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# Research on Temperature-measuring System Based on Magnesium Alloys' Ignition Test

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**Abstract:** How to judge magnesium alloys' ignition point accurately was a problem needed to be solved. A Traditional method with a thermocouple influenced the distribution of measured temperature field, which had a slow response speed and was difficult to shrink and automate. To address the above problems, a small colorimetric temperature measurement system was designed and its composition and operating principle were introduced; using a mutational site in optical radiation power received by temperature-measuring system was presented to determine the time when magnesium alloy began burning; moderate temperature blackbody furnace was utilized to calibrate statically to obtain static calibration coefficient; electrical heating slice resistance was presented to ignite magnesium alloys, which had advantages of simple operation, saving time and test materials; SCM was employed in data-processing; this system was portable, exquisite and reliable. The ignition test result of AZ80 with 0.75% Nd shows that, the results of colorimetric temperature measurement system and infrared thermometer are 873.9? and 879.1?, respectively, the relative error is 0.6%, which verifies the feasibility of this method.

**Key words:** Magnesium alloys, colorimetric temperature-measuring;ignition point, electrical heating method

## INTRODUCTION

Mg element distributes widely on the earth; Mg alloy materials have low density and high strength, which has a good applicable prospect in aviation, spaceflight, cars, machinery and other fields (Quan, 2012; Ge *et al*., 2012; Tan *et al*., 2011). But in fact, active chemical property makes Mg element easy to burn at high temperatures or when rubbing acutely, ignition-proof Mg alloy technology is able to address this shortcoming (Zhao *et al*., 2008; Zhang *et al*., 2011; Qin *et al*., 2013; Wang *et al*., 2011). Ignition test is an important parameter to represent flame retardant efficiency.

Now, contact-measuring method with a thermocouple was used at home and abroad, employing observational method or tangent method to establish ignition (Bobryshev and Aleksandrova, 1988; Yuan *et al*., 2013; Zhu *et al*., 2010), which had low response speed, bad repeatability of results and low measurement accuracy. This colorimetric temperature measuring system determined ignition according to changes of spectral radiation intensity before and after magnesium alloy's ignition point, which had small volume and good repeatability, was able to eliminate interference of emissivity changes and could be used to monitor on-line temperature when smelting and producing Mg alloys.

## COLORIMETRIC TEMPERATURE MEASURING SYSTEM DESIGN

Colorimetric temperature-measuring system consisted of sapphire window, objective lens, field lens, two narrow band interference filters in different peak wave lengths, two quadrant detector and signal processing circuit, whose functional block diagram was shown in Fig. 1. Sapphire window protected internal components from interfering and damaging by external high temperature, dust and so forth; objective lens converged received thermal radiation; field lens work almost in the focal plane of objective lens, which can decrease the range of radioactive beams of light, increase luminous flux and enable photo-surface to receive light more equably; two-quadrant detector can complete photovoltaic conversion and consists of four photosensitive diodes, the top and bottom PIN on lift and right side are linked respectively, gluing with narrow-band interference filters

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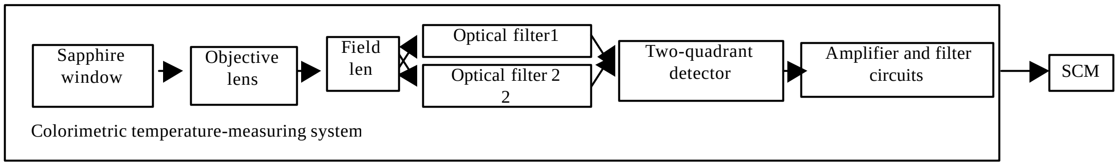

Fig. 1: Principle of colorimetric temperature-measuring system

in different peak wave lengths, the structure of integrating narrow-band interference filters with two-quadrant detector makes the whole system miniature; signal processing circuit magnifies and filters two voltage signals, finally SCM process and display data.

## PRINCIPLE OF COLORIMETRIC TEMPERATURE-MEASURING SYSTEM

Colorimetric temperature measurement determines temperature according to the function of ratio of two-waveband spectral radiation intensity received from measured temperature field and temperature. The theoretical basis is Plank's law. Radiation power of two wave bands received by two-quadrant detector is turned into light current:

$$R(T)=\frac{I_1(T)}{I_2(T)}=\frac{S(\lambda_1)\times\psi(\lambda_1)\times\tau(\lambda_1)\times\varepsilon(\lambda_1,T)\times\int_{\lambda_1-\Delta\lambda/2}^{\lambda_1+\Delta\lambda/2}M_1(\lambda,T)d\lambda}{S(\lambda_2)\times\psi(\lambda_2)\times\tau(\lambda_2)\times\varepsilon(\lambda_2,T)\times\int_{\lambda_2-\Delta\lambda/2}^{\lambda_2+\Delta\lambda/2}M_2(\lambda,T)d\lambda}\quad(1)$$

$$M_1(\lambda,T)=\frac{C_1}{\lambda^5 e^{C_2/\lambda_1 T}}\quad(2)$$

$$M_2(\lambda,T)=\frac{C_1}{\lambda^5 e^{C_2/\lambda_2 T}}\quad(3)$$

where, 2 and 3 are radiation of non-black-body at thermo-dynamic temperature in wavelength $\lambda_1$, $\lambda_2$, respectively. R (T) is the ratio of two wave bands' radiation power. $I_1$ (T) and $I_2$ (T) are two-way light current, $\Delta\lambda$is system bandwidth, S ($\lambda$), $\Psi$ ($\lambda$), $\tau$ ($\lambda$) are functions of optical system's spectrum transmittance, two narrow band interference filters' spectrum transmittance and two quadrant detector's response function, respectively. Order:

$$K=\frac{S(\lambda_1)\times\psi(\lambda_1)\times\tau(\lambda_1)\times\varepsilon(\lambda_1,T)}{S(\lambda_2)\times\psi(\lambda_2)\times\tau(\lambda_2)\times\varepsilon(\lambda_2,T)}\quad(4)$$

$$R_1(T)=\frac{\int_{\lambda_1-\Delta\lambda/2}^{\lambda_1+\Delta\lambda/2}M_1(\lambda,T)d\lambda}{\int_{\lambda_2-\Delta\lambda/2}^{\lambda_2+\Delta\lambda/2}M_2(\lambda,T)d\lambda}\quad(5)$$

So:

$$R(T)=K\cdot R_1(T)\quad(6)$$

## SCM MODULE DESIGN AND SIMULATION

**Scale conversion of non-linear parameters:** Input $R_1$(T) and output T are made into a reference table and written into internal storage. Considering the temperature measuring range is from 600? to 1000?, Tab.1 shows T in exact multiple of 10 and corresponding value 100×$R_1$(T). Every temperature corresponds 5-numeric digits' 100×$R_1$(T), which needs 2-byte internal storage in 8-bit MPU. Using dichotomous search to find out the corresponding result, it needs about 8 times(ln400/ln2˜8) to find tens digit of 100×$R_1$(T). After that, linear interpolation is used to obtain the unit and decimal place.

Take $R_1$ (T) = 3378 as an example, tens digit can be ensured as 79 according to Table 1, because 790? corresponds 3483 ($R_1$ (T)), 800? corresponds 3328 ($R_1$ (T)), the unit and decimal place are:

$$\frac{3483-3378}{3483-3328}\times10=6.77$$

So final temperature value is 790+6.77 = 796.77?.

**Selection of SCM:** The selected SCM is AT89C51, which has 4k-byte flash memory, 128-byte internal RAM. It can be wiped 1000 times repeatedly, which is convenient for the modification of product development machine. The 8-bit dual channel chip ADC0832 is chosen as A/D converter chip. This chip is successive approximation A/D converter, whose working frequency is 250 KHz, conversion time is 32 μs and average power consumption is only 15 mw. LCD1602 is used to display in two lines.

**Simulation results of SCM:** The simulation result of SCM is shown in Fig. 2. Proteus provides a simulation platform

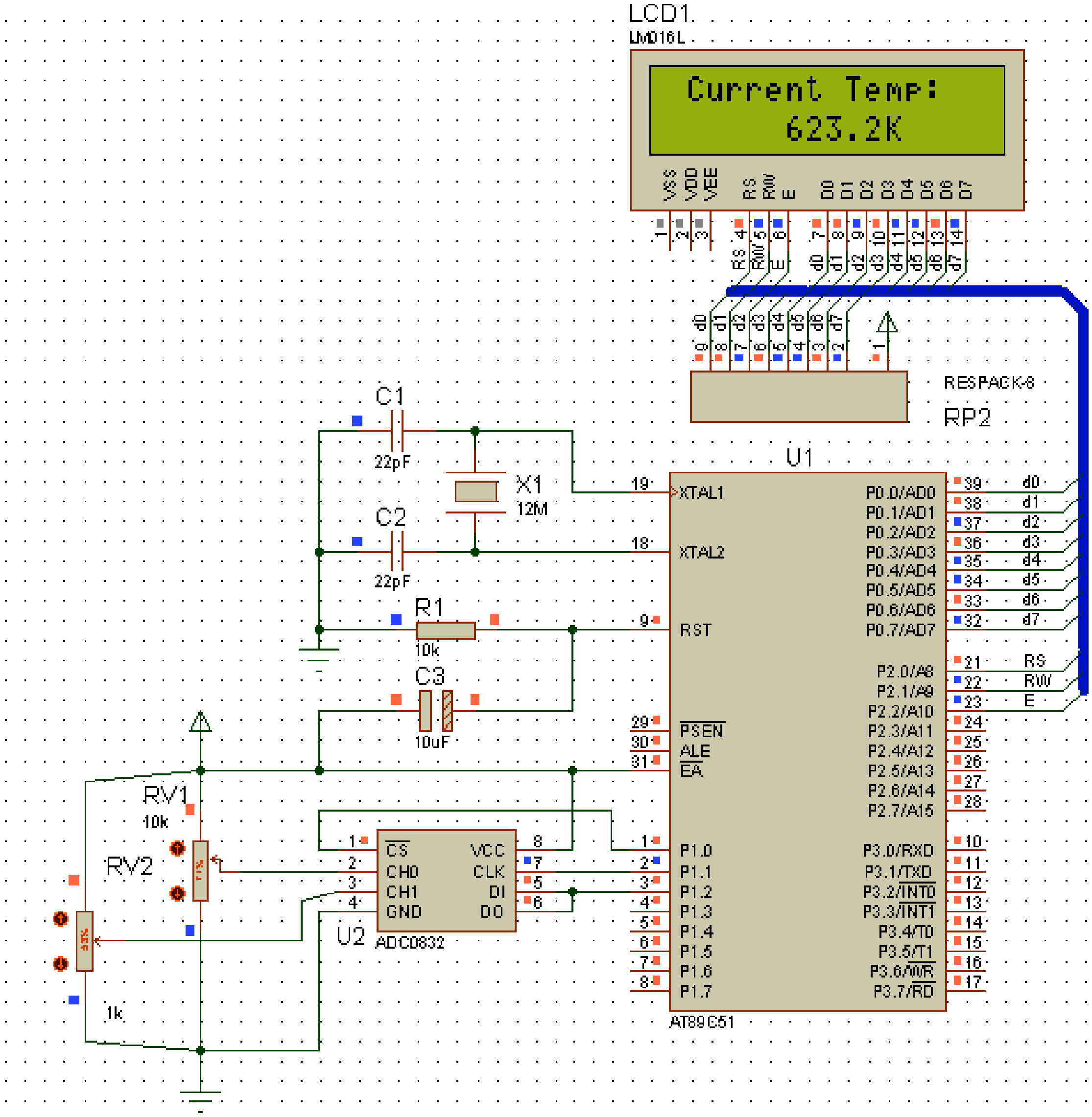

Fig. 2: Simulation result of SCM

for embedded system hardware and software design. Two lines output voltage range of colorimetric temperature-measuring sensor is 0~2.5V. When simulating, the analog input is 0~2.5V dc voltage, linking to ADC0832 CH0, CH1 channel through two slide rheostat, the collected 8-bit binary number multiplied by the conversion accuracy, converted to temperature after data processing. Data output OUT1~OUT8 are connected to AT89C51 P0 and the other three control sites P2.0~P2.2 controlled temperature display through LCD in real time. Virtual dc voltmeter was connected to analog input; the corresponding temperature was manually calculated and then compared with LCD display data to calculate the error.

## MAGNESIUM ALLOY IGNITION TEST

**System's static calibration:** SR20-32 medium temperature blackbody furnace was used for static calibration of colorimetric temperature-measuring system. Turn on the power and set the temperature from 600? to 800?, every 20? using data acquisition card to collect two-way output voltage at a time. Static calibration system is shown in Fig. 3. Order display temperature of blackbody furnace temperature is T, R1(T) could be obtained by formula. At the same time, the corresponding photocurrent was calculated according to the two-way output voltage of colorimetric temperature-measuring system to gain R(T),

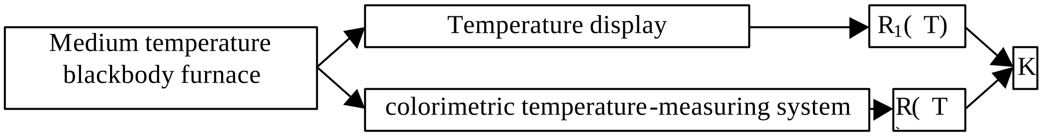

Fig. 3: Static calibration principle of colorimetric temperature-measuring system

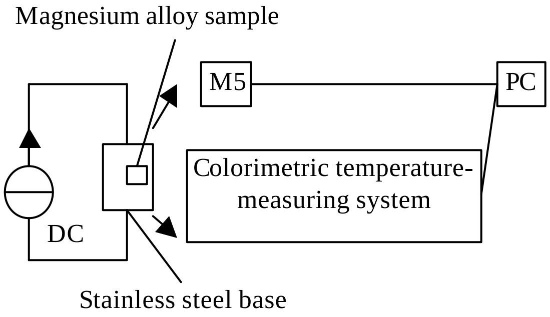

Fig. 4: Schematic diagram of magnesium alloy ignition test

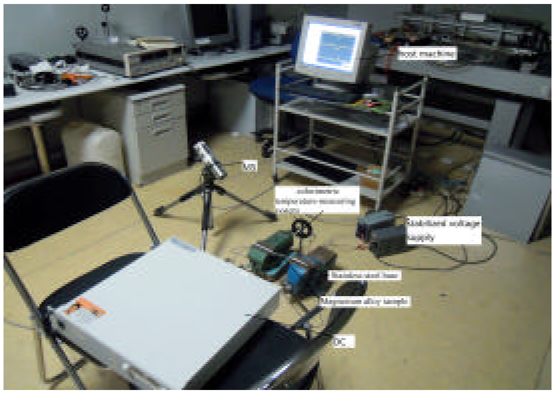

Fig. 5: Real diagram of magnesium alloy ignition test

then K was calculated according to the expression (6). The mean value of K was got, the adjusted R (T)-T curve was drawn and o temperature was determined according to R (T).

**Samples and base preparation:** The magnesium alloy samples (AZ80 with 0.75% Nd) was used in this experiment, mass fraction of main elements are: Al (7.41%), Zn (0.522%), Most of the rest is magnesium. Magnesium alloy was processed into slice sample (6×6×0.25 mm3), which is easy to be ignited.

When choosing the electric-heating slice chip as base, material resistivity should be larger, linear expansion coefficient should be moderate, melting point should be higher ( Due to the ignition point of the magnesium alloy is below 1000 ?, the material with ignition point higher than 1000? is needed), thus ensuring the basal material to conduct heat rapidly rather than deform excessively, even melt before magnesium alloy samples burn. Finally 304 stainless steel slice was chosen, cutting into $80\times15\times0.03$ mm$^3$, in order to enable magnesium alloy samples to be heated uniformly.

**Experiment scheme:** The schematic and real diagrams of magnesium alloy ignition test system are shown in Fig. 4 and 5. DC electrical source is produced by American Agilent (short for DC below), whose rated output is 60V/55A, providing current for electrical-heating chip resistor and enabling its temperature to rise. Infrared thermometer belonging to Modline5 series of American IRCON (short for M5 below) is chosen as a standard temperature-measuring instrument, namely, measurement result of M5 is regarded as the real temperature. Data acquisition card and Topview software belong to Sichuan Topology test and control technology, which are used to collect data, read and analyze two-way voltage. DC is linked to stainless steel base through wire; a sample is put in the middle of it. Then increase DC current slowly, making the temperature of the stainless steel base rising, once igniting the sample, stop adjusting DC. In the whole process, M5 and colorimetric temperature-measuring system aimed at the sample and data acquisition card is used to communicate with host machine, using Topview software to collect data.

**Experimental results and analysis:** The output voltage curves of M5 and colorimetric temperature-measuring system are shown in Fig. 6, CH1, CH2 and CH3 are corresponded to the output voltages of optical filter1 (650±30 nm), optical filter2 (850±30 nm) and M5, respectively.

Straight section exists between two peak values of CH3 curve in Fig. 6, because when magnesium alloy sample is burning, radiation energy mainly ranges from 500 nm to 800 nm but it becomes extremely small ($\lambda$>1000 nm), which enables M5 to intensively receive energy between 750 and 1050 nm, making the ratio of two voltages to exceed the range and the output of electric

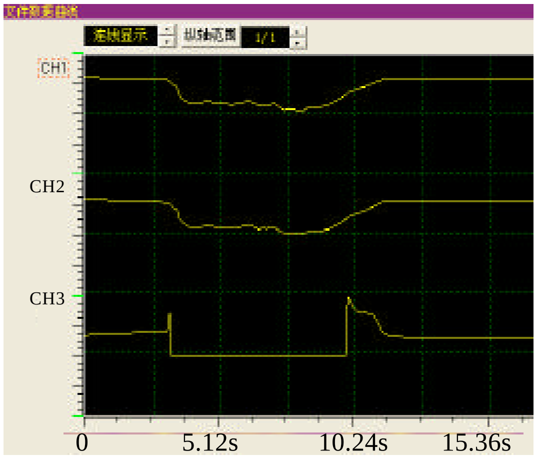

Fig. 6: Output voltage curves of M5 and colorimetric temperature-measuring system

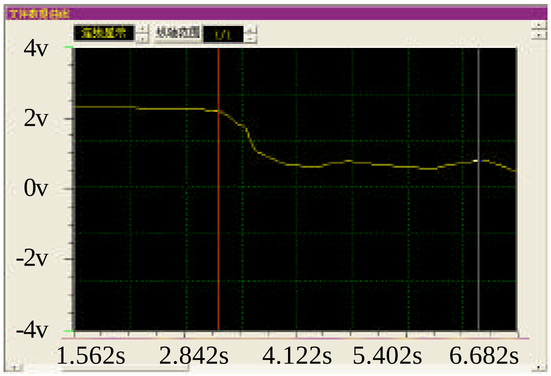

Fig. 7: CH1 result after filtering

circuit to be almost zero. Radiation energy received by colorimetric-temperature measuring system will exist a inflection point when magnesium alloy sample is ignited instantaneously. The time when magnesium alloy sample begins to burn can be confirmed as ignition time. Take the first experiment as an example, observing the curves of CH1 and CH2, the change rate of the curves begin to increase at 3.235 s (as shown in the Fig. 7 and 8). So magnesium alloy sample starts to burn at the time, M5 and colorimetric temperature measuring system are observed meanwhile (Table 2).

Table 2 shows that relative error e of temperature-measuring result between M5 and colorimetric temperature measuring system is approximately between 1 and 2%, which proves the feasibility of using the colorimetric temperature-measuring system to measure the ignition temperature of magnesium alloys, the error will remarkably decrease by measuring repeatedly and gaining the average value.

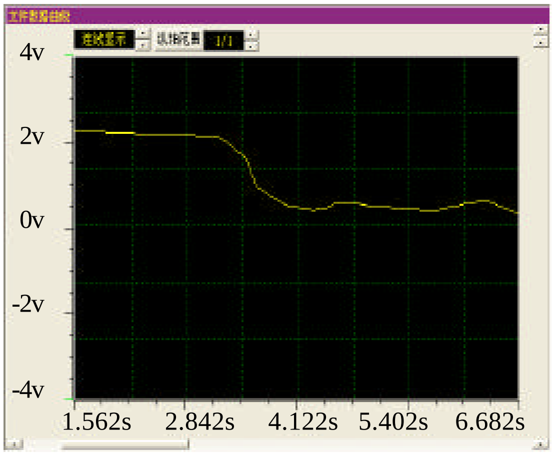

Fig. 8: CH2 result after filtering

Table 1: Reference table between temperature and 100×$R_1$(T)

| T/? | 600 | 610 | … | 790 | 800 | … | 990 | 1000 |
|---|---|---|---|---|---|---|---|---|
| $R_1$(T) | 10110 | 9450 | … | 3483 | 3328 | … | 1604 | 1553 |

Table 2: Results of M5 and colorimetric temperature measurement system

| Time | M5/V | M5/? | CH1/V | CH2/V | R(T) | T /? | e (%) |
|---|---|---|---|---|---|---|---|
| 1 | 3.44 | 875.2 | 2.174 | 2.081 | 0.778 | 891.7 | 1.90 |
| 2 | 3.37 | 869.9 | 2.213 | 2.172 | 0.875 | 883.5 | 1.56 |
| 3 | 3.28 | 862.7 | 2.256 | 2.229 | 0.901 | 879.0 | 1.89 |
| 4 | 3.49 | 879.4 | 2.018 | 1.873 | 0.769 | 868.4 | 1.25 |
| 5 | 3.53 | 882.3 | 1.980 | 1.697 | 0.648 | 873.1 | 1.04 |
| M5/? (Average) |  | 873.9 | T/?(Average) | 879.1 | 0.600 |  |  |

## CONCLUSION

The time of ignition point can be confirmed accurately according to changes of spectral radiant intensity to establish before and after the ignition point of magnesium alloy, which has the advantages of high precision and good repeatability. Integrated structure of the two-quadrant detector and filters can be produced easily and work reliably. The heat source of igniting the magnesium pieces with electrical heating method is adopted, which is more accurate and saving experimental materials and time. The ignition point of AZ80 with 0.75%Nd is measured, the average values measured by colorimetric temperature measuring system and M5 are 891.7? and 879.1?, respectively, whose relative error is 0.6%. This research has a very important reference value for correlation studies on ignition-proof magnesium alloy and online monitoring in magnesium alloy smelting.

## ACKNOWLEDGMENT

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