

New Optical Pyrometer for Measuring the Temperature of Aluminum Alloys

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1. INTRODUCTION

Improvement in the effectiveness and quality in the modern technological processes employed in the manufacture of aluminum and its alloys cannot be achieved unless the temperature can be measured to an accuracy of $\pm 0.5 - 1\%$.

In static processes, where there is a calm object surface, measurements of errors to this order of magnitude have been achieved by contact means using a thermocouple.

In dynamic processes, such as casting, rolling, extrusion etc., accurate continuous temperature control is possible using non-contact, in particular optical, methods. The advanced characteristics of the instruments used in this type of pyrometry (such as high speed, sensitivity, etc.), make it possible to measure relatively low temperatures.

The use of optical pyrometry methods in the aluminum industry is, however, associated with a number of fundamental difficulties, such as:

- the variable emissivity and transmission of intermediate media intervening between the pyrometer and the measured object in the course of measurements;
- the influence of the light reflected from external radiation sources; and

- the fluctuation of objects within the field of view of the optical pyrometer allowing only partial object sighting.

The harsh operating environment of the optical pyrometer – the wide temperature changes, dust and humidity, and the action of variable and permanent electro-magnetic fields – introduces secondary destabilizing factors that need to be corrected by various technical solutions.

All this makes modern optical pyrometry more complicated and therefore more expensive.

2. EMISSIVITY

There are several factors that affect the emissivity in the course of temperature measurement of aluminum and aluminum alloys:

- the influence of various physical and chemical processes (for example, the oxidation of liquid and solid material);
- machining of solid materials; and
- shape changes introduced by the profiles of different types of extrusion processes.

Not only is there a wide range of changes for the absolute value of emissivity, but also for its spectral distribution, i.e., the absolute value of the derivatives in the equation:

$\varepsilon_i(\lambda, T) = \varepsilon_j(\lambda, T) + \frac{\partial \varepsilon}{\partial \lambda} (\lambda_j - \lambda_i)^2 + \frac{\partial^2 \varepsilon}{\partial \lambda^2 n!} (\lambda_j - \lambda_i) \dots + \frac{\partial^n \varepsilon}{\partial \lambda^n n!} (\lambda_j - \lambda_i)^n =$ $\varepsilon_j \left(1 + \frac{\Delta \varepsilon_{ij}}{\varepsilon_j} \right)$	(1)
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The above conditions cause undetermined methodical errors in brightness, color or multi-color optical pyrometry, and are the main factors preventing its use for high accuracy temperature measurement of aluminum and its alloys.

In order to use the classical and known methods of brightness (2), color (3), or tricolor (4) pyrometry, additional information regarding the absolute values of the emissivity, or about their ratios in two or more spectral ranges is required.

Specifically:

brightness:	$T_{\lambda}^{-1} = T^{-1} - \frac{\lambda}{c_2} \ln \varepsilon_i(\lambda, T)$	(2)
or color:	$T_r^{-1} = T^{-1} - \frac{1}{\left(\frac{1}{\lambda_i} - \frac{1}{\lambda_j}\right) c_2} \ln \left(1 \pm \frac{\Delta \varepsilon_{ij}}{\varepsilon_j}\right)$	(3)
or tricolor:	$T_r^{-1} = T^{-1} - \frac{1}{\left(\frac{1}{\lambda_i} - \frac{2}{\lambda_j} + \frac{1}{\lambda_z}\right) c_2} \ln \left(1 \pm \frac{\Delta \varepsilon_{ij}}{\varepsilon_j}\right) \left(1 \pm \frac{\Delta \varepsilon_{jz}}{\varepsilon_i}\right)$	(4)

Where: T = real temperature of the object; $\lambda_i, \lambda_j, \lambda_z$ = effective values of wavelengths; $c_2 = 14388 \mu\text{m}$.

Currently, receiving such information is divided into active and passive methods. This paper discusses passive pyrometer measurement and, consequently, the passive methods of receiving information about $\varepsilon(\lambda, T)$ from self-thermal radiation of a real target.

According to our investigation, the uncertainty of non-linear analytical dependencies $\varepsilon = f(\lambda, T)$ of different surfaces in aluminum and aluminum alloy production and treatment excludes the possibility of receiving explicit information about $\varepsilon = f(\lambda)$. In this case, only the methods first introduced by Hoffman and Tingwaldt [1], and then by Pyatt [2], can be used.

3. SOME PASSIVE METHODS OF INFORMATION ABOUT $\varepsilon = f(\lambda, T)$

In their work, Hoffman and Tingwaldt [1], and then Pyatt [2], formulated not only the basic principles of receiving information about $\varepsilon = f(\lambda, T)$ directly from thermal radiation of a real target, but also the methods of formation of temperature corrections to the conditional temperature of a real target.

These methods are based on the measurements of the differences between two conditional temperatures at different spectral ranges. Calibration of these differences is either in accordance with temperature correction of the assumed temperatures, or in accordance with its emissivity.

For example, Hoffman and Tingwaldt [1] used a “Bioptrix” pyrometer to correct the color temperature normalized by the difference between the color and the brightness temperatures and measured the real temperatures of Fe, Ni, Mo, and Ta with an error of 10 – 20 degrees.

The analytical form of their transformations is as follows:

$$T = T_r - K (T_r - T_\lambda) = (1 - k) T_r - kT_\lambda \quad (5)$$

Where: T = real temperature of the object

T_r = color temperature of the object

T_λ = brightness temperature of the object

K = normalization factor.

Similar results were described later in papers [3] and [4].

Another fundamental importance of works [1] and [2] is that the authors found it possible to evaluate information about $\varepsilon = f(\lambda, T)$ independent of the object temperature, or by using the difference of the inverse values of color and brightness temperatures in the form:

$T_r^{-1} - T_\lambda^{-1} = \frac{\lambda}{c_2} \ln \varepsilon_r$	(6)
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or using the difference of inverse values for two brightness temperatures,

$T_{\lambda_i}^{-1} - T_{\lambda_j}^{-1} = \frac{\lambda_2 - \lambda_1}{c_2} \ln \varepsilon_r$	(7)
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or as shown in paper [2], using the difference of inverse values of two color temperatures, measured at three spectrum ranges in a form:

$\Delta T^{-1} = \frac{1}{\left(\frac{1}{\lambda_i} - \frac{1}{\lambda_j}\right) c_2} \ln \left(1 \pm \frac{\Delta \varepsilon_{ij}}{\varepsilon_j}\right) + \frac{1}{\left(\frac{1}{\lambda_j} - \frac{1}{\lambda_z}\right) c_2} \ln \left(1 \pm \frac{\Delta \varepsilon_{jz}}{\varepsilon_j}\right)$	(8)
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Moreover, Pyatt [2], formulated in both graphic and analytic form how to use this information (8) to measure the real temperature of the object. At the same time, in the 60's and 70's a number of publications [5] described "novel" methods of object emissivity evaluation independent of its temperature. These methods, however, as was mentioned in [6, 7] are a continuation of Hoffman and Tinwaldt's work [1].

The methods used to receive information about $\varepsilon(\lambda, T)$ described in [1] and [2] still remain, for the most part, the fundamental methods, and, we believe, make possible extension of the abilities of optical pyrometry.

These principles were used as the basis for creating the unique, new pyrometer that

was developed by 3T True Temperature Technologies Ltd. (Israel), and has

successfully been used for accurately measuring the temperature of aluminum and its alloys in different thermodynamic production and machining processes.

The main requirement for implementation of the methods discussed in [1] and [2] is the need for single-value relationships between the difference of two assumed temperatures, and the temperature correction of the assumed temperature. In two color and tricolor pyrometers the above relationship is rather limited.

In the 3T pyrometer, n spectral ranges are used for this purpose. In the case of aluminum and its alloys, temperature measurement with an error $\pm 1\%$ for four spectral ranges appears to be enough. Another important advantage of the newly designed pyrometer is the possibility of its use under the conditions of transmission fluctuations of intermediate media and partial object sighting in the pyrometer field of view. In addition, unlike other pyrometers, almost no impact is caused to the accuracy of the temperature measurement by the reflection of external radiation sources on the object.

4. THE 3T PYROMETER

The 3T pyrometer is based on separation of the signal to two channels as described in figure 1.

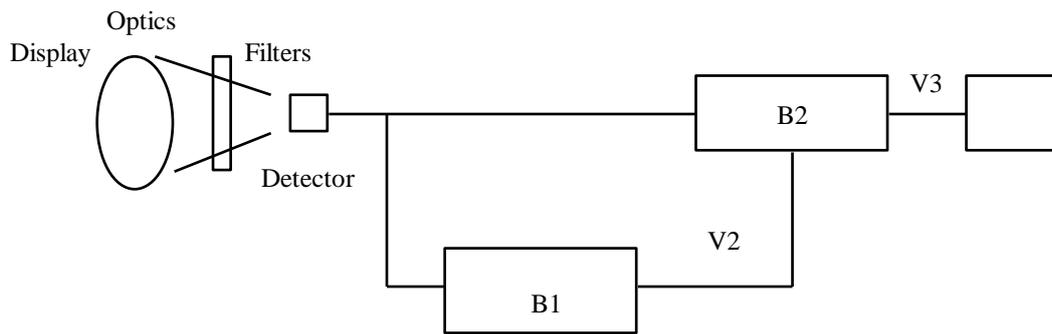


Fig. 1: Schematic diagram of the 3T pyrometer

V1 is the output of the detector, which is a function of the temperature, the emissivity and the transmission of intermediate media. The bottom block, B1, analyzes the signal in such a way that its output, V2, is not a function of the temperature, but only a function of the emissivity and the transmission of intermediate media.

V2 is used as a correction factor to calculate the true temperature, V3, which is the output of B2. V3 is a function of temperature only.

The pyrometer is microprocessor controlled (Intel, 80196), and the software includes an algorithm against emissivity or media variations and parasitic reflections. Temperature error is less than 1% for emissivity variations of 0.1 to 1.0. The temperature range is 300°C to 1,000°C and the time constant is from 51 mSec to 1,500 mSec.

5. TEST RESULTS

The 3T pyrometer was installed and tested in several aluminum facilities in Israel and Europe. A typical cycle of temperature at the press exit is shown in figure

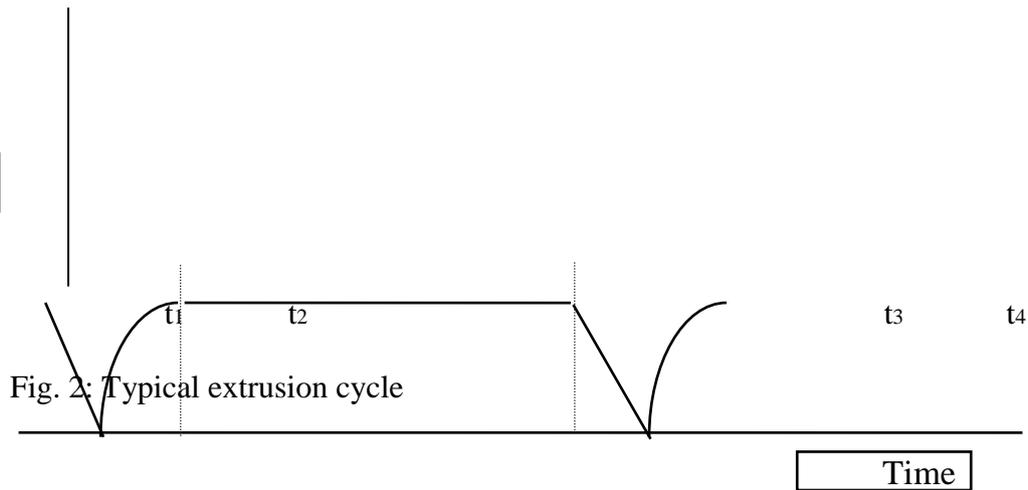


Fig. 2: Typical extrusion cycle

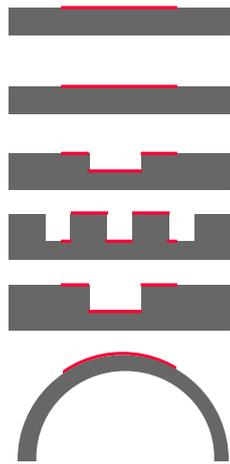
At t1, the press started to work and the temperature increased from 300° - 450°C to the extrusion temperature 530°÷580°C. At t2, the extrusion temperature was obtained and it remained at a similar level until the press stopped at t3. From this point, the temperature again dropped. The cycle repeated itself starting at t4.

The temperature was measured periodically by a special surface thermocouple and was compared with the pyrometer reading. If the extrusion speed was slow, the thermocouple measurement was performed during the extrusion, between t2 and t3. If the extrusion speed was fast, the thermocouple measurement was performed at t3.

The difference between the pyrometer reading and the thermocouple reading was 1 to 6 degrees. This test was repeated at different facilities and the same result was obtained. In order to have meaningful results, it was very important to select the proper thermocouple and to develop a proper way to measure the temperature of the aluminum profiles. Fig. 3 .Fig 4. Shows the results of the temperature measurements.

Fig. 3: Experimental Results

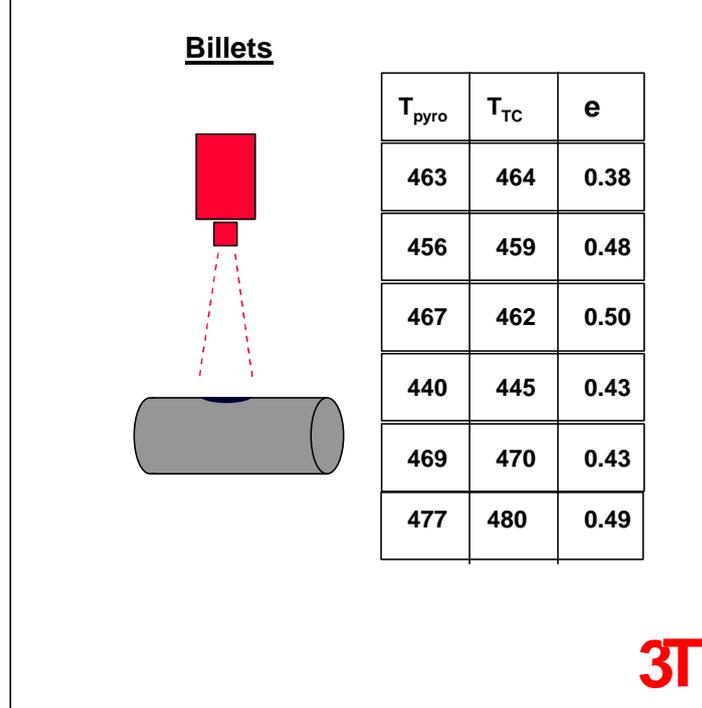
Profile Type



T_{pyro}	T_{TC}	e
565	563	0.08
562	560	0.11
557	554	0.12
544	540	0.27
573	570	0.20
551	556	0.09

3T

Fig. 4: Experimental Results



The 3T pyrometer provides several advantages to the user:

1. The displayed emissivity can be used as a quality factor because lower emissivity indicates a higher quality product.
2. Knowing the true temperature of the profiles allows the user to select the optimum speed for the extrusion process.
3. Reliable temperature readings are the base for the isothermal extrusion process.

REFERENCES

- 1) Hoffman, F., Tingwaldt, C. – *Optische Pyrometry*, page 134, Braunschweig
- 2) Pyatt, E.S., *British Journal of Applied Physics*, v.15, no.5, pages 264 –268
- 3) Dail, G.J., Fuhrman, M.C., DeWitt, D.P., Aluminum Association, April 12 – 14 1988