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Fast Fourier Transform Analysis of Welding Penetration Depth Using 2 kW CW Nd:YAG Laser Welding Machine

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Abstract We report experimental results on the correlations between welding penetration depth and the frequencies of the radiation from the welding pool. Various welding samples such as SUS304, brass, SUS316, etc. have been investigated with 2 kW CW Nd:YAG laser welding machine. The radiation signals from the plume generated by the interactions between the welding sample and laser with respect to the defocusing length was measured with fiber system collecting the plume signal. Analysis of the frequencies by using fast Fourier transform (FFT) shows that the penetration depth is deep as plume signal frequencies are low, shallow penetration depth for high frequencies. Frequencies up to 250 Hz for obtained signals can be analyzed with the discrete FFT. This is the useful method for closed loop control of the laser power with respect to the welding penetration depth and is used for real time inspection of the welding quality.

Keywords: FFT, Nd:YAG, Laser Welding, Monitoring

1. Introduction

Laser welding quality monitoring system has been rapidly developed with respect to high power lasers such as CO_2, Nd:YAG laser, etc. High power laser beam can be transported through the optical fiber so that it is much easier to detect radiation signal from welding zone by guiding back the radiation through the optical fiber and delivery optics which will be described in the experimental part. Equipped with optical fibers and optical systems in combination with robot arms, laser welding systems have a capability of the long distance delivery of the laser beam and of the precise control of the beam focus to easily enable the welding of the complicated parts which can not be achieved with conventional welding method. Consequently, the application of laser welding technology has been extended to many other precision machining processes. In our previous paper (Kim et al., 2003) the welding quality monitoring system has been introduced by using the fluctuated signals in the beginning and ending of the welding and was not more carefully examined than using discrete FFT. Here we report the frequencies analysis with discrete FFT method to evaluate the welding quality monitoring.

Especially laser welding has advantages to weld materials more precisely differently from conventional laser welding methods due to precise focusing of the laser beam and a little heat affected zone (HAZ). CO_2 and Nd:YAG laser have been used mostly for laser welding. In this work real time welding monitoring

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system for laser welding quality check have been developed using CW 2 kW Nd:YAG laser welding machine used to weld thin plates for car body, which requires the safety and precision.

There are many ways for laser welding quality monitoring such as capacitance change measurement between welding surface and a bundle of optics for focusing laser beam, using acoustic wave generated during laser welding, generated X-ray in real time, etc. (Postma et al., 2001; Watanabe et al., 1995; GmbH 4D, 2000; Beersiek et al., 1997; Tönshoff et al., 1996a; Tönshoff et al., 1995b; Tönshoff et al., 1998a). In this work real time welding quality monitoring system using thermal radiation, plume spectra, etc. generated during the laser welding has been developed. Also the correlations between laser power change, focal length change, etc. and photo-detector signals due to plasma, plume, etc. have been analyzed. Frequencies up to 250 Hz for obtained signals can be analyzed with the discrete FFT.

2. Experiment

The welding monitoring system was described well in our previous paper (Watanabe et al., 1995). The experimental setup for welding monitoring is shown in Fig. 1. After laser beam is focused through the optical fiber and collection lens, the thermal, plume, and plasma radiation signals are transported back to single element photodiode detector through the collection lens, optical fiber, the band pass filter, and collection lens again. The obtained photodiode detector signals are digitized and analyzed using a PC based oscilloscope (SDS-200).

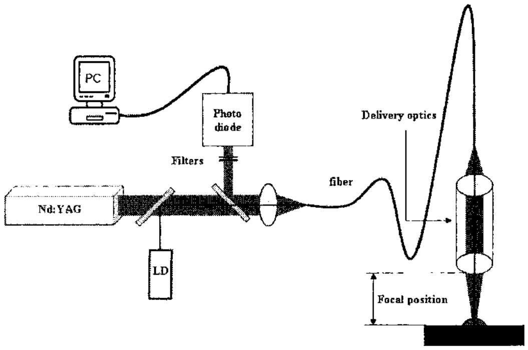

Fig. 1 Experimental setup for welding monitoring

We used CW Nd:YAG welding laser machine made by Trumph company with the 1064 nm wavelength, four step amplification resonator, 10 mm rod diameter, 150 mm rod length, and 2 kW average power. Laser beam was transported from the oscillator to the welding pool using optical fiber with 600 μm diameter and 0.22 numerical aperture (NA). The laser beam is focused on the welding area using a lens with 200 mm focal length. The laser beam waist size on the welding area was controlled by adjusting z-axis distance of the stage holding the welding sample. We used the programmable CNC machine code to adjust the distance of the stage. Diode laser beam with equal path as that of Nd:YAG laser beam illuminated on the welding surface to check the welding position. The laser beam size focused on the welding surface is approximately 800 μm, and the moving speed of the stage of 40 mm/s. We used several welding materials such as SUS304, brass, and SUS316 to investigate the effects on the welding penetration depth by changing laser focal length between -10 mm and 10 mm. Also laser powers were changed from 1.2 kW to 1.8 kW.

3. Results

Table 1 shows the experimental conditions for the welding samples. We used several welding samples with different thicknesses. We used a sample plate with 2 mm thickness, double plates with 1 mm thickness in front side and 1 mm in back side (We noted it as 1 mm + 1 mm), double plates with 2 mm thickness in front side and 1 mm in back side (2 mm + 1 mm) and double plates with 1 mm thickness in front side and 2 mm in back side (1 mm +

2 mm). Correlation between the laser penetration depths with respect to the focal length changes of the laser beam and the reflected radiation signals was obtained. The laser beam was defocused from +10 mm to -10 mm with respect to the reference point on the surface of the welding sample. Welding distance was 70 mm and welding speed of 40 mm/s. Fig. 2 shows the front and back surfaces of the welded plates with 1 mm + 1 mm thickness. As shown in the back surface of the welding sample of Fig. 2, the laser penetration depth due to the laser focus changes is shallow at the defocusing point and deep at the focal point of the center of welding sample. Fig. 3 shows the radiation signals for the sample 2. In Fig. 3 horizontal axis is welding time in ms unit and the vertical axis radiation intensity. The welding starting and ending positions in welding sample was set to be equal as welding starting and ending time in radiation signal to confirm the laser penetration depth with respect to the change of the laser defocusing length. The radiation signal fluctuates in the beginning of the welding, stable after that like DC signal, fluctuates again, and welding is ended. As shown in Fig. 3 the penetration depth is maximum as welding signal is like DC signal and the radiation signal is minimum. In other words we can know that welding quality is best when the radiation signal is like DC as shown in the back surface of the welded plate which shows the penetration depth of the welded plate.

Table 1 Welding conditions for several welding materials

	Welding Materials	Laser Power	Moving speed of stage	Focus Change	Gas
Sample 1	SUS304 (1t+1t)	1.5 kW	40 mm/s	-10 mm → +10 mm	air
Sample 2	SUS304 (1t+1t)	1.2 kW	40 mm/s	-10 mm →+10 mm	air
Sample 3	BRASS (1t+1t)	1.2 kW	40 mm/s	-10 mm → +10 mm	argon
Sample 4	SUS316 (1t+2t)	1.8 kW	40 mm/s	-10 mm → +10 mm	argon
Sample 5	SUS316 (1t+2t)	1.5 kW	40 mm/s	-10 mm →+10 mm	argon

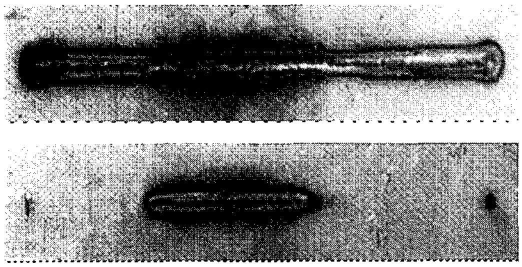

Fig. 2 The front surface (above) and back surface (bottom) of the welded plates.

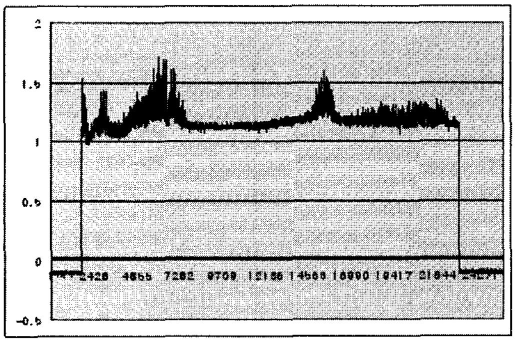

Fig. 3 Radiation signals from welding pool

The radiation signal is reduced because the radiation signal is not reflected well and absorbed inwards and transmitted the welding sample as the welding pool is deeper. Due to this phenomenon the welding beads can be observed on the back surface of the welded sample instead of the welding front surface. This is due to the pushing of the welding pools by the laser. In addition to the laser pushing the collected radiation signal can be reduced due to plasma and plume shape distribution change with respect to the change of the welding depth and laser power. If we use CW laser beam for the laser welding, the laser beam is absorbed into the welding pool and plasma above the welding pool is generated. If the laser beam is illuminated continuously into the welding pool, the laser beam can be blocked due to the plasma so that the temperature of the welding pool is not increased anymore. Then plasma is formed and disappeared repeatedly so that the temperature change in bad welding part is abrupt. However, thermal input of the laser beam for good welding part is exhausted into the bottom side of the welding pool. Thus the temperature in the welding pool for good welding part is lower than that of bad welding part. The temperature change of the plasma above the welding pool is small so that the obtained photodiode signal is small and less fluctuated. These trends are shown in Fig. 3.

We check the frequencies of the fluctuation signals with the discrete FFT method. 25000 data points are divided by 500 windows and FFT has been done for those 500 windows. Fig. 4 shows those FFT results obtained from the radiation signals. As shown in Fig. 4 the small amplitude of obtained signals was obtained for good quality of welding at the each frequencies. The fluctuation frequencies can be more carefully examined with more data sample points to know the welding quality more clearly with more frequencies. If we used the amplitude of the frequencies for the different samples, we can use these data for the feedback signals for controlling laser power to get good welding quality of the materials by setting the maximum boundary for the good quality of the welding signals.

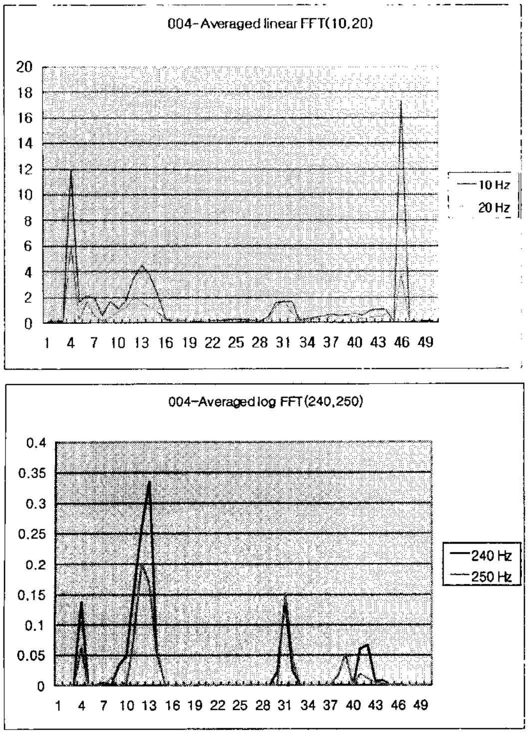

Fig. 4 FFT frequencies of radiation signals from welding pool

The radiation signal is reduced because the radiation signal is not reflected well and absorbed inwards and transmitted the welding sample as the welding pool is deeper. Due to this phenomenon the welding beads can be observed on the back surface of the welded sample instead of the welding front surface. This is due to the pushing of the welding pools by the laser. In addition to the laser pushing the collected radiation signal can be reduced due to plasma and plume shape distribution change with respect to the change of the welding depth and laser power.

Also, plume frequencies can be checked in detail and the dynamics of the welding pool with the combination of the optical methods with acoustic method in the future can be understood.

4. Conclusions

The correlations between laser penetration depth and the frequencies of the radiation from the welding pool are reported. Analysis of the frequencies using FFT shows that the laser penetration depth is deep as plume signal frequencies is low, shallow penetration depth for high frequencies. Frequencies up to 250 Hz for obtained signals can be analyzed with the discrete FFT. Finally we conclude that small signal change in FFT signal shows good welding quality so that welding quality can be monitored using this signal. Thus monitoring the change of FFT signal and welding quality monitoring can be effectively controlled using the feedback loop of this signal.

Acknowledgments

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