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Correlation between the keyhole depth and the frequency characteristics of light emissions in laser welding

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Abstract

This paper presents a study of the frequency characteristics of the light emissions in laser beam welding. It is based on short-time frequency analysis of the light intensity oscillations and it results in the identification of the parameter directly correlated to the actual depth of penetration. Applicability of this parameter for characterization of the welds is demonstrated for a variety of welding parameters settings usually used in industrial practice. In addition, the method of short-time frequency analysis is used to detect the eigenfrequencies of keyhole oscillations which are hardly observable by other methods.

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Keywords: Laser welding; keyhole depth; light intensity oscillations; frequency analysis.

1. Introduction

The deep penetration laser welding represents a modern technology widely used in industrial manufacturing. Its principle lies in interaction of a high power laser beam with a metal workpiece, during which a thin capillary, called keyhole, is formed within the workpiece as described by Kaplan, 1994 or Otto et al., 2011. The keyhole depth determines the depth of the resulting weld and, therefore, represents an important characteristic of the welding process. However, due to the high temperature of the plasma filling the keyhole and forming a bright plume above it, the direct measurement of the keyhole depth is impossible.

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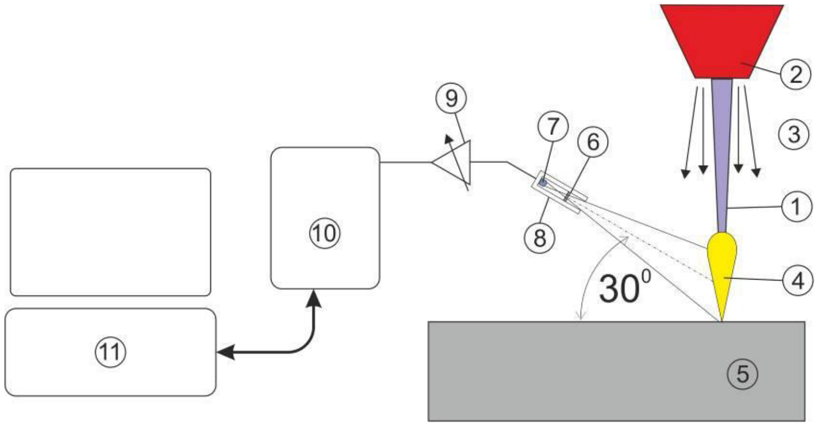

Fig. 1. Experimental setup of the laser welding machine: 1 – laser beam, 2 – coaxial nozzle, 3 – shielding gas, 4 – plasma plume, 5 – workpiece, 6 – neutral density absorptive (grey) filter, 7 – photodetector , 8 – photodetector mounting tube, 9 – amplifier with adjustable gain, 10 – data acquisition device, 11 – personal computer with control software.

In recent years, a number of studies have been carried out to find a parameter which is correlated to the depth of keyhole and which can be inferred from the measurable process characteristics. However, the studies based on simple statistical analysis of the light intensity coming from the interaction zone such as by Sibillano et al., 2005 or Haran et al., 1997 have not found any such parameter. The more sophisticated studies based on frequency analysis of the light intensity oscillations such as by Nakamura et al., 2000 revealed that the frequency spectrum differs for the deep and shallow penetration, but the suitable parameter correlated to the actual weld depth also has not been found.

In this paper we build on our previous studies (Mrna et al., 2012, Sarbort et al., 2013 – in review) and we present a detail study of the light intensity oscillations by means of the short-time frequency analysis, which results in identification of desired parameter directly correlated to the actual depth of penetration. We discuss the experiments leading to this result and we demonstrate the applicability of this parameter for characterization of the welds for a variety of welding parameters settings usually used in industrial practice. In addition, we show that the method of short-time frequency analysis can also serve to detect the eigenfrequencies of keyhole oscillations described by Kroos et al., 1993 which are hardly observable by other methods.

2. Theoretical and Experimental Study

The starting point of seeking for a deterministic indicator (parameter) that would be directly correlated to the keyhole depth was represented the following physical considerations. When the most important welding parameters such as the welding speed, the laser beam power and its geometry are chosen optimally, the welding process is relatively stable, the keyhole depth remains constant and the resulting weld bead is smooth. On the contrary, when the welding parameters are chosen inappropriately, the welding process becomes unstable, the keyhole and the melt pool around it significantly oscillate which results in variable weld depth and rough surface of the weld bead. The oscillations of the system are inevitably reflected in the dynamics of the plasma plume, so it is expectable that also the frequency characteristics of observed light intensity are affected by these oscillations. Therefore, it is natural to seek for a correlation between the keyhole depth and the frequency characteristics of the light intensity oscillations.