Measuring Methods for Temperature of the Grinding Wheel Surface

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Abstract

For thermal analyzing on the grinding phenomenon, it is necessary to measure the temperature of microscopic area in very short time. There are two representative methods, one is the thermocouple method and another one is the infrared radiation thermometer. The new type of infrared radiation thermometer with optical fiber was developed in the response time and the measurable area. The minimum response time was 3×10^{-6}s and the diameter of measurable area was limited to just 110×10^{-6}m. Consequently, this thermometer measured the exact grinding temperature that correlated with calibration curves of S45C, grinding wheel (WA80) and compared with the results of thermocouple (alumel-S45C). The obtained temperature depended on the heat flow rate during the grinding operation and the oxidation of removed chips. The measured signal also indicated two parts, one was the base part and another was the impulse part. The heat energy generated by the oxidation was larger than the total amount of the energy supplied by the grinding operation.

INTRODUCTION

Grinding temperature is effected by surface integrity, surface texture and mechanical strength of the industrial products. Because there are some reasons to happen the heat-affected zone, the microcracks and the tears and so on (Ono, K. (1972)[1]). In order to analyze grinding temperature it is very important to realize high dignity of the industrial products. So far, the measuring method is used well known with a thermocouple, however it has relatively a long time constant dependent on its heat conductivity. It also both materials needs to constitute thermocouple circuit. Therefore thermocouple method is not fit measuring method for high speed temperature sensing and for grinding on insulating material like ceramics.

On the other hand, the new type of infrared radiation thermometer with optical fiber was also developed to measure the high speed change of temperature on the grinding wheel surface (Ueda, K. et al. (1989)[2]). The response time of the thermometer, which obtained some characteristics of output signals, was compared with that of a ther-

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mocouple. The output signals also were broken down to an impulse part and a base part in the signal.

NOMENCLATURE

C_p : mixed specific heat of alumel and S45C at constant pressure [kJ/kgK]
K_g : output correct coefficient [-]
K_p : -3dB point coefficient [-]
l : length [m]
R : measuring distance [m]
S_h : heat source area [m^2]
S_m : measurable area [m^2]
t : depth of cutting [m]
v : feed speed [m/s]
V : grinding speed [m/s]
V_c : corrected output voltage [volt]
V_m : measured output voltage [volt]
W : mass [kg]
θ : angle of attack [deg]
θ_{max} : maximum angle of attack [deg]
λ_m : mixed thermal conductivity of alumel and S45C [W/mk]
τ_t : time constant [s]

EXPERIMENTAL APPARATUS

Figure 1 shows the measuring systerm (thermocouple) for grinding temperature. Such a measuring method was adopted by J.Peklenik (1958)[3] to measure grinding temperature at the point of abrasive grain. In the experiment thermocouple which consisted of alumel wire (diameter:25×10^{-6}m) and block of S45C. Alumel wire isolated by two micaceous leaves (thickness:15×10^{-6}m) embedded into S45C blocks. This measuring system obtained signals when abrasive grain cut S45C blocks. On the other hand, figures 3 and 4 show the measuring system (infrared radiation thermometer with optical fiber) for grinding temperature. Optical fiber was inserted into a small perforated hole in the block, and it was located 100×10^{-6}m from the grinding wheel surface.

Optical fiber also was a standard ZrF_4 fiber (core diameter:70×10^{-6}m,N.A.:0.2). The photoelectric device was a InAs (time constant: 100×10^{-9}s, peak wave length 3.2×10^{-6} m). Minimum response time for the measuring system was 3×10^{-6}s. The relationship between heat source area and the measurable area is very important for measurement (Holman, J. P. (1986)[4]). When the heat source area is less than the measurable area, it is possible to be modified by eq. (1) as follows including the distance and heat source area (c.f. APPENDIX).

$$V_c = \frac{Vm}{K_p K_g} \qquad (1)$$

Each experiment used the plunge cut surface grinding with only one pass with dry and down cutting (V:25 m/s, v:0.25 m/s, t:20×10^{-6}m).

RESULTS AND DISCUSSION

Thermocouple has some advantages such as 1) cheap price, 2) good accuracy, 3) possible to measure inner temperature in body. Conversely it has some disadvantages such as 1) need for direct sensing measurement, 2) not short time constant, 3) necessity of thermoelectric circuit and so on. On the other hand, the infrared radiation thermometer has some advantages such as 1) remote sensing measurement, 2) high speed, and it has some disadvantages such as 1) only measuring limited to surface temperature, 2) expensive price and so on.

Figure 7 shows the measuring signals by thermocouple. The base part gradual slope and several impulses stood on the signal. The time length from the signal start point to the impulse end point corresponded to a half of the grinding wheel's chord length

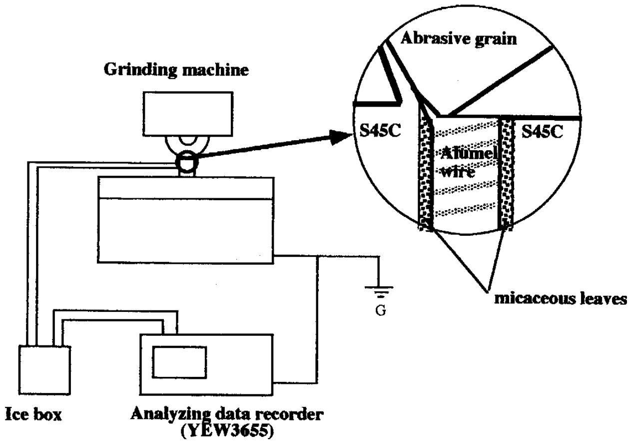


Fig.1 Measuring system (thermocouple)

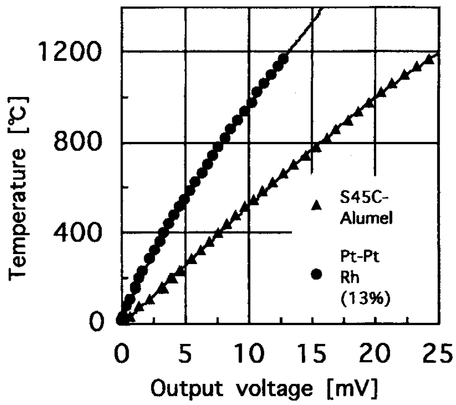


Fig.2 Temperature calibration curve for thermocouple

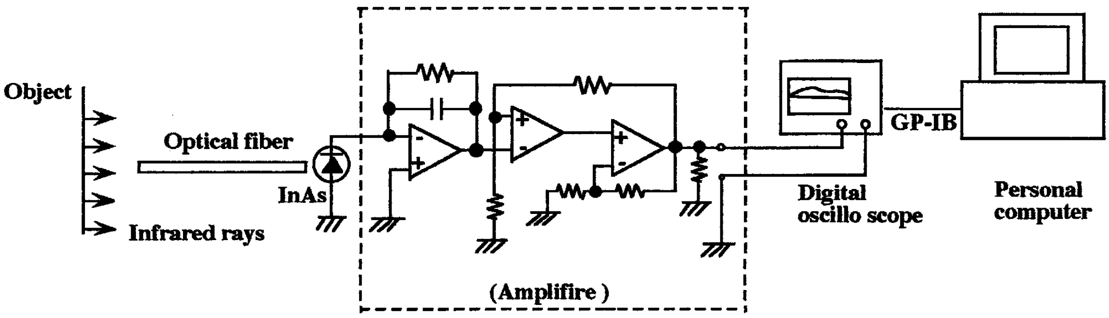
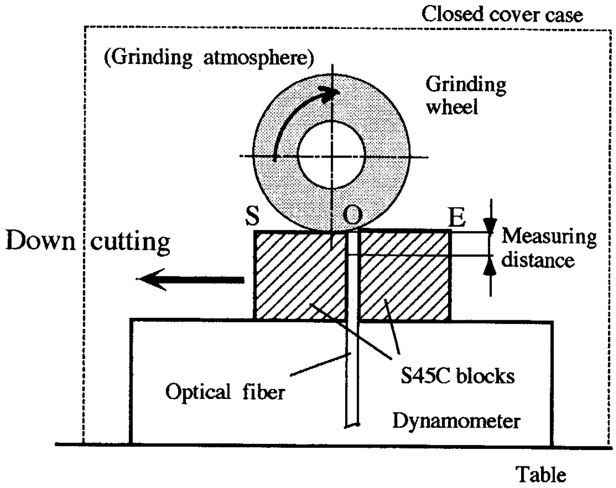


Fig.3 Measuring system (infrared radiation thermometer with optical fiber)



Grinding point
S: Start, O: Optical fiber, E: End point

Fig.4 Schematic diagram for test section

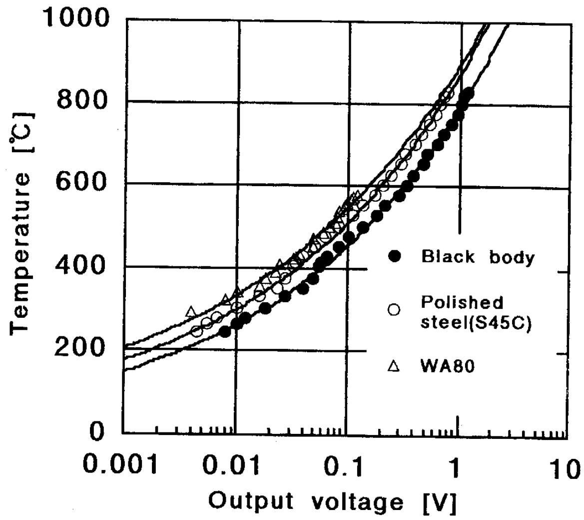


Fig.5 Temperature calibration curve for infrared radiation thermometer

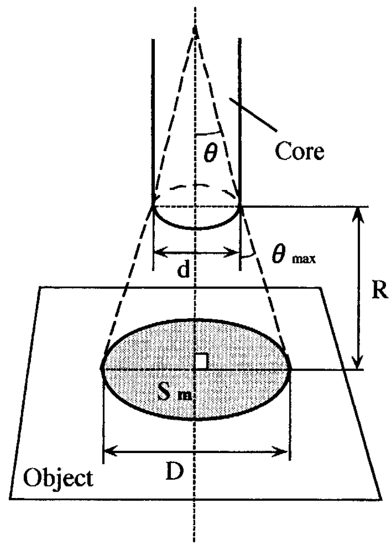


Fig.6 Relationship between R and Sm

time, It showed a maximum temperature 500℃ on the impulse part and 250℃ on the base part.

Figure 8 shows the measuring signals by infrared radiation thermometer. The shape of the signal is different from that of a thermocouple. Both signals had the base part gradual slope and several heavy impulses. The time length of the signals between the signal start point and the signal end point is the same as the time length from the optical fiber. Measured maximum temperature showed 660℃/630℃ (WA80/S45C) on the impulse part and 450℃/420℃ (WA80/S45C) on the base part.

Time constant of the present thermocouple is calculated by eq.(2) as follows,

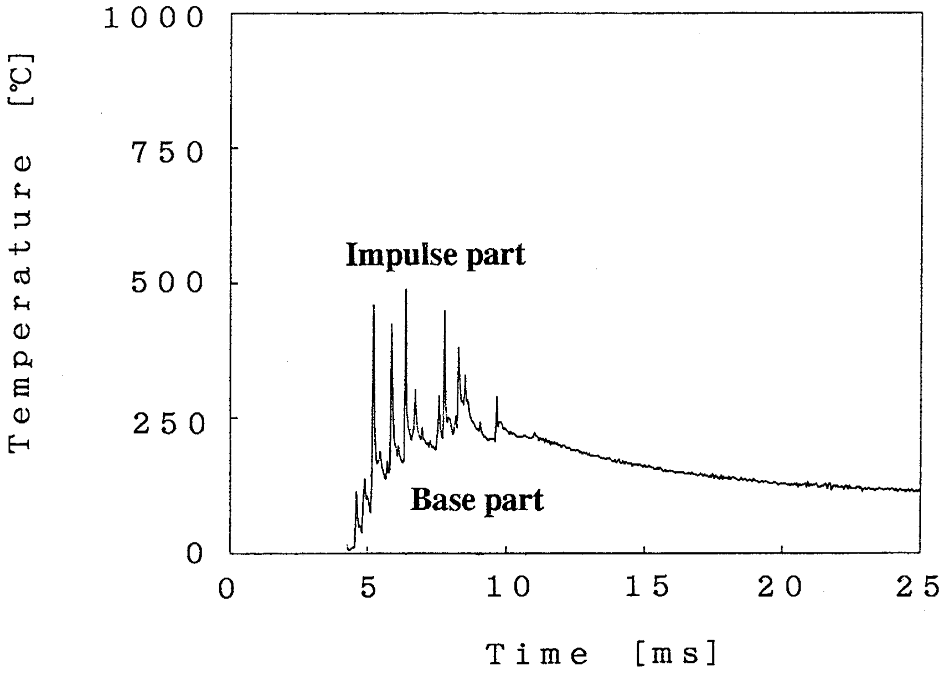


Fig.7 Measuring signal by the thermocouple

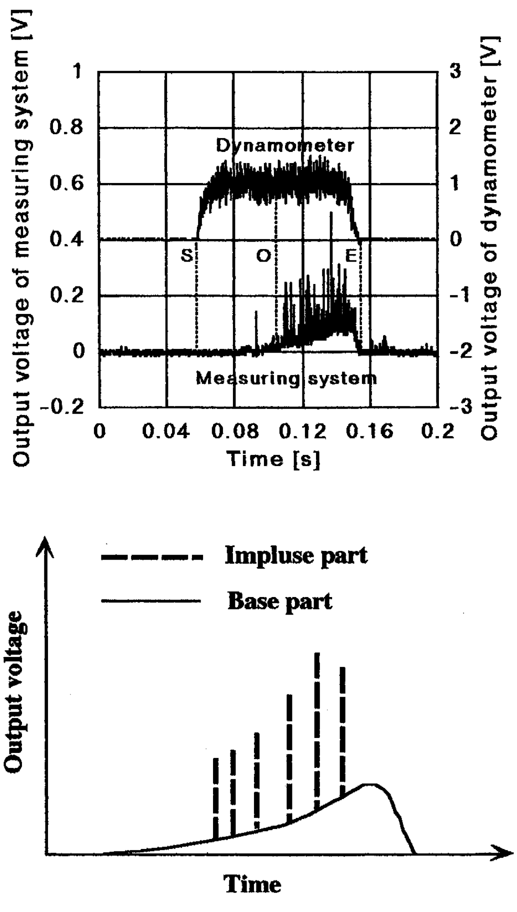


Fig.8 Measuring signal by the optical fiber (air atmosphere)

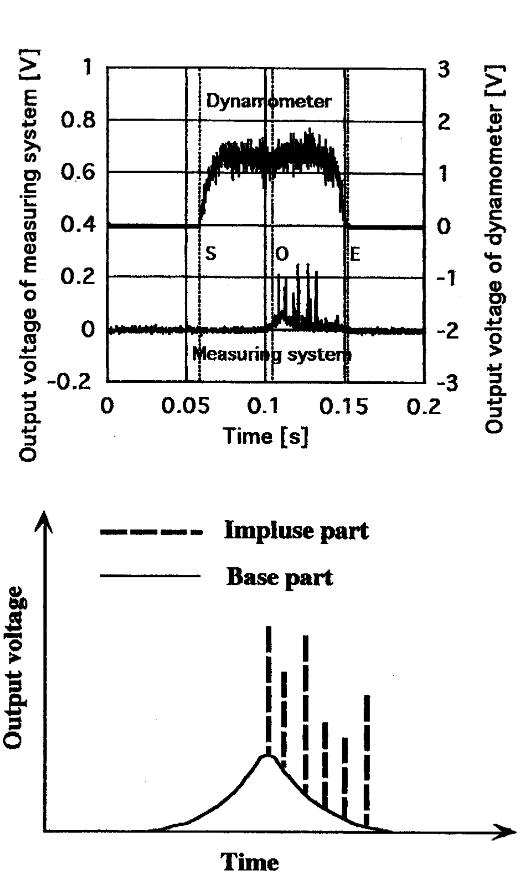


Fig.9 Measuring signal by the optical fiber (nitrogen gas atmosphere)

$$\tau_t = \frac{Wc_p}{S\frac{\lambda_m}{I}} \tag{2}$$

The time constant of thermocouple (alumel-S45C) was 5.4×10^{-3}s. This value is not fast enough to measure the grinding point (8×10^{-3}s) or the abrasive grain point (1×10^{-6}s) that passes through on the diameter of alumel wire. The thermocouple method limits the action of response time for this experiment. On the other hand infrared radiation thermometer was able to measure characteristic signal because of response time that was faster than the thermocouple. The main difference of the signal shape is influenced by oxidation of S45C chips that was written by Outwater, J.O. and M.C. Shaw (1952)[5] on his paper. In order to an experiment nitrogen gas atmosphere was tried to confirm the effect of oxidation of S45C chips.

Figure 9 shows the measuring signals in the nitrogen gas atmosphere by infrared radiation thermometer. The triangular base part and the impulse base part are shown in the figure 9. Signals are not showed wide range like one in the air atmosphere. Impulse and base on the air atmosphere were effected by oxidation. The heat energy generated by the oxidation was larger than the total amount of the energy supplied by the grinding operation. The above stated terms are confirmed from observation that the removed chips didn't emit light in the nitrogen gas atmosphere. The time length from base start point to base peak point is the same as half of grinding wheel's chord time length. The length of changed impulse time and scale level of a removed chip also were the same. So the base part output corresponded with the temperature of the grinding wheel surface, and the impulse part output corresponded with the temperature of S45C chips. When the grinding point came above the embedded optical fiber, the measuring value indicated the actual the temperature of the grinding wheel surface, because both of the signal levels above the embedded optical fiber were the same in the air and nitrogen gas atmosphere. The measuring system for grinding temperature gives many signals and includes much information compared with the thermocouple system.

CONCLUSIONS

(1) Measuring system by infrared radiation thermometer with optical fiber was available to measure the faster response time than that of thermocouple method.
(2) The measuring signals by infrared radiation thermometer with optical fiber have a base part and an impulse part, the base part output corresponded with temperature of the grinding wheel surface, and impulse part output corresponded with the temperature of S45C chips.
(3) Measurement method by infrared radiation thermometer with optical fiber was possible to measure S45C grinding temperature including heat energy generated by the oxidation.
(4) When the grinding point came above the embedded optical fiber, the measuring value indicated the actual temperature of the grinding wheel surface.

References

1) Ono, K. (1972), Grinding finishing, Tokyo. Makishoten.
2) Ueda, K: et al. (1989), Studies on Grinding Mechanism Using Infrared Radiation Pyrometer with Optical Fiber, Trans. JSME, 55, 516, pp.2251-2258
3) Peklenik, J. (1958), Mechanismus des Schleifens und die Uberschliffzahl, Ind.-Anz., Vol. 1, No.3, pp. 10-17.
4) Holman, J. P. (1986), Heat transfer, 6th ed., N.Y., McGraw-Hill.
5) Outwater. J. O. and Shaw, M. C. (1952),Surface Temperature in Grinding, Trans. ASME, Vol. 74, No. 1, pp.73-86.

APPENDIX

Figure A1 shows relationship between heat source diameter (8.5×10^{-3}m) and measuring distance. When measuring distance is 20×10^{-3}m, the measurable area and heat source area become the same value. Around the measuring distance 20×10^{-3}m point the decrease of output voltage indicated. Hence, when the heat source area was larger than the measurable area the output voltage at -3dB point was defined to calculate the coefficient K_p as follows,

$$K_p=\frac{V_{(-3dB)}}{V_{(Sm<Sh)}}$$
$$=0.707$$

K_g and K_d in eq.(1) are

$$K_g=AK_d{}^B$$
$$K_d=\sqrt{\frac{S_m}{S_h}}$$

From Figure A3 the factors A and B are obtained as follows,
A=1.045673 B=-1.584329

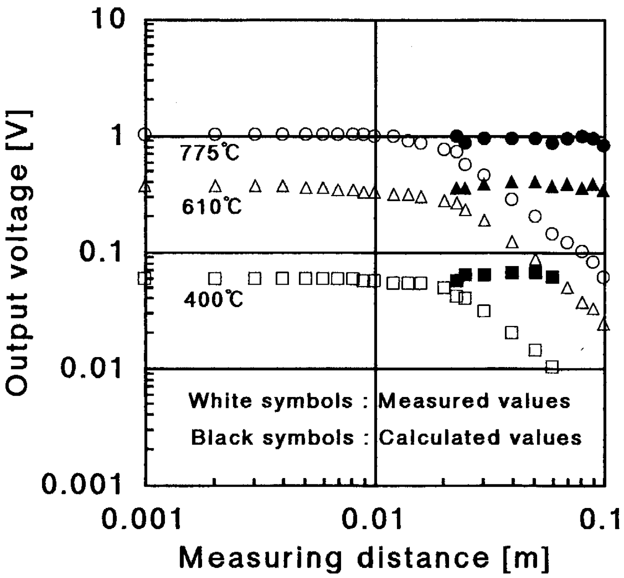


Fig.A1 Relationship between measuring distance and output voltage

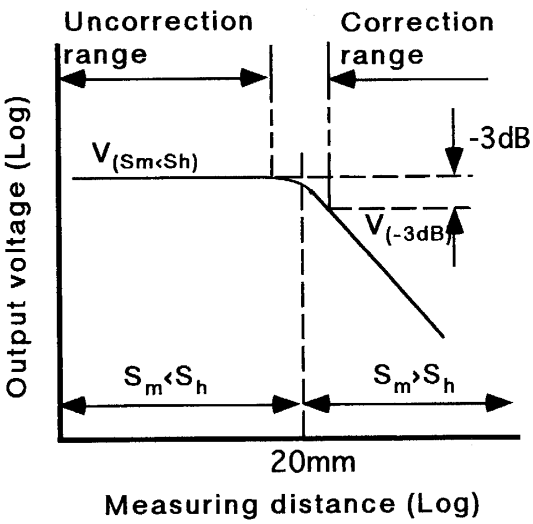


Fig.A2 Schematic diagram of -3dB point

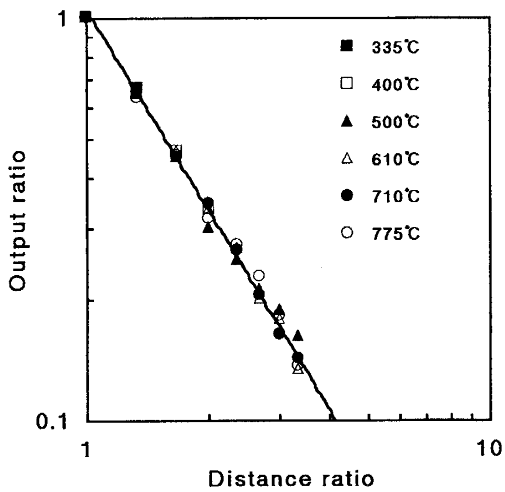


Fig.A3 Relationship between distance ratio and output ratio in correction range