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INFLUENCE OF ROTATION WATER JET KINEMATICS ON EFFECTIVENESS OF FLAT SURFACE TREATMENT

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ABSTRACT

Analyses of surface treatment effectiveness using rotational multi-orifice nozzles are presented in the paper. Theoretical models of such jet traces distribution during flat surface treatment operations are presented too. Criteria of after-treatment traces distributions and their influence on rotational nozzles kinematics are also discussed in. Presented analytical results point out an influence of such most important kinematical parameters like: traces width, rotational velocity and feed rate of nozzles equipped with different orifices number, on such kind surface treatment efficiency.

1. INTRODUCTION

The surface treatment using the high-pressure hydro-abrasive jet requires to a certain degree a homogeneous distribution of post-machining marks. It is especially important in case of machining with a rotary head. Under such the conditions, the stream marks are formed in the shape of prolate cycloids, which sometimes, especially in case of multi-nozzle heads form complicated systems of trajectories (Borkowski J., Borkowski P., Budniak Z., Chomka G., Sobczak R., 2003).

Analyzing the system of such the post-machining marks makes it possible to evaluate a series of interesting process variables. One of the more significant issues is the effectiveness of the surface treatment, especially the possibility to optimise the kinematics of whirling water stream. The present work could be considered as universal in character because it includes analyses of many features common to different methods of the surface treatment using the high-pressure hydro-abrasive jet (Borkowski P., 2002).

2. ROTARY HEAD CHARACTERISTICS

A rotary head furnished with 1 to 5 water nozzles has been analyzed. Due to a twisted arrangement of nozzles in a two- or four-orifice head developed in this study, the rotational self-driving system was obtained. The flat shape of the casing makes it possible to obtain the aerodynamic braking, therefore the rotational speed of such the heads usually will not exceed 15 s^{-1}. An RD 3000 three-orifice head made by Hammelmann, which owing to the aerodynamic braking does not exceed the limit of 15 s^{-1} as well, is also marked by self-driving design. Such the heads can find application to high-pressure guns of the simplest, lance-type design (e.g. an SP 30 type). Next stationary one- and five-orifice heads characterized by the simplest design would require SP 3000 rotational spray guns made by Hammelmann. All of these heads are furnished with “P” type sapphire orifices 0.25÷1 mm in diameter.

Figure 1 illustrates a diagram for the flat-surface treatment using a rotary head.

3. TRAJECTORIES OF POST-MACHINING MARKS MADE BY ROTARY JET

Trajectories of post-machining marks made by rotary jet in motion are formed in the shape of prolate cycloids (Fig. 2). It is a curve drawn by point P positioned on an extended radius of a circle rolling without slipping along the straight line. Its parametric equation is expressed by the following formula:

$$\left.\begin{aligned} x &= r\cos(\varphi_0 - \varphi) + v_g t = r\cos(\varphi_0 - \omega t) + v_g t, \\ y &= r\sin(\varphi_0 - \varphi) = r\sin(\varphi_0 - \omega t), \end{aligned}\right\} \tag{1}$$

A typical example of trajectories of post-machining marks produced on the flat surface machined with a symmetric rotary head is presented in Fig. 3. Two characteristic regions could be distinguished on the “network” of these marks:

- central zone (A), where trajectories of streams are intersecting at small angles and are practically perpendicular to the direction of the head advance,
- peripheral zones (B), the most distant ones from the central axis of such the collective mark, where angles of intersection of these jet trajectories are very large, while they alone are arranged almost parallel to the direction of the head advance.

4. ANALYSIS OF POST-MACHINING MARKS DISTRIBUTION

An arrangement of marks presented in Fig. 3 makes the surface in central zone (A) is much less accurately cleaned then in peripheral zones (B). An analysis of the shape and the surface areas distributed between such the marks revealed a distinct influence of the head advance. Examples illustrated in Fig. 4 show it distinctly. Significant differences occurred also when heads with nozzles arranged at different angles (Fig. 5) and on different radii (Fig. 6) were applied.

5. MODEL OF SUFACE TREATMENT USING WHIRLING WATER JET

Mostly multi-orifice rotational heads are used for the efficient surface treatment. However, a theoretical model of such surface treatment is easier to develop for a single water jet making use of a diagram presented in Fig. 7.

An analysis of geometric relations following from this diagram makes it possible to calculate the radius P that appears on the post-machining mark as:

$$P = \sqrt{L^2 \cdot tg\varepsilon^2 + R^2 + 2 \cdot L \cdot R \cdot tg\varepsilon \cdot \sin\delta} \tag{2}$$

BA trajectory of post-machining marks could be determined after analysing the relative motion of the head, where the relative motion is a rotary motion of the head with the velocity n, however the transportation is the longitudinal advance v_g. This creates the basis enabling to determine the values of the nozzle-orifice coordinates in relation to the local coordinates X_w, Y_w.

$$\left.\begin{aligned} \frac{X_{cw}}{P} = \cos\alpha_c \Rightarrow X_{cw} = P \cdot \cos\alpha \\ \frac{Y_{cw}}{P} = \sin\alpha_c \Rightarrow Y_{cw} = P \cdot \sin\alpha_c \end{aligned}\right\} \tag{3}$$

Then, the total coordinates of post-machining marks on the work material surface could be calculated as a sum of coordinates of transportation and relative motion:

$$\left.\begin{aligned} X_c = X_{ow} + X_{cw} \\ Y_c = Y_{ow} + Y_{cw} = Y_{cw} \end{aligned}\right\} \tag{4}$$

In a mathematical model, the adequate analogue terms are assigned to the real terms, and the analogue diagram is developed by adequate method of modeling respecting the transformations of real coordinate systems into mechanical coordinate systems.

Approaching the specific model of the flat surface treatment using the multi-nozzle heads, five heads from the above-mentioned rotary heads have been taken into consideration.

A MatLab computer program was used to make the calculations and draw the diagrams. This program was supplemented with a CYKLO.M additional program allowing the diagrams with cycloids to be subject to a thorough analysis.

6. EFFECTIVENESS OF THE SURFACE TREATMENT WITH ROTARY JETS

The theoretical effectiveness of the surface treatment is expressed by the ratio of the total number of marks produced during this process to the whole area of the work surface, i.e. determined by the overall dimensions of the mark affected by whirling jets flowing out from the working head.

An analysis of the effectiveness of cleaning the surface with a high-pressure water jets was carried out using the graphic display in a **.jpg* format, showing the post-machining marks produced while cleaning by the rotary head. The drawings, which were used for analysis, were prepared for different adjustable process parameters of the surface treatment.

This is exemplified by Fig. 8 consisting of three parts. The main part illustrates the machined surfaces (shaded) which follows from the post-machining marks presented in the form of self-crossing prolate cycloids. The other two diagrams illustrate the distribution of the effectiveness of surface treatment (showing the accuracy of surface cleaning approaching to 90%) after the crosswise and lengthwise passing of the water jet.

When the total covering of the work surface was obtained, which responses to the totally dark spot in the main drawing, the diagrams of the machined surface fraction, presented in the two other drawings, assume the shape of a straight line indicating a 100% level.

7. INFLUENCE OF KINEMATIC PARAMETERS ON SURFACE TREATMENT EFFECTIVENESS

7.1. Influence of the marks width produced by the jet

The width of the mark produced by the water jet on the work surface exerts the crucial effect on the effectiveness of such the treatment. This width mainly depends on the diameter of the nozzle and the water pressure. To obtain the marks similar in width the nozzles with the largest diameter should be mounted in the most distant hole of the head from its axis of rotation, whereas the nozzles with the smallest diameter should be arranged as near as possible to this axis.

An influence of the width of the mark, represented by the diameter of the nozzle, on the effectiveness of cleaning the flat surface is presented in Fig. 9.

Each of the rotary working head under the analysis produces the system of marks different in width. Nevertheless, the calculated effectiveness of the surface treatment is correct because its evaluation is based on the comparison of the total area of marks produced during the process with the overall dimensions of the work surface. So, one can understand why the highest effectiveness of the surface treatment was each time obtained on the external edges of the post-machining marks which were thickened there to the maximum. It was found from the analysis of the simulation calculations, which are presented in Fig. 9 that the most marked influence on the theoretical effectiveness of the surface treatment by water jet was exerted by the number of active nozzles of the working head. Also increased diameters of the nozzles being applied, decisive in the width of the individual elementary water jets, had the noticeable effect on the above-specified effectiveness.

It should be admitted respecting the quality reasons, that the satisfactory effects of the surface cleaning (over 95%) were already obtained at the width of the jet formed using the head furnished at least with two jets 0.45 mm in diameter.

7.2. Influence of the rotational speed of the head

An influence of the rotational speed of the heads with a different number of nozzles on the effectiveness of the flat surface treatment is illustrated by the plots of Fig. 10.

An analysis of the systems of the post-machining marks and their plots revealed that on increasing the rotational speed of the working head and the number of its nozzles, also the effectiveness of the surface cleaning should be increased. Good results of the surface treatment (over 95% of potential effectiveness of treatment) was obtained in practice for three-nozzle working heads rotating at speeds over 3.3 s^{-1} and two-nozzle heads rotating at speeds over 4.1 s^{-1}, however such the effectiveness was guaranteed by the head furnished only with a single nozzle at speeds over 5 s^{-1}.

7.3. Influence of the travel speed

It is understood that on increasing the speed of travel of such heads, the effectiveness of the surface treatment was diminishing. An example illustrating the influence of such the speed on the effectiveness of the flat surface cleaning is given in Fig. 11.

It follows from the experimental results that the most effective method of increasing the qualitative effectiveness of the cleaning consists in diminishing the speed of travel of the working head, which causes the post-machining marks to be thickened. At the lowest speeds considered here, of the order of 11 mm/s, the satisfactory effectiveness of the treatment (95%) could be obtained using even the rotary heads furnished only with a single nozzle. In case of the rotational speed analyzed here (1.7 s^{-1}) the unsatisfactory qualitative effects of the flat surface treatment occur at the speed of travel of the working head just above 20 m/s, regardless of the number of the nozzles applied.

8. CONCLUSIONS

The discussion conducted in the present paper made it possible to develop the relevant computer application, which enabled to carry out a simulation of the processing and optimize the effectiveness of the surface treatment using the rotary head. From the above the following conclusions more general in character could be drawn:

- The high-pressure water jet formed by the rotary working head, which makes the advancing motions, creates the post-machining marks in the shape of prolate cycloid. At the same time, the highest effectiveness of the surface treatment was each time obtained on the external edges of the post-machining marks, which were thickened there to the maximum.
- The width of the mark produced by the water jet on the work surface, which fundamentally affects the effectiveness of such the treatment, mainly depends on the diameter of the nozzle and the water pressure.
- An increase in the rotational speed of the working head and the number of nozzles leads to an increase in the qualitative effectiveness of the surface treatment.
- The most effective method for increasing the qualitative effectiveness of the surface treatment consists in diminishing the speed of travel of the working head, which causes the thickening of the post-machining marks.

9. ACKNOWLEDGEMENTS

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10. REFERENCES

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11. NOMENCLATURE

r – radius of rolling circle,
φ_0 – initial angle of P point position for t=0,
ω – angular velocity of the head,
v_g – axial velocity of the head,
S_w – orifice on a face of a nozzle,
K_w – mark of a point being analysed on the work surface,
P – radius of a post-machining mark,

R – radius of an outlet whole in the head,
L – distance between the face of a nozzle and the work surface,
ε – angle between axes of the jet and the head,

12. GRAPHICS

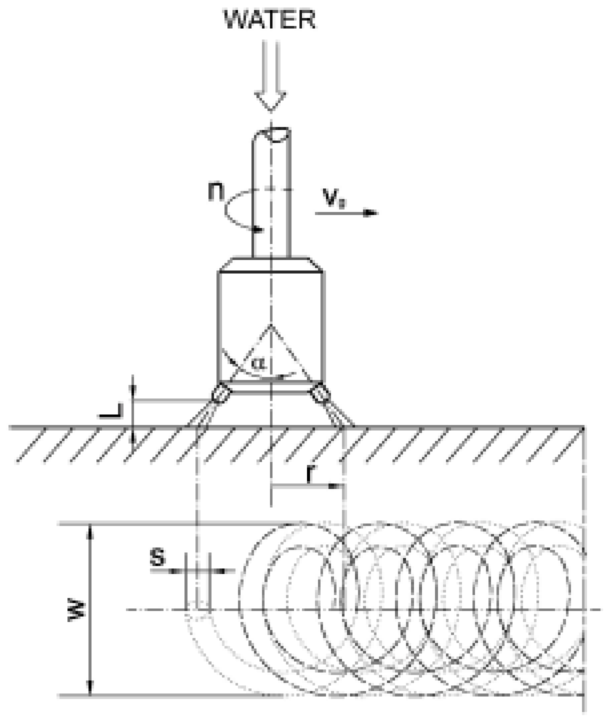

Figure 1. Schematic view of flat surface treatment using rotary head equipped with two water nozzles

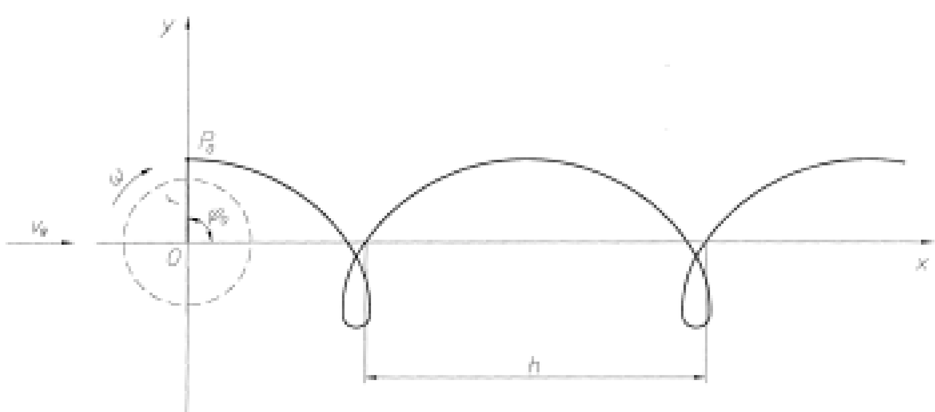

Figure 2. Schema of prolate cycloid creation

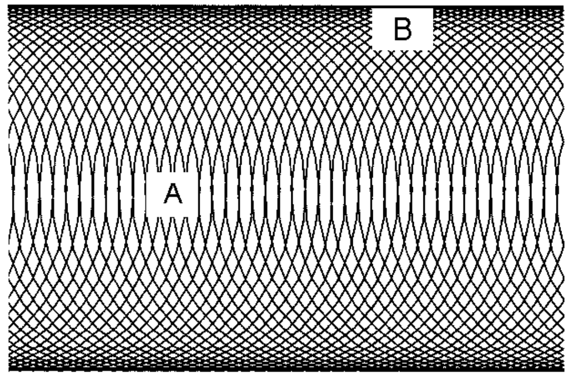

Figure 3. Trajectories of post-machining marks

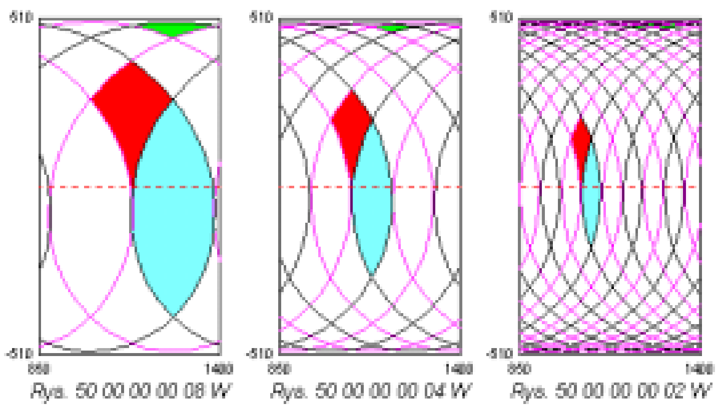

Figure 4. Influence of nozzle feed rate on post-machining marks concentration

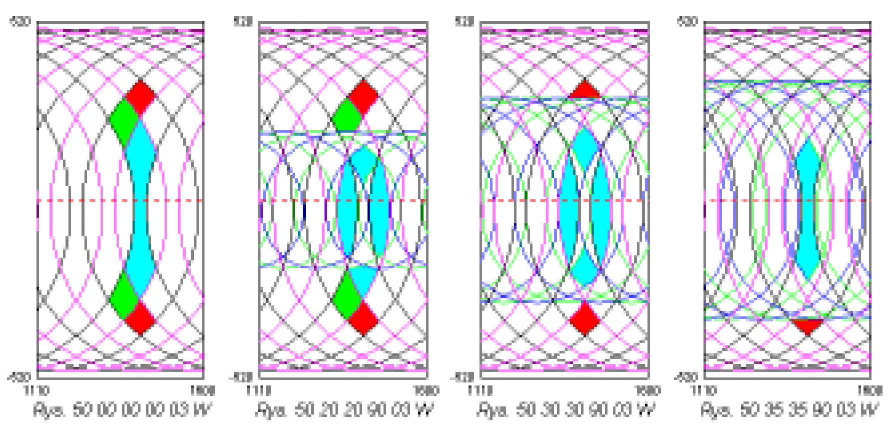

Figure 5. Influence of two extra orifices characterized by different radius displaced in 90° regarding 1 and 2 orifices on post-machining marks concentration.

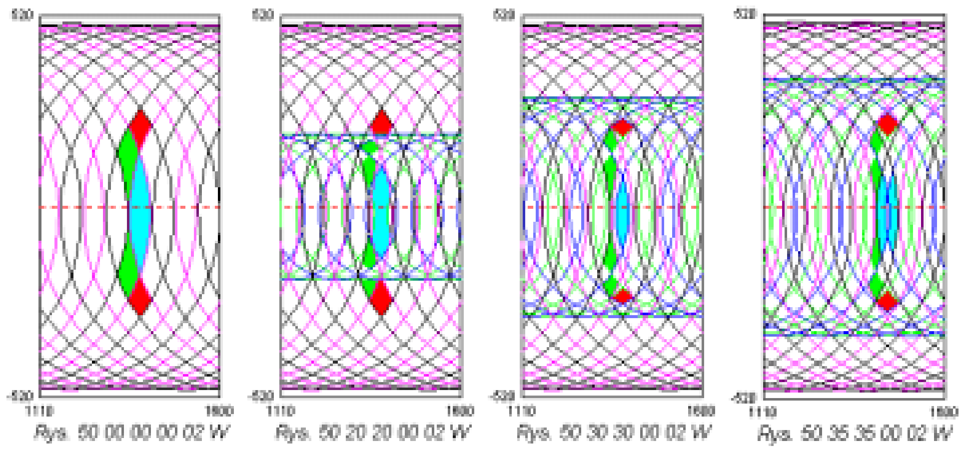

Figure 6. Influence of 2 extra orifices characterized by different radius displaced symmetrically and synchronized on post-machining marks concentration

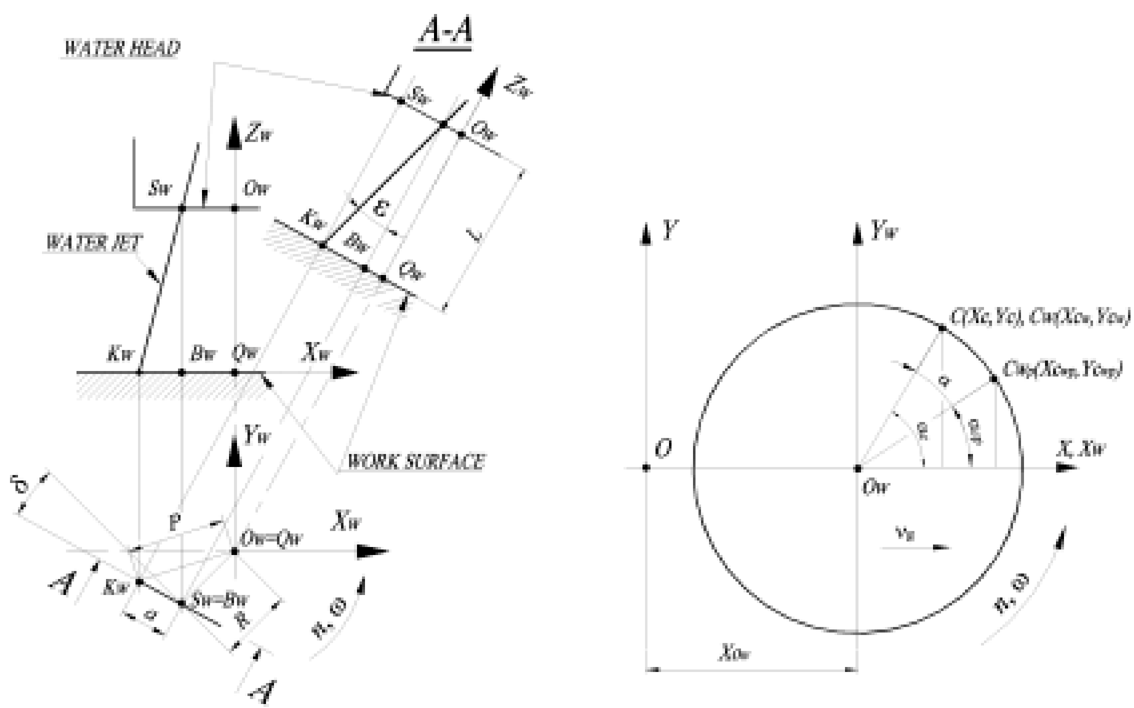

Figure. 7. Analytical schema of surface treatment using one-orifice rotary nozzle

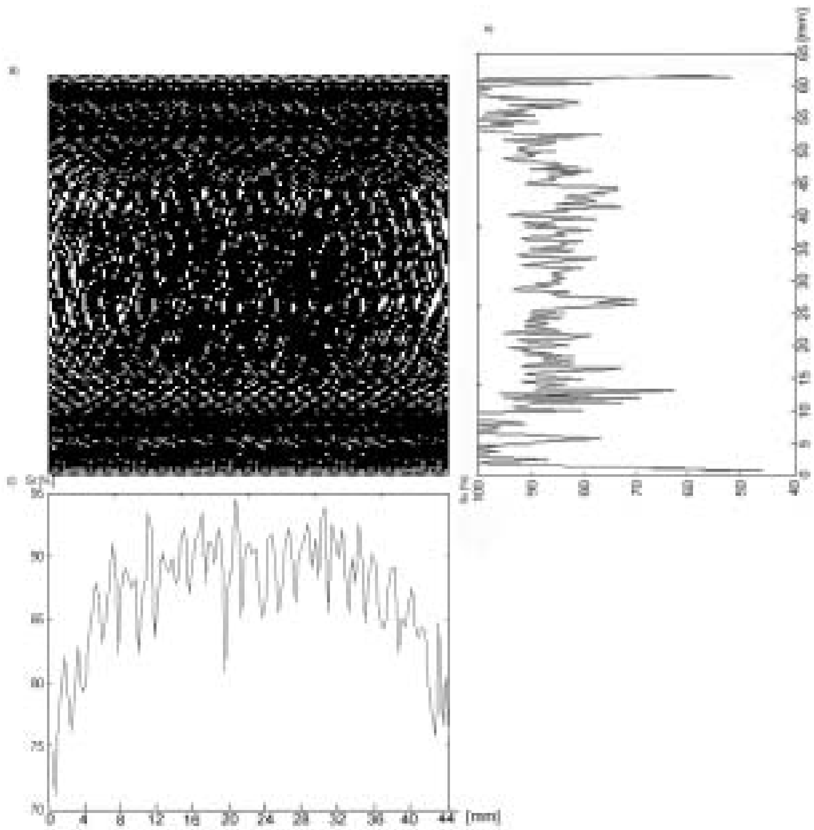

Figure. 8. Surface treatment effectiveness using 5 orifices nozzle (n_o=1,7 s^{-1}, v_g=25mm/s, L=100 mm for d_w= 0,3 mm), where: a) view of post-machining marks on surface, b) percentage participation of treated surface all along the sample width, c) percentage participation of treated surface all along the sample length

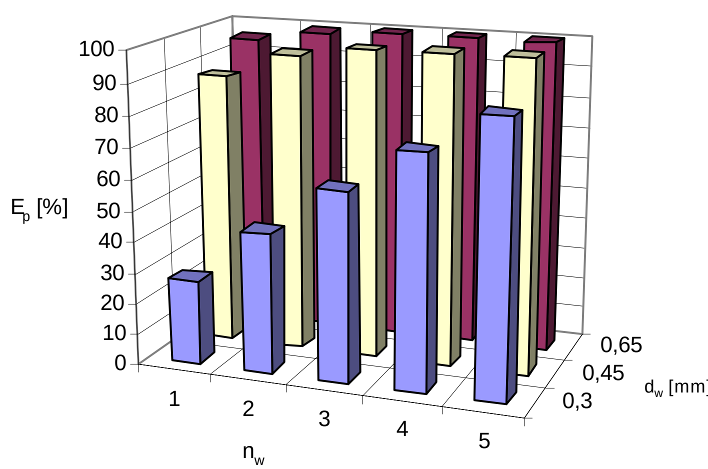

Figure. 9. Influence of water orifices number and their diameter on flat surface treatment effectiveness for n=1,5 s^{-1}, v_g=25 mm/s, L=100 mm

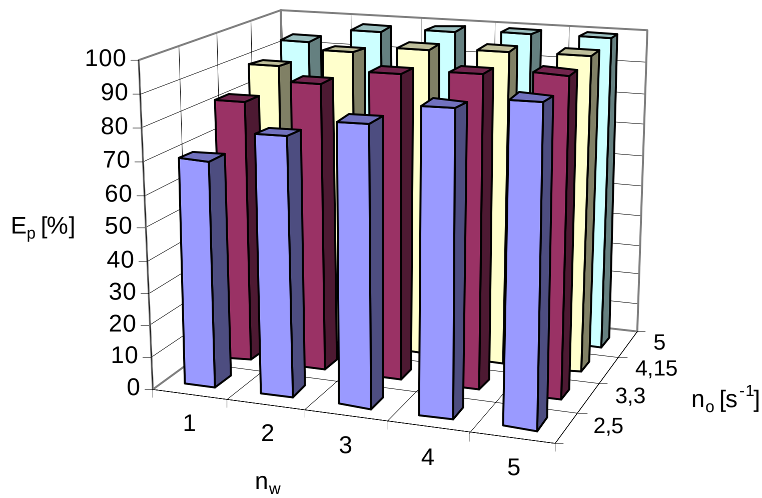

Figure. 10. Influence of water orifices number and nozzle rotary velocity on flat surface treatment effectiveness for d_w=0,35 mm, v_g=26 mm/s, L=100 mm

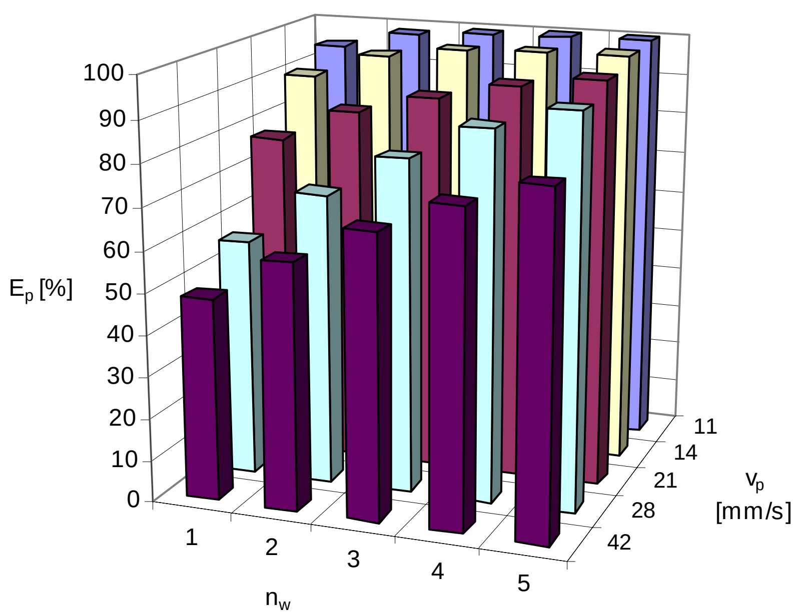

Figure. 11. Influence of water orifices number and rotary nozzle feed rate on flat surface treatment effectiveness for n=1,7 s^{-1}, d_w=0,4 mm, L=100 mm