

## ANALYSIS AND SIMULATION OF THE DIRECTIONAL EFFECT IN VIBRATION-ASSISTED MICRO-WEDM

### PHÂN TÍCH VÀ MÔ PHỎNG SỰ ẢNH HƯỞNG CỦA PHƯƠNG DAO ĐỘNG TRONG MICRO-WEDM CÓ DAO ĐỘNG HỖ TRỢ

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#### ABSTRACT

*The advantage of vibration-assisted WEDM had been demonstrated through many re-searches. When vibration was applied to the WEDM process, the machining efficiency and machined surface quality were both improved. However, the directional effect caused by the difference between the vibration direction and the machining direction has not been studied. This paper presents the numerical analysis and simulation for studying the directional effect in a vibration-assisted micro-WEDM. The pressure variation in the machining area which affects the flushing efficiency of the dielectric was analyzed using ANSYS CFD software. The vibration direction was found to have significant effect on the flushing of the debris formed during the machining process. The simulation results also showed that the angular difference between the cutting direction and vibration direction should be kept lower than  $45^\circ$  to maintain efficient debris flushing.*

**Keywords:** *Vibration-assisted WEDM, Directional effect, Flow velocity, Fluent analysis*

#### TÓM TẮT

*Các ưu điểm của WEDM sử dụng dao động hỗ trợ đã được chứng minh qua rất nhiều nghiên cứu. Các kết quả nghiên cứu đã cho thấy rằng, khi dao động hỗ trợ được áp dụng vào quá trình gia công WEDM, hiệu quả của quá trình gia công cũng như chất lượng bề mặt đều được cải thiện đáng kể. Tuy nhiên, trong quá trình gia công, khi phương dao động và phương chuyển động của dao không trùng nhau, sự sai lệch đó có thể có ảnh hưởng nhất định đến quá trình gia công. Trên thực tế, các nghiên cứu về vấn đề này đến nay vẫn chưa được đưa ra. Do đó, những ảnh hưởng của phương dao động sẽ được phân tích và mô phỏng và các kết quả nghiên cứu sẽ được giới thiệu, thông qua bài báo này. Trong nghiên cứu được đưa ra, sự thay đổi áp suất, tốc độ dòng chảy do dao động tạo ra sẽ được phân tích sử dụng công cụ mô phỏng CFD của phần mềm ANSYS. Kết quả mô phỏng cho thấy, thay đổi áp suất và tốc độ dòng chảy trong khu vực cắt bị ảnh hưởng đáng kể bởi sự thay đổi phương dao động. Kết quả mô phỏng cũng cho thấy rằng, góc sai lệch giữa phương dao động và phương cắt nên được duy trì thấp hơn  $45^\circ$  để đảm bảo sự hiệu quả của quá trình gia công.*

**Từ khóa:** *WEDM có dao động hỗ trợ, Phương dao động, Phân tích dòng chảy, Vận tốc dòng*

#### 1. INTRODUCTION

EDM is a non-contact machining method which utilizes short-pulse plasmas with super high temperature (up to 40,000 K) for eroding workpiece's material. Therefore, EDM can machine hard and super-hard mate-

rial regardless of its hardness. Moreover, since EDM is a non-contact method, it can be used to machine complex geometries and work effectively on high-aspect-ratio or low stiffness structure [1,2].

Flushing of the debris (mixture of eroded material and dielectric) is considered as one of the most important factors in EDM. The flushing in a conventional EDM is performed by a dielectric circulation system. When discharges happen, materials of both the tool and workpiece are melted. A part of the molten metal is re-solidified and attaches on the surface, meanwhile the remained molten material dissolves into the dielectric liquid and forms the debris. To ensure that the discharge process can work effectively, the debris must be flushed out and replaced by the fresh dielectric. Therefore, the discharge efficiency of an EDM process is, in fact, depended on the flushing efficiency. In conventional EDM, when high-aspect-ratio or complex structures are fabricated, the flushing of debris is not easy, making the machining efficiency very low.

Many methods had been proposed to improve the flushing efficiency of an EDM process. Vibration-assisted EDM is known as one of the most popular methods to improve the machining efficiency in EDM. Ultrasonic vibration-assisted method was originally introduced by Kremer et al. early in 1989 [3]. The results obtained from this research showed that with ultrasonic-vibration applied to the tool electrode, the material removal rate could be significantly improved. High pressure variation in the machining gap was found to be the main reason for the improvement. In WEDM, researches of the vibration-assisted micro-WEDM showed that, the vibration should be applied to the workpiece rather than to the wire to maximize the effect of the vibration [4,5].

In most of the previous researches on vibration-assisted EDM, vibration direction and cutting direction are coincided. However, during the machining process, especially in WEDM, cutting direction and vibration direction can be deviated. This can change the effect of the vibration to the machining process and its performance. Therefore, the study of the directional effect in a vibration-assisted

EDM system is significant and should be carried out.

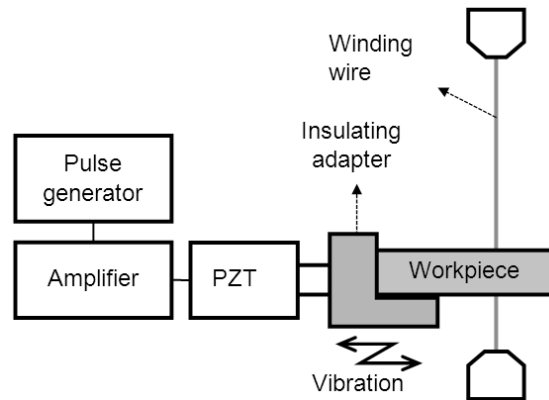


Fig. 1. Configuration of the vibration system

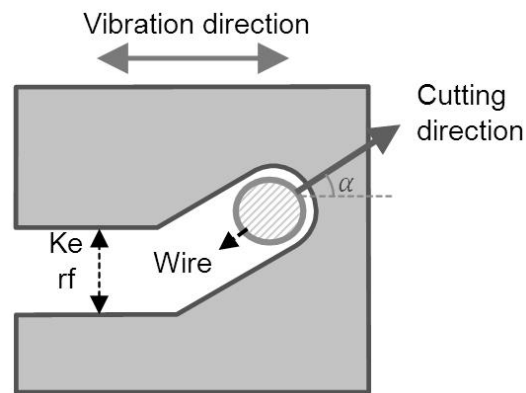


Fig. 2. Directional different in vibration-assisted WEDM

This paper presents the analysis and simulation of the dielectric flow in the machining area when the cutting direction changes with respect to the vibration direction. The simulation was applied to different deviated angles using ANSYS CFD software.

## 2. VIBRATION-ASSISTED $\mu$ -WEDM

### 2.1 System configuration

Fig. 1 shows the configuration of the developed vibration-assisted  $\mu$ -WEDM. The workpiece of the  $\mu$ -WEDM system was vibrated by a PZT actuator. Since the workpiece in a  $\mu$ -WEDM is usually small in size, the effect of its mass to the vibration system can be neglected. The diameter of the wire is set to 70  $\mu\text{m}$  and the kerf is set to 90  $\mu\text{m}$  according to actual experiment using 10 nF capacitor and voltage of 120 V. The dielectric used in

the process is the Total Diel MS 7000 EDM oil. The vibration frequency is set to 1500 Hz which is the optimal frequency for the selected workpiece.

### 2.1 Directional effect in the system

Fig. 2 shows the angular difference between the cutting and vibration directions. With vibration the circulation of the debris can be improved significantly as described in the research work of Hoang and Yang []. When the cutting direction is changed, the path of the circulation will change, as shown in Fig. 3. When the control pulse is ON, the workpiece is driven toward the wire pushing the dielectric out of the gap between the workpiece and the wire. In contrast, when the control pulse is OFF, the workpiece is retracted and the dielectric is sucked into the working gap. In the case where the cutting and vibration directions are coincided, path 1 and path 2 is even. When the angle between the cutting and vibration directions varies, the relative distance between the wire and edges of the cut slot will change, making path 1 and path 2 uneven. This change can affect to the pressure variation formed by the aided vibration.

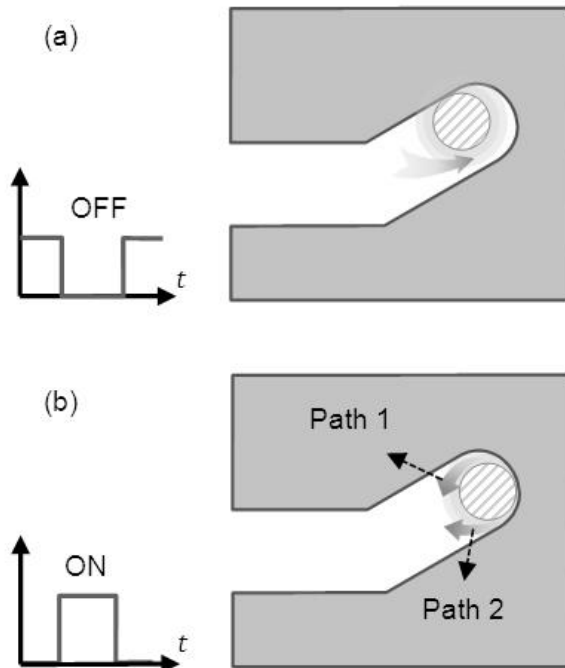


Fig. 3. Directional different in vibration-assisted WEDM

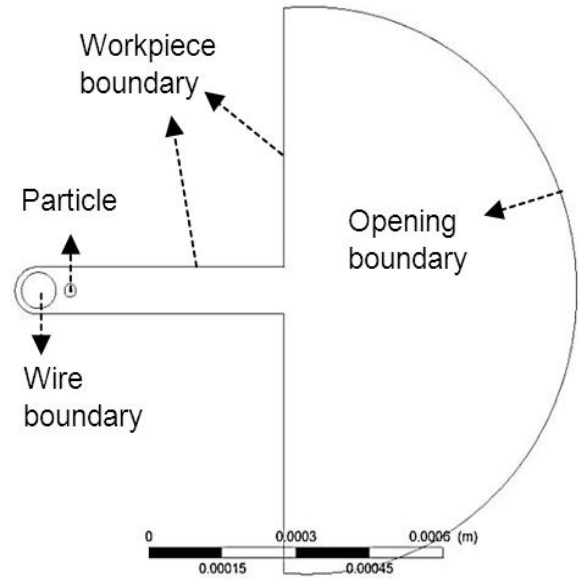
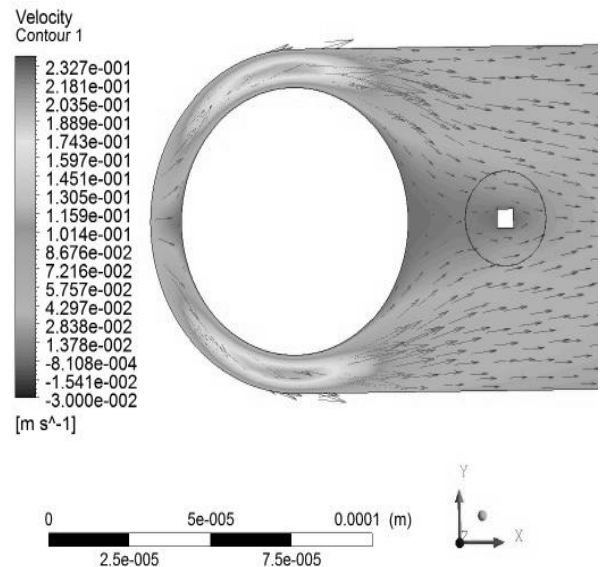


Fig. 4. Problem modeling

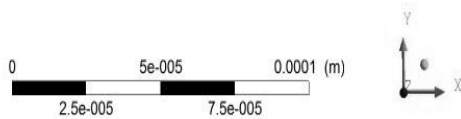
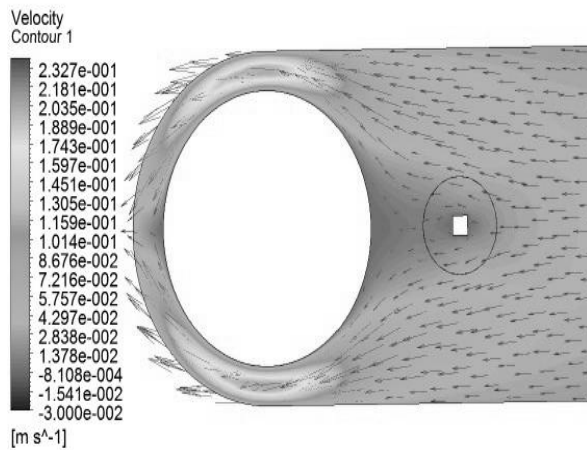
### 3. FLOW ANALYSIS

The vibration-assisted micro-WEDM problem had been simplified to a CFD problem as shown in Fig. 4. The width of the cut slot is 90  $\mu\text{m}$  and the thickness of the simulated area is 1  $\mu\text{m}$ . Since the feed rate of the electrode is very small compared to the speed of the movement caused by vibration, it can be neglected. A particle is created in the middle of the slot to monitor the influence of the flow.

a)  $\alpha = 0^\circ$



(a)



(b)

**Fig. 5.** Simulated flow velocities at  $a = 0^\circ$ 

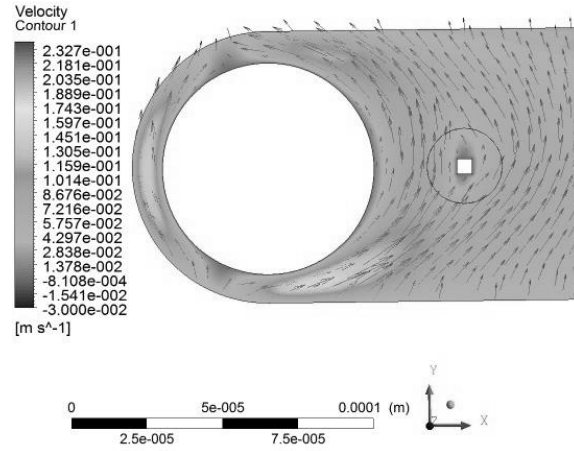
Fig. 5 shows the simulated velocity of the dielectric flow inside the cut slot in the case where the cutting and vibration directions are coincided. The flow of the dielectric is distributed equally at two flowing paths.

#### b) $a \text{ khác } 0^\circ$

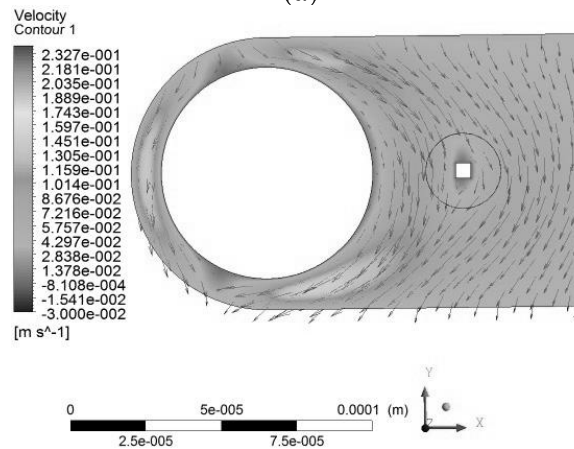
Fig. 6 shows the simulated velocity of the dielectric flow inside the cut slot when the cutting direction changes with respect to the vibration direction. The velocity of the path 2 flow is always higher than that of path 1 and also higher than that in the case when . This can be attributed to the reduction of the space between the wire and the cut edge of the workpiece.

#### c) $a = 90^\circ$

Fig. 7 shows the simulated velocity of the dielectric flow inside the cut slot when the cutting and vibration directions are perpendicular. It can be seen that the velocity of the dielectric flow is much smaller than that of the other cases. Since in this case path 1 is almost close in X and Y direction, the contribution of vibration to the flushing efficiency is in fact not significant.



(a)



(b)

**Fig. 7.** Simulated flow velocities at  $a = 90^\circ$ 

## 4. SIMULATION RESULTS

Fig. 8 shows maximum values of the monitored force of the flow on the particle at different deviated angles. The force on X-direction tended to decrease when the deviated angle increased. Meanwhile, the force on Y-direction tended to increase when the deviated angle decreased.

The maximum values of the velocity of the liquid flow at different deviated angles are shown in Fig. 9. It can be seen that the maximum velocities at path 1 and 2 are equal when . When , the maximum velocity at path 1 decreased along with the increase of the deviated angle. Meanwhile, the maximum velocity at path 2 increased only with . When was increased beyond , the maximum velocity at path 2 started to decrease.

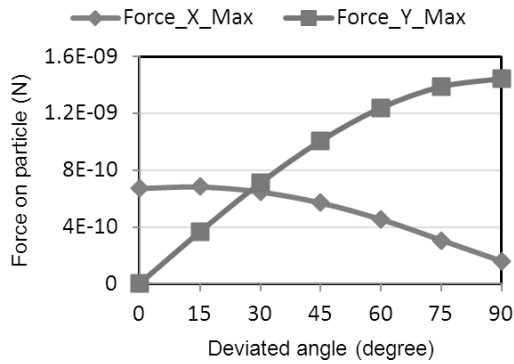


Fig. 8. Directional different in vibration-assisted WEDM

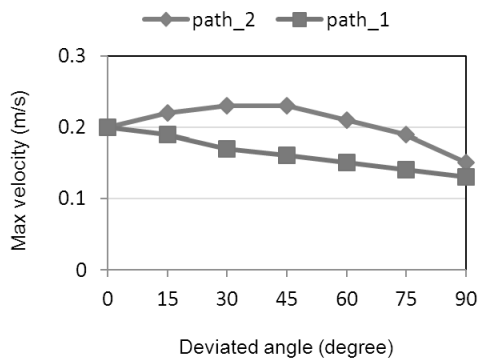


Fig. 9. Directional different in vibration-assisted WEDM

## 5. CONCLUSION

The study and simulation of the directional effect in a vibration-assisted micro-WEDM have been presented in this paper. Important conclusions are as follow:

- The flow of dielectric inside the machining gap is significantly affected by the difference between cutting and vibration directions.

- With deviated angle smaller than 45° the maximum velocity is higher than that in the case where the cutting and vibration directions are coincided.

## ACKNOWLEDGEMENT

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