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Technical note

A novel acoustic monitoring method of laser peening

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ABSTRACT

The acoustic monitoring method of laser peening has aroused a great deal of interest for realizing the non-destructive detection and real-time monitoring. Considering the special characteristics of the acoustic signal generated in the laser peening, we have explored a new signal processing method for feature extraction, which is based on the intrinsic relationship between the adjacent data in the signal series. During the implementation, we measure the cosine similarity of neighboring subsequences for presenting that interrelation. After investigating the variation of the cosine similarity in the series, evident features could be observed visually, and useful characteristic value could be extracted to assist in identifying the working state. As a result, the effectiveness of the new method is well verified and its application potential is worthy of expectation.

1. Introduction

Laser peening, prevailing to the conventional shot peening, is a relatively novel and promising technique for improving the surface mechanical property of metallic materials owning to the extremely high laser-induced shock wave [1]. Due to its magnificent effect on improving the fatigue performance and enhancing the corrosion resistance property, ever since this new technique appeared, it has attracted increasing attentions and interests [2]. In order to keep up with its extensive application in both civilian and military fields, the condition monitoring is necessarily introduced to guarantee the normal processing condition [3]. Commonly, the monitoring method by means of testing the various property indexes of the processed material is relatively time-consuming and expensive [4], while the acoustic monitoring technique, owning to its low cost and easy operation, has attracted wide attentions. In recent years, owing to the persistent study on that acoustic signal in the laser peening, its spreading rule has been explicitly investigated and relating feature has been effectively uncovered [5–9]. On the basis of that, the acoustic condition monitoring of laser peening is immensely developing. Among them, some scholars have calculated the energy parameter of the acoustic signal to monitor laser peening [10], and some researchers have proposed a real-time method to monitor the laser peening via the time-of-flight of the acoustic shock wave [11,12]. Admittedly, these methods have behaved well in state detection, while there still exists wide improving scope in the acoustic monitoring.

In this study, we have proposed a new approach to process the acoustic signal for feature extraction. On the basis of the intrinsic relationship between the adjacent data in the signal series, we calculate the cosine similarity of the neighboring subsequences for indirectly describing that interrelation of adjacent data. The cosine similarity varies along with the evolution of signal series, and the evident features could be effectively revealed. From its employment on processing the experiment acoustic signal, the results show that the new acoustic signal processing method performs well in condition monitoring with quick and easy operation, which proves its potential in further practical applications.

2. Methodology

Considering that the acoustic signal is a typical time series, the adjacent data is to some extent correlated and dependent due to the time continuity [13], and the interrelation of the adjacent data could be treated as the interior motivation of generating the whole acoustic signal. In order to describe that interrelation for digging out the hidden information, we intend to measure the similarity between the adjacent subsequences for indirectly describing the links of adjacent data. Among the various similarity measurements, we choose the cosine similarity which is a non-dimensional metric [14.15].

Assuming $\{x_n\}$ to be a signal series, the cosine similarity of the adjacent subsequences $X_i = \{x_i, \; x_{i+1}, \ldots, \; x_{i+k-1}\}$ and

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$X_{i+1} = \{x_{i+1}, x_{i+2}, \ldots, x_{i+k}\}$ ($i \in [1, n-k]$, and k is the length of the subsequences), can be expressed as following [16]:

$$p_i = \frac{(x_i, x_{i+1}, \ldots, x_{i+k-1}) \cdot (x_{i+1}, x_{i+2}, \ldots, x_{i+k})}{\sqrt{\sum_{j=0}^{k-1}(x_{i+j})^2} \times \sqrt{\sum_{j=0}^{k-1}(x_{i+1+j})^2}}, \quad (1)$$

After the cosine similarity p_i is successively figured out, the original signal series $\{x_n\}$ can be converted into a cosine similarity sequence for feature extraction.

For the sake of verifying the new method, we conduct the laser peening experiment for obtaining acoustic signals. The schematic diagram of experiment is shown in Fig. 1, and the laser plus is set to be wavelength of 1064 nm and plus width of 20 ns. Besides that, the acoustic signal is collected and stored by the software of Dewesoft, while the sampling frequency is settled to be 20 kHz.

When conducting the experiment, the water switch is firstly turned on to form flowing water confinement. Then, with the preliminary setting, the laser plus is irradiated through the water confinement and impinges on the protective coating, which immediately vaporizes into plasma. Rapidly, that plasma is detonated in limited space, and high pressure shock wave is generated for modifying the materials. Simultaneously, parts of the shock wave transverses the confinement coating and quickly attenuates in the air to be acoustic signal, which is captured by the acoustic sensor and transmitted to the working computer for storing.

As contrast experiments, the location of the acoustic sensor is variable, and the distance D between of the sensor and the impinging point of laser plus is set to be 60 cm, 70 cm and 80 cm, respectively. When the location of the sensor is determined, the laser output energy is set to be adjustable parameter, the value of which is varied among 3 J, 4 J, 5 J and 6 J. Additionally, with certain laser energy, confinement state is switched by controlling the start and stop of the flowing water (with and without confinement layer).

3. Results and discussion

3.1. Feature extraction

Take one segment of the acoustic signal generated from the laser peening (Fig. 2) for observation, and it can be noticed that the acoustic signal is the combination of shock wave and common acoustic wave.

Assume that sampling acoustic signal segment as $\{x_n\}$ (time duration is 1.5 s), and by means of the newly proposed approach, we successively figure out the cosine similarity of the neighboring subsequences X_i and X_{i+1} (the length of subsequences here is set to be 2000 as example). Then, the variation of the cosine similarity is displayed in Fig. 3, where we can see that there exists an evident trough resembling the shape of letter "H", which corresponds to the appearance of shock wave feature in the acoustic signal (Fig. 2). For the shock wave plays an important role in the laser peening, related features could be extracted from the H-type trough. Between the two sudden changes of the trough range, the cosine similarity tends to be a stable value, and we extract that stable value in the trough region to be the characteristic value.

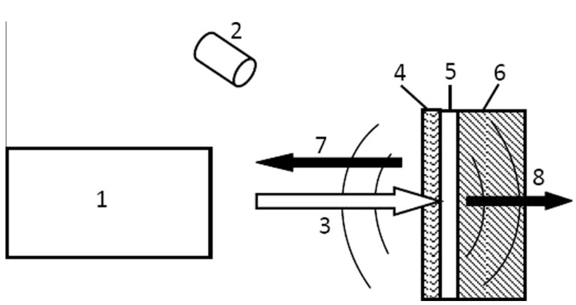

Fig. 1. Schematic diagram of laser peening experiment (1: laser generator, 2: acoustic sensor, 3: laser beam, 4: confinement layer, 5: protective layer, 6: target workpiece, 7: acoustic shock wave, 8: shock wave).

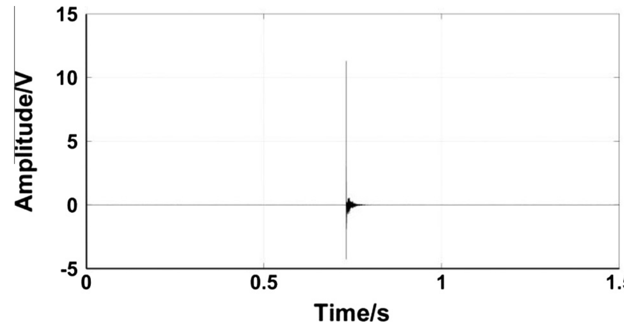

Fig. 2. The acoustic signal which is induced by laser energy of 3 J with confinement layer and collected at D = 60 cm.

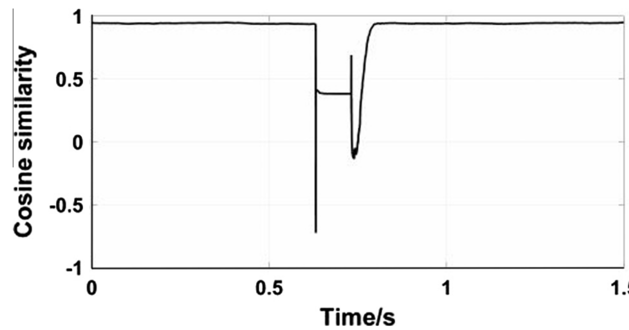

Fig. 3. Variation of the cosine similarity of adjacent subsequences in the acoustic signal series.

Table 1
Mean value and standard deviation of the cosine similarity characteristic values obtained from acoustic signals which are generated from working condition of certain laser energy and confinement state when D = 60 cm.

D = 60 cm	With confinement		Without confinement	
	Mean value	Standard deviation	Mean value	Standard deviation
3 J	0.368	0.022	0.291	0.002
4 J	0.455	0.007	0.388	0.026
5 J	0.506	0.008	0.457	0.004
6 J	0.538	0.036	0.495	0.007

3.2. Condition monitoring

During the analysis, we compute the cosine similarity characteristic value of each acoustic signal collected in the experiment, and then we extract the mean value and standard deviation of characteristic values which are obtained from the acoustic signals collected at same location with identical laser energy and confinement layer. As the working condition varies, the mean values and standard deviations are shown in Tables 1–3, in which we can see that the characteristic value increases with the rise of laser energy; when lacking of confinement layer, the characteristic value obviously declines; as the acoustic wave spreads farther, the corresponding characteristic value gradually reduces. In addition, the standard deviation of the characteristic value is relatively small, which means that the characteristic value remains stable in multiple measurements.