



ON MEASURING THE REFLECTION COEFFICIENT OF STEELS

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Abstract: This paper explains why it is essential to know what the reflection coefficient of different types of steel is. The reflection coefficient is one of the major parameters influencing the laser treatment of products made up of those alloys. Major factors influencing its values have been analyzed. Methods for measuring the reflection coefficient of various ground surfaces and industrial coating of products have been created. A device for measuring the reflection coefficient has been designed.

Keywords: laser treatment, reflection coefficient, steels, methods.

I. Introduction

The employment of lasers in materials treatment has increased dramatically in the last decade: metals and alloys – scribing, engraving, cutting, welding, hole drilling, thermal hardening, strengthening, lamination; nonmetals – contour machining of plastic, leather and rubber, engraving of glass, etc.

It is important to determine the major factors influencing these processes and how these factors interact. One of the quantities that directly influences the above mentioned processes is the reflection coefficient. It must be determined for each specific material so that correct, numeral experiments can be made. These experiments determine the operating intervals of power density, treatment speed (excluding drilling holes), frequency, number of repetitions, etc.

II. Exposition

The aim of this study is to create methods for determining the reflection coefficient of products made of different types of steels (tool steel, construction steel, stainless steel) and to design a measuring device for lasers operating in the visible and the infrared spectrum.

A. Theoretical considerations

The main optical characteristics – reflection coefficient R and absorption capability A are of great importance in the laser treatment processes. For opaque substances like steels the following dependence is applied:

$$R + A = 1 \quad (1)$$

One and the same factors influence the reflection coefficient R and the absorption capability A [1]:

- condition of the treated surface;
- wavelength of laser radiation;
- power density of laser radiation;
- surface temperature of the sample;

Because of dependence (1) some of these factors will be discussed when analyzing their influence on the reflection coefficient and others will be discussed when analyzing their influence on the absorption capability.

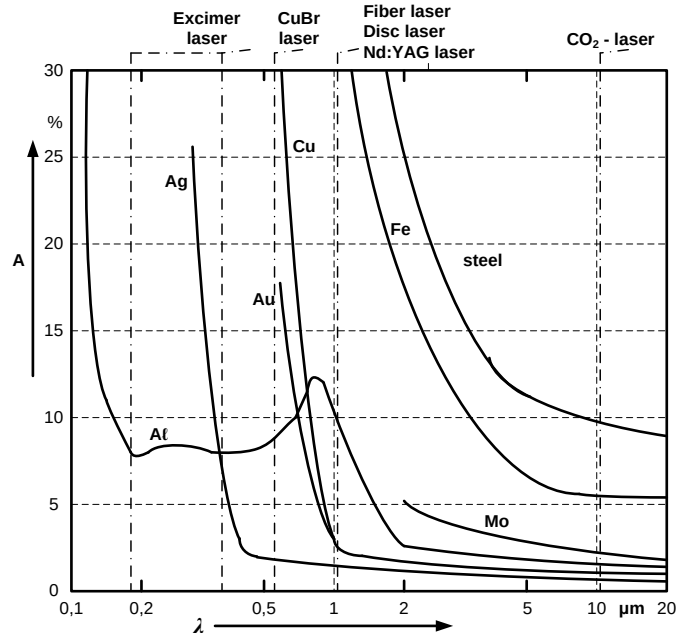
The reflection coefficient R depends to a great extent on the condition of the treated surface [2]. The class of roughness is its main characteristic [3]. It is observed that as the roughness of the treated material increases the reflection coefficient decreases. Roughness commensurable to the wavelength considerably increases the depth of penetration of laser radiation. Therefore, in certain specific cases it is advisable that a preliminary mechanical treatment of the sample surface should be performed in order to decrease the reflection coefficient.

When the treatment of the metal takes place in oxidizing environment an oxidized layer forms on its surface which also decreases R .

Fig. 1 shows the dependence of the absorption capability on the wavelength $A = A(\lambda)$ for different metals and steel. The data are obtained in room temperature. In normal conditions the value of the absorption capability A of most metals is relatively small. As the wavelength λ increases the absorption capability decreases.

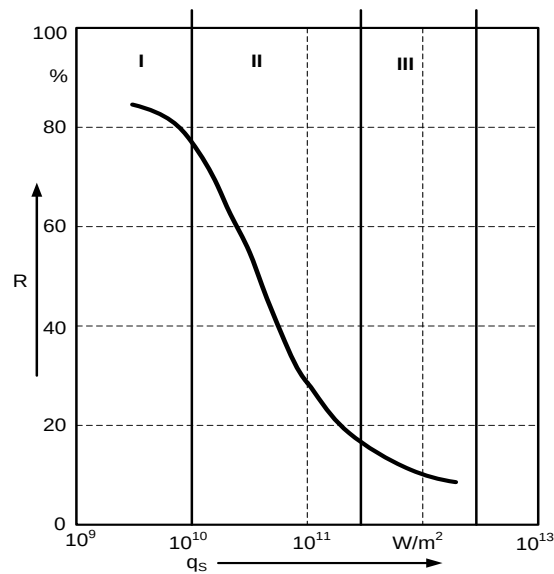
The influence of the power density of the laser radiation q_s on the reflection coefficient R is studied in [4]. Fig. 2 shows the dependency of the reflection coefficient R on the power density of the laser radiation q_s for aluminum. Three areas are distinctly outlined:

Figure 1 Dependency of the absorption capability A on the wavelength λ of the laser radiation for certain metals and alloys



- area I ($q_s \in [1 \cdot 10^9; 1 \cdot 10^{10}] \text{ W/m}^2$), where the reflection coefficient R is in its normal range, i.e. R is not dependent on the power density. Within this range of power density the sample is heated without melting or evaporating in the area of influence;
- area II ($q_s \in [1 \cdot 10^{10}; 5 \cdot 10^{11}] \text{ W/m}^2$), where the material starts melting and a sharp decrease in the reflection coefficient R is observed;
- area III (power density $q_s \in [5 \cdot 10^{11}; 5 \cdot 10^{12}] \text{ W/m}^2$, where the values of the reflection coefficient R are comparatively small. The material starts evaporating, and a groove forms in the area of treatment.

Figure 2 Dependency of the reflection coefficient R on the surface power density q_s of the laser radiation for aluminum Al.



When the power density range is $q_s \in [5 \cdot 10^{12}; 1 \cdot 10^{13}] \text{ W/m}^2$ a crater forms in the influenced area. An explosive evaporation of the material occurs and the resulting shock wave transmits its impulse to the material in the area of treatment.

When the power density of the laser radiation is $q_s > 1 \cdot 10^{13} \text{ W/m}^2$ a high temperature plasma cloud forms near the sample surface. The laser radiation is absorbed in this plasma cloud.

According to the studies of a great number of authors [5]–[6] the power density of the laser radiation $q_s > 1.10^{12}$ W/m² is not used for laser treatment of metals and alloys.

Another factor that influences the absorption capability A (accordingly the reflection coefficient R) is the surface temperature T . Experimental studies of a great number of authors [7]–[10] show that the higher the temperature T the greater the absorption capability A of metals and alloys.

Most commonly in theoretical calculations the following linear approximation of the dependency $A(T)$ is used:

$$A(T) = A_0 + n'(T - T_0), \quad (2)$$

where A_0 is the absorption capability of the material at temperature $T_0 = 273,15$ K, n' is a constant dependent on the material and the characteristics of the laser radiation.

With the help of linear approximation (2) numerical calculations can be made to obtain the temperature field in the area of influence.

B. Designing a device for determining the reflection coefficient

Fig. 3 shows a diagram for determining the reflection coefficient, samples and work pieces made of different types of steels. The reflection coefficient of the sample (3) is to be determined here. The radiation of laser source (1) expands in an expander (2) and falls on the sample (3). The reflected radiation falls on a silicon photodiode (4). Fig. 4 shows its spectral characteristic. It has maximum radiation sensitivity and a wavelength of $\lambda = 900$ nm. The diagram shows that it can successfully be used for radiation in the range of $\lambda \in [450, 1100]$ nm, i.e. in the near infrared area and in the whole visible area of the spectrum. It is suitable for the laser sources shown in table I. All these lasers are widely used in steel treatment processes. The signal from the photodiode is amplified by an operational amplifier (5). After that it is turned from analog into digital signal by an analog-to-digital converter (6). Data are processed by a microprocessor system (7) and then displayed on an alphanumeric liquid crystal display (8).

Figure 3 Scheme for determining the reflection coefficient
1 – Laser; 2 – Expander; 3 – Sample; 4 – Photodiode; 5 – Operational Amplifier;
6 – Analog-to-Digital Converter; 7 – Microprocessor System; 8 – Display

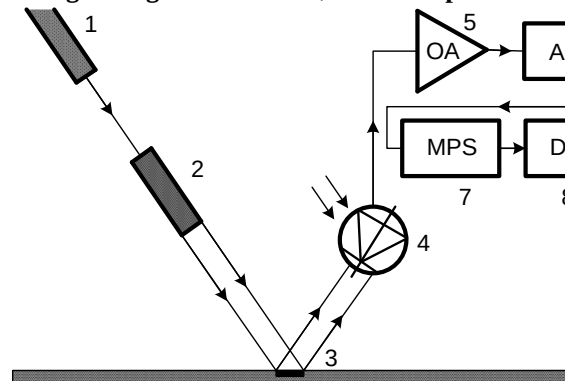


Figure 4 Spectral characteristic of a silicon photodiode

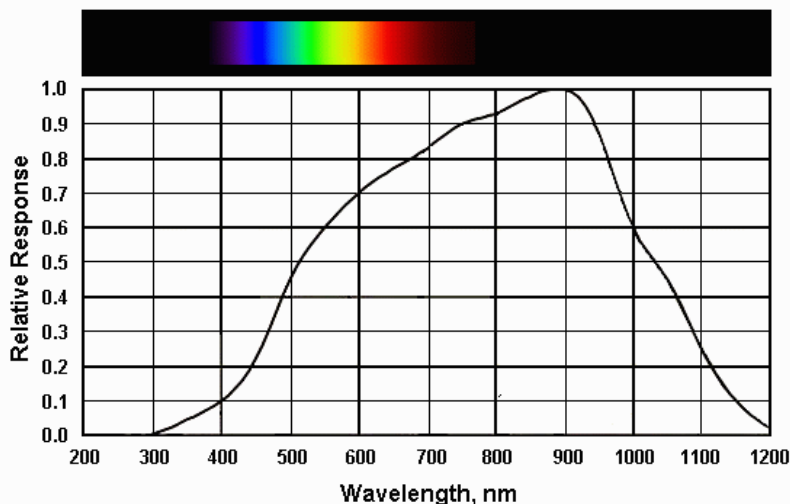


Table II Laser sources in the near infrared area and in the visible area of the spectrum

Laser	Wavelength λ , nm
CuBr laser	511 & 578
Diode laser	790 ÷ 100
Disc laser	1060
Nd:YAG laser	1064
Fiber laser	1064
Yt:YAG laser	1070

C. Methods for determining the reflection coefficient

When determining the reflection coefficient of steels the following steps are used:

- The value of the voltage U_d is measured in a dark place;
- An extremely well-polished steel plate is placed and its voltage $U_{\min}$ is measured;
- A sample of the examined steel in the shape of a plate is placed and then lit by the laser source;
- The value of the quantity U_x is measured;
- The reflection coefficient is determined by the formula

$$R = \frac{U_d - U_x}{U_d - U_{\min}} \cdot 100\%$$

The same methods can be used for metals, alloys other than steel and opaque nonmetals.

III. Conclusion

This device is intended for the industry, in particular for laser operational processes in steel treatment like marking, engraving, cutting, welding, hole drilling, scribing, etc. It can be successfully used both in research laboratories and as a part of the learning process at schools, universities and colleges. It is intended for lasers in the visible and the near infrared area [11]–[12]. If the photo receiver is suitable it can be designed for lasers in the far infrared and ultraviolet area.

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