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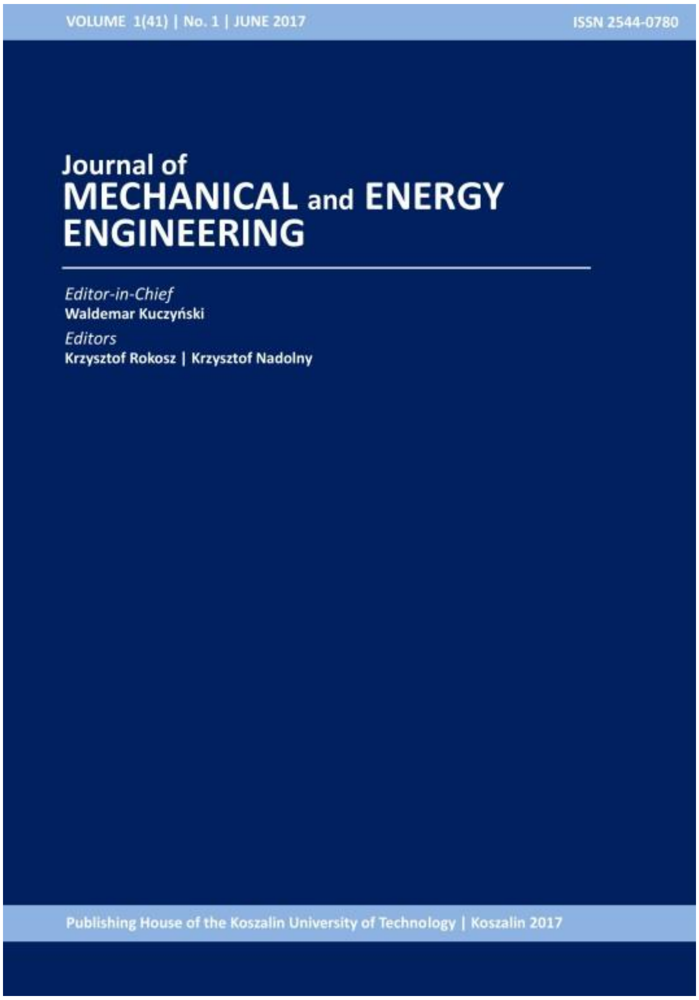

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APPLICATION OF PIV METHOD TO STUDY THE SPEED DISTRIBUTION OF OIL MIST PARTICLES IN THE ORTHOGONAL CUTTING PROCESS

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Abstract: The paper presents the use of the PIV method in experimental studies on the speed distribution of oil particles contained in oil mist delivered into a cutting zone with minimum quantity (MQL). During investigations an orthogonal sample was of an aluminum alloy PA7N was machined using HS18-0-1 high-speed steel cutter. The oil mist was delivered into the cutting zone by a single spray nozzle directed at the tool rake surface. Two angular settings of the spray nozzle were applied in relation to the surface of the machined sample. Based on the images obtained by the PIV method, the distribution of the oil particles in the cutting area was determined according to the setting the spray nozzle. Studies have indicated more favorable conditions for the delivery of oil mist at the angle of spray nozzle at 85°. These conclusions were confirmed by measuring the cutting force in tangential direction to the machined surface.

Keywords: orthogonal cutting, MQL, Particle Image Velocimetry (PIV), cutting force

1. INTRODUCTION

The use of coolants in cutting machining delivered with minimum quantity using MQL method (minimum quantity lubrication) has caused interest in the way oil is sprayed in the cutting zone. This has a direct effect on the lubrication efficiency in the contact area of cutting tool with the workpiece surface, and therefore decides on the machining results (technological quality of the surface layer, tool life).

One of the ways to expand research capabilities and to observe lubricant behavior in the machining zone is to use the Particle Image Velocimetry (PIV) method [1-4].

The goal of the research described in this paper was to observe the behavior of oil mist in the cutting zone and to measure the tangential cutting force for specific machining conditions. The limited technical capabilities of the PIV method have led to the use of orthogonal cutting. This type of cutting allows to analyze the process in a two-dimensional system, using the full advantages of the PIV method.

2. MEASUREMENTS USING PIV METHOD

The PIV method involves brushing a narrow stream of light (mostly laser) into a fluid region in which fine particles of another phase are scattered, called the seeds, and registering images of the particles. The seeds, in the form of fine particles of solids, is illuminated in the flow plane by two laser pulses, which follow shortly one by one. The time of a single laser pulse is several nanoseconds, while the time between pulses is several microseconds. Diffusion of light through the droplets allows the camera to record images with high speed and spatial resolution. The obtained image is analyzed by means of classical macular photography, usually through analogue or digital fourier processors. As a result, the absolute velocity components of the particles lying in the illuminated measuring plane [5, 6] are obtained.

The diagram in Figure 1 shows the principle of measuring the flow of oil mist using the PIV method. As a seed, small particles of oil were used in the compressed air and carried with it. The flow plane is illuminated twice with a laser (the time between pulses is determined by the average flow velocity). The light reflected from the particles is recorded on a special CCD sensor, and then the image is transferred to the computer.

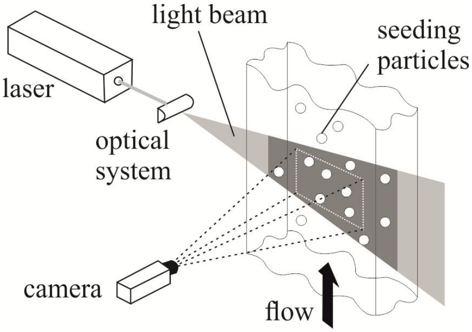

Fig. 1. Typical stand for the PIV method

For further computer processing, the digital image is divided into smaller basic fields. Then the local vector of displacement of two images of the seed molecules is determined for each base field (using auto- and cross-correlation methods). The value of the velocity vector for each particle is calculated from the known value of its displacement and the time *Δt* between the two mentioned images.

3. MATERIALS AND METHODS

A test stand was used for the study, the diagram of which is shown in Figure 2.

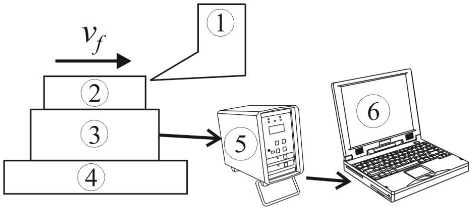

Fig. 2. Experimental stand –track for cutting force measurement: 1) tool, 2) workpiece, 3) special dynamometer holder, 4) worktable, 5) charge amplifier, 6) data acquisition card + computer

Orthogonal cutting tests were performed on a milling machine at which the cutting speed is achieved through the table feed system. A specially designed handle was attached to the machine table along with the KISTLER type 9272 piezoelectric dynamometer. The test samples were fastened to the fixture. In addition, KISTLER 5019A, KISTLER 2855A4 and KISTLER DynoWare 2825A were included in the cutting force measurement circuit.

During the study, PA7N aluminum alloy was cut. Samples dimensions were: 50 × 60 × 2 mm. As tool, HS18-0-1 high-speed steel knife with a relief angle of 8° and an attack angle of 35° was used. The following cutting parameters were used: cutting depth $a_p = 0.5$ mm, table feed speed $v_f = 0.2$ m/s.

To generate the oil mist using MQL method single-channel MicroJet MKS-G100 device by Link (Germany) was used as well as oil type MICRO 3000 supplied by the manufacturer of the device. The spray nozzle delivered the oil aerosol to the knife attack surface with an oil flow rate of 15 ml/h. Two angular positions of the spray nozzle in relation to the workpiece surface were applied: 1) 45° (Fig. 3a) and 2) 85° (Fig. 3b). For comparison cutting trials without using any type of coolant were performed (Dry Machining).

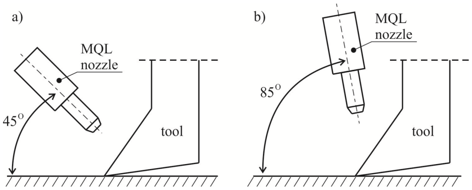

Fig. 3. Setting of the spray nozzle in the cutting zone: a) at an angle of 45°, b) at an angle of 85°

For the research using the PIV method, the experimental position of the Department of Thermal Technology and Refrigeration Engineering of the Lodz University of Technology was used [7].

4. RESULTS AND DISCUSSION

Figure 4 shows an images of an oil mist stream made with a CCD camera which were a part of a PIV stand. Depending on the setting of the spray nozzle, the oil mist was delivered to the cutting surface at 45° (Fig. 4a) and 85° (Fig. 4b) according to the machined surface.

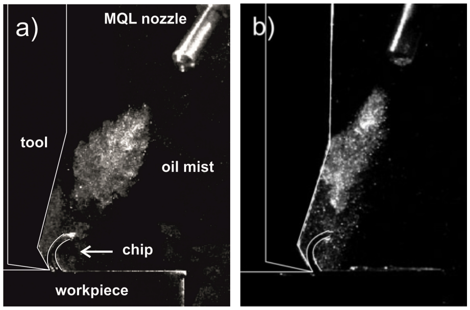

Fig. 4. Decomposition of oil molecules in the oily mist delivered with minimal quantity into the cutting area for: a) 45°, b) 85°; Image taken with CCD camera by PIV method (splitting image into basic fields)

By analyzing the behavior of the sprayed oil particles in the cutting zone, it is clear that in the first case (Fig. 4a), the oil mist filled the space between the rake face and the chip, penetrating into the machining zone (zone of contact between tool and workpiece surface). Increasing the pitch angle of the spray nozzle (Fig. 4b) reduced the amount of oil particles entering the cutting zone.

Figure 5 shows the selected oil mist delivery sequence between the rake surface and the chip which is formed.

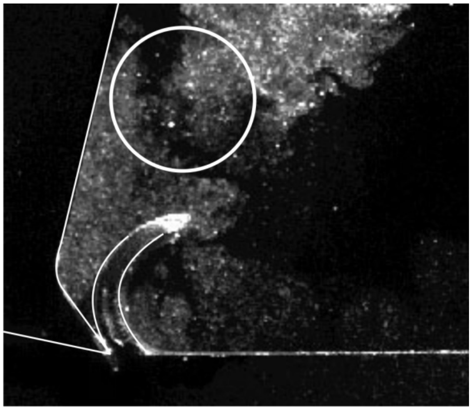

Fig. 5. Image of interaction area of the oil mist delivered with minimum quantity (MQL); 3-times magnification (spray nozzle at 45°)

The image was magnified 3-times to further trace the behavior of the oil particles contained in the compressed air. On the image can be observed the differentiation of their size, apart from mist appears also particles greater than 0.2 mm. This is clearly visible on the area indicated by the circle on Fig. 5. The resulting chip and its shape promote the growth and accumulation of oil molecules between the frictional surfaces.

To explain the reason for changing oil mist behavior according to the angular setting of the spray nozzle, vector distributions of total velocity of oil particles in compressed air were developed. Figure 6 shows the total vector velocity vector superimposed on the image recorded using a CCD camera at a 45° nozzle slope. Fig. 7 shows an analogous distribution for the 85° nozzle inclination. In both cases, there is also a decomposition without a superimposed CCD image.

As it appears from the images above, setting the spray nozzle angle at too high value (in this case 85°), causes bouncing off some oil molecules from the cutting tool and chip. As a result, fewer oil mist particles arrive at the point where the tool is contacted with the workpiece, thereby degrading lubrication.

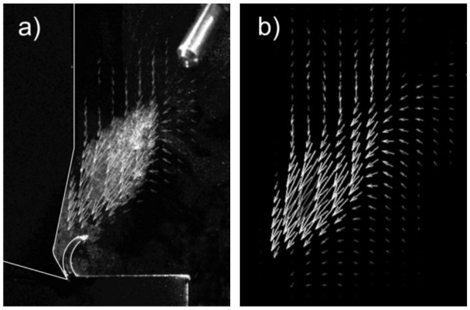

Fig. 6. Vector distribution of the total speed of the oil mist particles: a) superimposed on a CCD camera image, b) without an image (spray nozzle at 45°)

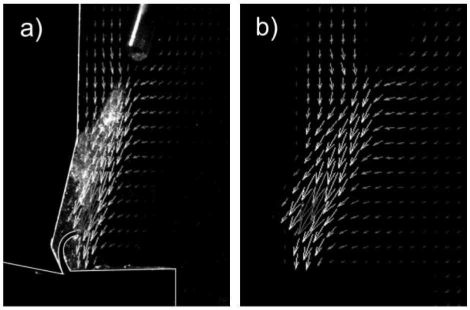

Fig. 7. Vector distribution of the total speed of the oil mist particles: a) superimposed on a CCD camera image, b) without an image (spray nozzle at 85°)

Using the software provided with the PIV stand, the maps of the total velocity distribution of the oil mist particles (Figure 8) and the map of the spiral fields (Fig. 9) were elaborated. This analysis allows to precisely define all phases and areas of velocity in the lubricant stream.

Irrespective of the incision angle of the spray nozzle, the images obtained from the experiments have some distortions resulting from the considerable difference in the width of the workpiece to the width of the tool. The maximum velocity of the oil mist in the nucleus was approximately similar in both cases (4.116-4.328 m/s). It should be noted that for a nozzle set at 85° the nucleus was closer to the chip, which led to the introduction of large oil mist swirls. The oil molecules, after being reflected from the creating chip, penetrated extensively beyond the contact area between tool and the workpiece surface. Changing the nozzle position relative to the individual elements involved in the cutting process has therefore resulted in a change in the particle vortex from positive to unfavorable.

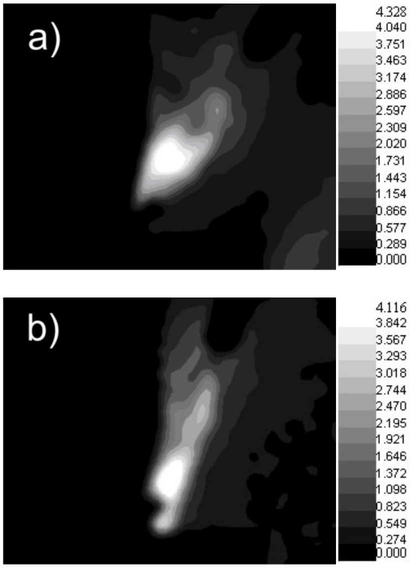

Fig. 8. Maps of total velocity distribution fields (in m/s) of oil mist particles – spray nozzle set at an angle: a) 45°, b) 85°

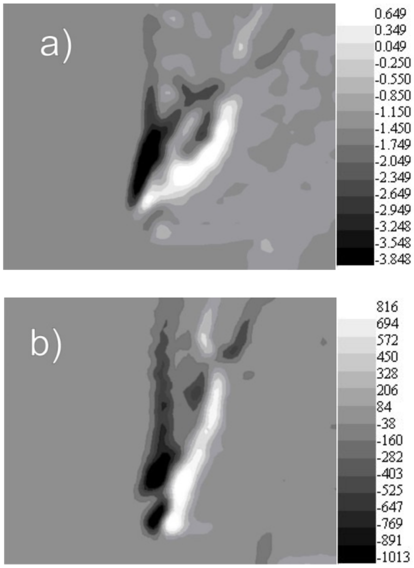

Fig. 9. Maps of the distribution of vortex fields (in 1/s) of oil mist particles – spray nozzle set at an angle: a) 45°, b) 85°

Figure 10 shows the values of the cutting force F_t measured tangentially to the workpiece surface obtained during the experiments. The values obtained during dry machining (DM) and machining using oil mist (MQL), respectively, were compared from the side of cutting tool attack surface for two angular spray nozzle settings: MQL_45 and MQL_85.

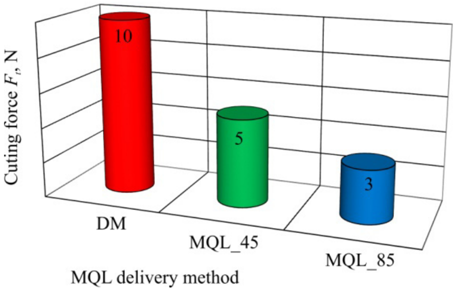

Fig. 10. Comparison of F_t cutting force values according to oil mist delivery conditions

As shown in Fig. 10, the MQL method results in a lower F_t cutting force values compared to machining without using a coolant (DM). This indicates improved cutting conditions through better lubrication in the tool-to-workpiece contact area.

Figure 10 also indicates that the value of the cutting force F_t depends on the method of introducing the oil mist. The force values obtained for the two angular positions of the spray nozzle (MQL_45 and MQL_85) confirm the observations resulting from PIV image analysis. Differences in force values in both cases indicate the high impact of the angular position of the spray nozzle affecting the lubrication conditions in the cutting zone.

5. CONCLUSIONS

Based on the studies and analyzes performed, the following conclusions can be made:

1. The PIV method is effective for investigating the distribution of microparticles of coolants in cutting processes using 2D layout. For cutting tools with complex shapes, the PIV 3D method should be used. However, it is very expensive due to specialized hardware and software.
2. The PIV method allows to determine the speed of the oil molecules contained in the oil mist in the cutting zone. It also allows the analyzes of results of oil particle distribution studies in the form of vector maps or vorticity maps. In cutting processes this is important because of their complexity. Optimizing the cutting process and coolant delivery direction in this case is very important in view of the degree of wetting and lubrication of the components directly cooperating with each other.
3. The method of setting the spray nozzle and the choice of the surface to which the coolant is delivered is important because of the forces that appear during cutting process. It seems that this should result in wear of tool tip and significantly affect the quality of the machined surface.

4. In further investigations, it is necessary to extend variability of the cutting parameters and to use a greater number of spray nozzle positions.

References

1. Iskandar Y., Tendolkar A., Attia M.H., Hendrick P., Damir A., Diakodimitris C. (2014). Flow visualization and characterization for optimized MQL machining of composites. *CIRP Annals - Manufacturing Technology*, vol. 63, iss. 1, pp. 77-80.
2. Rahim E.A., Dorairaju H., Asmuin N., Mantari M.H.A.R. (2015). Determination of mist flow characteristic for MQL technique using Particle Image Velocimetry (PIV) and Computer Fluid Dynamics (CFD). *Applied Mechanics and Materials*, vol. 773-774, pp. 403-407.
3. Diakodimitris C., Iskandar Y.R., Hendrick P., Slangen P. (2013). New approach of gas-liquid computational fluid dynamics simulations for the study of minimum quantity cooling with airblast plain-jet injectors. *Journal of Manufacturing Science and Engineering*, vol. 135, iss. 4, DOI: 10.1115/1.4024632.
4. Wójcik R. (2008). Application of new kinds of cooling media and supplying methods during surface grinding. *Archives of Mechanical Technology and Materials*, vol. 28, no 4, pp. 137-145 (in Polish).
5. FLOWMAP (2000). *Particle Image Velocimetry instrumentation, installation and user guide*, Dantec Measurement Technology.
6. Adrian R.J., Westerweel J. (2011). *Particle Image Velocimetry*. Cambridge University Press, New York.
7. Sawicki J., Wójcik R., Górecki G. (2010). Utilization of PIV method and computer simulation in determinatin of surface layer state in surface grinding process. *Materials Engineering*, no 4, pp. 1203-1205 (in Polish).

Biographical notes

Ryszard Wójcik received his M.Sc. degree in Mechanical Engineering in 1988. In 1997 he defended his PhD thesis in the field of Machine Construction and Operation, and in 2008 he obtained the postdoctoral degree of habilitated at the Faculty of Mechanical Engineering of the Lodz University of Technology. In 1975 he started working at the Institute of Machine Tooling and Machine Building Technology at the Lodz University of Technology where he is currently employed as an Associate Professor. His research activities focus on issues related to the surface layer constituted during cutting process, monitoring of processes as well as analysis of an aerologic systems. He participated in 10 national research projects as well as dozens of international and national conferences. He has published more than 80 scientific papers in international and national journals and conference materials. He is the author of 4 monographs and 6 national patents.

Wojciech Stachurski received his M.Sc. degree in Production Engineering and Ph.D degree in Machinery Construction and Operation from Lodz University of Technology, in 2001 and 2008, respectively. Since 2003 he has been a researcher in the Institute of Machine Tools and Production Engineering at the Lodz University of Technology, where currently he works as an assistant professor. His scientific interests focus on abrasive processes, technological researches of the surface texture as well as wear and durability of cutting tools. He has participated in 3 national research projects as well as 5 international and 13 national conferences. He has published more than 50 scientific papers in various international and national journals. He is also the author of 2 national patents.