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Optimization of Hopkinson Bar Structure for Measuring Discharge Reaction Force in WEDM

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There is an inevitable problem that limits the improvement of machining accuracy in wire electrical discharge machining (WEDM), that is vibration of wire electrode caused by kinds of force accompanying discharge process. It is known that discharge reaction force is one of the most influential forces, which is formed by the oscillation of discharge bubble. H owever, it is difficult to measure the discharge reaction force itself directly because of properties of wire electrode such as tiny surface and low rigidity. In this study, a novel force measurement method was proposed based on Hopkinson bar measurement theory. In the novel force measurement setup, the end structure of the Hopkinson bar was designed to be smaller than the cross-section area of the bar trunk, aiming to measure the discharge reaction force acting on the end of the Hopkinson bar without large disturbance to the discharge gap phenomena. To explore the best structure of the Hopkinson bar, models built in COMSOL Multiphysics software were elaborated according to the theory of elastic wave. The propagations of the stress wave in different designs were analyzed. Finally, the optimal design was found to enable the stress wave to propagate without a large loss of energy.

NOMENCLATURE

z = axial direction of Hopkinson bar
σ_z = z component of stress tensor

1. Introduction

It is known that wire vibration is one of the most imperative factors affecting the machining accuracy in wire electrical discharge machining (WEDM). The influence of discharge reaction force generated by the bubble oscillation on wire vibration has not yet been fully clarified due to its complicated spatial-time revolutions and difficulties of direct measurement.

Inspired by the success in the measurement of discharge reaction force during sinking EDM [1], Gu et al. employed a Hopkinson bar with the diameter of 8 mm to measure this force acting on the workpiece during WEDM [2]. Nevertheless, measurement of the discharge reaction force acting on the wire electrode is more useful for the study of wire vibration.

The Hopkinson bar design for measurement is based on the linear elastic wave theory [3]. Fukatsu et al. [4] studied the stress propagation generated by a step force in two-dimensional analysis for Hopkinson bar and they found that the stress propagation along a bar is related to the force acting area on the end surface of the Hopkinson bar.

Gu et al. [5] proposed a specific structure on one end surface of the Hopkinson bar, which was considered to be useful to measure the force acting on the wire electrode caused by the discharge reaction force.

Therefore, to optimize the structure of the Hopkinson bar, it is necessary to study the stress propagation and judge the validity of the output signals of the Hopkinson bar with specific structures. In this study, models built in COMSOL Multiphysics software were elaborated to explore the optimum structure of Hopkinson bar. Finally, the novel Hopkinson bar method was proved to be valid since there was no large loss of energy for the axial stress propagation.

2. Simulation of Hopkinson bar

2.1 Hopkinson bar theory

As shown in Fig. 1, the stress at the end surface of the Hopkinson bar generated by the discharge reaction force in the interelectrode gap can propagate along the Hopkinson bar. Thus, the strain gauges pasted onto the side surface of the bar can output the stress signal.

2.2 Simulation

Solid mechanics in COMSOL was employed to simulate the stress propagation along the Hopkinson bar. As shown in Fig. 2 (a), a 2D axisymmetric model with the material of steel was built as the bar model. An external force F with the waveform of one period of a sinusoidal function shown in Fig. 3 was imposed uniformly on the end surface of the bar. l_1 is the distance between the measuring point of the stress and the end surface where F is applied.

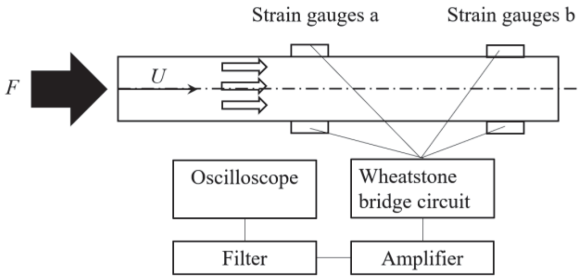

Fig. 1 Stress propagation of Hopkinson bar method

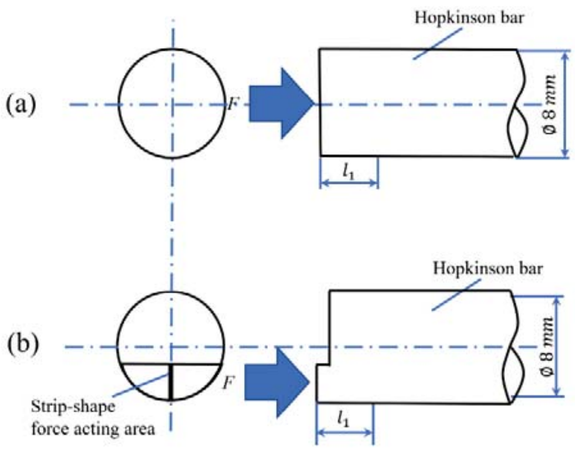

Fig. 2 COMSOL model

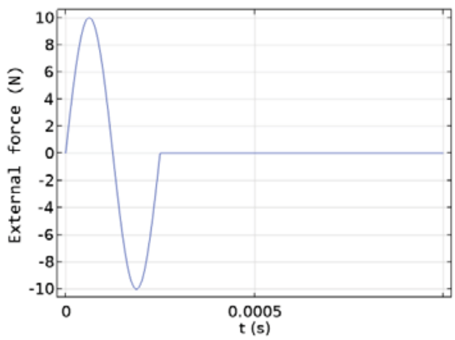

Fig. 3 External force

In the simulated results, the blue line in Fig. 4 shows a perfect sinusoidal function waveform for the stress at the center of cross section of the bar with the distance $l_1 = 10\ mm$. The waveform found from $t = 6 \times 10^{-4}\ s$ is the reversely transmitting wave generated due to the reflection at the end of the bar. The amplitude is $200000\ N/m^2$, which is equal to the stress value caused by the external force F. This result proved that the force can propagate along the Hopkinson bar in Fig. 2 (a) without any disturbance.

2.3 Stress propagation along optimal Hopkinson bar

In the optimal design of the Hopkinson bar proposed by Gu et al. [5], a half of the force acting on the wire might be imposed on a small strip-shape area of the end structure as shown in Fig. 2 (b). Therefore, it is necessary to calculate the stress propagation along the optimal Hopkinson bar. The result is shown by the orange line in Fig. 4. By comparison of the stress between normal Hopkinson bar and optimal Hopkinson bar, it is found that the specific structure does not affect the stress propagation so much.

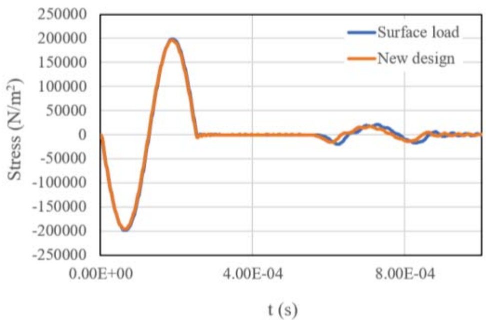

Fig. 4 σ_z at $l_1 = 10\ mm$

3. Conclusions

To explore the best structure of the Hopkinson bar for the measurement of discharge reaction force acting on the wire electrode in WEDM, a solid mechanical model was built in COMSOL Multiphysics software. The studied results show that there is no obvious distortion in the stress signal propagating along the Hopkinson bar even with the optimal design of the Hopkinson bar. It is believed that the new design with a small force acting area is valid to transform the force information.

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