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INVESTIGATION OF THE ABRASIVE WATER JET DIVERGENCY

I. M. Hlaváčová*, L. M. Hlaváč, L. Gembalová*****

Summary: *The term waterjet divergency was introduced and defined. Divergency was measured in material (steel) in static regime - piercing - and then compared with jet divergency in free air measured in dynamic regime - cutting. The cutting divergency was measured for two different traverse speeds 2 meters per sec and 10 meters per sec. The experimental results are summarized and discussed. The results of experiments are compared with theoretical value. The influence of the abrasive mass flow rate on the jet divergency is mentioned.*

1. Introduction

Since 1997 the problems of surface quality and cutting efficiency have been studied in the frame of various projects at the Institute of Physics of the VŠB – Technical University of Ostrava (Hlaváč, 1998; Hlaváč, 2001; Hlaváč et al., 2007). Within the framework of this research several undesirable phenomena depreciating the quality of the resulting cut approve during abrasive water jet cutting. One of them is the broadening or narrowing of the cutting kerf that result into declination of the walls of cut. This effect is caused primarily by the fact that the jet itself is broadening during its passage through the space. On the other hand the abrasive particles in the cover layer of the jet are slowed down more intensively due to their interaction with the material and therefore the effective cross-section of the jet may decrease. In order to describe the longitudinal course of the jet active diameter the divergency of the axial symmetrical water (abrasive water) jet was introduced, using the analogy to the electromagnetic beam, meaning the angle between the jet axis and the line inherent in the peripheral cover sheet.

2. Theoretical model

Divergency of the abrasive liquid jet is primarily determined by the geometrical layout of the source equipment, i.e. mixing chamber, liquid nozzle orifice, focusing tube diameter and the

* Ing. Irena M. Hlaváčová, PhD., Institute of Physics, VŠB - Technical University of Ostrava, 17. listopadu 15/2172, 70833 Ostrava - Poruba; tel.: +420.597323147, e-mail: irena.hlavacova@vsb.cz

** Prof. Ing. Libor M. Hlaváč, PhD., Institute of Physics, VŠB - Technical University of Ostrava, 17. listopadu 15/2172, 70833 Ostrava - Poruba; tel.: +420.597323147, e-mail: libor.hlavac@vsb.cz

*** Ing. Lucie Gembalová, Institute of Physics, VŠB - Technical University of Ostrava, 17.listopadu 15/2172, 70833 Ostrava - Poruba, Czech Republic; tel.: +420 597323366, e-mail: lucie.gembalova.st@vsb.cz

amount of liquid and abrasive material mixed in the system. Provided that other parameters are constant the length of the focusing tube is expected to be the most important geometrical factors determining the divergency. Starting from the geometrical layout this equation is valid

$$\delta = arctg\,\frac{d_a - d_o}{2\left(l_a + l_{TA}\right)} \qquad (1)$$

The parameters in the equations are as follows: δ - angle of divergency [rad or °], d_o - water nozzle diameter [m], d_a - diameter of the focusing (mixing) tube [m], l_a - length of the focusing (mixing) tube [m], l_{TA} - distance between the water nozzle outlet and the focusing tube inlet [m].

For parameters used in our laboratory ($d_o = 0.25$ mm, $d_a = 1.02$ mm, $l_a = 76$ mm, $l_{TA} = 13$ mm) the calculated value of the divergency is $\delta = 4.3$ mrad (i.e. nearly 0.25°).

3. Experimental methods

The experimental procedures for determination of the jet divergency may be different starting from the visualization of the jet structure by the x-rays or another suitable technique and closing with evaluating the diameter of the area in material significantly affected by the jet. As far as the visualization methods are unrealisable for us, two different methods for evaluation of the efficient area of the jet were realized. The divergency that we call the *piercing* one was determined from measurement of the aperture prepared by unmoving jet penetration into the material. In order to exclude the effect of the backflow of the jet the "piercing" was realized on the sidewall of the steel sample.

a) b)

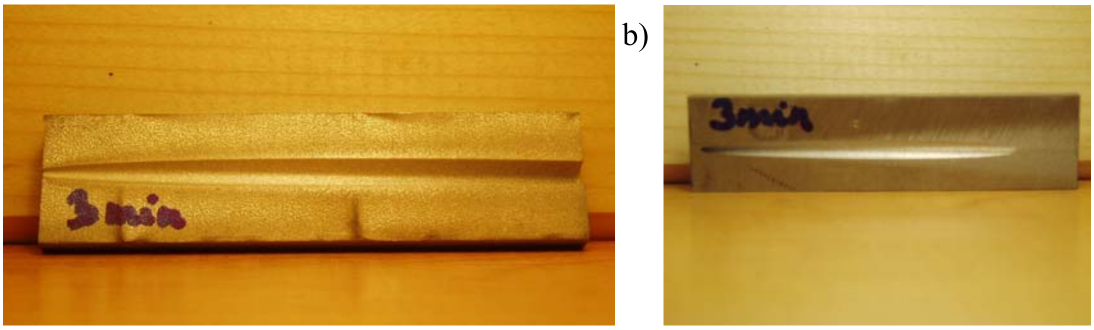

Fig. 1. Measurement of the waterjet piercing divergency on steel samples: (a) well arranged; (b) wrong arrangement

This method, however, requires careful adjustment of jet axis parallel to the surface of the sample. If the adjustment is incorrect, the pierced hole may be deceptive (see Fig. 1-b) from the point of view of the divergency. Nevertheless even such faulty hole confirms the fact that the jet is widening almost linearly. From the right figure it can also be well observed, that passing a certain path the abrasive particles lose a great part of their energy and therefore they are not able to cut away the material, their influence on the wall should rather be described as polishing.

The divergency called by us *cutting* one was determined from the jet track widths for moving jet. Either the inlet and outlet width of the kerfs prepared in material of the definite thickness can be measured or the width of the non-cutting tracks can be measured for various stand-off distances of the focusing tube outlet from the material surface.

Fig. 2. Measurement of the waterjet cutting divergency on steel samples

As far as the cutting of a steel plate thick enough to evaluate the jet divergency with sufficient accuracy is rather time consuming, we decided to apply the method based on the evaluation of the non-cutting tracks width (see Fig. 2). The steel plates were blasted with waterjet in the stand-off distance varying from 2 mm up to 110 mm. Two different traverse speeds were applied. The acquired traces were measured using optical microscope.

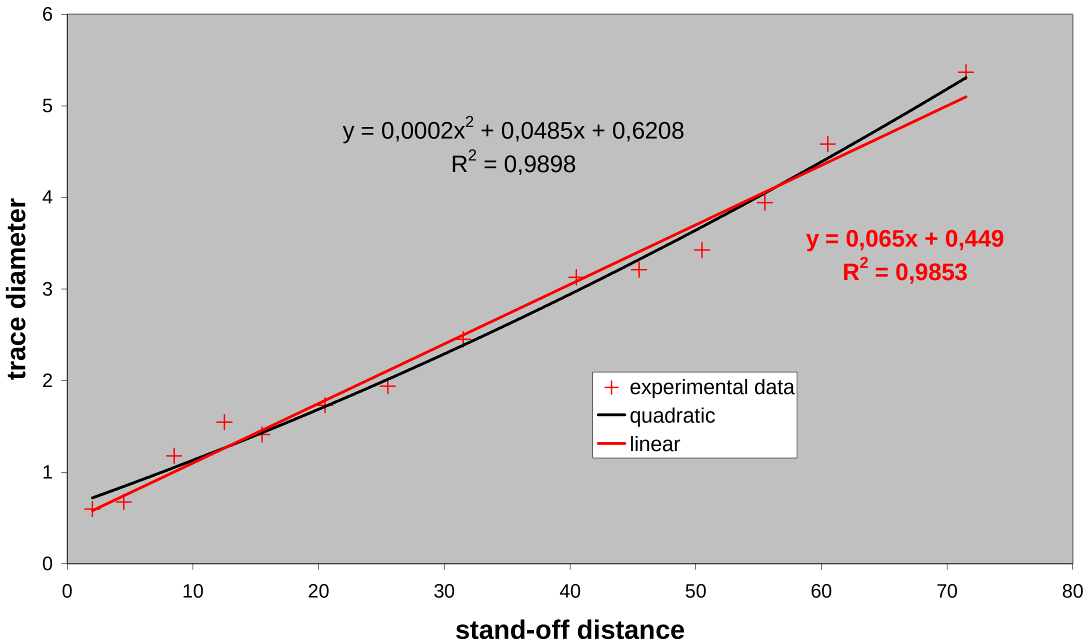

Fig. 3. Graphical evaluation of the waterjet divergency in the free air; traverse speed 2 meters per minute

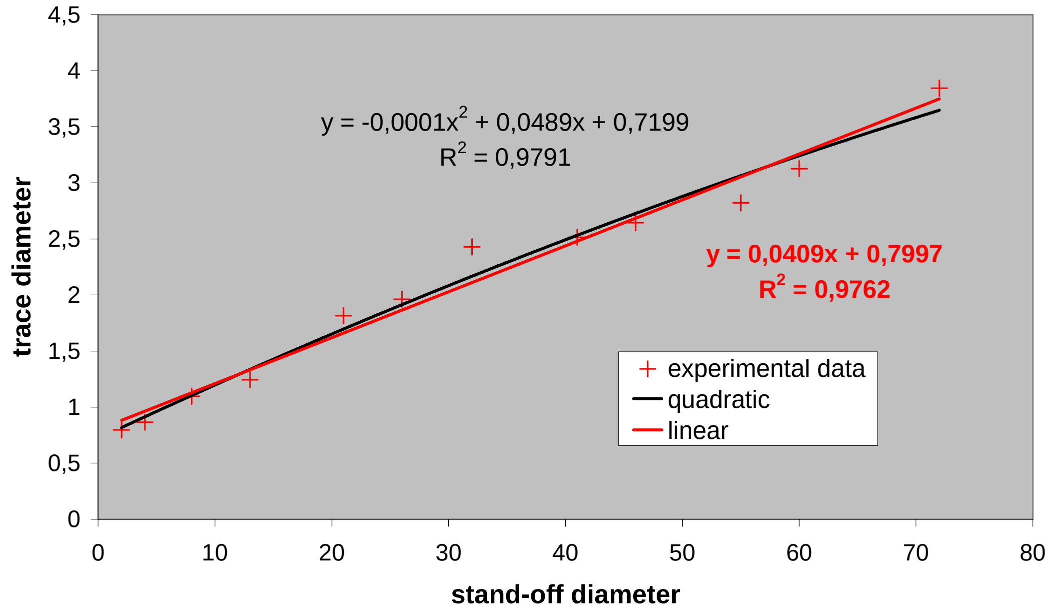

Fig. 4. Graphical evaluation of the waterjet divergency in the free air; traverse speed 10 meters per minute

4. Discussion

Some simplifying assumptions were made during analysis. The first one is that the jet is axial symmetrical. The second one is that the velocity profile is identical in all longitudinal cross-sections of the jet including jet axis. The third assumption is that the velocity profile of the abrasive liquid jet is almost identical with the one of the pure liquid jet, i.e. the outer contour (the liquid-air interface) of the longitudinal cross-section of the jet in the plane including jet axis form the legs of the axial symmetrical trapezium (the shorter base of which is the projection of the outlet diameter of the focusing tube). This assumption, however, was proved to be incorrect because our experimental results proved that presence of the abrasive in the jet leads to significant widening of the jet.

The theoretical value of divergency calculated from the relationship (1) is obviously lower than the measured one, but it fairly corresponds to the value measured for the pure water (3 mrad, i.e. 0.16°). The increasing abrasive supply turned divergency to the worse values – from 2° for the minimum abrasive mass flow rate (traverse speed 2000 mm.min^{-1}) up to 5° for the maximum possible mass flow rate usable with our experimental equipment (traverse speed 2000 mm.min^{-1}).

One of the most important experimental results with unmoving jet is that the surface layers of the sample are damaged even by very slow abrasive particles from the outer zone of the jet. These particles are powerless for further enlargement of the drilled hole, however, taking into account the cover surface of the jet as the interface between liquid jet and pure air this divergency is about 12° whilst the divergency determined from the diameter changes of the drilled holes is about 4°.

Measurement of jet traces on the metal surface (only slight facial damage was prepared) yield information about divergency of the moving jet. For conditions equivalent to the ones of unmoving jet the divergency was 3.73° (traverse speed 2000 mm.min^{-1} - Fig. 3) and 2.35° (traverse speed 10000 mm.min^{-1} - Fig. 4).

Graphical evaluation proved that the waterjet divergency in the free air grows up almost linearly, the quadratic approximation, however, seems to yield slightly better results but the difference is not significant. The jet trace is rather narrower for the higher traverse speed corresponding to the fact that the outer abrasive particles with lower energy have less time to interact with the material and so the damage is less observable.

Some static experiments on wood, ice and plexi-glass samples were carried out as well. Only the last material seems to be suitable for further experiments, the samples made from other two materials were destroyed during piercing because of their internal inhomogeneity (wood) and extreme fragility (ice).

5. Conclusions

It is rather difficult to formulate a general model describing divergency of the abrasive water jet because this quantity is influenced not only by the material physical parameters but also by its structure (homogeneity). Nevertheless, our up-to-date results indicate that it is possible to prepare at least some database of the most common divergency values for significant configurations and materials. This is our further aim.

Acknowledgement

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