Review of Real-Time Temperature Measurement for Process Monitoring of Laser Conduction Welding

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Abstract- **Laser welding has been applied to various industries, in particular, automotive, aerospace and microelectronics. Primary aim of joining two metals by keeping their properties unaltered, that can be only possible by controlling temperature, heating and cooling rates. However measurement of weld pool temperature during laser spot welding is a difficult task because of the short pulse duration, often lasting only a few milliseconds, highly transient nature of the process, and the presence of a metal vapour plume near the weld pool. This paper deals with the application and developments of acoustic, optical, thermal, spectral and ultrasonic techniques for weld pool temperature monitoring. The advantages and limitations of these techniques are also discussed.**

Keywords: Laser welding; Sensing technology

I. Introduction

In recent years, laser welding has been widely used in manufacturing for vehicle assembly in automotive production and in electronics industry due to its high speed. A primary concern over the industry spectrum is to detect real-time temperature of weld pool .Therefore, a number of on line measurement system have being developed to control optimization of laser welding process. This paper is to review on line sensing system developed over past few years for real time weld pool temperature measurement systems The paper begins with a brief introduction of determination of weld pool surface temperature during laser welding .Then sensing techniques such as acoustic and optical emission sensors are presented which is comes under literature survey.

II. Process Signals Of Laser Welding

In laser welding process concentrated beam of coherent light directing on a very small spot that produces a fusion zone .During this laser- material interactions energy is emitted in an infrared forms which can be used as process signals . This process signals can be measured using suitable sensors. Since this signals contain information about the beam-material interaction.[1,2]

For instance, during Nd:YAG-laser spot welding, the process signal radiation is in the visible and infrared range. For CO_2 laser keyhole welding, the plasma generated which emits light with a wavelength between 190nm and beyond 400nm, and the spatter emits light with a wavelength between 1000nm and 1600nm [2]. In addition, the geometrical parameters of the keyhole and melt pool also contain useful information which can be used to inspect the welding quality.

III. Determination Of Weld Pool Temperature

In Laser welding process the focal spot is targeted on the surface of metal by adjusting focal length above the weld target, and laser beam is subjected to the large amount of concentrated light energy, which is converted into thermal energy to melt the surface of metal. After this process it is necessary to finding out relationship between weld quality characteristics and emission characteristics which are depend on weld pool geometry and surface temperature of weld pool. So it is important to detect weld pool temperature to obtained excellent quality of weld. Fig 2 shows basics to determination of weld pool temperature.[4]

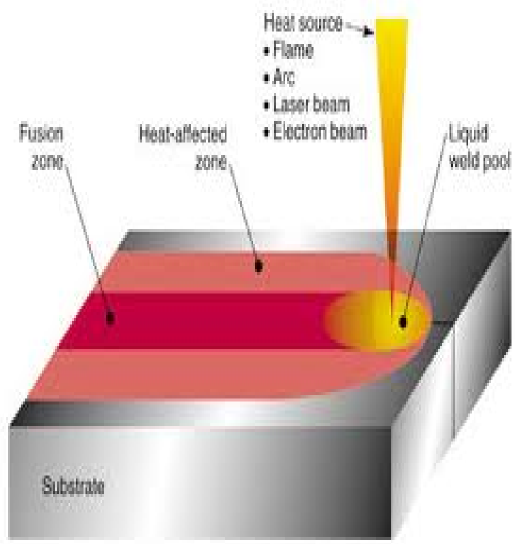

Fig .2 Weld pool temperature determinations

IV. Review Of Sensing Techniques

Laser beam welding is a highly flexible tool represents in many applications. For accurate real-time tracking and inspecting, the high-performance sensors are extremely demanded in laser welding process. Generally the camera imaging techniques and photodiode based sensor technique are demandable in laser welding process. Camera images contain information on the two-dimensional spatial distribution of the emitted process radiation and photodiode in combination with an optical filter is a fast sensor which is sensitive to a specific spectral region.

A. Camera imaging technique as Sensor

CCD, CMOS camera or array sensor has been often used to monitor the continuous process. CMOS camera is advantageous because of to use defined regions of interest on the chip and conversion of light intensity to voltage is not linear but logarithmic. By using high resolution, digital CMOS sensors and high-speed, real-time image processing technologies monitored signal reliability can be significantly increased.[4,7,17]

- A thermal imaging system is used for monitoring the laser welding process. It is based on a CMOS standard colour camera.
- In this model, the red and green interpolated colour Planes from this camera are filtered to estimate for each pixel the Temperature by a -wavelength Pyrometer technique. [5,3]
- In this paper, main drawback of such a system is the low dynamic range which requires a precise calibration by adjustment of the camera shutter speed in order to position the range as close as possible to the vaporization point of the material. A higher dynamic range can be achieved by using a 10 or 12 bit camera.[12]
- Measured temperatures along the weld bead using an infrared camera and compared the results with an analytical model obtained using Green's functions. They concluded that the measured temperatures depend on weld penetration but did not indicate how to estimate penetration from the measured temperatures. [14]
- The keyhole stability was investigated using a high speed camera to determine the weld Quality.
- Light emissions from plasma plume were monitored using photo sensors to capture the image for processing using matlab.[5]

Brown N[5] presented a system for process monitoring of laser beam welding based on a CMOS-camera. The system observed the welding process online and coaxial to the laser beam. It was used to investigate the geometrical parameters of the keyhole.

B. Photo detector Based Sensor

The spectral regions that are analysed mostly with this kind of sensor set-up are the IR-region and the UV and visible spectral region. The IR region is related to the surface emissions of the melt pool and the UV and visible region is related to the plasma/plume. Ultraviolet (UV), visible or infrared (IR) detectors, has been widely used to converted the flux density of the radiation emitted by the welding process into an electrical signal. Optical filter is often placed in front of the detector to confine the spectral ranges of the whole sensor system. Diode infrared and near-infrared lasers that can serve as an ideal heating source are particularly suitable for micro texturing of sensitive materials because of the low thermal load on the components and the non-contact nature of the process. This type of detector is a high temporal resolution of the recorded signals and a low price compared to other devices like spectrographs or cameras. However, the temperature measurement by contact sensors such as a thermocouple may cause a risk of disturbing the temperature field and the convection of a weld pool. In addition, the temperatures have to be measured in many locations in order to obtain the temperature distribution and thus troublesome work of fixing sensors becomes inevitable. By non-contact temperature measurement radiation thermo-metric is advantageous in obtaining the surface temperature distribution without influencing the temperature of a measured object. So, two color hygrometry techniques used to obtain the surface temperature of weld pools, in which the weld pool was photographed by a high speed camera during arc welding.

- Two wavelengths (950 and 980 nm) of light in the infrared range were selected from the thermal radiation light emitted from the weld pool.[12]
- It determines the temperature from the ratio of radiation intensity of two lights, under the condition that the radiation emissivity can be regarded as constant within closely different wavelengths.
- Two colour pyrometer is advantageous to visualise two-dimensional temperature field of molten metal in real time by combining with high speed camera. [4]

The work, which was untaken by *Chen et al* , *Farson et al* and *Hugel et al* , also showed that detecting the plasma/plume signal or the reflected laser using optical detectors is a kind of simple and effective way to real time monitor the welding process. Ostendorf et al investigated the laser spot welding in the micro joining applications. The sensor system was based on a silicon photodiode and a dedicated software package. The optical bandwidth of the photodiode covered from 300nm to 1100nm. Their experimental results showed that the system was capable of detecting and analyzing the process emission for laser micro spot welding.

C. OTHER SENSING TECHNIQUES

Besides the sensors presented above, there are also other sensors being used for welding monitoring such as visual, thermal and ultrasonic and etc. A brief introduction of their applications will be given in this section.

- *Sibillano, Antonio Ancona, and Vincenzo Erardi[9]* have reported on the development of sensors for real time monitoring of laser welding processes based on spectroscopic techniques. The system is based on the acquisition of the optical spectra emitted from the laser generated plasma plume and their use to implement an on-line algorithm for both the calculation of the plasma electron temperature and the analysis of the correlations between selected spectral lines.

- *Chen H.B,Roy, Stephen Morgan and Boris Regaard* [1,2,3**]** have developed several approaches for the detection of the melt pool circle in laser welding applications. Author used direct view onto the melt pool that is possible in a narrow wavelength band with a coaxial aligned high speed CMOS imaging sensor. The high speed approaches that enable real-time monitoring of the melt pool parameters.[13]
- *X. He and T. Deb Roy [16]* **,** developed system for Measurement of weld pool temperature during laser spot welding which describes how to estimate weld pool temperatures experimentally and theoretically. The concentrations of Fe and Cr in the vapour increased slightly while the concentration of Mn in the vapour decreased somewhat with the increase in power density. The vapour composition was used to determine an effective temperature of the weld pool.
- *J. Shao and Y Yan [8]* author carried out review on online monitoring of temperature and inspection of weld quality with the help of acoustic, optical, visual, thermal and ultrasonic techniques and latest development of laser welding applications.
- *Teresa S [*9] used a plasma charge sensor (PCS) to measure weld penetration and detect weld defects. The plasma behaviour was observed during welding through measurement of the space charge voltage induced on an electrically insulated welding nozzle. They showed that the induced voltage is a measure of plasma temperature and thus of the welding *R fachberger* [10] studied the surface temperature variation in the laser brazing of a pin-to-hole joint using an infrared radiation sensor. The transient heat flow was analysed using the finite element method. The effect of process parameters was investigated to enable the prediction of the appropriate process parameters from the measured and calculated results.
- *Bardine .F,Roy[4]* applied the bi-dimensional monochromatic and the 1-spot multi-wavelengths pyrometers to monitor the surface temperature in Nd:YAG continuous laser welding. They identified the variation of brightness temperature with operational parameters and detected certain typical welding defects.
- *H.C Winkle* [15] also presented a system, which consisted of a pyrometer and three Si photodiodes, to monitor and control laser welding. Lim et al applied a point infrared sensor for the study of the pulsed laser spot welding.

From the above literature survey reveal that several authors have suggest several method to measure temperature of weld pool surface. Every method has its own advantages and disadvantages. The above authors have not demonstrated methods to measure weld pool surface temperature of thin sheets. So, our work deals with the development of experimental setup to measure on line weld pool surface geometry and temperature.

V. DISCUSSION

The study of the previous work reviews that a wide range of sensors has been used to monitor the laser welding processes. Every sensor has its advantages and limitations. Two wavelength pyrometer sensors has been extensively investigated and appears to be a good choice for detecting material phase transformation. However, the sensor is limited to specified temperature range which in not suitable in laser welding. There has few applications of AE reported in microelectronics industry so far. Optical detectors have been widely used over a wide range of industries since they are relatively simple, cheap and effective. Although some commercial systems are available, signal processing and classification would be crucial for the further development of this technique. CCD, CMOS camera or array sensor has been often used to monitor the continuous process. A thermal imaging system has many advantages over other techniques used for detection of weld pool temperature. It is based on a CMOS standard color camera; the red and green interpolated color planes from this camera are filtered to estimate each pixel temperature by a dual-wavelength pyrometer technique. It is believed that sensor fusion system in conjunction with latest advance in statistical and artificial intelligence would play an important role in laser welding monitoring and inspection.

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