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RESEARCH

# The Wear of the Focusing Tube and the Cut-Surface Quality

*The wear of the focusing tube is a very important feature of the abrasive water jet machining. Of all rejected focusing tubes, 85% are worn. Similarly, the age of focusing tube influences the cut geometry and quality of machined surface. With regard to the stated, wearing of the focusing tube is subject of this paper. Focusing tube outlet diameter was measured as well as its influence on the surface quality.*

***Keywords:*** *focusing nozzle, wear, surface quality, abrasive water jet*

## 1. INTRODUCTION

Continuous development of high pressure water jet machining was initiated in the first decade of the twentieth century.

Abrasive water jet machining is an unconventional method of machining. It has been industrially applied for a long period of time. The most common operations performed by this method of machining are cutting, polishing, cleaning, etc. In all stated options, the machining mechanism is based on erosion. The fact that no major rise in temperature occurs at machining in the processing zone is a huge advantage of this machining method. Figure 1. shows the working part of an abrasive water jet installation is most commonly called water jet head or nozzle [6].

The inlet water entering the water jet head (nozzle), most commonly at 3000÷4000 bar pressure, passes through jewel. The diameter of the orifice (jewel) entry ranges from 0,18÷0,4 mm. Extremely small diameter of the nozzle ensures very high water speed, amounting up to 900 m/s. The jet subsequently arrives at the mixing chamber the diameter and length of which are usually 6 mm and 10 mm respectively. Owing to the Venturio effect vacuum occurs, sufficient to absorb a particular amount of abrasive dependent on the abrasive nozzle diameter. Water jet speeds up the abrasive particles accompanying them through a long cylindrical focusing tube. Figure 2 presents the process.

Focusing tube is usually made of tungsten carbide. Its inner diameter and length range from 0,8 to 1,6 mm and 50 to 80 mm respectively. It is tungsten carbide that is used owing to its high resistance to abrasive wear.

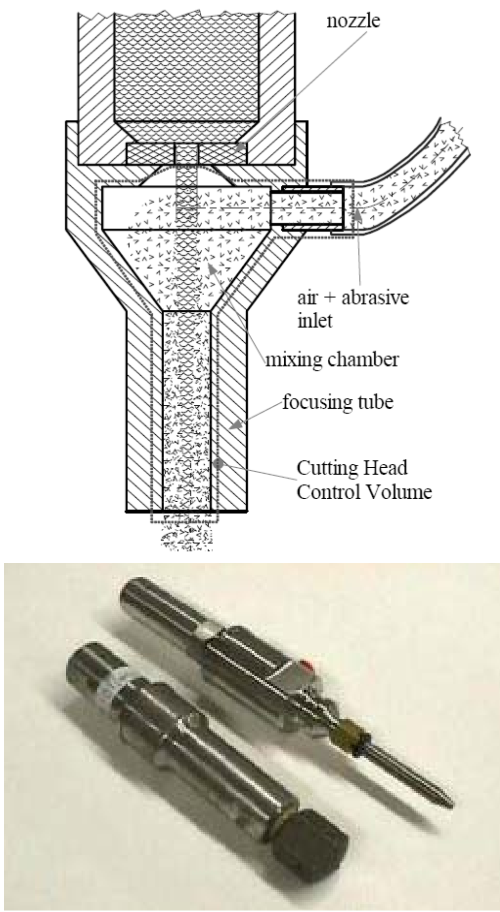


**Figure 1.** Water jet head

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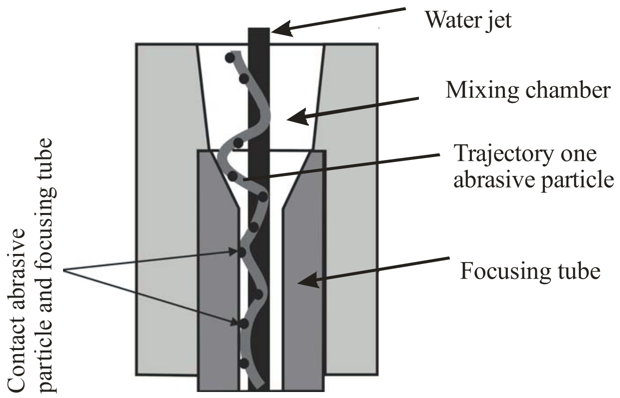


**Figure 2.** Scheme of the mixing process [6]

## 2. FOCUSING TUBE WEAR

The term 'wear' is used to manifest a number of issues, such as:

- Tube weight loss,
- The incidence of wear patterns along the inner surface,
- Change of the outlet geometry,
- Exit diameter increase.

The initial wear of the focusing tube is easiest identified by monitoring of the tube weight loss. The tube is measured before the beginning of the process as well as over the period of machining. Weight loss is induced by the erosion of the inner wall of the focusing tube which also brings about the incidence of wear patterns along the inner surface of the tube. Excessive usage of the focusing tube causes changes in the exit geometry, i.e. the occurrence of the opening eccentricity. The eccentricity is defined by the ratio between the smallest and the biggest size at the exit.

The most common method for monitoring of the state of the focusing tube is monitoring of the exit diameter. A number of authors have found linear relationship between exit diameter and time.
Different parameters of the machining, i.e. size of abrasive particles, focusing tube length govern the increase in the exit diameter.

Figure 3. presents basic model of focusing tube wear. On tube entrance, abrasive particles hit the inner wall under different and broad angles. When focusing tube has sufficient length, movement of abrasive particles at the end of the tube is parallel to the inner wall. Basic mechanisms of focusing tube wear are appearance of micro-cuts and micro-cracks.

The most common method used to track the condition of focusing tube is tracking of diameter at the exit from the tube.

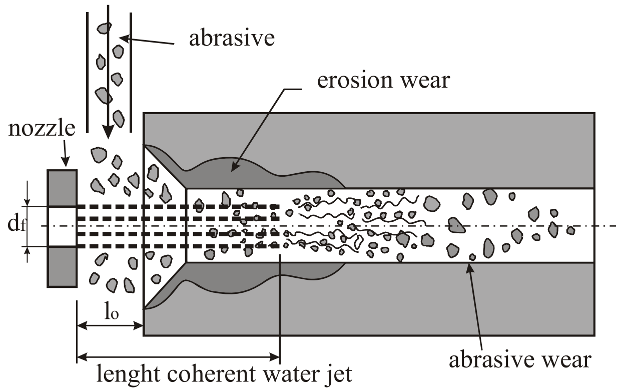


**Figure 3.** Basic model of focusing tube wear

Different parameters of machining process like working pressure, size of abrasive particles, length of focusing tube, can influence to change of diameter at the exit. Figure 4. Presents the dependence between diameter change and time (5), for the tube made entirely of tungsten carbide with diamond entrance.

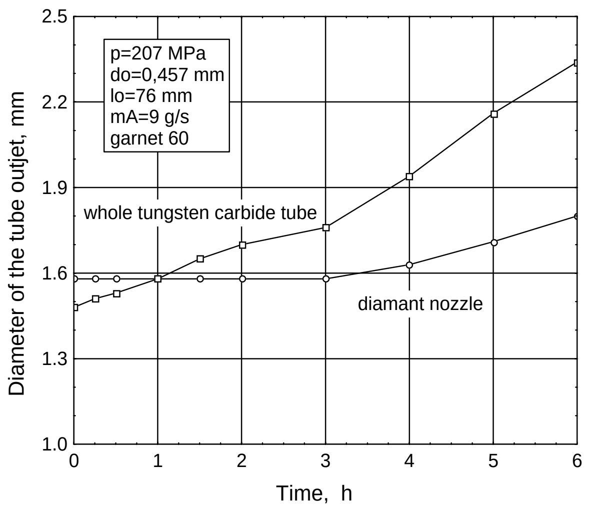


**Figure 4.** Change of the output diameter of the focusing tube as a function of the cutting time

Figure 5. presents characteristic appearance of worn focusing tubes. Uneven wearing traces in length of focusing tube can be spotted, which occurs when diamond nozzle and focusing tube are not centered well. Then more significant wear occurs at the entrance of the tube because abrasive particles hit directly to the wall of the focusing tube. It leads to faster wearing of the tube and lower quality of machined surface.

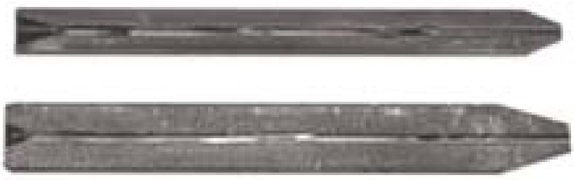

**Figure 5.** Characteristic appearance of focusing tube wear

## 3. PROPERTIES OF SURFACES MACHINED BY ABRASIVE WATER JET

Major properties of surfaces machined by abrasive water jet are as follows:

- cutting width
- cone cutting
- roughness of the machined surface.

All these properties are indicators of quality of the machined surface. In this paper, roughness of the machined surface, i.e. the influence of the state of the focusing tube, has particularly been addressed.

Typical appearance of the surface machined with abrasive water jet is shown in Fig. 6.

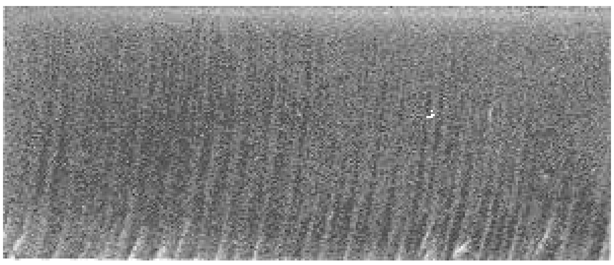

**Figure 6.** The surface machined with abrasive water jet

As shown in the picture, typical striations can be seen on the machined surface. In the upper section (almost to the mid-part), these striations are almost vertical, and curved in the lower section. The upper part is related to the primary machining zone (the water jet inlet part). The incidence of this is due to the loss of jet energy during the cutting process, i.e. diverting of the water jet through the material. Curved striations indicate jet direction through the machined material.

## 4. EXPERIMENTAL INVESTIGATIONS

In this paper, the focusing tube wear was investigated by the half of the exploitation life of the tube. The ROCTEC©100 focusing tube has been investigated. The data provided by the producer suggest 120 hours of exploitation life of the tubes. The following parameter values at which the focusing tube was being exposed over the study were constant, i.e.

- working pressure p = 3500 bar
- abrasive flow Qa = 306 g/min
- abrasive type – garnet, MASH#80

The diameter of the focusing tube outlet was measured at the beginning of the process using a new tube. It was subsequently checked over 10- to 15-hour interval.

Measuring of the diameter of the tube outlet was concurrent with cutting of samples made of different materials so as to monitor the effect of the focusing tube wear on roughness of the machined surface. These sample materials were used:

1. X5CrNi18.9 *(*Č4580): Rm=630 MPa; $R_{p0.2}$=205 MPa
2. marble, dry state compressing solidity $\beta_{max}$=109 MPa, density 2.71 g/cm$^3$
3. PMMA (Polymethyl methacrylate), density 1.150 to 1.190 kg/m$^3$

All samples were treated at identical cutting speed (V=120 mm/min). Ra was used as major roughness parameter.

Ra parameter was checked at five and three spots along the sample length and heights respectively, as shown in Fig. 7.

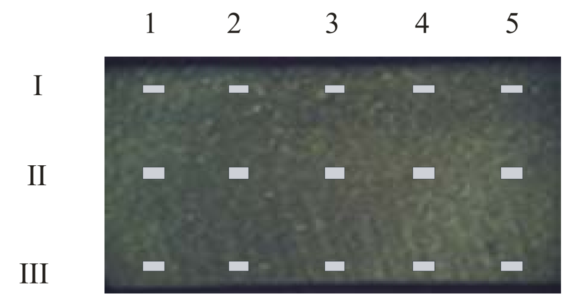


**Figure 7.** Checking spots along the machined sample surface

The table below presents values of the diameter of focusing tube outlet in the function of the cutting time.

**Table 1.** Values of the diameter of focusing tube outlet, $d_f$ being in the function of the cutting time.

| T, min | 0 | 855 | 1545 | 2345 | 3195 |
|---|---|---|---|---|---|
| $d_f$, mm | 1.02 | 1.055 | 1.109 | 1.152 | 1.318 |

According to the study results presented in Table 1. a diagram has been created showing to what extent focusing tube wear depends on cutting time. As shown in the figure 8, the longer duration of cutting the wider diameter of the focusing tube outlet. As previously noted, a number of authors firmly suggest linear correlation between these parameters, therefore the broken line in the figure stands for linear function which, by the smallest quadrate method, best provides approximate values of the correlation obtained by the study.

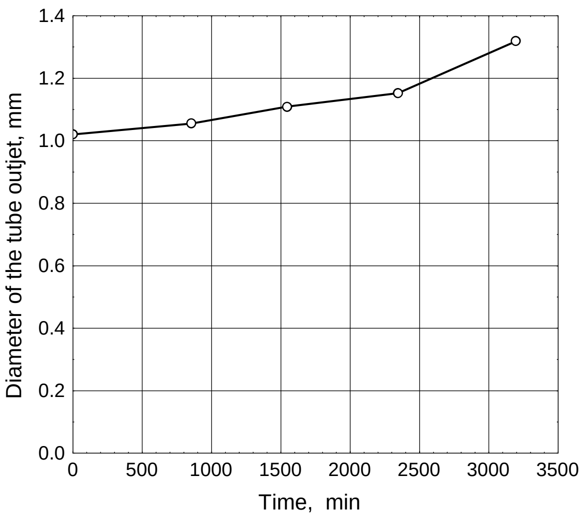


**Figure 8.** Change of the diameter of the tube outlet, df being in the function of cutting time

Tables 2, 3 and 4 shows the Ra values for iron X5CrNi18.9 (Č4580), marble and PMMA (Polymethyl methacrylate) in the function of cutting time.

**Table 2.** The average Ra values functioning as cutting time for X5CrNi18.9 (Č4580)

| T, min | | 0 | 855 | 1545 | 2345 | 3195 |
|---|---|---|---|---|---|---|
| Ra µm | I | 2.79 | 3.182 | 3.162 | 3.478 | 3.794 |
| | II | 2.616 | 3.136 | 3.328 | 3.11 | 3.026 |
| | III | 2.864 | 2.854 | 3.006 | 3.164 | 3.808 |

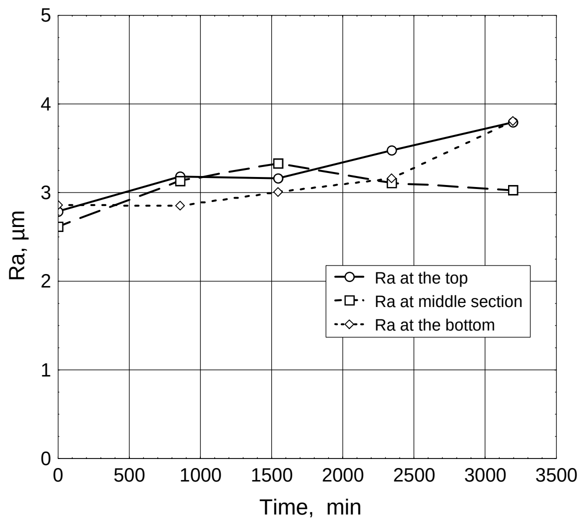


**Figure 9.** Change in Ra function of cutting time for X5CrNi18.9 (Č4580)

**Table 3.** The average Ra values functioning as cutting time for marble

| T, min | | 0 | 855 | 1545 | 2345 | 3195 |
|---|---|---|---|---|---|---|
| Ra µm | I | 3.078 | 3.41 | 4.46 | 4.52 | 4.48 |
| | II | 3.212 | 3.406 | 3.126 | 3.478 | 3.484 |
| | III | 4.294 | 3.482 | 3.282 | 3.92 | 3.458 |

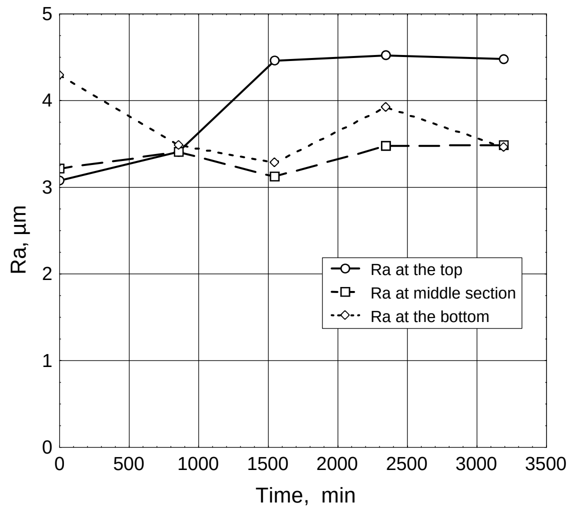


**Figure 10.** Change in Ra function of cutting time for marble

**Table 4.** The average Ra values functioning as cutting time for PMMA (Polymethyl methacrylate)

| T, min | | 0 | 855 | 1545 | 2345 | 3195 |
|---|---|---|---|---|---|---|
| Ra µm | I | 2.92 | 3.916 | 3.972 | 4.124 | 3.876 |
| | II | 3.754 | 3.57 | 3.912 | 3.966 | 4.008 |
| | III | 3.564 | 4.144 | 4.008 | 4.296 | 4.182 |

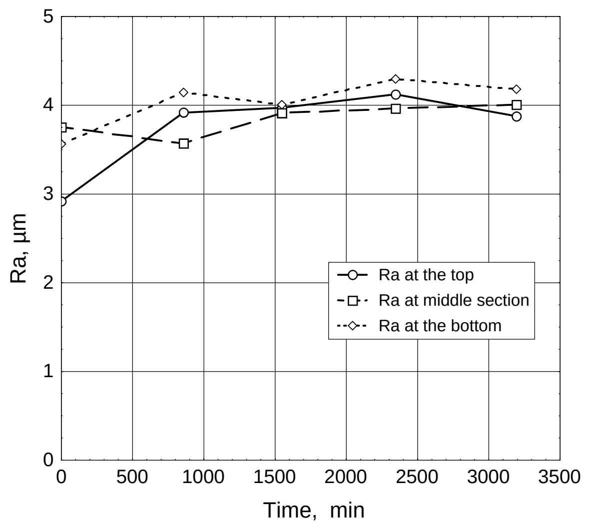


**Figure 11.** Change in Ra function of cutting time for PMMA (Polymethyl methacrylate)

Roughness was checked at PERTHOMETER S5P.

Figure 9 presents roughness change, i.e. change in Ra function of cutting time for X5CrNi18.9 (Č4580) which has been monitored at three different heights of the machined sample.

1. at the top
2. at middle section
3. at the bottom

Figures 10 and 11 show changes in Ra roughness parameter functioning as cutting time at three heights of the sample, for marble and PMMA (Polymethyl methacrylate).

All diagrams infer rise in the Ra roughness parameter with cutting time. This clearly suggests firm correlation between roughness of the machined surface and focusing tube wearing.

## 5. CONCLUSION

This paper presents the results of the investigation of the correlation between cutting time, change in the diameter of the focusing tube outlet and quality of the machined surface.

It has been suggested that longer duration of cutting induces the increase in the diameter of the focusing tube outlet, this correlation being almost linear. Further experiments are required in order to obtain more accurate correlation of the stated parameters.

Similarly, close relationship between quality of the machined surface and cutting time is also obvious. The longer the working time of the tube the more pronounced roughness of the machined surface for the stated working parameters. This correlation is quite obvious in iron and PMMA (Polymethyl methacrylate) , whereas serious irregularities have been evidenced in marble. Roughness at the bottom of the sample occurred regularly as compared to the one at the top of the sample.

In brittle materials, such as marble, pronounced wavering has been evidenced, which may further explain why the results of marble investigation show irregularities. Further investigations are required so as to check and explain this claim.

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