Advanced Experiments Design for the Three-Torch Plasma Cutter Testing

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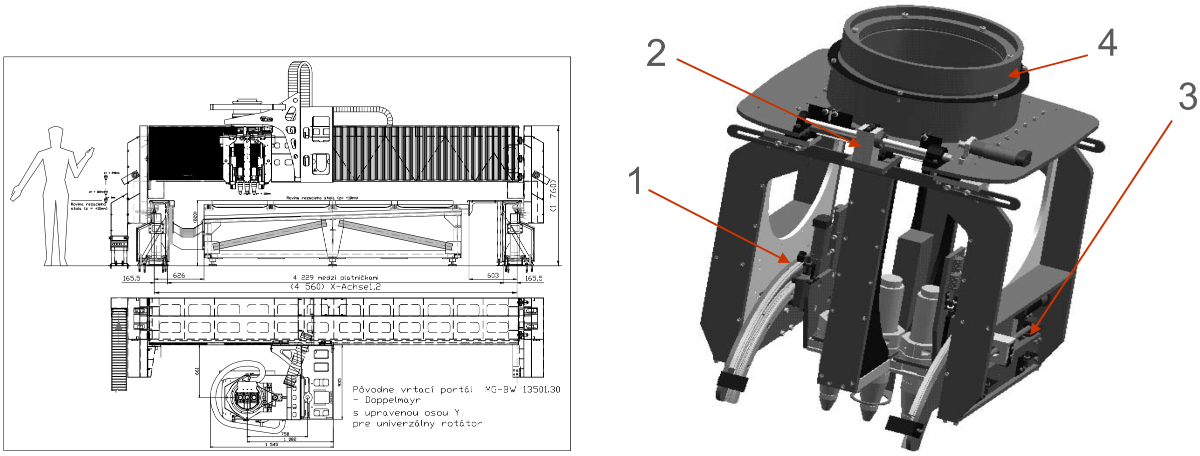
Abstract*. Nowadays exist many applications of CNC plasma cutting machines. They are focuses namely for preparation of products for following technological procedures (welding in most cases). A brand new advanced Triple Torch Plasma Rotating Unit has been developed in cooperation of the Faculty of Mechanical Eng., STU in Bratislava and Microstep-Group. The phase of technological tests requires determination of the repeated positioning accuracy of the developed unit. Therefore number of experiments must be performed. The presented paper introduces modified experiments design with significantly decreased number of measurements.*

Keywords*: Experiments design, Plasma Bevel Cutting, Triple Torch Unit, Positioning Accuracy*

1. Introduction

The Triple Torch Plasma Rotating Unit is designed as the independent console-unit with six own controlled axes and required degrees of freedom. The unit is attached to the *Z* axis of a conventional CNC plasma cutting machine (see Fig. 1a). The unique design of a triple torch plasma unit enables complex preparation of metals for further technological operations during a single production step, thus significantly saving production costs.



a) b)

Figure 1 The Triple Torch Plasma Rotating Unit mounted on the Z axis of CNC plasma cutting machine (Study for Microstep-Group and IQM Zvolen)
a) general view, b) detail of the Triple Torch Plasma Rotating unit
1 – torch inclination, 2 – “trio” axis, 3 – horizontal torch axis, 4 – rotation of the rotating unit

2. Design of experiment models

Described prototype has not been tested in practice. As the cut quality is the most important requirement, proper experiments proving the assumed quality parameters must be performed [7]. The repeatable accuracy of torches positioning in different operation modes must be verified first.

In general, experiment is defined as any intervention to the system with the aim to observe or measure effects of that intervention [1], [2], [3]. Experiment involves combination of different values (levels) of facts that are considered to affect the output from the system. As testing of all variations (tests) represents improperly big amount of tests, incomplete experiment designs are recommended. They investigate only a restricted selection from all possible combinations. Experiment design according to Taguchi represents an approach that significantly reduces amount of necessary tests and introduces also further advantages.

When designing experiment with plasma cutting machine, its kinematics was taken as a basis. Nine main factors, affecting the positioning accuracy, were selected (see Table 1).

Table 1 Main factors for testing of the repeated accuracy of positioning, together with suggested levels for individual factors (values taken for a single real machine)

Factor	Factor description	Min. value	Max. value	Level 1	Level 2	Level 3	Level 4
A	Movement along *x* axis of the CNC machine (mm)	0	5 000	0	1 800	3 200	5 000
B	Movement along *y* axis of the CNC machine (mm)	0	12 000	0	4 000	8 000	12 000
C	Movement along *z* axis of the CNC machine (mm)	0	300	0	100	200	300
D	Torch H1 horizontal movement (mm)	-115	115	- 115	- 65	65	115
E	Torch H2 horizontal movement (mm)	-115	115	- 115	- 65	65	115
F	Torch H1 inclination (°)	- 45	45	- 45	45	-	-
G	Torch H2 inclination (°)	- 45	45	- 45	45	-	-
H	Rotation of the whole cutting head (°)	0	360	0	120	240	360
I	“Trio” movement (mm)	-94	94	94	-43	43	94

Literature describes two-level multi-factors experiment designs most often. We recommend at least four levels for selected factors in this application (see Table 1). To be able to execute measurements for each level for all nine factors, total number of tests reaches $N = 4^7 \times 2^2 = 4\ 096 \times 4 = 65\ 536$. If each measurement is repeated for five times, overall number of tests reaches $N = 5 \times 65536 = 327\ 680$. That is quite a lot.

3. Methodology for testing the repeated positioning accuracy

Positioning accuracy x_i is defined as the difference between the measured (programmed) position P_{ij} and the desired position P_i [6], thus

$$x_i = P_{ij} - P_i \tag{1}$$

Positioning accuracy of the plasma cutting machine can be measured in different modes:

1) each axis (mechanism) is measured separately. Resulting overall positioning accuracy is calculated,
2) positioning accuracy is measured for combination of movements in several axis. Resulting overall positioning accuracy is calculated again,
3) positioning accuracy is measured for combination of movements in all axes.

Proposed experiments design follows the third measurement mode [1], [2].

4. Design of multi-levels multi-factors experiments

Method employing Taguchi's approach to quality control is most suitable for experiments design in cutting machine testing. We recommend to apply the modified version of orthogonal configuration L32($2^1 \times 4^9$) [8]. It is a composite model for 32 tests. Original version considers one two-level factor and nine four-level factors. This model is modified for two two-level factors and seven four-level factors, so L32 ($2^2 \times 4^8$). Last column is not full.

Table 2 Design of combined modified model L32

	1	2	3	4	5	6	7	8	9	10	**Measured values**				
Test No.	A	B	C	D	E	F	G	H	I	-	y_1	y_2	y_3	y_4	y_5
1	1	1	1	1	1	1	1	1	1	0					
2	2	2	2	2	2	2	2	2	2	0					
3	3	3	3	3	3	1	2	3	3	0					
4	4	4	4	4	4	2	1	4	4	0					
5	3	4	2	2	3	1	1	3	4	0					
6	4	3	1	1	4	2	2	4	3	0					
7	1	2	4	4	1	1	2	1	2	0					
8	2	1	3	3	2	2	1	2	1	0					
9	2	3	3	4	1	1	1	2	3	0					
10	1	4	4	3	2	2	2	1	4	0					
11	4	1	1	2	3	1	2	4	1	0					
12	3	2	2	1	4	2	1	3	2	0					
13	4	2	4	3	3	1	1	4	2	0					
14	3	1	3	4	4	2	2	3	1	0					
15	2	4	2	1	1	1	2	2	4	0					
16	1	3	1	2	2	2	1	1	3	0					
17	3	2	1	4	2	1	2	3	2	0					
18	4	1	2	3	1	2	1	4	1	0					
19	1	4	3	2	4	1	1	1	4	0					
20	2	3	4	1	3	2	2	2	3	0					
21	1	3	2	3	4	1	2	1	3	0					
22	2	4	1	4	3	2	1	2	4	0					
23	3	1	4	1	2	1	1	3	1	0					
24	4	2	3	2	1	2	2	4	2	0					
25	4	4	3	1	2	1	2	4	4	0					
26	3	3	4	2	1	2	1	3	3	0					
27	2	2	1	3	4	1	1	2	2	0					
28	4	3	4	2	2	2	2	1	1	0					
29	2	4	1	3	4	1	2	2	1	0					
30	1	3	2	4	3	2	1	1	2	0					
31	4	2	3	1	2	1	1	4	3	0					
32	3	1	4	2	1	2	2	3	4	0					

For described model L32 is valid: production of any pair of column vectors is not vector integrated in configuration and is not orthogonal to any other vector from configuration at the same time. Only influence of main factors is usually assumed in such configuration. Influence of possible interactions is neglected.

Strategy for experiments execution is as follows:

1) experiment based on orthogonal configuration is executed and main effect of each factor is estimated,
2) estimates of main effects are used to select the best combination of levels of individual factors. Prognosis of output for selected combination is estimated.
3) if obtained result does not confirm the prognosis, one can assume that interactions deflect the estimates of main effects. Then actions must be taken to eliminate interactions and new experiment must be executed.

Total number of $N = 5 \times 32 = 160$ experiments is obtained for five repetitions of each measurement. That means reduction to 0.05**%** of the original complete experiments design.

5. Conclusions

Presented paper introduces possibility of reduced experiments design, prepared by a Taguchi approach, for real technological application. Reduced design significantly decreases number of required measurements but still provides enough information for further analysis and following technical modifications of tested device.

This paper represents only a theoretical basis for experiments design. Further modifications are expected after obtaining real measurement data in technological practice.

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