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An on-line pulse trains analysis system of the wire-EDM process

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ABSTRACT

Ignition delay time (Td) has been widely used to distinguish the abnormal discharges from the normal ones in wire electrical discharge machining (WEDM) process. In this paper an on-line analysis system for the causality of the Td data sequences was developed to evaluate the machining performance of WEDM process. The system is composed of a stand-alone Td processing circuitry and a user-friendly computer program for data analysis. The Td processing circuitry calculates and records the Td of every single electrical discharge in the first place, and then transmits the Td data via an embedded communication port to a desktop or notebook computer. The computer program, after performing the analysis tasks, will display the result in a graphic way. Two mathematical algorithms were employed for the analysis: autocorrelation function and Fourier transform. Through experiments under different working conditions, it was found that the autocorrelation function could be used to detect if arc or short circuit discharges take place consecutively, and to distinguish the WEDM process with similar Td distributions. On the other hand, the spectral analysis revealed that several factors were identified to be able to induce certain periodic patterns of Td data. These factors include the length of wire electrode, the water pressure, etc.

1. Introduction

The machining performance of the wire electrical discharge machining (WEDM) process lies in the discharging condition between the electrodes. However, since the gap between the electrodes is too small to be observed directly, the discharging condition can only be monitored by way of examining the discharge waveforms, i.e. the waveforms of the gap voltage and the discharge current.

The beginning of waveform analysis in EDM process dates back to 1970s. Snoeys and Cornelissen (1975), by comparing the variation of gap voltage, classified the discharging condition into four categories—effective discharge, arc, short circuit and open circuit. In the CIRP conference in 1979, the CIRP Scientific Technical Committee E, in its Summary Specification of Pulse Analyzer for Spark-Erosion Machining, suggested that the types of discharge waveforms could be divided into four categories to represent the normal, arc, short circuit, and open discharges. For the WEDM process, Watanabe et al. (1990) proposed that the discharge waveform could be put into three categories – normal, deion and arc – through the study of current peak, spark voltage, current pulse length and pulse energy. Later on, Liao and Woo (1997) developed a waveform discrimination system by way of measuring the time period from the rising of gap voltage to the starting of ignition current.

The researches mentioned above were mostly based on the waveform discrimination and the statistics of discharge pulse trains. From the mathematical point of view, the physical nature of the electrical discharges in WEDM is a stochastic process. On the other hand, the process is made up by a series of electrical discharges. Since the discharge is ignited one after another, the discharges are also a sequence of events with causality themselves. Hence the electrode gap condition made and left by the previous discharges would inevitably affect the present and following discharges.

This study is devoted to develop an on-line system to investigate the causality of the electrical discharges in WEDM process. The system includes both hardware and software components. The hardware component is a microcontroller-based circuitry for recording the Td data during the WEDM process and then, via RS-232 interface, transferring the data to a personal or notebook computer for further processing by the software component. The software component is a multi-window calculation and displaying program, performing the autocorrelation function and the spectral analysis of the Td data received form the hardware component. Several experiments were conducted, with the developed system, to confirm the validity of the system.

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2. Algorithms

In order to investigate the causality of the Td data, two of time series methods were employed in this study: autocorrelation function and the spectral analysis. The autocorrelation function is to identify the possible existence of consecutively repeated sequence in the Td data trains. The spectral analysis, based on the technique of Fast Fourier Transform (FFT), is to explore the periodic patterns, if any, in the Td data trains. In addition to these two mathematical methods, the Td distribution is also presented by the developed system to reveal the statistic nature of the Td data.

2.1. Autocorrelation function

The autocorrelation function of Td data is expressed as Eq. (1).

$$\rho_k = \frac{(1/(n-k))\sum_{t=1}^{n-k}(\mathrm{Td}_t - \overline{\mathrm{Td}})(\mathrm{Td}_{t+k} - \overline{\mathrm{Td}})}{(1/n)\sum_{t=1}^{n}(\mathrm{Td}_t - \overline{\mathrm{Td}})^2} \quad (1)$$

where n is the size of the Td data series ($n = 1024$ in this study). Td time series data is denoted as Td_t with subscript t as the sequence number. $\overline{\mathrm{Td}}$ is the mean value of the Td_t, and k is the sequence shift (or time lag). The resulted ρ_k means the autocorrelation coefficient of time lag k.

The autocorrelation function of a data series describes the correlation between the different data points in sequence. If theρ_k is zero regardless the lag k, it means the Td data series are inter-independent and implies that the electric discharge process of WEDM is a genuine random process. Otherwise, the Td data series might be inter-correlated to each other in some extent.

2.2. Spectral analysis

In electrostatics, the intensity of the electrical field between a pair of electrodes is inversely proportional to the gap width between the electrodes, given the electrical potential across the electrodes is fixed. Since the electrical discharges would be easier to be ignited in an intensive electrical field, a narrower electrode gap width would result in a shorter corresponding Td, and vice versa theoretically.

There are many factors that may impose influences on the discharge gap (electrode gap) width, so as the Td duration. These factors include the vibration of the WEDM machine itself, the machining debris in the discharging process, the spraying pressure of working fluid (de-ionized water), the external vibration onto the workpiece from any sources, and even the intrinsic feedback oscillation of the ignition circuitry (Fig. 1).

One of the widely suspected factors imposing influences on the Td duration is the mechanical wave induced over the wire electrode.

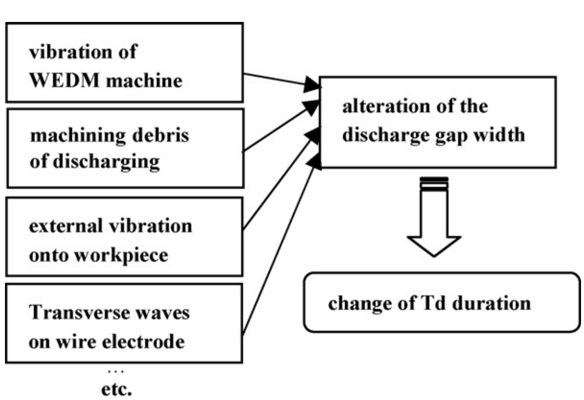

Fig. 1. The probable causes contributed to the discharge gap width, so as to the Td duration.

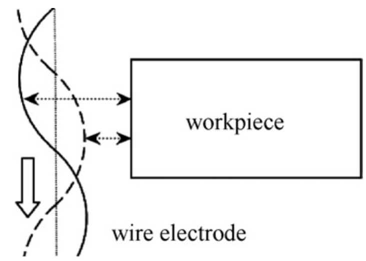

Fig. 2. Illustration of the change of the gap width between the electrode and the workpiece due to running waves along the wire electrode. The arrow represents the moving direction of the waves.

In WEDM machines, the wire electrode is constantly maintained in a fixed length with predetermined longitudinal tension throughout the machining process. During the short period of ignition "on time," an external electromagnetic force due to the ignition current is exerted onto the wire electrode. Since the wire electrode can be taken as a simple string, this intermittent external force may, in theory, induce a transverse mechanical wave running along the wire electrode, imposing a periodical alternation the gap width between the wire electrode and the workpiece, as illustrated in Fig. 2.

However, how much influence would be imposed onto the Td duration by every individual factor is a complicated question to be answered, because these factors may confound with each other among themselves. From a systemic point of view, the electric discharging process itself could be taken as a black box with input variants such as the servo voltage, the discharge energy, the feed rate of workpiece, the speed and tension of wire, etc. In the mean while, the output of the black box could be the Td data or some other index regarding the machining performance, as designated.

Under such presumption, the major question raised herewith is that: Are these factors, together or separately, could induce periodic patterns of Td data which can be revealed in spectrum? To answer the prerequisite question, Fast Fourier Transform was introduced for spectral analysis of the Td data in this study.

3. System configuration

The system developed in this study is composed of hardware and software, whose configurations will be introduced respectively as followings.

3.1. Hardware configuration

The stand-alone hardware device for Td measuring and recording is a combination of four subunits as displayed in Fig. 3:

1. High-voltage differential probe.
2. Ignition current detection probe.
3. Waveform rectification circuit.
4. Td measuring/recording unit.

3.1.1. High-voltage differential probe

To detect the voltage gap between two electrodes, PINTEK DP-100 high-voltage differential probe was used in the study. This voltage probe is the only commercial product employed in the system. The bandwidth of the probe is 100 MHz which guarantees the fidelity of the input voltage signal. Along with the input voltage tolerance of 6500 V, the input impedance is as high as 54 MΩ which ensure that the WEDM process is not interfered by the proposed system.