A Study of Transient Temperature Measuring System Based on LabVIEW for Droplets

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***Abstract*—During the material accumulation process derived from the deposit of molten particles after impacting, flattening, cooling and solidification, the transient temperature variation directly affects splatting behaviors and forming quality. The transient temperature history of splatting process has received considerable attention in this field. LabVIEW by National Instruments is a user friendly and powerful graphical development environment for signal acquisition, measurement analysis, and data presentation. In this paper, a temperature acquisition and measuring system based on a fast-response thermocouple is designed under LabVIEW software platform. In addition, a digital method is used to compensate for the cold junction temperature and calibrate the nonlinearity between the output signal and the temperature obtained by the thermocouple. The measurement of Sn-Pb droplet splatting transient temperature indicates that the system is of low cost, high accuracy, simple operation, visual interface, etc., and the system can also be used widely for other transient high temperature measurement.**

Keywords-labview; fast-response thermocouple; transient temperature measurement; droplet splatting

I. INTRODUCTION

Recently, the thermal spraying technology is mostly concentrated on researching the process itself. However, it is unable to explain the inherent mechanism of coating forming and failure nature by the scientific standard, and it is difficult to build the whole theoretic system to denote the process of coating forming. Because coatings can be viewed as the continuous and irregular pileup of a number of droplets, the researches on the splatting behaviors of impact, deformation, cooling, solidification of a single droplet is crucial for the optimization and control of the coating quality, and directly affects microstructure and mechanism function of coating.

According to existing studies, the temperature is one of the most important factors that affect the complex splatting behaviors. This is because the molten droplets after impinging onto the substrate are cooled rapidly, solidified strongly and shrank intensively in a very short time. The inner stress of droplet, due to limitation of droplet itself and substrate, can not be released along the boundary of droplet between the interfaces of coating. In addition, during the heating and cooling process, the expansion coefficient mismatch between the coating and the substrate can produce inner stress as well. These residual stresses directly lead to the coating failure, such as crimping, cracking, wrapping of droplet, the formation adhesion failure, etc.

However, because the size of the spraying droplet is quite small (10~100μm), and after impinging onto substrate the deformation and cooling time is quite short (10~20μs), it is difficult to directly observe the splatting behaviors of the droplet during thermal spraying by experiment method. According to the literature [1], the rule of reynolds mechanical simulation is used to investigate the splatting in thermal spraying by low-speed big droplets impinged on the substrate with Sn-Pb alloy droplets. The rule is also used in this paper to measure the temperature variation of droplets splatting.

A series of related researches have been developed to observe the temperature variation of droplets splatting at present. In 1952, Ranz and Marshall firstly watched the temperature evolution of vapor droplet using the thermocouple; Moreau[2] and Gougeon[3] adopted fast pyrometers aimed at the substrate to measure the temperature variation during impact to solidification period; Vardelle[4] and Wang[5] used optical pyrometers to measure the temperature of droplets before and after impinging on the substrate; Aziz and Chandra[6] used a commercially available thermocouple for measuring surface temperature variation of tin droplets after impact; Heichal[7] and Choi[8] selected thin film thermocouples to measure temperature variation of the surface contact point. However, those reports mostly concentrate on improving technology and analyzing experimental results. The design of the measuring system is rarely reported in plasma spray forming.

With the development of modern measurement technology, the measurement technology based on LabVIEW (laboratory virtual instrument workbench) as development software has been an important direction for modern measurement. According to the rule of reynolds mechanical simulation, the paper designs a transient temperature measuring system of low-speed big droplets on the basis of fast-response thermocouple. It is testified that the system is feasible through measuring the temperature curve of Sn-Pb alloy droplet splatting.

II. THE OVERALL DESIGN OF SYSTEM

The main function of this system observes the temperature change during the droplet splatting, based on data acquisition through PC. The experimental equipment is shown in figure 1.

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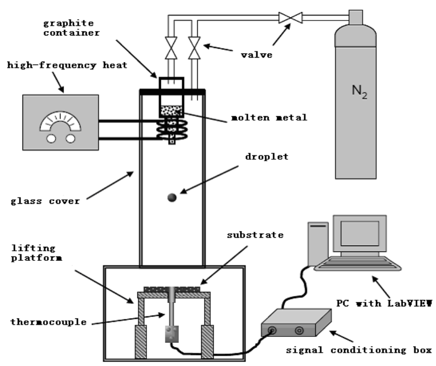

Figure 1. The experimental equipment

A. Design of Hardware

The temperature measuring system is composed of five parts, as shown figure 2. We selected a commercially corrosive thermocouple (response time can be up to 10μs, maximal temperature can be up to 2800℃) produced by NANMAC, containing a signal conditioning box. And an insertion and high capability data acquisition card DAQ-2204 (ADLINK Technology Inc) was adopted.

Working process of this system is as follows. Firstly, thermocouple converts analog temperature signals into analog voltage signals. Secondly, in order to eliminate disturbance and enhance accuracy, the analog voltage signals are processed by the signal conditioning box through amplification, filtering, etc. Thirdly, the adjusted analog voltage signals are converted into the digital voltage signals by analog-to-digital converter on the DAC (data acquisition card), and then these signals are temporarily stored in RAM (random access memory) through DMA (direct memory access) channel, avoiding the intervention of the central processor unit of the PC. Finally, the data of every experiment in RAM are read into the hard disk of the PC and processed by LabVIEW software.

B. Design of Software

To increase the efficiency of software development and enhance transportability, extensibility and maintainability, the function of the system is separated into several modules, such as temperature acquisition module, temperature compensation and calibration module, file management module, etc. During the process of design, every module can be developed and measured independently, and then is assembled into a whole system. The front panel of the system is shown in figure 3.

Figure 2. The temperature measuring system

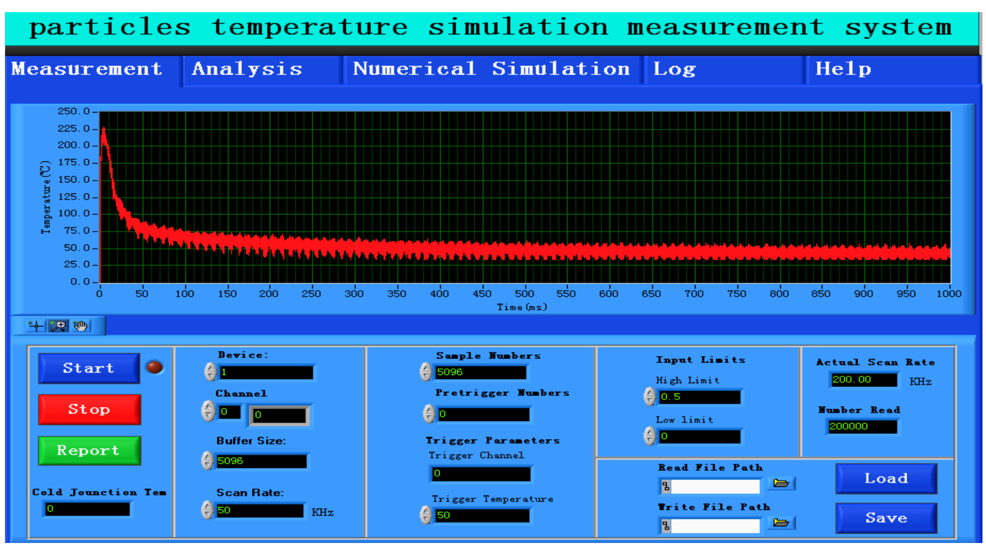

Figure 3. The front panel of temperature measuring system

1) Temperature acquisition module

Temperature acquisition is closely related to the DAC. The basic mission of DAC is the physical signal extraction and measurement. In this paper, temperature acquisition module is used to control the whole data acquisition system, including parameter configuration, state switch, result output, etc. Figure 4 shows the flow chart of temperature acquisition. Next is the specific process, and the driver modules are shown in figure 5.

- PLV AI Config VI configures a buffered analog input operation, including configuring the hardware and allocating a buffer.
- PLV AI Start VI starts a buffered analog input operation. This VI sets the scan rate, the number of scans to acquire the conversion clock source, and the trigger conditions. Then, the VI starts an acquisition.
- PLV AI Read VI reads specified number of scans of data from a buffered analog input acquisition.
- PLV AI Clear VI stops an acquisition operation.

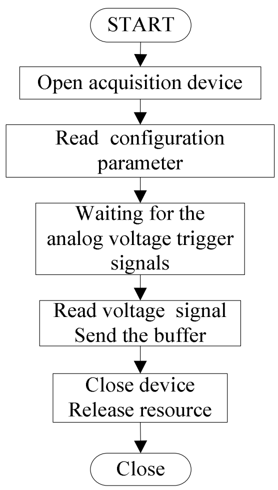

Figure 4. The flow chart of temperature acquisition

2) Temperature compensation and calibration module

The connection between thermocouple and DAC is called the reference junction or cold junction. The connecting wire lead to the reference junction voltage or CJV (cold junction voltage) like as thermocouple. Thus, actual voltage acquired by DAC should include the CJV and the TJV (thermal junction voltage) measured by thermocouple. The CJV compensation is the primary mission of temperature measurement.

There are two ways to compensate the CJV of thermocouple [9]. 1) Hardware compensation. The way is that the CJV is counteracted by the voltage produced by special circuit. 2) Digital compensation. The way is as follows. Firstly, another thermocouple measures the cold junction temperature directly, acquiring the voltage signal. Then, the signal which is disposed through a serial of ways again is converted the CJV. At last, the CJV plus the TJV is the actual voltage. In view of inherent high cost of hardware compensating, the system selects the second way. The scheme of temperature compensation is shown in figure 6.

The temperature compensation is designed according to the middle temperature law. The equation relevant to the CJV can be shown as follows:

$$E_{AB}(t,t_0)=E_{AB}(t,t_1)+E_{AB}(t,t_0) \tag{1}$$

Where t, t_0, t_1 denote respectively the actual temperature, the standard temperature and the cold junction temperature. In order to search and compute from the reference table of the thermocouple conveniently, we assume that the standard temperature is 0 ℃. The above equation is simplified as follows:

$$E_{AB}(t,0)=E_{AB}(t,t_1)+E_{AB}(t_1,0) \tag{2}$$

Where E_{AB} $(t, 0)$ is the voltage exported by thermocouple when the cold junction temperature is 0℃. E_{AB} (t, t_1) is the voltage exported by thermocouple when the cold junction temperature is t_1. E_{AB} $(t_1, 0)$ is the cold junction compensation voltage.

E_{AB} (t, t_1) can be directly measured. As long as the cold junction temperature t_1 is acquired, the temperature can be converted with the reference table and the value of E_{AB} $(t_1, 0)$ can be obtained. The value of E_{AB} $(t, 0)$ is computed according to Eq. (2), and then E_{AB} $(t, 0)$ is converted into the actual temperature t by the reference table.

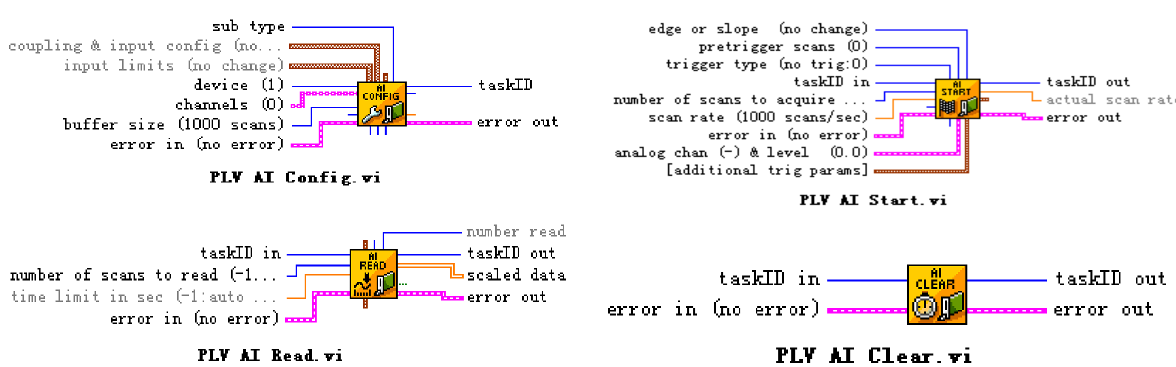

Figure 5. Driver modules relevant to data acquisition

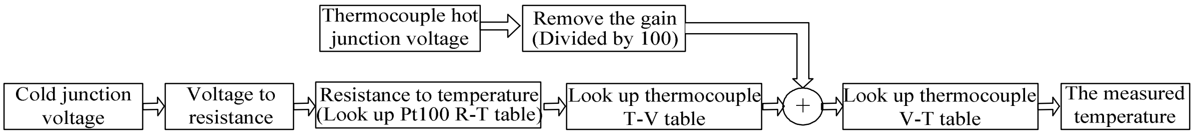

Figure 6. The scheme of temperature compensation

In addition, nonlinearity exists in both output signal and temperature obtained by thermocouple [10, 11]. If nonlinearity is not calibrated, the measurement error will be expanded. Therefore, we must calibrate nonlinearity and make linearization with the direct look-up table and program computation. The step is as follows:

- Building the reference table. Temperature value has a unique quantitative relation with index value of array, that is, temperature value is an integer and increase 1℃ in turn.
- Contrasting the voltage value with the voltage stored in array. Assuming that measured voltage locates between two voltages stored in array, the temperature value is calculated through linear interpolation method.

Finally, attention must be paid to the change of temperature caused by electromagnetic interference or zero drift which lead to decrease of the measurement accuracy. In order to reduce the effect, the way that collect one hundred voltage values during ten milliseconds is adopted, and their arithmetic mean is computed respectively. Then, the data are sampled on the basis of those arithmetic mean values, and substituted in subsequent calculation.

3) File management module

As shown in figure 7, it is the flow chart of this module. The function of this module is used for real-time results recording, storing and accessing, and satisfying the need of statistics analysis and inquiry in the future.

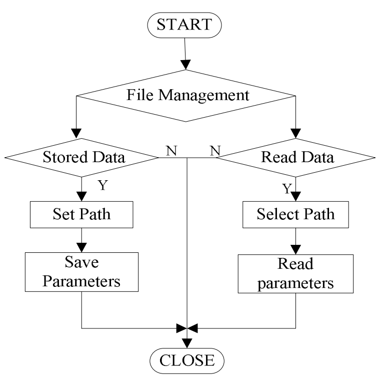

Figure 7. The flow chart of file management module

III. ANALYSIS OF TEST RESULT

The system measures the transient temperature variation, using a free-falling Sn-Pb alloy droplet (70%Sn~30%Pb, Melting Point: 190℃, Diameter: 3.98 mm, Velocity: 3.28m/s) for the simulation of droplet splatting. Figure 8 shows the temperature variation curve of Sn-Pb droplet splatting.

At the beginning, the temperature curve rises sharply. When time is 4.475 ms, the peak value of the curve is higher than its melting point, up to 206℃. After the peak value, the curve falls rapidly. The falling rate of the curve decreases slowly along with time increasing, and finally the temperature converges to room temperature.

By comparing the temperature curve of this paper with that of Bennett's [12], Aziz's [6] and Wang's [5], it is approved that the temperature measuring system described in this paper is feasible. According to literature [13, 14], the durative flattening time maintain 5~20ms for the droplet of 2 mm in diameter and with the velocity of 1.6~3.3 m/s. It is testified again that the system is reliable.

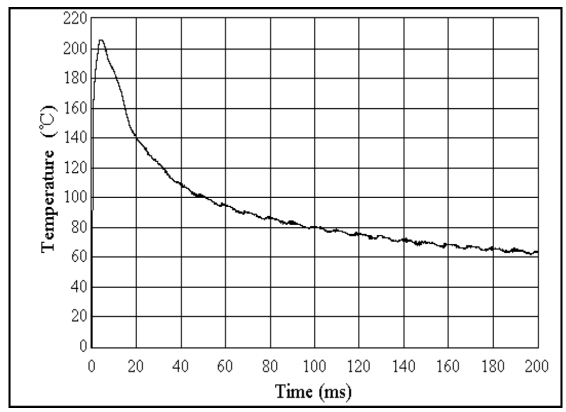

Figure 8. The temperature variation curve of Sn-Pb

IV. CONCLUSIONS

The temperature measuring system using fast-response thermocouple is developed on the basis of LabVIEW. There are many advantages, such as low cost, simple operation, friendly interface, high accuracy, etc. It is indicated that the system can be applied to measure the transient temperature variation of droplet splatting through the validation of Sn-Pb alloy droplet. In addition, the system possesses the function of displaying, reading and analyzing, and can also be used widely in other field of transient temperature measurement.

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