Numerical Simulation Analysis of Five-Step Variable-Diameter Pipe with Solid-Liquid Two-Phase Abrasive Flow Polishing

Junye Li¹, a Hengfu Zhang¹, b, Guiling Wu², c*, Jinglei Hu¹, d, Yang Liu¹, e and Zhihui Sun 2, f

¹College of Mechanical and Electric Engineering, Changchun University of Science and Technology, Changchun 130022, China
²Changchun Aviation Hydraulic Pressure Control Corporation Limited. Changchun 130000, China
E-mail: aljy@cust.edu.cn, b946595471@qq.com, cfstving@126.com,
d1340113539@qq.com, e5282510202@qq.com, fstving101@163.com

Abstract. In many areas of precision machining abrasive flow polishing technology has an important role. In order to study the influence of abrasive flow on the polishing effect of variable diameter parts, the fifth step variable diameter tube was taken as the research object to analyze the dynamic pressure and turbulent kinetic energy distribution of inlet velocity on the fifth-order variable diameter tube influences. Through comparative analysis, the abrasive flow polished variable diameter pipe parts have very effective and significant polishing effect and the higher the inlet speed, the more significant the polishing effect.

1. Introduction

With the gradual improvement of science and technology, the requirements for surface precision of mechanical products also increase, so a variety of micro-processing technology research is also increasingly in-depth, abrasive flow polishing technology as a micro-processing technology to improve the surface finish, micro-processing technology in a place. Abrasive flow polishing technology enables finishing such as micro-holes or complex channel surfaces to improve the surface finish of workpieces, enabling abrasive flow technology to solve difficult machining problems that conventional machining techniques can’t polish complex workpiece surfaces, making it unique in the field of precision and ultra-precision machining.

Tube parts in food, pharmaceutical, automotive, military and other industrial production and daily life has a very wide range of applications, has become an integral part of industrial manufacturing. Due to the special nature of the work environment and the use requirements, these pipe fittings are often required to have a high inner surface finish. To improve the smoothness of the inner surface of these pipe parts, it must be polished surface. However, due to the various types of tube radius of curvature, different angles of rotation bending, irregular shape and the internal structure is more complex, the traditional surface polishing technology is often difficult to finish the finishing of its inner surface. In recent years, abrasive flow polishing technology has gradually entered the field of precision manufacturing and scientific research people. The abrasive flow polishing technology can provide consistent polishing effect on the cross-surface polishing of some complex molds, and has the advantages of high polishing efficiency, low noise, Low cost advantages, so it is suitable for the polishing of the inner surface of the pipe parts. It is of extremely important significance and value to
enhance our country's position in the field of precision and ultra-precision machining. Among them, the design of variable-diameter pipe has drawn attention and attention. Abrasive flow processing variable diameter pipe technology is also growing. Variable caliber pipe structure is varied, including sudden expansion pipe, sudden contraction pipe, expanding pipe, reducing pipe, gradual pipe, etc. In this paper, the numerical simulation analysis of the fifth-order variable caliber pipe is mainly carried out. As shown in Fig.1. The total length of the fifth-step variable-diameter pipe is 12 mm, and the length of each step is equal to 2.4 mm. The diameter of each pipe of the variable-diameter pipe is respectively 0.6 mm, 0.8 mm, 1.0 mm, 1.2 mm and 1.4 mm.

![Figure 1. Fifth-order variable-diameter pipe cross-section diagram](image)

2. Initial Condition Setting and Numerical Simulation Analysis of Five-Order Variable-Diameter Pipe Grinding with Abrasive Flow

2.1. Abrasive Flow Polishing Fifth-Order Variable-Diameter Pipe Initial Conditions Setting

2.1.1. Entrance boundary conditions. Assuming that the state of abrasive flow at the entrance is turbulent, the k-epsilon (2eqn) model is chosen for the turbulence model. The liquid phase is aviation hydraulic oil, the solid phase is silicon carbide particles, the volume fraction of silicon carbide particles is set to 0.2, and the initial temperature is set to 310K.

2.1.2. Exit boundary conditions. Since the pressure and velocity at the outlet are not known before the simulation of the fluid, the outlet is directly connected to the outside world and the flow state is assumed to be a fully developed turbulent flow, the boundary condition at the outlet end is set to be a free outlet.

2.1.3. Wall boundary conditions. As the abrasive flow processing is the processing of the workpiece wall, the workpiece is stationary during processing, the cutting force on the wall mainly comes from the pressure driven by the fluid under the flow of particles flowing through the workpiece to be processed. For a fixed workpiece to be machined surface, the relative slip between the abrasive grain and the wall surface is the movement of the particle itself, so the boundary conditions of the wall surface should be selected for the non-slip wall boundary conditions.

2.2. Abrasive Flow Polishing Fifth-Order Variable Diameter Pipe Numerical Simulation Analysis

Fluent software was used to simulate the fifth-step variable-diameter pipe, the material of the five-step variable-diameter pipe is made of stainless steel. In order to better understand the effect of different initial velocity on the polishing quality of abrasive flow, the fluid behavior of abrasive flow under
different initial velocity needs to be analyzed. According to the actual situation of the workpiece and the machine tool, the numerical simulation of the inlet velocity of 30 m/s, 40 m/s, 50 m/s and 60 m/s were carried out respectively. The dynamic pressure cloud under different initial velocity was obtained by numerical simulation. As shown in Fig. 2.

(a) Entrance speed is 30 m/s

(b) Entrance speed is 40 m/s

(c) Entrance speed is 50 m/s

(d) Entrance speed is 60 m/s

Figure 2. Dynamic pressure cloud at different inlet velocities

It can be seen from the dynamic pressure cloud at different inlet velocities in Fig. 2 that the dynamic pressure at the entrance of the abrasive and the first-order area of the workpiece is the smallest. And the diameter of the workpiece becomes smaller and the abrasive velocity increases and the dynamic pressure increases under a certain flow rate, severe abrasive movement, and abrasive flow on the fifth-order workpiece polishing the best. The dynamic pressure at each cross-hole increases, which indicates that the abrasive particles cross at the cross-hole violently, and the impact of the abrasive particles on the cross-hole is violent, so that the cross-hole can be rounded to improve the
processing quality and processing efficiency.
By observing the results of numerical simulation, further numerical analysis of the fifth-order variable-diameter pipe polished by abrasive flow was made. Because the change of dynamic pressure was more obvious in each step, the data area of each step was analyzed and the dynamic pressure distribution in the five regions is shown in Table 1.

Table 1. Under different inlet velocity of the fifth-order variable diameter pipe dynamic pressure data distribution table

| Entrance speed(m/s) | Dynamic pressure(×10^6MPa) |
|---------------------|-----------------------------|
|                     | First-order area | Second-order area | Third-order area | Fourth-order area | Fifth-order area |
| 30                  | 0.346            | 1.20              | 4.18             | 14.5              | 33.4            |
| 40                  | 0.713            | 2.38              | 7.95             | 26.5              | 59.3            |
| 50                  | 1.24             | 4.02              | 13.0             | 42.3              | 92.6            |
| 60                  | 2.49             | 7.38              | 21.8             | 64.6              | 133             |

Analyzing the data in Table 1, dynamic pressure changes can be analyzed from the data sheet.
(1) First of all, the dynamic pressure changes under the same speed conditions can be seen from the data table, the fifth-order area > fourth-order area > third-order area > second-order area > first-order area, the fifth-order workpiece area of the smallest diameter, maximum dynamic pressure, abrasive flow on the fifth-order area polishing the best.
(2) Analyzing the dynamic pressure under different inlet velocities, the dynamic pressure in the five data areas shows an increasing tendency with the entrance velocity increasing, and the dynamic pressure in the fifth-order region also increases most obviously. It is concluded that increasing the inlet velocity can increase the dynamic pressure of the abrasive so as to make the abrasive movement more violent, thus increasing the inlet velocity and enhancing the grinding effect on the workpiece wall.
In order to better study the numerical simulation of the fifth-order variable-diameter pipe with abrasive flow, the same initial settings of different inlet velocities are obtained, and the turbulent kinetic energy cloud chart under different inlet velocities is shown in Fig.3.
From the turbulent kinetic energy cloud at different inlet velocities in Fig. 3, it can be seen that as the abrasive inflows from the inlet, the turbulent kinetic energy of the abrasive in the first-order area of the workpiece is the smallest. As the order increases, the turbulent kinetic energy increases. The turbulent kinetic energy of the stratosphere is the largest, which shows that the bigger the grinding force is, the better the grinding effect is.

In order to analyze the influence of turbulent kinetic energy on the fifth-order variable-diameter pipe, the data of the turbulent kinetic energy of the wall of each work piece is analyzed only because the abrasive particles on the wall of the work piece will affect the workpiece grinding. Five Table 2 shows the numerical distribution of turbulent kinetic energy on the workpiece wall in the region.

| Entrance speed(m/s) | First-order area | Second-order area | Third-order area | Fourth-order area | Fifth-order area |
|---------------------|------------------|-------------------|------------------|------------------|-----------------|
| 30                  | 0.736            | 1.69              | 3.89             | 8.93             | 47.1            |
| 40                  | 1.27             | 2.89              | 6.56             | 14.9             | 76.2            |
| 50                  | 1.95             | 4.37              | 9.82             | 22.1             | 111             |
| 60                  | 2.72             | 6.06              | 13.5             | 30.0             | 149             |

Analyze Table 2, it can be seen visually that the turbulent kinetic energy of the abrasive at the exit of the big hole (first-order area) to the exit of the small hole (fifth-order area) gradually increases under the same inlet velocity, Internal turbulent kinetic energy increases. It can be concluded that the abrasive flow enhances the grinding force at the intersection and has the best deburring and rounding effect. With the increase of velocity, the turbulent kinetic energy is strengthened and the grinding ability of the inner wall of the small hole is strengthened, the most significant polishing effect.

3. Conclusion
Based on the numerical simulation analysis of the polished pipe with variable diameter, the effects of different initial velocity on the quality of the abrasive flow were analyzed. The following conclusions can be drawn:

(1) With the abrasive entering the cavity of the workpiece, the dynamic pressure under the same initial velocity conditions gradually increases with the decreasing of the workpiece cavity. The fifth-order work area has the smallest inner diameter and the highest dynamic pressure. The abrasive
flow has the best polishing effect on the fifth-order area. Secondly, the analysis of dynamic pressure at different inlet velocities shows that the dynamic pressure in the same area increases with the entrance velocity increasing, and the dynamic pressure increases most obviously in the fifth-order area, which means that increasing the inlet velocity can increase abrasive dynamic pressure, so that abrasive movement more intense, thereby increasing the entrance speed to enhance the role of the workpiece wall grinding.

(2) Turbulent kinetic energy gradually increases with the decrease of workpiece cavity under the same inlet velocity. The turbulent kinetic energy of the abrasive gradually increases from the entrance of the big hole (first-order zone) to the small hole (fifth-order zone). It can be concluded that the abrasive flow at the same speed increases the grinding force of the small-diameter workpiece, and the deburring and rounding effect is good. The turbulent kinetic energy in the same area increases with the increase of processing speed. That is, with the increase of velocity, the turbulent kinetic energy is strengthened and the polishing effect is the most obvious.

4. Acknowledgements
The authors would like to thank the national natural science foundation of china No. NSFC 51206011, Jilin province science and technology development program of Jilin province No.20160101270JC and No.20170204064GX, project of education department of jilin province NO.2016386.

5. References
[1] Ji Shiming, Zhang Ding. Simulation and experiment of precision machining of soft grinding flow [J]. Electrical and Mechanical Engineering, 2012, 29(3):245-248.
[2] Li Dingpeng, Qian Jianping, Huang Weiping, et al. Numerical simulation of flow field in rotating drive [J]. Ordnance automation, 2015, 34(5):14-17.
[3] Junye Li, Zengwei Zhou, Lili Wei, Xinming Zhang, Xu Ying. Quality influence and process parameters optimization of T-pipe in abrasive flow finishing [J]. Advances in Mechanical Engineering, 2017, 9(8): 1-13.
[4] Li Junye, Xu Ying, Yang Lifeng, et al. Experimental study on grinding flow of non-linear tube parts [J]. China Mechanical Engineering, 2014, 25(13):1729-1733.
[5] Li Junye, Liu Weina, Yang Lifeng, et al. Study of Abrasive Flow Machining Parameter Optimization Based on Taguchi Method [J]. Journal of Computational & Theoretical Nanoscience, 2013, 10(12):2949-2954.
[6] Ji Shiming, Zhang Wei, Tan Dapeng. Analytical method of sparse liquid-solid two-phase flow field based on phase field model [J]. Electrical and Mechanical Engineering, 2012, 29(12):1376-1381.
[7] Yin Yanlu, Teng Qi, Li Junye, et al. Simulation analysis of abrasive flow field based on large eddy numerical simulation [J]. Electrical and Mechanical Engineering, 2016, 33(5):537-541.
[8] Dong Liang, Liu Houlin, Dai Cui, et al. Application of different turbulence models in 90° elbow numerical simulation [J]. Journal of Huazhong University of Science and Technology, 2012, 40(12):18-22.
[9] Li Jun-ye, QIAO Ze-min, YANG Zhao-jun, et al. Influence of abrasive concentration on the processing quality of abrasive flow in mesoscopic scale[J]. Journal of Jilin University(Engineering and Technology Edition),2017,47(3):837-843.(in Chinese)
[10] [Li Junye, Liu Weina, Yang Lifeng, et al. Numerical simulation of the behavior of grape flow in the micro-hole of injector [J]. Coal Mine Machinery, 2010, 31(10):56-58.
[11] YANG Zhi-yin. Large-eddy simulation: Past present and the future [J]. Chinese Journal of Aeronautics, 2015, 28(1): 11-24.
[12] LI Jun-ye, XU Ying, YANG Li-feng, et al. Research on Abrasive Flow Machining Experiments of Non-linear Tubes[J]. The Chinese mechanical engineering, 2014, 25(13):1729-1733.