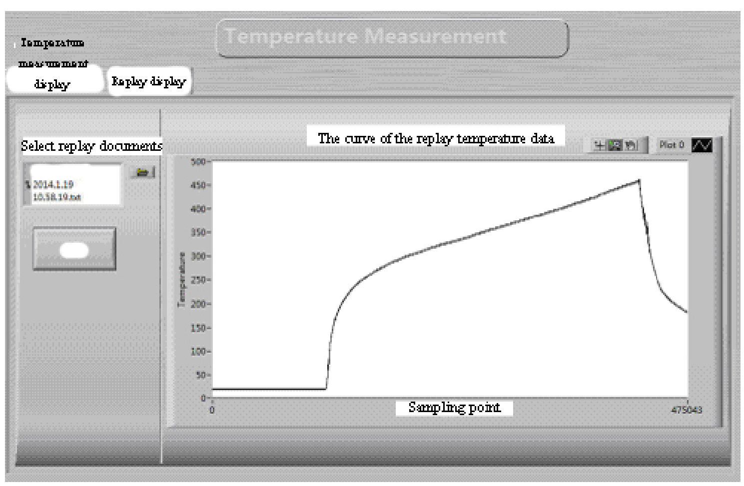


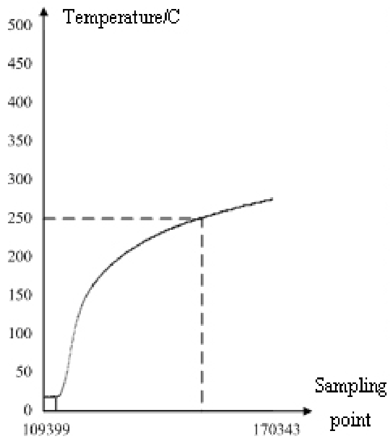
Figure 8. The Experiment System

Figure 9(a) is the transient cutting temperature curve of the measured points which are located nearby the cutter main blade, the curve includes the stages of pre-start cutting, cutting start, cutting from low speed to high speed, cutting ending. When the cutting start, the cutting temperature rises sharply, then the cutting temperature keeps rising, but the rising speed is descending. After the cutting ending, the cutting temperature descends sharply.

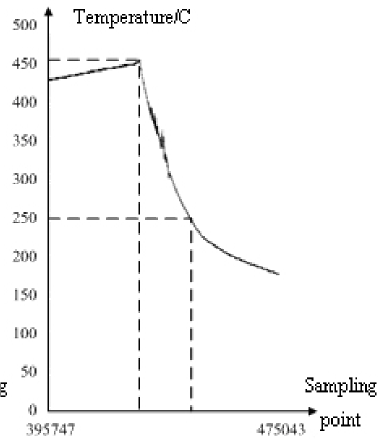
Figure 9(b) is the curve of cutting starting stages where the cutting temperature rises sharply, the cutting starts at the sampling point of 112879, and the cutting temperature is indoor temperature at this moment; After that, the cutting temperature rises sharply, the temperature can reach 250 centigrade at the sampling point of 152889, the whole rising time is 6.06s. Figure 9(c) is the curve of cutting ending stages where the cutting temperature descends sharply, before the cutting ending the temperature keeps rising but the speed is descending, the temperature is 464 centigrade at the sampling point of 427724, the cutting is end at this moment. After that the temperature descends sharply, the temperature is 250 centigrade at the sampling point of 444798, the descending time of the temperature is 2.59s.



(a) The temperature curve of measurement results



(b)cutting start: the temperature rises sharply



(c) cutting end: the temperature descends sharply

Figure 9. One Group of Test Result

This paper also uses other machine tools to test and the results are the same. When the cutting starts, the temperature rises with the time and speed increasing. After the cutting is end, the temperature descends sharply. The temperature rising curve and descending curve are rapid and smooth. The result is matching with the theoretical analysis, and it shows that this paper's system can accomplish the rapid online measurement of the cutting temperature.

5. Conclusion

This paper develops a kind of thermocouple cutting temperature measurement system. The theoretical analysis and experiment results show that the system measurement uncertainty degree is 0.58%, the measurement range is from 0 to 1300 centigrade; this system can accomplish the online measurement of the cutter cutting temperature, the measurement results are matching with the theoretical analysis; this system has the advantages of low cost, strong practical utility and high reliability. This system can also use for the studying of cutter abrasion, cutter longevity, online monitoring the cutter security and guaranteeing the quality of the process.

The system of this paper can display the cutting temperature changes of the whole cutting process in real time, including the cutting starting stage where the cutting temperature rises sharply and the cutting ending stage where the temperature descends sharply. But this paper didn't conduct the quantitative theoretical analysis and experiment study of system time corresponding characteristics; this is the focus of the follow-up work in this paper.

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