

# Experimental Study and Application of Ultrasonic Vibration Technology in Enhancing Deep-Hole Drilling Tool Performance

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**Abstract:** This study delves into the application of ultrasonic vibration technology in enhancing the performance of deep-hole drilling tools and its consequential effects on the machining process. By integrating ultrasonic vibrations, this research aims to unveil how such vibrations refine the interaction between the tool and material during deep-hole drilling, thereby achieving a reduction in frictional forces, a decrease in machining temperatures, an increase in the efficacy of cutting fluids, and an improvement in chip removal. The experimentation employed an array of tools, including internally cooled welding-style end-face cutters, multi-edged BTA, and single-edged BTA, to investigate the performance variations under different machining parameter configurations. The findings indicate that, compared to conventional drilling methods, ultrasonic vibration-assisted deep-hole drilling substantially elevates machining efficiency, enhances hole wall quality, and significantly reduces tool wear while prolonging tool life.

**Keywords:** Ultrasonic Vibration Technology, Deep-Hole Drilling, Tool Performance, Machining Efficiency.

## 1. Introduction

Deep-hole drilling, as a pivotal machining technique within the modern manufacturing industry, finds extensive application across domains such as aerospace, automotive manufacturing, mold industry, and the production of energy equipment[1]. The unique challenges of deep-hole machining—such as substantial processing depths, tool deviation susceptibility, and the difficulty in heat dissipation—elevate the technical complexity of this process. Conventional deep-hole drilling approaches grapple with several impediments, including accelerated tool wear, diminished processing efficiency, compromised hole wall integrity, and escalated production costs[2]. These impediments severely constrain the applicability and quality of deep-hole drilling, thus necessitating innovative technological solutions.

In recent years, ultrasonic vibration technology has garnered widespread attention due to its potential to enhance processing efficiency and improve machining quality[3]. By introducing ultrasonic frequency vibrations during the machining process, this technology alters the contact dynamics between the tool and the workpiece, effectuating a fine control over friction, heat generation, and cutting forces, thereby substantially enhancing machining performance[4]. Particularly in the realm of deep-hole drilling, ultrasonic vibration technology not only fortifies the tool's resistance to wear and extends its lifespan but also augments the quality of the machined surface, mitigates process-induced errors, and achieves objectives of high efficiency and precision in machining[5].

## 2. Mechanism of Vibratory Drilling

Ultrasonic-assisted drilling technology, an advanced method for precision machining, builds upon traditional drilling processes by incorporating high-frequency ultrasonic

vibrations, creating a dynamic, intermittent contact mode between the tool and the workpiece[6]. The essence of this technology lies in utilizing vibrations within the ultrasonic frequency spectrum to meticulously modulate the mechanical and thermal environment during drilling. Such modulation, achieved by periodically altering the state of contact between the tool and the workpiece, optimizes stress distribution and heat transfer in the machining contact area, significantly reducing the thermal load on both the workpiece surface and the tool[7-9].

Figure 1 depicts the mechanism of ultrasonic vibration in deep-hole drilling, where  $x_1$  and  $x_2$  represent two orthogonal axes with low stiffness, characterized by stiffnesses  $k_1$  and  $k_2$ , and dampings  $c_1$  and  $c_2$ , respectively;  $y$  and  $z$  correspond to the directions of cutting depth and feed, respectively;  $F$  denotes the resultant cutting force within this plane,  $\alpha$  is the angle between  $x_1$  and the  $y$ -axis;  $\beta$  is the angle between  $F$  and the  $y$ -axis. At the micro-level, the introduction of ultrasonic vibrations induces high-frequency cycles of contact and separation between the tool and workpiece, not only reducing the average coefficient of friction in the cutting area but also diminishing the cutting force, and through enhanced thermal exchange in the cutting zone, it contributes to lowering the machining temperature. Furthermore, this periodic separation facilitates the penetration and lubrication of the cutting fluid, thereby improving the formation and evacuation of chips and lessening tool wear[10].

More significantly, the high-frequency vibrations applied in ultrasonic drilling disrupt the continuous cutting mode, transforming it into an intermittent cutting state. In such a state, the peak cutting forces are substantially lowered, preventing tool deformation and damage that could arise from excessive cutting forces, and also reducing machining errors caused by uneven force distribution, thus ensuring an increase in machining efficiency while maintaining precision and surface integrity[10-13].

By employing longitudinal high-frequency vibrations,

ultrasonic-assisted drilling further refines the micro-contact mechanics between the drill bit and the workpiece, enabling more precise positioning of the drill bit during each micro-contact event, which in turn enhances the positional accuracy of the borehole[14]. This technology not only exhibits unique advantages in improving cutting performance and machining quality but also significantly reduces tool wear and production costs, offering an efficient and reliable technological solution for deep-hole drilling and other precision machining applications[15].

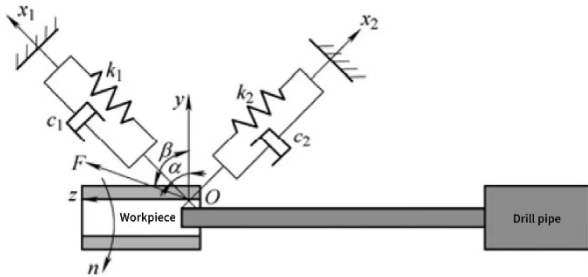


Figure 1. Ultrasonic Vibration Mechanism for Deep-Hole Drilling

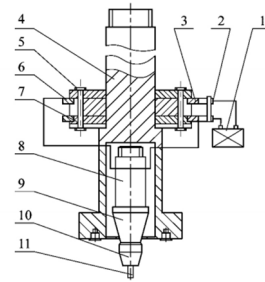
### 3. Experimental Design

#### 3.1. Experimental Apparatus and Materials:

For the experimental tooling, commonly used tools in the process of deep-hole machining were selected—internally cooled welding-style end-face cutters, multi-edged BTA, and single-edged BTA cutters—due to their excellent cutting performance, high stability, and proficient chip evacuation capabilities[16].

The ultrasonic vibration equipment employed was developed by the Shanghai University of Engineering Science. This ultrasonic vibration drilling apparatus can be mounted directly onto the spindle of a deep-hole drilling machine for

micropore drilling operations. It is equipped with devices to adjust the frequency, current, and voltage during the drilling process[17].



1—Ultrasonic Generator; 2—Brush Holder; 3—Brush; 4—Tool Shank; 5—Bolt; 6—Slip Ring; 7—Slip Ring Holder; 8—Transducer; 9—Amplitude Rod; 10—Drill Chuck; 11—Drill Bit.  
a) Schematic Diagram



b) Actual Device Diagram

Figure 2. Ultrasonic Vibration Drilling Device

#### 3.2. Experimental Parameter Design

Based on common parameters for deep-hole machining, specific settings for exposed length, frequency, current, and voltage were established for each tool type, alongside determining the ratio of start-up energy to maximum energy. The detailed table is as follows:

Table 1. Experimental Design and Analysis

Tool Type	Exposed Length (mm)	Frequency (kHz)	Current (mA)	Voltage (V)
Φ25L1150 Internally Cooled Welded End-face Cutter	1085	20.3	451	184
	1090	20.2	460	198
	1095	20.1	364	180
	1100	20.1	679	107
	1110	20	784	74
	1120	19.8	688	112
Φ25L2635 Multi-edged BTA with Internal Φ15	2570	20.2	551	146
Φ20L1440 Single-edged BTA with Internal Φ12	1375	20.8	583	121
	1390	20.7	510	155
	1380	20.7	592	118
	1385	20.7	437	173
	1377	20.7	410	65
	1379	20.7	547	152

### 4. Results and Analysis

#### 4.1. Experimental Data

Under the premise of conducting at least three repetitions

for each experimental condition to ensure data reliability, we meticulously documented the start-up energy, maximum energy, power, and observed atomization effects as shown in Table 2.

**Table 2.** Experimental Design and Analysis

Tool Type	Exposed Length (mm)	Frequency (kHz)	Current (mA)	Voltage (V)	Start-up Energy (%)	Maximum Energy (%)	Atomization Effect
<b>Φ25L1150 Internally Cooled Welded End-face Cutter</b>	1085	20.3	451	184	20%	25%	weak
	1090	20.2	460	198	20%	25%	weak
	1095	20.1	364	180	20%	25%	weak
	1100	20.1	679	107	20%	25%	weak
	1110	20	784	74	20%	25%	weak
	1120	19.8	688	112	20%	25%	weak
<b>Φ25L2635 Multi-edged BTA with Internal Φ15</b>	2570	20.2	551	146	20%	25%	Strong
<b>Φ20L1440 Single-edged BTA with Internal Φ12</b>	1375	20.8	583	121	20%	25%	weak
	1390	20.7	510	155	20%	25%	No Response
	1380	20.7	592	118	20%	25%	weak
	1385	20.7	437	173	20%	25%	No Response
	1377	20.7	410	65	20%	25%	weak
	1379	20.7	547	152	20%	25%	weak

## 4.2. Analysis

The table presents performance data under various tool types and parameter configurations in the ultrasonic vibration drilling experiments. Within the series of internally cooled welded end-face cutters (Φ25L1150 with an internal diameter of Φ16.5), despite variations in exposed length, frequency, current, and voltage, the start-up energy and maximum energy remained constant at 25%, and the power consistently at 91%, with a predominantly weak atomization effect. This indicates that within this parameter range, adjustments to these variables have limited impact on atomization. In contrast, the multi-edged BTA tool with an internal diameter of Φ15 (Φ25L2635) exhibited a strong atomization effect under similar frequencies and slightly higher currents, suggesting that a longer exposed length might contribute to enhanced atomization effects. For the series of single-edged BTA tools with an internal diameter of Φ12 (Φ20L1440), despite a constant power of 91%, variations in atomization effects from weak to none were observed under different parameter settings, highlighting the significant influence of specific combinations of current and voltage on atomization.

## 5. Conclusion

The analysis indicates that the parameters of exposed length and current significantly affect the atomization effects, whereas the power level maintained a consistent stability throughout the experiments. This suggests that the atomization effects are more closely linked to the mechanical vibration parameters than to the power input. These insights could serve as valuable guidance for the refined optimization of parameter settings within the ultrasonic vibration drilling methodology.

The research findings underscore the significant advantages conferred by the adoption of ultrasonic vibration technology in deep-hole drilling, notably enhancing both tool performance and the quality of machining. By fine-tuning the ultrasonic vibration's frequency, amplitude, and additional pertinent parameters, there's a tangible opportunity to markedly diminish the forces and heat generated during cutting, better the lubrication during the cutting phase, and enhance the breaking and removal of chips. Such adjustments lead to an uplift in machining efficiency and an enhancement

of the surface quality. Moreover, the investigation highlighted the pronounced impact of exposed length and current parameters on atomization, laying the groundwork for enhanced optimization strategies in the ultrasonic vibration drilling technique.

Repeated trials employing multi-edged BTA tools have corroborated these insights, vividly demonstrating potent atomization effects, as depicted in Figure 2.



**Figure 2.** Atomization Effects in Repetitive Experiments

In summary, ultrasonic vibration technology demonstrates significant advantages in enhancing the performance of deep-hole drilling tools, offering robust technological support for elevating the standards and expanding the application scope of deep-hole machining techniques.

## References

- [1] WANG L J, WANG X, ZHAO H F. Effect of the cutting ratio on cutting forces and the drill life in vibration drilling[J]. The International Journal of Advanced Manufacturing Technology, 2004, 24(11): 865-872.
- [2] ISOBE H, UEHARA Y, HARA K. Effect of ultrasonic vibration drilling on cutting stress distribution[J]. Key Engineering Materials, 2012, 523-524: 191-196.
- [3] BARANI A, AMINI S, PAKTINAT H, et al. Built-up edge investigation in vibration drilling of Al2024-T6[J]. Ultrasonics, 2014,54(5): 1300-1310.

- [4] LIAO Y S, CHEN Y C, LIN H M. Feasibility study of the ultrasonic vibration assisted drilling of Inconel superalloy[J]. *International Journal of Machine Tools & Manufacture*, 2007, 47(12-13): 1988-1996.
- [5] MAKHDUM F, PHADNIS V A, ROY A, et al. Effect of ultrasonically-assisted drilling on carbon-fibre-reinforced plastics[J]. *Journal of Sound & Vibration*, 2014, 333(23): 5939-5952.
- [6] HEISEL U, STEHLE T, SCHAAL M, et al. Burr formation in short hole drilling by ultrasonic assistance[J]. *Production Engineering*, 2014, 8(1): 1-6.
- [7] ALAM K, HASSAN E, BAHADUR I. Experimental measurements of temperatures in ultrasonically assisted drilling of cortical bone[J]. *Biotechnology & Biotechnological Equipment*, 2015, 29(4): 753-757.
- [8] LI Z, YANG D, HAO W, et al. A novel technique for micro-hole forming on skull with the assistance of ultrasonic vibration[J]. *Journal of the Mechanical Behavior of Biomedical Materials*, 2015, 57: 1-13.
- [9] PAKTINAT H, AMINI S. Ultrasonic assistance in drilling: FEM analysis and experimental approaches[J]. *International Journal of Advanced Manufacturing Technology*, 2017, 92(5-8): 2653-2665.
- [10] LOTFI M, AMINI S. Experimental and numerical study of ultrasonically-assisted drilling[J]. *Ultrasonics*, 2016, 75: 185-193.
- [11] YAN Mingpeng, SHAO Hua. Tool temperature and wear in ultrasonic vibration drilling titanium alloy[J]. *Tool Engineering*, 2011, 45(8): 26-30.
- [12] AZIZ M, OHNISHI O, ONIKURA H. Novel micro deep drilling using micro long flat drill with ultrasonic vibration[J]. *Precision Engineering*, 2012, 36(1): 168-174.
- [13] SUGANTHI X H, NATARAJAN U, RAMASUBBU N. A review of accuracy enhancement in microdrilling operations[J]. *The International Journal of Advanced Manufacturing Technology*, 2015, 81(1): 199-217.
- [14] ZHANG Xuechen, LU Kang, SHI Yaochen, et al. Theoretical analysis and experimental research of vibration drilling bit rigidity[J]. *Manufacturing Technology & Machine Tool*, 2017(11): 52-55.
- [15] YANG Jie, TIAN Xitian, LIU Shunuan. Study on ultrasonic vibration drilling of titanium alloy[J]. *Aeronautical Manufacturing Technology*, 2015, 58(15): 83-85.
- [16] WU Mingyang, ZHAO Xu, CHEN Yong, et al. Research on mechanism and experimental of chip breaking during high pressure cooling turning of superalloys with PCBN tool[J]. *Chinese Journal of Mechanical Engineering*, 2017, 53(9): 187-192.
- [17] MA LiJie, LIU Guanjun, WANG Guicheng. Study on mechanism of breaking chip of axial vibration drilling[J]. *Machinery Design & Manufacture*, 2009(2): 228-230.