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# THE USE OF *PLACKETT-BURMAN* PLANS AND THE ANALYSIS OF EXPERT OPINIONS, IN ORDER TO ASSESS THE SIGNIFICANCE OF CONTROLLABLE PARAMETERS OF THE PLASMA CUTTING PROCESS

# WYKORZYSTANIE PLANÓW PLACKETTA-BURMANA I ANALIZY OPINII EKSPERTÓW W CELU OCENY ISTOTNOŚCI PARAMETRÓW STEROWALNYCH PROCESU CIĘCIA PLAZMOWEGO*

*This article evaluates the significance of controllable parameters in the plasma cutting process, using the Plackett-Burman Method and the Analysis of Expert Opinions Method. The plasma cutting process was tested using a WPA-6000 Compakt plasma cutter, on non-alloy steel, of the S235JR EN 10025-2:2007 grade, with a carbon equivalent of 0.35%. The effect of the thickness of the sheet, the current flow rate, the cutting speed, the gas pressure during cutting, the height of the torch during cutting, the pierce delay time and the initial pierce height, were analysed. The research revealed the influence of the controllable parameters tested, in the plasma cutting process, on selected output parameters, surface cut drag lines, the width of the kerf at the inlet and outlet, and the value of the perpendicularity of the kerf on the surface of the base. The greatest influences were recorded for intensity of cutting current, cutting speed and gas pressure during cutting. The results obtained were confirmed by the results of the analysis of expert opinions.*

***Keywords***: *plasma cutting, cutting parameters, the Plackett-Burman method, method for the analysis of expert opinions.*

*W artykule dokonano oceny istotności parametrów sterowalnych procesu cięcia plazmowego za pomocą metody Placketta-Burmana i analizy opinii ekspertów. Badania procesu cięcia plazmowego przeprowadzono przy użyciu przecinarki plazmowej WPA-6000 Compakt na stali niestopowej konstrukcyjnej gatunku S235JR EN 10025-2:2007 z ekwiwalentem węglowym wynoszącym 0.35 %. Analizowano wpływ grubości blachy, natężenia prądu, prędkości cięcia, ciśnienia gazów podczas cięcia, odstępu palnika od blachy podczas cięcia, czasu dziurkowania oraz wysokości startu. Badania ujawniły wpływ badanych parametrów sterowalnych procesu cięcia plazmowego na wybrane parametry wyjściowe, w szczególności na skok śladów cięcia, na szerokość szczeliny na wejściu i wyjściu oraz na wartość prostopadłości szczeliny do powierzchni bazowej. Największe wpływy zarejestrowano dla natężenia prądu, prędkości cięcia oraz ciśnienia gazu podczas cięcia. Otrzymane wyniki badań zostały potwierdzone wynikami analizy opinii ekspertów.*

***Słowa kluczowe***: *cięcie plazmowe, parametry cięcia, metoda Placketta-Burmana, metoda analizy opinii ekspertów.*

## 1. Introduction

Micro- small- and medium-sized production enterprises, wanting to maintain a competitive advantage, introduce both product and process innovations. Process innovations introduce changes in the processes implemented in the company. One of the key production processes, in steel construction companies, is the cutting process where one of the most popular cutting technologies is plasma cutting [16].

Plasma cutting can be used in the unitary or serial production of steel structures, as well as in various types of overhaul and repair works [10], in both conductive and non-conductive materials [16]. The process of plasma cutting consists in melting and ejecting metal from the cutting kerf with a concentrated, plasma electric arc, glowing between the unprotected electrode and the work-piece being cut. The stream temperature of the plasma is influenced by many factors, including electrical, kinematic and technological factors.

The basic plasma cutting parameters are the intensity of the cutting current, the arc voltage, the cutting speed, the type and the pressure, as well as the rate at which the plasma gas flows, the electrode type and its construction, the diameter of the convergent nozzle and the position of the torch, relative to the work-distance [19].

(*) Tekst artykułu w polskiej wersji językowej dostępny w elektronicznym wydaniu kwartalnika na stronie ***www.ein.org.pl***

The incorrect choice of plasma cutting conditions increases the width of the kerf, causes rounding of the upper edges and becomes less than perpendicular. Under other conditions, metal overhangs appear at the bottom edge and there may be no intersection. Along the bottom edge of the cut, dross forms in the form of small, linearly arranged balls of molten material that attach to the surface, creating streaks that are difficult to remove. Also, along the upper edge of the cut, a foamy, somewhat spherical accumulation of molten material collects; however, this can easily be removed. In addition, at the top of the cutting edge, small pieces of molten material collect, randomly [12, 19].

The influence on defects, of the controllable parameters of the plasma cutting process, created during the machining process has been presented in many publications. In [25], the influence of the speed of the feed, on the changes of critical surface features and micro-structure properties, in close proximity to the edges, during plasma cutting, has been shown. The analysis carried out in [3] showed that cutting speed and arc voltage affect the conditions of the formation of the slit and also, that their interaction affects the details when it comes to shaping the slit after cutting. In spite of this, cutting traces may exhibit different profiles, depending on the side under consideration. This effect must be taken into account when designing components for plasma cutting. It has also been emphasised that high-quality parts, viz., Tolerance Class 2, according to ISO 9013, can be obtained as a result of experimental research, aimed at selecting the right values for the parameters of the process.

In [7], the results of testing the width of the slit in the upper and lower zones and the angle of the kerf convergence, are presented and depend on the cutting speed, the thickness of the work-piece and the arc current. A full factor experiment, with three independent variables on two levels, one of the most widespread DoE methods (Design of Experiments) was applied to the present studies. A similar method was used in [4] when investigating the impact of the cutting speed, the flow of the plasma gas and the arc voltage on the quality of the Hardox-400, 12 mm steel cutting surface. In [20], the impact of four parameters was analysed, viz., the impact on the cutting speed, the cutting current, the gas pressure and the height of the torch from the surface of the object and also, their impact on surface roughness, the depth of heat affected zone (HAZ) and the deviation from perpendicularity when cutting S235 steel- with a thickness of 15 mm.

Analysis was carried out using the Taguchi method, which was also used in [5], for analysing the impact, on the air pressure, of the diameter of the nozzle, the velocity, the cutting current and the voltage of the arc and the rate of penetration of the hole in the steel plate. It was shown that when using the $3^4$ plans, 81 combinations are required, whereas Taguchi Type L9 plans required a much lower number of combinations.

In [25], a mathematical model was developed in order to optimise the impact of the  cutting current, the arc voltage, the cutting speed, the value of the ratio between the cutting height and the start height, the shielding gas pressure and the ratio of allowance to the required width of cutting on the input parameters of the machining process which include the cutting width in the upper and lower parts, the deviations in the kerf sizes at the top and bottom, the angle of inclination of the cutting traces, the roughness of the surface, the rate of dross removal, the percentage ratio (%) between the length of the edges covered with dross and flash/runoff and the total length of the cut. In [14], the laser and plasma, employed in cutting the sheets and boards from medium and high-strength steels, was optimised. As independent parameters, the intensity of the current, the cutting speed, the distance between the nozzle and the object and gas pressure were used. Deviations from perpendicularity, with regard to the kerf, the roughness of the surface after cutting, as also the dimensions of the dross were optimised. In [13], it was found that when cutting thick, steel plates, the correct choice made, regarding the intensity of the cutting current, as well as the cutting speed, affects the width and the straightness of the cut as also the roughness of the cut surface and the depth of the thermal influence zone. The cutting quality of S355 structural steel was examined in [24]. It was found that when controlling the cutting speed, the topography of the cutting surface and the micro-structure of the thermal influence zone depend on the type of gases used. Investigations of the thermal impact zone for the austenitic plasma cutting of steel with a thickness of 10 - 30 mm and cutting speeds of 710 - 2030 mm/min, were carried out in [15]. It was found that these factors significantly affect structural changes and the micro-hardness of the zone analysed.

Thus, many factors are important in the plasma cutting process; this makes it difficult to regulate and ensure that the requirements of ISO 9013 are complied with. The few attempts to use DoE methods for this purpose either significantly limit the number of factors studied or require a large amount of research. The use of the Taguchi method requires the implementation of tests at several variable levels, which is not always easy. As a solution to the problem, DoE uses and applies methods such as the Plackett-Burman plans. These are the saturated plans, so-called, which require a number of tests, viz., N=k+1, where k - the number of variables tested- which should be a multiplicity of 4.

At present, saturated plans for 4, 7, 11, 15, 19, 23, 27, 31, 35, 39, 43, 47, 63 and 127 variables have been developed [9]. Such plans are widely used in various research areas, in such as the production of nanoparticles [21], drugs [8, 11], polymers [1], and fuel production [2]. The development of the Plackett-Burman method is presented in [18, 22]. The limitation of the above-mentioned plans is the requirement to ensure that tests are carried out at strictly defined points, which limits the scope of changes in the factors analysed. On the other hand, this method affords the opportunity to perform accurate statistical calculations, in particular, to calculate multidimensional linear regression coefficients [9, 23].

The purpose of the present study is to assess the significance of controllable parameters in plasma cutting, using Plackett-Burman plans and expert assessment methods.

## 2. Test conditions

One of the most widely used types of steel in steel construction was used for the present research, namely, unalloyed structural steel of the S235JR EN 10025-2: 2007 grade- formerly St3S steel- with a carbon equivalent of 0.35%.

Tests on plasma cutting were carried out using the WPA-6000 Compakt plasma cutter with a SMART CNC control programme equipped with a table with CNC control and the 133WDM ForCut plasma source. The cutter was equipped with two burners, *viz.,* a plasma burner for cutting boards, with a thickness of up to 30 mm and a gas burner for cutting boards, with a thickness of up to 150 mm. Compressed air was applied as a plasma-forming and protective gas and was supplied to the cutting zone through air filters and a dryer. An illustration of the plasma cutting and the basic schematic of plasma torch, are shown in Fig. 1.

An analysis was performed of the influence of the controllable parameters of the plasma cutting process, on the output parameters of 7, technological factors, namely sheet thickness, cutting current, cutting speed, gas pressure during cutting, height of the torch during cutting, pierce delay time and initial pierce height. The elimination analysis plan, based on the Plackett-Burman method, is presented in Table 1.

The range of changes in the factors studied, was selected experimentally, so that all associations of values could be realised. In Fig. 2 the cutting parameters examined along with characteristic views of the samples are presented. The following cutting parameters were examined, namely, the cutting stroke traces (P), the width of the kerf at the entrance (sg) and at the exit (sd), the height of the discharges/dross

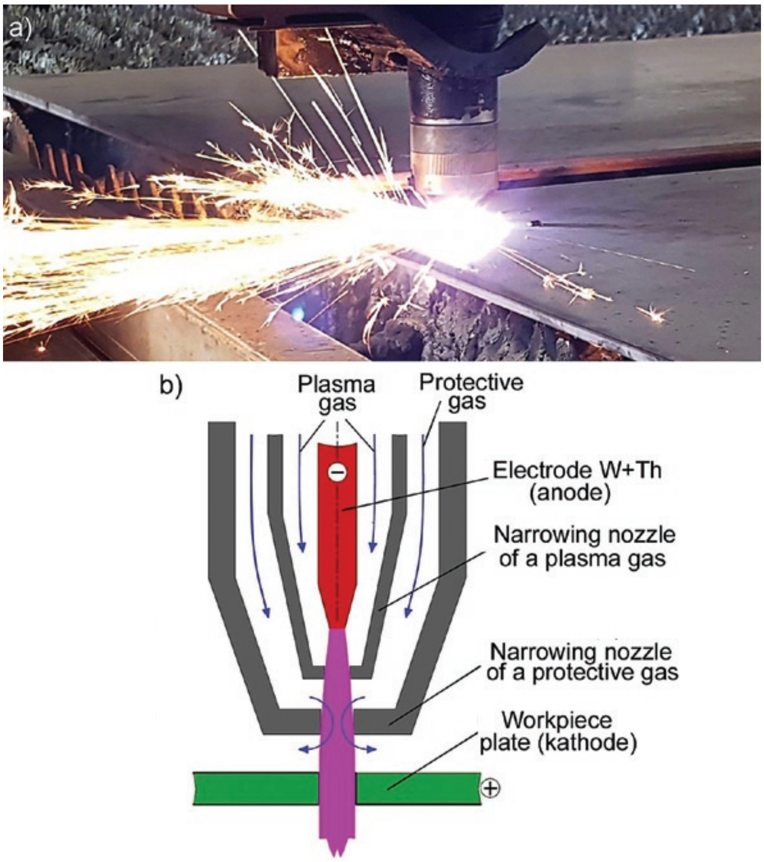


Fig. 1. Plasma cutting (a) and schematic of plasma torch (b)

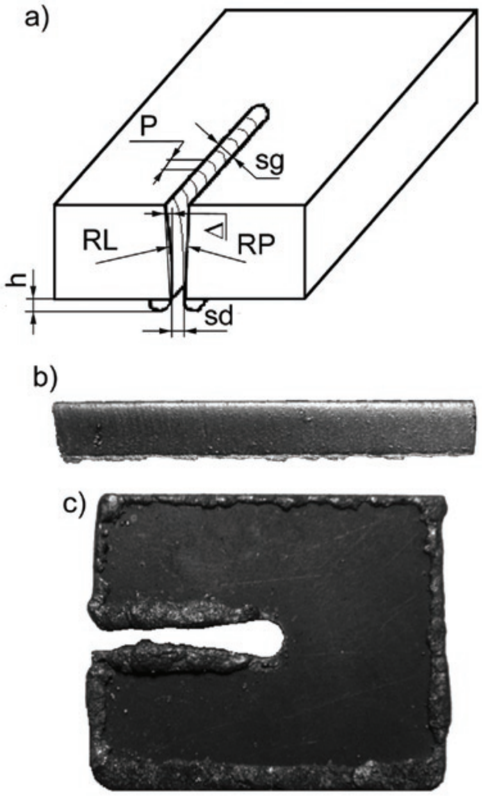


*Fig. 2. Sample after plasma-cutting: a) schematic diagram of the test factors, b) lateral surface of the slit, c) lower surface of the sample*

*Table 1. Plan and test conditions*

| Test point no. | Values and codes for the test factors | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Metal sheet thickness [mm] | X1 | Cutting current [A] | X2 | Cutting speed [mm/min] | X3 | Gas pressure during cutting [bar] | X4 | Height of the torch during cutting [mm] | X5 | Pierce delay time [s] | X6 | Initial pierce height [mm] | X7 |
| 1 | 4 | –1 | 80 | –1 | 2600 | –1 | 6 | 1 | 3.5 | 1 | 0.4 | 1 | 4 | –1 |
| 2 | 12 | 1 | 80 | –1 | 2600 | –1 | 5 | –1 | 3 | –1 | 0.4 | 1 | 7 | 1 |
| 3 | 4 | –1 | 130 | 1 | 2600 | –1 | 5 | –1 | 3.5 | 1 | 0.1 | –1 | 7 | 1 |
| 4 | 12 | 1 | 130 | 1 | 2600 | –1 | 6 | 1 | 3 | –1 | 0.1 | –1 | 4 | –1 |
| 5 | 4 | –1 | 80 | –1 | 6500 | 1 | 6 | 1 | 3 | –1 | 0.1 | –1 | 7 | 1 |
| 6 | 12 | 1 | 80 | –1 | 6500 | 1 | 5 | –1 | 3.5 | 1 | 0.1 | –1 | 4 | –1 |
| 7 | 4 | –1 | 130 | 1 | 6500 | 1 | 5 | –1 | 3 | –1 | 0.4 | 1 | 4 | –1 |
| 8 | 12 | 1 | 130 | 1 | 6500 | 1 | 6 | 1 | 3.5 | 1 | 0.4 | 1 | 7 | 1 |

(h), the deviation of the perpendicularity of the sides of the kerf in relation to the base surface (Δ) and the values of the arcs of the fracture surface on both the left (RL) and right (RP) sides.

The calculations were made using Statistica 13.3 Software**,** where the coefficients of linear regression equations were calculated on the basis of Pareto coefficients and the significance of the influence of the test factors, on the selected output parameters of the cutting process, was determined.

Analyses of the results of questionnaire surveys, conducted among experts, were made using the comparison in pairs method, such as the Kendall Tau Correlations method and the Spearman Rank Order Correlations method; Statistica 13.3 Software was also used**.** A probability level of 95% was assumed.

## 3. Results of the study

An example of the results of the calculation of the coefficients of regression equations and Pareto coefficients is presented in Fig. 3. Values of coefficients $b_0$, $b_1$, $bi$ are suitable for the equation:

$$y = b_0 + \sum_{i=1}^{n} b_i X_i \ , \qquad (1)$$

and prove the following: $b_0$ - regarding the level of influence of the size tested, $b_i$ - regarding the intensity and direction of factors $X_1$ ... $X$i - on the test size.

| Entry parameters | Efect | Standard error | t(16) | p | -95, % Conf. int. | +95, % Conf. int. |
|---|---|---|---|---|---|---|
| Mean/Constant | 2,168333 | 0,006627 | 327,1727 | 0,000000 | 2,154284 | 2,182383 |
| (1) Depth | 0,121667 | 0,013255 | 9,1789 | 0,000000 | 0,093567 | 0,149766 |
| (2) Current | 0,411667 | 0,013255 | 31,0575 | 0,000000 | 0,383567 | 0,439766 |
| (3) Speed | -0,205000 | 0,013255 | -15,4659 | 0,000000 | -0,233099 | -0,176901 |
| (4) Pressure | -0,060000 | 0,013255 | -4,5266 | 0,000344 | -0,088099 | -0,031901 |
| (5) Distance | 0,040000 | 0,013255 | 3,0177 | 0,008171 | 0,011901 | 0,068099 |
| (6) Time | 0,066667 | 0,013255 | 5,0296 | 0,000123 | 0,038567 | 0,094766 |
| (7) Height | 0,021667 | 0,013255 | 1,6346 | 0,121650 | -0,006433 | 0,049766 |

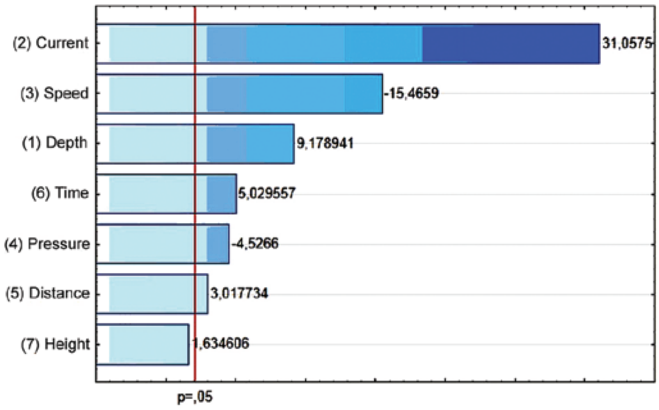


*Fig. 3. The influence of test parameters on the stroke of the cutting traces, q.v. the results of calculations and the Pareto diagram.*

According to the (DoE) planning principles of the research, values $X_{1....} Xi$ were used as relative, in the range from -1 (minimum) to +1 (maximum).

When analysing the results of statistical calculations, it was determined that all the parameters examined affect the stroke of the surface cut drag lines. The width of the kerf at the inlet and outlet does not affect the initial pierce height nor does it affect the deviation of the sides of the kerf to the base surface, namely, the start height and gas pressure. The height of the flash dross depends solely on the gas pressure, the thickness of the sheet and the cutting current. However, the radius of the arcs of the kerf is completely uncontrollable. The conclusions presented confirm the calculated coefficients of $R^2$ determination of the regression dependencies, presented in Table 2.

Regression dependencies, important for calculating the size of the values examined, with a probability of 0.95, are presented below. Dependence data can be used in the same way as is used for the calculation of the expected values of the factors tested, as well as for the development of the optimisation programme, by such as the linear programming method.

*Table 2. Coefficients of $R^2$ determination of the calculations of the factors studied*

| Coefficients of $R^2$ determination for | | | | | | |
|---|---|---|---|---|---|---|
| The stroke of cutting drag lines | The width of the kerf at the entrance | The width of the kerf at the exit | Dross buildup | Deviation of perpendicularity | Kerf arc on the left side | Kerf arc on the right side |
| 0.9607 | 0.9831 | 0.9820 | 0.7050 | 0.9606 | 0.1183 | 0.1239 |

*Table 3. Results of studies on the assessment of the conformity of expert opinions*

| No. of experts | Preflow gas pressure [bar] | Cutflow gas pressure [bar] | Height of the torch during cutting [mm] | Arc voltage [V] | Cutting current [A] | Cutting speed [mm/min] | Initial pierce height [mm] | Pierce delay time [s] | height of the torch during piercing [mm] |
|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| 1 | 7 | 3 | 4 | 8 | 1 | 2 | 5 | 6 | 9 |
| 2 | 8 | 2 | 9 | 4 | 1 | 3 | 5 | 6 | 7 |
| 3 | 7 | 3 | 4 | 1 | 2 | 5 | 6 | 8 | 9 |
| 4 | 6 | 4 | 5 | 2 | 1 | 3 | 7 | 9 | 8 |
| 5 | 6 | 3 | 2 | 1 | 5 | 4 | 7 | 8 | 9 |
| 6 | 7 | 5 | 3 | 9 | 2 | 1 | 4 | 6 | 8 |
| 7 | 6 | 5 | 4 | 7 | 2 | 1 | 3 | 9 | 8 |
| 8 | 3 | 7 | 1 | 6 | 2 | 4 | 5 | 8 | 9 |
| 9 | 10 | 9 | 8 | 3 | 1 | 2 | 6 | 5 | 7 |
| 10 | 7 | 4 | 3 | 9 | 1 | 2 | 6 | 5 | 8 |
| 11 | 8 | 3 | 7 | 6 | 1 | 2 | 4 | 5 | 9 |
| 12 | 6 | 2 | 4 | 5 | 1 | 3 | 8 | 9 | 7 |
| 13 | 7 | 4 | 5 | 6 | 2 | 1 | 3 | 8 | 9 |
| 14 | 6 | 5 | 7 | 2 | 3 | 1 | 4 | 8 | 9 |
| 15 | 6 | 4 | 5 | 3 | 1 | 2 | 8 | 9 | 7 |

The regression dependencies, obtained for the range of cutting parameters studied, are presented below:

- the stroke of cutting drag lines:

$$P = 1.239{+}0.175X1{-}{+}0.405X20.128X3{-}{+}0.358X40.258X5 {+}0.572X60.262X7{-}; \quad (2)$$

- width of the kerf at the entrance:

$$sg = 2.168{+}0.122X1{-}{+}0.412X20.205X30.06X4{-}{+}0.04X5 {+}0.067X6; \quad (3)$$

- width of the kerf at the exit:

$$sd ={-}\ 1.7290.442X1{+}0.472X20.628X30{-}.285X5{-}{+}0.095X6 {+}0.172X7; \quad (4)$$

- dross buildup:

$$h = 0.856{-}{+}0.209X10.187X20.384X4{-}; \quad (5)$$

- deviation in the perpendicularity of the sides to the base surface:

$$\Delta = 0.800{-}{+}0.220X10.243X2{+}0.258X3{+}0.110X50.207X6{-}; \quad (6)$$

- the value of the arches of the kerf surface on the left side RL = 3.987 mm;
- the value of the arcs of the kerf surface on the right-side RP = 5.532 mm,

where X1 ...X7 – normalised values for sheet thickness, intensity of cutting current, cutting speed, gas pressure during cutting, height of the torch during cutting, pierce delay time and pierce height, respectively.

Analyses of this kind makes it possible to minimise production losses, as they allow technological factors to be decided which could be the basis for effective process control and a guarantee of the required effects.

The results of the **Plackett-Burman** method were compared with the results of the analyses of expert opinions. In order to determine the validity of plasma cutting parameters, a survey was conducted among micro and small enterprises producing steel constructions with the help of expert opinions. Employees from 15 Polish companies, with a minimum of 5-years' experience in the field of cutting sheet metal played the role of the experts. In the study, the experts assessed the significance of the parameters affecting plasma cutting. The following parameters were specified, viz., preflow gas pressure, cutflow gas pressure, height of the torch during cutting, arc voltage, cutting current, cutting speed, initial pierce height, pierce delay time and height of the torch during piercing numbered from 1 to 9 by rank (1 being the highest rank in the parameter). The results of the research are presented below (Table 3).

Data analysis included verification of the compliance of expert opinions regarding the importance of individual parameters affecting plasma cutting. For this purpose, the Kendall-Smith Concordance coefficient [6] was applied. For the assessments of the 9 parameters made by 15 experts, the value of the Kendall-Smith Index obtained, was at the level of 0.608. The significance of the concordance coefficient was assessed using the chi-square o (k1–) degrees of freedom, where k: number of parameters being evaluated. From the chi-square distribution tables [8] it follows that for df = 8 – and a significance level of 0.95 – there are grounds for rejecting the null/zero hypothesis, which means that the convergence of expert opinions is not accidental and there is consensus in their positions.

For the study group in question, an analysis was also carried out using the Comparison in Pairs method, such as the Kendall Tau Correlations method (Table 4):

The results of the analysis show a significantly positive relationship between parameters 1 and 3, 6 and 7, with the most significantly positive relationship being between parameters 5 and 9. Negative relations between parameters 2 and 6, 4 and 6 and 1 and 8 were also recorded. These relationships are marked in red in Table 3. The occurrence of these relationships was confirmed by the Spearman Rank-Order Correlations method. The following results were obtained for pairs of parameters that were characterised by a positive relation: for 1 and 3: R = 0.519, t (N2–) = 2.192, p = 0.047, for 6 and 7: R = 0.648, t (N2–) = 3.066, p = 0.009, for 5 and 9: R = 0.590, t (N2–) = 2.632, p = 0.021. For parameter pairs 1 and 8, the following values were obtained R = –0.790, t (N2–) = –4.639, p = 0.000, for parameters: 4 and 6: R = –0.517, t (N2–) = –2.180, p = 0.048, where R: Spearman's Correlation coefficient, t - significance test. The negative relationship between parameters 2 and 6 was not confirmed.

As a consequence, the validity ranking for the parameters tested in the plasma cutting process was determined on the basis of sorting the average values of expert assessments. In Fig. 4, the parameters examined were segregated, according to the principle where the highest validity corresponds to the lowest average value.

Based on the above analysis, it was found that the most important parameters in the plasma cutting process are intensity of cutting current, cutting speed and cutflow gas pressure, thus confirming the effectiveness of using DoE methods, including the Plackett-Burman plans, in order to assess the significance of controllable process parameters in the plasma cutting process.

## 4. Conclusions

As a result of the research, the influence of basic plasma cutting factors on the characteristics of the cutting of carbon steel sheets, with a thickness of 4 - 12 mm, was determined. In order to determine the importance of the influence of the factors studied, the Plackett-Burman saturated plans, so-called, were used, ensuring, on the one hand,

*Table 4. Results of studies on the assessment of the conformity of expert opinions*

| Parameters tested | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | – 0.203 | 0.418 | 0.113 | –0.37 | –0.134 | –0.186 | –0.691 | –0.119 |
| 2 | –0.202 | 1 | –0.065 | 0.139 | 0.246 | –0.379 | –0.219 | –0.034 | –0.012 |
| 3 | 0.417 | –0.065 | 1 | –0.229 | –0.340 | –0.178 | –0.074 | –0.113 | –0.267 |
| 4 | 0.113 | 0.139 | –0.229 | 1 | –0.172 | –0.405 | –0.335 | –0.266 | –0.059 |
| 5 | –0.371 | 0.246 | –0.340 | –0.172 | 1 | –0.092 | –0.316 | 0.201 | 0.547 |
| 6 | –0.134 | –0.379 | –0.178 | –0.405 | -0.092 | 1 | 0.517 | 0.083 | 0.025 |
| 7 | –0.186 | –0.219 | –0.074 | –0.335 | –0.316 | 0.517 | 1 | 0.204 | –0.354 |
| 8 | –0.691 | –0.034 | -0.113 | –0.266 | 0.201 | 0.083 | 0.204 | 1 | –0.103 |
| 9 | –0.119 | –0.012 | –0.269 | -0.059 | 0.547 | 0.025 | –0.354 | –0.103 | 1 |

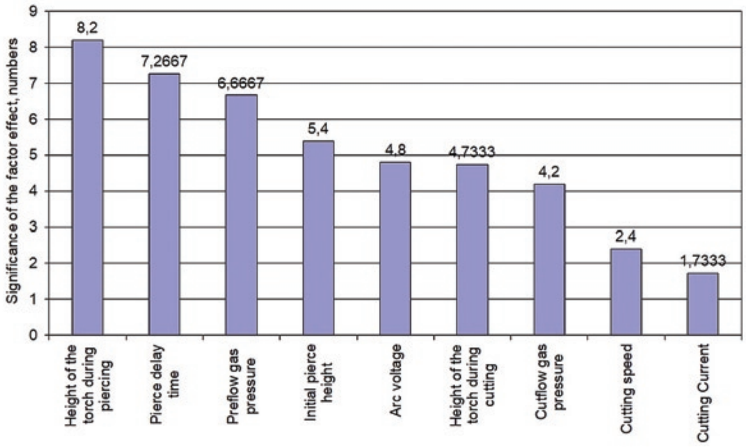


*Fig. 4. The significance of parameters in the plasma cutting process according to the expert opinion method*

minimisation of the number of tests as compared to other methods while on the other hand, giving a detailed statistical analysis of the measurement results. The equations of multidimensional linear regression obtained were confirmed by the opinion of expert practitioners. The relationships between the parameters were determined and the three most important parameters in the plasma cutting process were indicated *viz.,* intensity of current, cutting speed and gas pressure during cutting.

The application of the existing dependencies, in a production company, opens up the possibility of minimising production losses while the plasma cutting process is still being developed; this is based on a significant assessment of the process of the controllable parameters of plasma cutting.

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