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THE TURNING FORCE ANALYSIS USING THE ″MINITAB″ SOFTWARE

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ABSTRACT

This paper presents a new way to analyze the experimental results of the cutting force of the cylindrical turning process. Making use of the modern technology and the Minitab software, this paper shows the way to analyze the influence of the parameters (the thickness and the feed rate) on the cutting force and to conduct the ANOVA analysis for this particular manufacturing process. The determination of the capability of this technological process is the last step of this analysis. This work leads the way of the modern analysis of other manufacturing processes and experimental results.

Keywords: turning, Minitab, ANOVA, DOE, cutting force.

1. INTRODUCTION

The experimental data analysis plays a very important part for the complete understanding of an experimental process and for the future predictions of the process characteristics.

The process used as an example in this paper is the cylindrical turning, while the analyzed data are gathered through an experimental set-up aimed to determine the force developed during this engineering process. This experiment constitutes a classical laboratory that the undergraduate mechanical engineering students are attending in order to understand the turning process. The paper analyses the second part of the laboratory: the data analysis.

The experimental and industrial analysis of the data using a modern software is accepted nowadays. Minitab is one of these softwares [1]. In industry, educational process and research, this software is used in a variety of domains: turning [3, 6, 11, 16, 21÷23], vehicle design/testing [4, 13, 20, 24], non-conventional machining [7, 8, 10, 17, 25], milling [2], extruding [15], casting [5, 9, 12, 18, 19], etc.

Here, the Minitab software is used to examine the dependence of the cutting force of the cylindrical turning process on the process thickness and feed rate as well as the capability of the process as follows:

- The Taguchi method is used to design the experiment, to create the matrix of the experiment and to analyze the results in the steps 1÷3 presented bellow;
- ANOVA method is used to establish the statistical influence of the parameters in the step 4;
- the nonlinear regression analysis gives us the algebraic formula of the dependence of the cutting force on the process parameters in the step 5;
- the capability of the process to give certain results is calculated and presented numerically and graphically by the step 6.

2. MODEL CONSTRUCTION

We are considering the case of a cylindrical turning process with the parameters presented by Table 1. The two parameters, thickness (″t″ [mm]) and feed rate (″s″ [mm/rot]) have four levels of variation.

We design the experiments having in view Table 1 and Taguchi's Design Of Experiments (DOE) theory that indicates the necessity of $L_4^2 = 16$ experiments.

Table 1. Factors and levels of the analysis.

Factor	Unit	Level			
		1	2	3	4
t	mm	0.5	1.0	1.5	2.0
s	mm/rot	0.063	0.128	0.204	0.317

The modern technology helps us to organize, develop and analyze in a better way the experiment. Following the steps defined by Neagu [14], using the ″Minitab″ software, the steps of the model construction are the following:

- the determination of the experimental matrix (Step 1);
- the construction of the experimental matrix (Step 2).

Step 1. The determination of the experimental matrix

The "Stat → DOE → Taguchi → Create Taguchi Design" sequence allows us to choose the number of factors (2) and the number of levels (4) as Fig. 1 indicates.

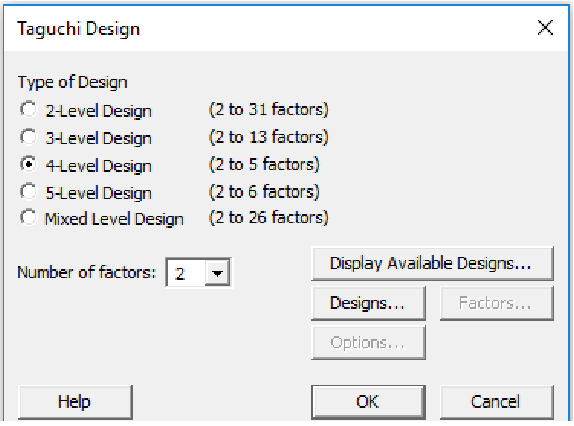


Fig. 1. The DOE set-up.

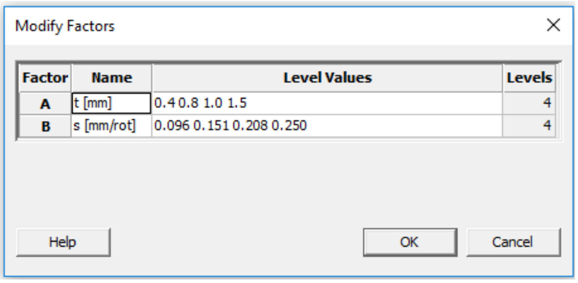
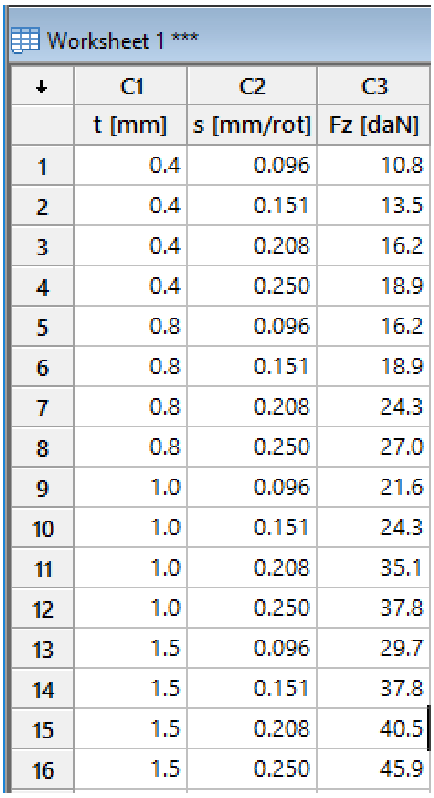


Fig. 2. The definition of the factors name and the level values.



Worksheet 1 ***

↓	C1	C2	C3
	t [mm]	s [mm/rot]	Fz [daN]
1	0.4	0.096	10.8
2	0.4	0.151	13.5
3	0.4	0.208	16.2
4	0.4	0.250	18.9
5	0.8	0.096	16.2
6	0.8	0.151	18.9
7	0.8	0.208	24.3
8	0.8	0.250	27.0
9	1.0	0.096	21.6
10	1.0	0.151	24.3
11	1.0	0.208	35.1
12	1.0	0.250	37.8
13	1.5	0.096	29.7
14	1.5	0.151	37.8
15	1.5	0.208	40.5
16	1.5	0.250	45.9

Fig. 3. The working sheet of the experiment.

The "Stat → DOE → Modify Design" selection gives us the possibility to define the name and the level values as Table 1 indicates. Figure 2 reflects this process, while Fig. 3 shows the new form of the worksheet.

Step 2. The construction of the experimental matrix

The results of the experiment are placed on the third column "C_3" of the worksheet and they have the values indicated by Fig. 3.

3. MODEL ANALYSIS

This analysis contains the following elements:
- the analysis of the Taguchi model (Step 3);
- ANOVA analysis of the experimental results (Step 4);
- the nonlinear regression analysis of the cutting force (Step 5);
- the capability analysis of the technological process (step 6).

Step 3. The analysis of the Taguchi model.

The "Stat → DOE → Taguchi → Define Custom Taguchi Design" sequence allows us to define the factors (Fig. 4) while the "Stat → DOE → Taguchi → Analyze Taguchi Design" selection allows us to define the response of the analysis (Fig. 5). In the window presented by Fig. 5, we choose:

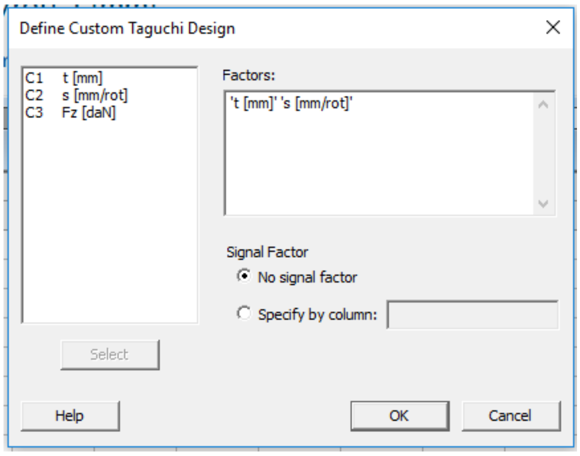


Fig. 4. The definition of the factors.

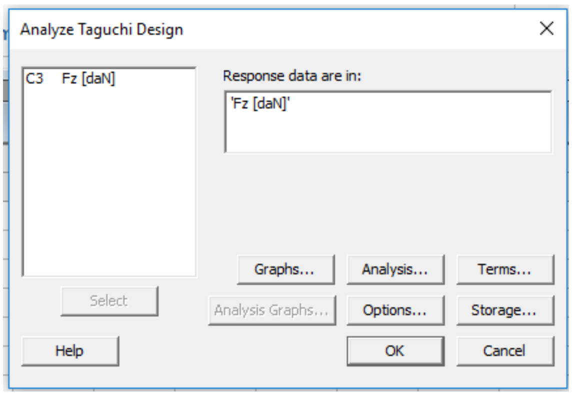


Fig. 5. The analysis response definition.

■ ″Graphs″, ″Analysis″ and ″Storage″ that allows us to choose, further: ″Signal to Noise ratios″ and ″Means″.

■ ″Terms″ that allows us to define the analysis factors (Fig. 6)

■ ″Options″ is followed by the selection ″Smaller is better″ (Fig. 7) because we are looking for a smaller cutting force.

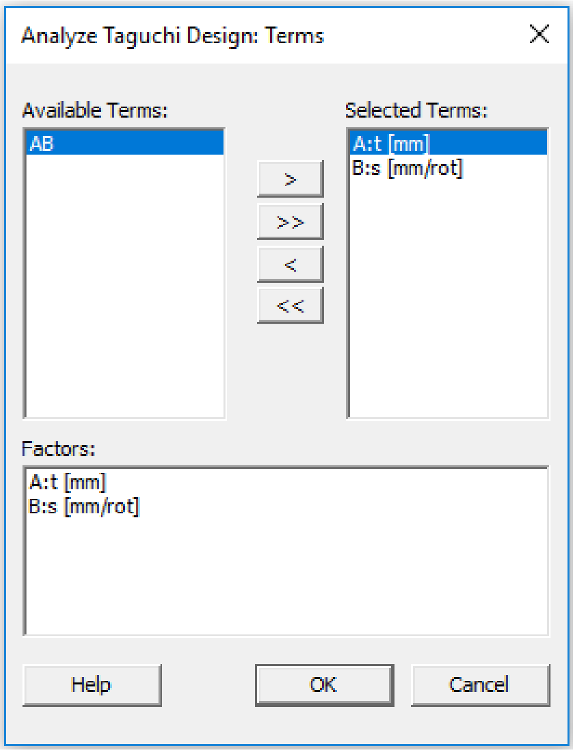


Fig. 6. The terms selection.

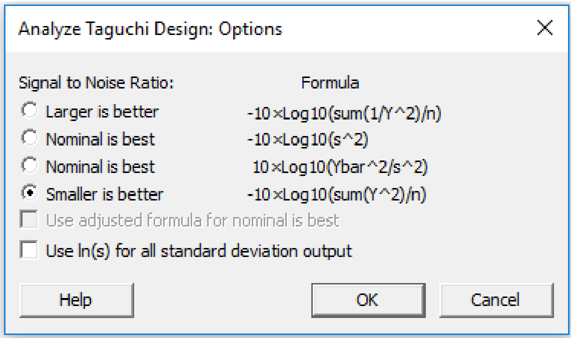
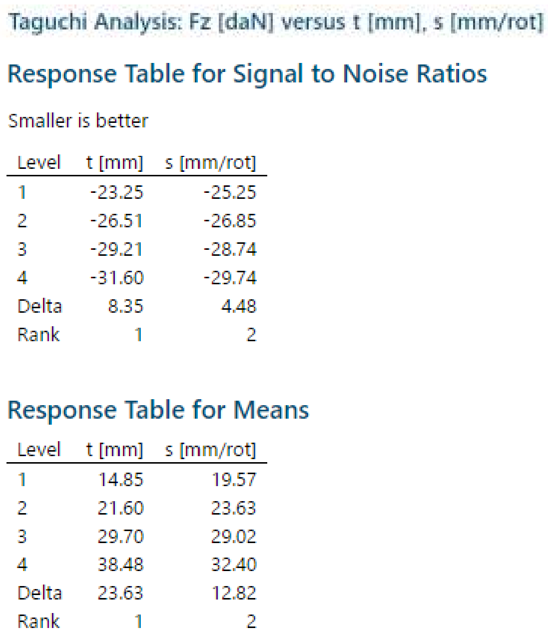


Fig. 7. The options of the Taguchi design.



Taguchi Analysis: Fz [daN] versus t [mm], s [mm/rot]

Response Table for Signal to Noise Ratios

Smaller is better

Level	t [mm]	s [mm/rot]
1	-23.25	-25.25
2	-26.51	-26.85
3	-29.21	-28.74
4	-31.60	-29.74
Delta	8.35	4.48
Rank	1	2

Response Table for Means

Level	t [mm]	s [mm/rot]
1	14.85	19.57
2	21.60	23.63
3	29.70	29.02
4	38.48	32.40
Delta	23.63	12.82
Rank	1	2

Fig. 8. The Taguchi analysis: F_z [daN] versus t[mm], s[mm/rot].

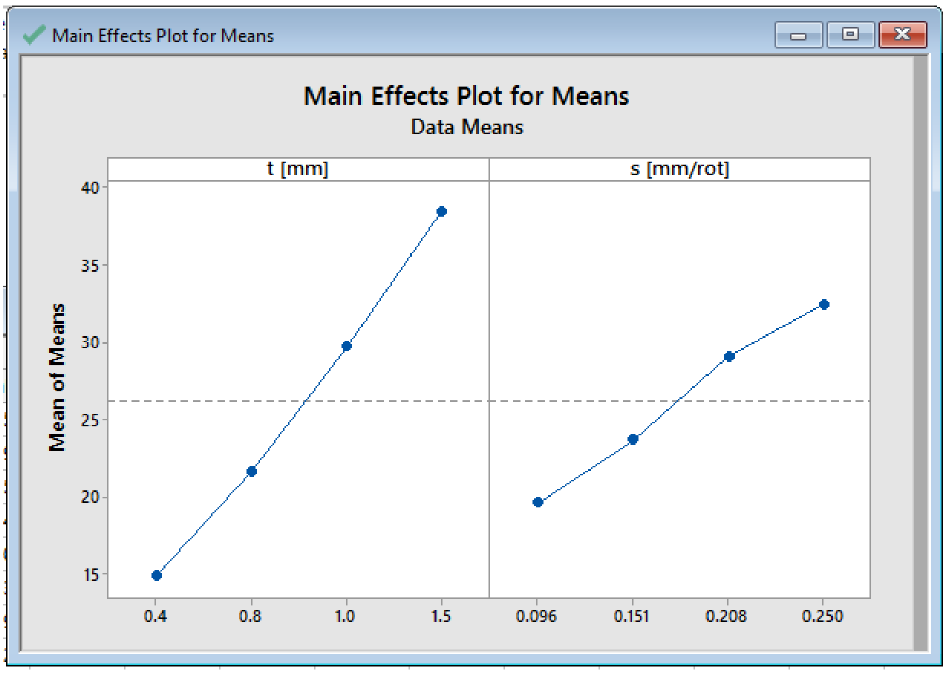


Fig. 9. Cutting force variation.

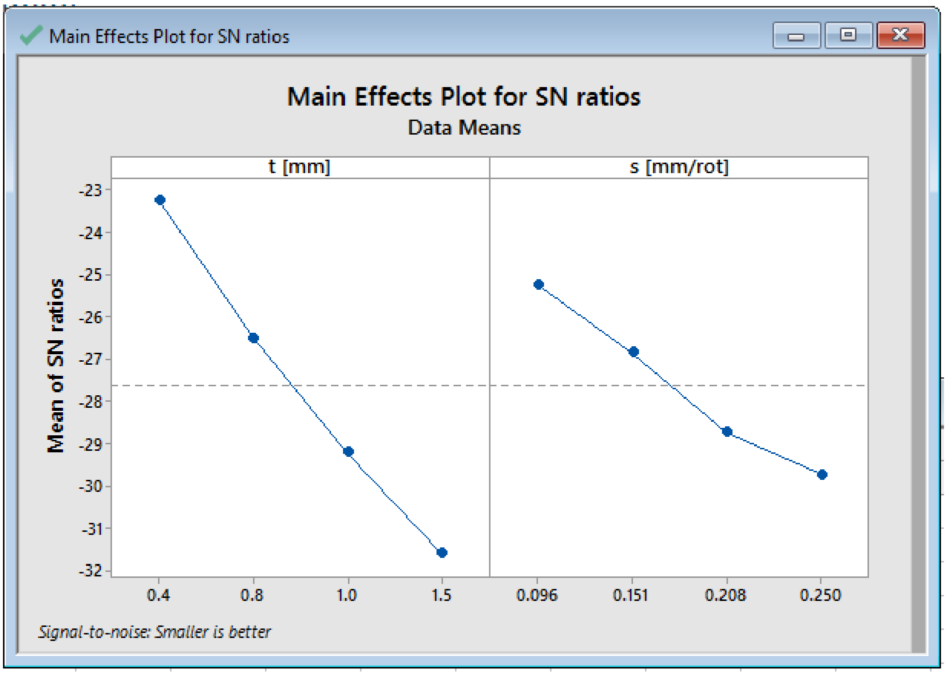


Fig. 10. SN variation.

As a result of these selections, in the session window, we obtain the following results:

● the mean cutting force and the Signal/Noise ratios for each level (Fig. 8).

● the cutting force variation (Fig. 9) as well as the SN (Signal to Noise) variation (Fig. 10) as a function of the two parameters.

Figure 8 reveals that the depth, "t", has the maximum influence on the cutting force as its rank is 1, while the rank of the feed rate, "s", is 2. This result is valid for the mean values analysis as well as the signal to noise ratios analysis.

The increase of the mean values with both parameters ("t" and "s") is revealed graphically by Fig. 9 which shows that a smaller depth and feed rate is desired in order to have a smaller cutting force.

Figure 10 reveals the SN, signal to noise ratio, variation on the process parameters. As we desire a high value of SN, smaller process parameters are desired. We regain the same conclusion obtained from Fig. 9.

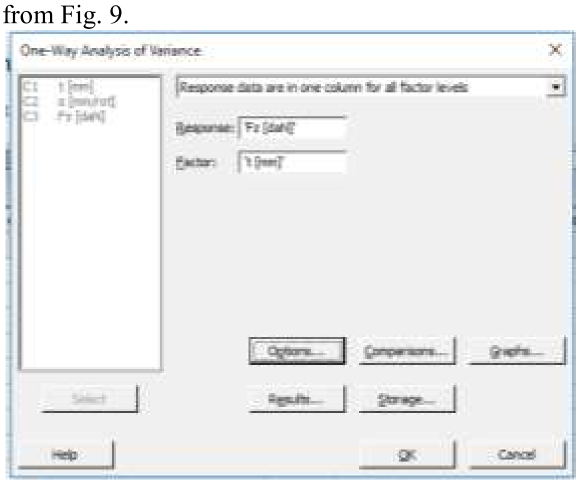


Fig. 11. The ANOVA selection.

Step 4. ANOVA analysis of the experimental results.

The "Stat → ANOVA → One Way" selection and setting successively "t" (Fig. 11) and "s" as the factors, we obtain the ANOVA analysis for each factor.

Figure 12 and Fig. 13 present the ANOVA analysis results for the "t" factor and the "s" factor, respectively. They show that both parameters have a significant influence on the cutting force as the "F-value" (11.49 for the depth, "t", and 1.19 for the feed rate, "s") is bigger than the threshold. We notice, again, that the depth has a higher influence than the feed rate.

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
t [mm]	3	1251.6	417.20	11.49	0.001
Error	12	435.6	36.30		
Total	15	1687.2			

Fig. 12. ANOVA analysis results for "t".

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
s [mm/rot]	3	387.7	129.2	1.19	0.354
Error	12	1299.4	108.3		
Total	15	1687.2			

Fig. 13. ANOVA analysis results for "s".

Step 5. The nonlinear regression analysis of the turning force.

The "Stat → Regression → Nonlinear Regression" selection allows us to search for a formula of the vertical force of the turning process:

$$Fz = c \cdot t^{a} \cdot s^{b} \tag{1}$$

(Fig. 14), where "a", "b" and "c" are real constants.

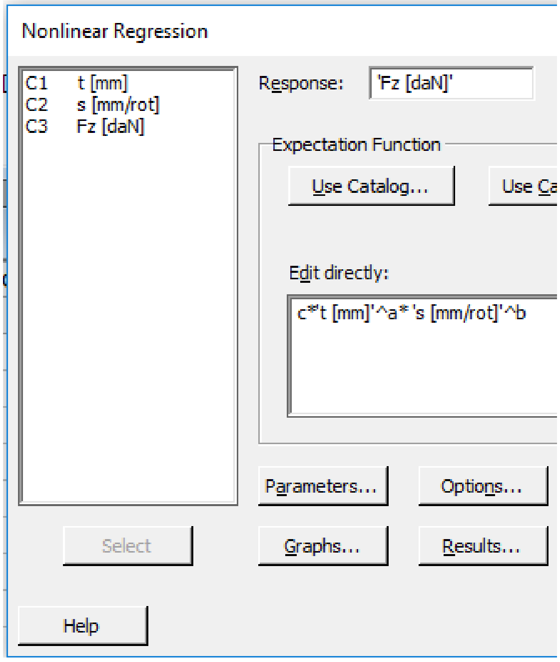


Fig. 14. The nonlinear regression.

In the iteration process that find these unknowns, the starting values for the "a", "b" -and "c" parameters as well as their lower and upper values are given. The case considered here is presented by Fig. 15.

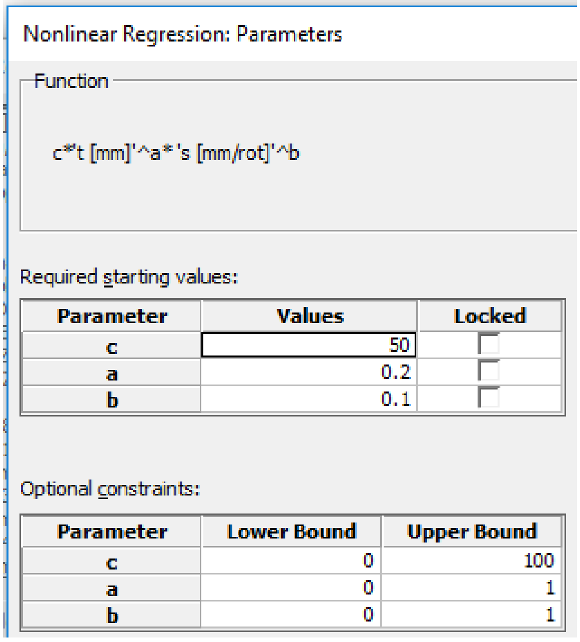


Fig. 15. The parameters of the nonlinear regression.

For this particular situation, the coefficients that fit the best the experimental values as well as the formula of the cutting force is given by Fig. 16:

Equation

Fz [daN] = 71.4272 * 't [mm]' ^ 0.755525 * 's [mm/rot]' ^ 0.525815

Fig. 16. The cutting force (F_z) formula.

Step 6. The capability analysis of the technological process.

The "Stat → Quality Tools → Capability Analysis → Normal" selection leads us to the software window presented by Fig. 17. We specify: "Data are arranged in" : "F_z[daN]"; "Lower Specification Limit" (LSL): 5; "Upper Specification Limit" (USL): 50.

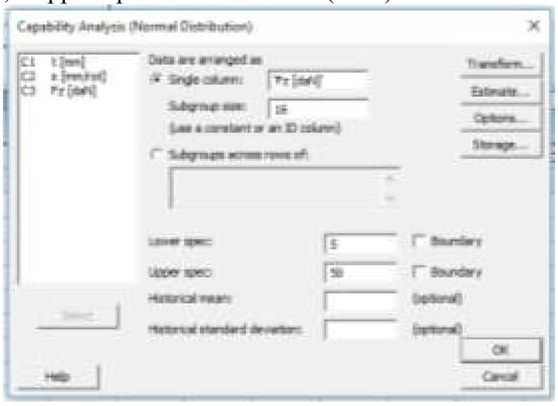


Fig. 17. The capability analysis.

The capability analysis graph presented by Fig. 18 reveals a C_p value of 0.7 and a C_{pk} value of 0.65 which indicates the capability of the process to deliver the results in the required quality domain.

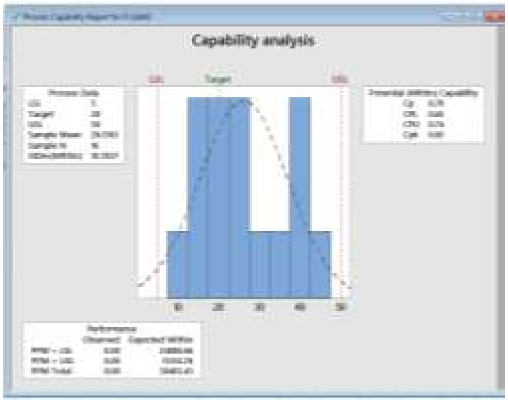


Fig. 18. The process capability.

4. CONCLUSIONS

This paper presents a new way to study the cutting force of the turning process, the influence of the parameters and the process capability.

Concentrating on the second part of the laboratory, the data analysis, this work makes use of the modern technology, the Minitab software, to establish the degree of influence of the parameters on the cutting force, the ANOVA statistical analysis of the influence of these parameters, the cutting force formula as well as the turning process capability.

These results can be an example of the way in which the modern technology can be used to analyze the experimental data and to understand the technological process.

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