International Journal of Research in Engineering and Science (IJRES)
ISSN (Online): 2320-9364, ISSN (Print): 2320-9356
www.ijres.org Volume 11 Issue 4 ǁ April 2023 ǁ PP. 329-336

Effect of Technology Parameters on the Components of Cutting Force in Hard Turning 9xc Steel With Carbide Insert Using Mos_2 Nfmql

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Abstract
The method of minimum quantity lubrication (MQL) is widely applied in machining because of its many advantages, especially in contributing to environmental protection. The lubricating efficiency of the MQL method is significantly improved when nanofluid is used. Nanofluids are prepared by mixing nanoparticles into conventional cutting oils. In this study, the MQL method with MoS_2 nano-cutting oil was applied to the hard turning of 9XC steel. The Box - Behnken experimental design method was selected to analyze the influence of technological parameters on cutting force and determine the optimal set of parameters. The study performed the Multi-objective optimization Fx, Fy and Fz and determined the optimal set of technological parameters. The cutting force components reached the minimum value Fz=43.9 N and Fy=341.7 N and Fx=57.2 N when machining with the concentration of MoS_2 nanoparticles 2.24%, cutting speed 89.6 m/min and feed rate 0.147 mm/rev. In particular, based on the contour diagrams, the research has also provided technological indications in different machining conditions.

Keywords: *Hard turning, 9XC, Nanofluids, MQL, Cutting force*

Date of Submission: 02-04-2023 Date of acceptance: 14-04-2023

I. INTRODUCTION

In recent years, clean machining and sustainable machining are becoming the development trend of cutting metal and are interesting to many researchers. Following this trend, machining processes are trying to use the minimum amount of cutting oil, avoiding the need to recycle cutting oil and avoiding waste of cutting oil after use in the environment. Therefore, the method of minimum quantity lubrication (MQL) is widely studied and applied [1-3]. In the MQL method, a small amount of metal cutting oil is introduced into the work area as a mist to improve the frictional conditions in the cutting zone. Studies show that using the MQL method gives better surface quality, and longer tool life than overflow and dry machining methods [4].

To continue to improve the efficiency of MQL in machining hard materials, a new direction is currently of great interest, which is the use of Nanofluid solution (mix nanoparticles having high hardness or good ability with normal lubricant). Nanofluids are being studied for applications in machining because of their many advantages in terms of thermal properties and lubricating properties [5]. The application of nano-cutting oil to lubricate and cool the cutting area has been studied by many authors. Sharma et al. have analyzed and evaluated the effectiveness of the application of MQL with nano-cutting oil in the machining process [6]. The research results have shown that the nanofluid minimum quantity lubrication method (NFMQL) shows promising results compared with the conventional cutting oil MQL method in terms of cutting zone temperature and surface roughness.

In recent years, the application of cooling lubricants mixed with MoS_2 nanoparticles in machining has been interested by a number of researchers. Studies on the application of MoS_2 nanofluids in the grinding process show that it is possible to reduce the specific energy and reduce the surface roughness when grinding [7]. Parash Kalita has studied and applied the MQL method with MoS_2 nanofluid to the cast iron grinding process [8]. Research has shown that the MQL-NFMoS2 method has the ability to reduce specific energy and improve surface quality compared to the overflow machining method. ZHANG Dongkun et al (2014) analyzed the effect on surface roughness and unit cutting force when applying nanofluid with 3 different types of nanoparticles (MoS2, ZrO2 and Carbon nanotube) [9]. The analysis results show that the application of nanoparticles can reduce the unit cutting force and reduce the surface roughness of the machined surface. In which, using MoS2 nanofluid gives a more noticeable effect than the other two types. Yanbin Zhang et al analyzed the lubricating efficiency of

MoS_2/CNT nano hybrid oil when grinding TiTan alloy [10]. Research results show that a Hybrid nanofluid is more effective than using a type of nanoparticle. In 2015, Yanbin Zhang also studied the application of NF-MoS_2 nano-cutting oil to the grinding process. Research results show that MoS_2 particles increase the lubricating efficiency of cutting oil, thereby contributing to reducing cutting heat and cutting force during grinding [11].

However, most of the studies only stop at surveying and evaluating the efficiency of the machining process using MoS_2 nanofluid compared to other machining processes without giving a set of optimal machining parameters. At the same time, the studies on applying the MQL method with MoS_2 nano-cutting oil to the hard turning process are limited. In this study, we mainly focus on analyzing the influence of MoS_2 nanoparticle concentration, cutting speed and feed amount on the cutting force when turning 90CrSi steel using hard alloy coated inserts.

II. EXPERIMENT AND METHOD

In this research, all experiments are arranged as shown in Figure 1. The workpiece is made of 9XC steel with a diameter of 40 mm and is heat treated to a hardness of 60-62 HRC. The cutting tool used is a coated carbide insert with the symbol CNMG120404-TM T9125 (Figure 2.2) mounted on the KYOCERA body with the code PCLNR 2020 K-16. The experimental process was carried out on a Taiwan universal lathe CS-460x1000. The MQL system uses NOGA's MQL nozzle (Noga mini cool MC1700); The components of the cutting force are measured directly during the cutting process with a three-component Kistler force sensor as shown in Figure 1. Nanofluid was made by Mixing MoS_2 nanoparticles into emusil oil solution and ultrasonically vibrated with frequency of 40Khz in usually only 30-45 min using Ultrasons –HD ultrasonicator. MoS2 nanoparticle has a layered structure with an average size of 30 nm manufactured by China Luoyang.

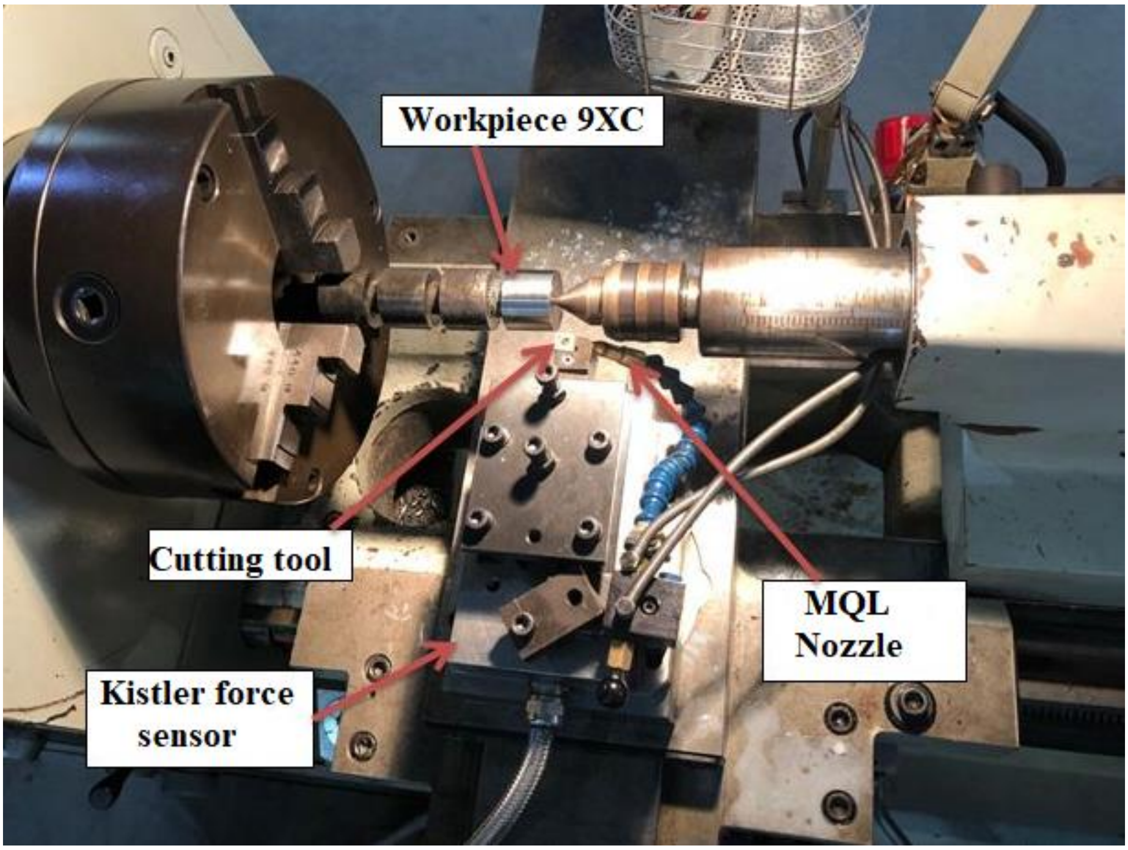

Figure 1. The experimental setup

The study focuses on analyzing the influence of nanoparticle concentration, cutting speed and feed rate on 3 components of cutting force when turning 9XC steel using the MQL method. The survey parameters and their values are shown in Table 1. Design Expert 11 was used to design a matrix of 30 experiments according to the Box - Behnken optimal model with 03 variables, three levels, and iteration 2. Experiments were carried out according to the RunOrder process, and the value of 3 components of cutting force is measured directly; The results of the evaluation parameters according to the experimental planning scheme are shown in Table 2.

Table 1 Input parameter values and experimental variables

Input parameter	**Symbols**	**Levels**	
		Low	**High**
nanoparticle concentration (CN-%)	A	1	3
Cutting speed (V-m/min)	B	80	160
Feed rate (f-mm/rev)	C	0,1	0,2

Table 2. Experiments and results

Std	**Run**	**A:CN**	**B:V**	**C:f**	**Fx (N)**	**Fy (N)**	**Fz (N)**
17	1	3	80	0,15	49,01	418,38	51,21
19	2	3	160	0,15	46,68	367,69	45,65
10	3	2	160	0,1	58,26	668,85	58,41
12	4	2	160	0,2	67,69	390,49	54,44
3	5	1	160	0,15	54,01	409,39	46,89
16	6	1	80	0,15	45,97	441,03	52,36
29	7	2	120	0,15	51,39	378,18	43,55
14	8	2	120	0,15	44,12	338,99	38,09
4	9	3	160	0,15	46,25	371,28	46,23
22	10	1	120	0,2	42,57	491,93	51,35
30	11	2	120	0,15	58,3	406,31	49,48
18	12	1	160	0,15	53,24	391,74	45,15
24	13	2	80	0,1	54,77	333,81	44,78
2	14	3	80	0,15	50,22	414,58	50,34
5	15	1	120	0,1	52,68	540,16	62,51
13	16	2	120	0,15	61,73	422,22	52,74
26	17	2	80	0,2	90,25	375,36	42,91
8	18	3	120	0,2	36,89	448,13	48,32
15	19	2	120	0,15	47,87	377,35	49,58
28	20	2	120	0,15	40,57	342,9	43,48
23	21	3	120	0,2	35,98	454,14	47,55
21	22	3	120	0,1	49,68	557,1	60,52
9	23	2	80	0,1	49,97	319,12	42,79
7	24	1	120	0,2	42,11	471,38	51,92
25	25	2	160	0,1	34,69	686,34	52,9
6	26	3	120	0,1	44,9	549,45	62,09
1	27	1	80	0,15	46,96	408,31	48,41
20	28	1	120	0,1	55,56	540,14	62,28
11	29	2	80	0,2	94,14	398,16	43,22
27	30	2	160	0,2	67,6	386,63	55,91
17	1	3	80	0,15	49,01	418,38	51,21
19	2	3	160	0,15	46,68	367,69	45,65

III. RESULT AND DISCUSSION

ANOVA analysis for components of cutting force was performed on Design Expert 11 software with 95% confidence level. The significance level of the research models is evaluated through Fisher's coefficient and the probability P value for the model. The results of the ANOVA analysis for Fx are shown in Table 3. The Model F-value for Fx of 2.12 implies there is a 7.78% chance that an F-value this large could occur due to noise. P-values less than 0.0500 indicate model terms are significant. In this case A^2, B^2 are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve your model. The Lack of Fit F-value of 18.04 implies the Lack of Fit is significant. There is only a 0.01% chance that a Lack of Fit F-value this large could occur due to noise.

Table 3. ANOVA for Fx

Source	Sum of	df	Mean	F-value	p-value
Model	2585,681	9	287,2978	2,118178	0,077838
A-CN	70,09876	1	70,09876	0,516821	0,480517
B-V	174,7023	1	174,7023	1,288038	0,269829
C-f	367,8724	1	367,8724	2,712235	0,115205
AB	53,14805	1	53,14805	0,391848	0,538409
AC	0,427812	1	0,427812	0,003154	0,95577
BC	174,0045	1	174,0045	1,282894	0,270759
AÂ^2	833,327	1	833,327	6,14392	0,02222
BÂ^2	598,4308	1	598,4308	4,412087	0,048569
CÂ^2	185,0464	1	185,0464	1,364303	0,256529
Residual	2712,688	20	135,6344		
Lack of Fit	2064,312	3	688,1041	18,04165	1,58E-05
Pure Error	648,3759	17	38,13976		
Cor Total	5298,369	29			

The results of the ANOVA analysis for Fy are shown in Table 4. The Model F-value for Fy of 7.95 implies the model is significant. There is only a 0.01% chance that an F-value this large could occur due to noise. P-values less than 0.0500 indicate model terms are significant. In this case B, C, BC, A^2, C^2 are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve your model. The Lack of Fit F-value of 37.41 implies the Lack of Fit is significant. There is only a 0.01% chance that a Lack of Fit F-value this large could occur due to noise.

Table4. ANOVA for Fy

Source	Sum of	df	Mean	F-value	p-value
Model	190469,4	9	21163,26	7,951422	6,25E-05
A-CN	802,7306	1	802,7306	0,3016	0,588961
B-V	19857,04	1	19857,04	7,46065	0,012861
C-f	37903,22	1	37903,22	14,24093	0,001194
AB	261,9761	1	261,9761	0,098429	0,756972
AC	952,443	1	952,443	0,35785	0,556417
BC	61015,72	1	61015,72	22,92472	0,000112
AÂ^2	13925,53	1	13925,53	5,232075	0,033204
BÂ^2	2468,588	1	2468,588	0,927493	0,347016
CÂ^2	53945,77	1	53945,77	20,26841	0,000218
Residual	53231,39	20	2661,569		
Lack of Fit	46229,56	3	15409,85	37,41418	1,05E-07
Pure Error	7001,824	17	411,872		
Cor Total	243700,7	29			

The results of the ANOVA analysis for Fz are shown in Table 5. The Model F-value of 2.30 implies there is a 5.81% chance that an F-value this large could occur due to noise. P-values less than 0.0500 indicate model terms are significant. In this case C, A^2, C^2 are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve your model. The Lack of Fit F-value of 13.38 implies the Lack of Fit is significant. There is only a 0.01% chance that a Lack of Fit F-value this large could occur due to noise.

Table 5. ANOVA for Fz

Source	Sum of	df	Mean	F-value	p-value
Model	608,6097	9	67,6233	2,299411	0,058063
A-CN	5,0176	1	5,0176	0,170615	0,683961
B-V	54,6121	1	54,6121	1,856988	0,188121
C-f	160,4022	1	160,4022	5,454195	0,030051
AB	0,11045	1	0,11045	0,003756	0,951742
AC	3,40605	1	3,40605	0,115817	0,737165
BC	0,0288	1	0,0288	0,000979	0,975346
AÂ²	134,1442	1	134,1442	4,561336	0,045253
BÂ²	33,67388	1	33,67388	1,145021	0,297339
CÂ²	215,5016	1	215,5016	7,327751	0,013569
Residual	588,1793	20	29,40896		
Lack of Fit	413,1768	3	137,7256	13,37887	9,85E-05
Pure Error	175,0024	17	10,29426		
Cor Total	1196,789	29			
Cor Total	243700,7	29			

Figure 2 shows the influence of input factors on the mean value of the cutting force Fx. The cutting force Fx has the same direction as the direction of the feed movement, so it is most strongly influenced by the feed rate and increases with the increase of the feed. However, in the small feed rate region (0.1-0.12 mm/rev), the cutting force Fx tends to decrease slightly with increasing feed rate. At the same time, the nanoparticle concentration also significantly affects the cutting force Fx. When increasing the nanoparticle concentration to 2%, the cutting force Fx tends to increase, and continuing to increase the particle concentration, the force Fx decreases. The cutting speed also significantly affects the cutting force Fx, when the cutting speed increases from 80 to 130, the cutting force Fx tends to decrease. If the cutting speed continues to increase up to 160 m/min, the cutting force increases again. This is in agreement with published results on the effect of cutting speed on cutting force Fx. However, within the scope of the survey, the cutting force Fx only varies a small amount, so it does not affect the quality and machining accuracy much, especially when finishing with small feeds.

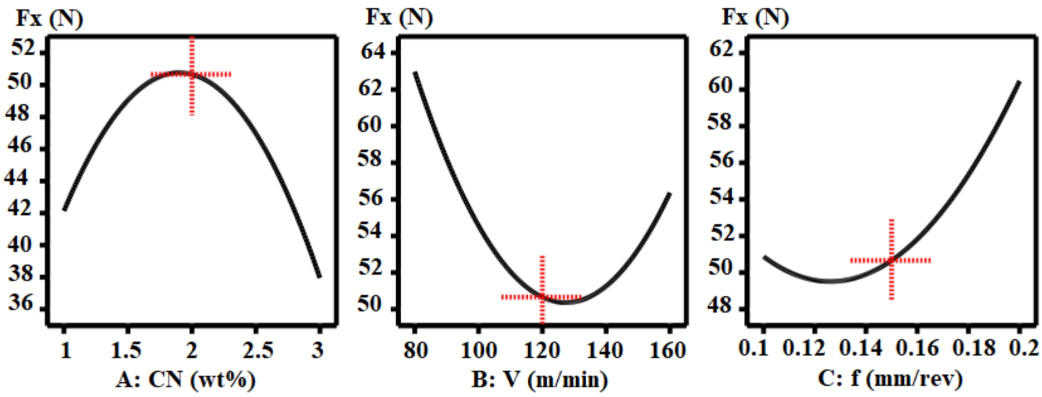

Figure 2. Effect of input factors on cutting force Fx

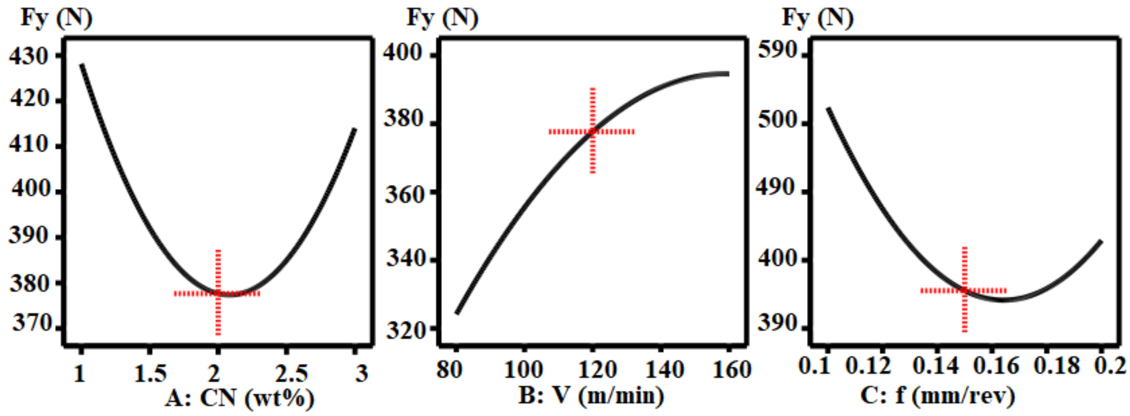

Figure 3. Effect of input factors on cutting force Fx

The influence of the survey parameters on the objective function Fy is shown in Figure 3. Cutting Force Fy is a component of the cutting force perpendicular to the machined surface, and greatly affects the quality and machining accuracy. The Fy force tends to decrease with increasing nanoparticle concentration. However, when the nanoparticle concentration increases sufficiently high, the shear force Fy tends to increase gradually. The reason is that when the nanoparticle concentration is large, the nanoparticles tend to cluster, making it difficult to penetrate the cutting area, leading to an increase in the cutting force. While the feed rate has a great influence on the value of the cutting force Fy, the increase in the feed rate increases the cutting area and is the main cause of the increase in the cutting force Fy.

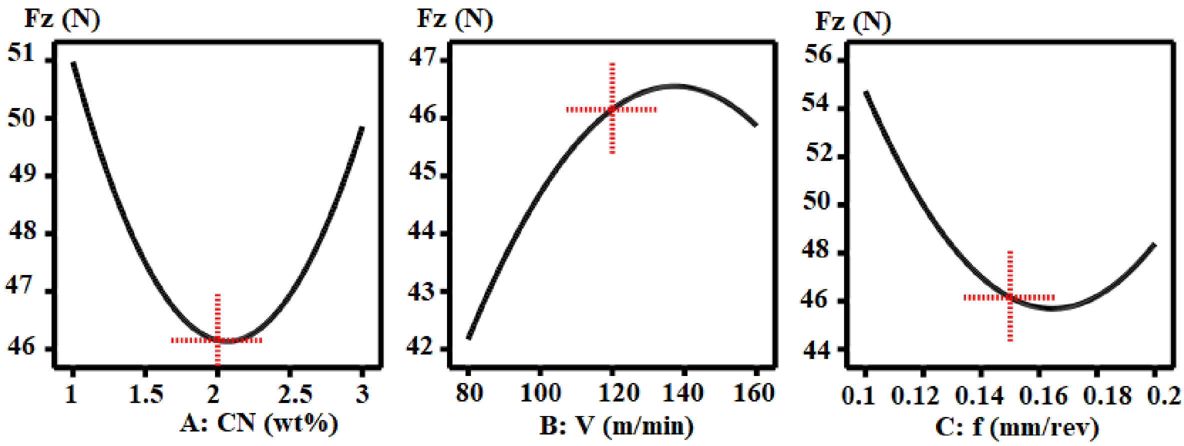

Figure 4. Influence of factors on cutting force Fz

Figure 4 shows the influence of the survey factors on the cutting force Fz. The cutting force Fz decreased with increasing nanoparticle concentration from 1-2%, but the change range was not large (51-46N). During the machining process of MoS2 nanoparticles, along with oil droplets entering the cutting zone, the nanoparticles have the form of plates and have a strong lubricating ability, resulting in reduced friction in the cutting zone. Research results also show that the tangential shear force Fz increases with increasing cutting speed.

The optimal technological parameters for cutting force components when turning 9XC steel using MQL with MoS2 nanoparticles are determined through the optimization module on Design expert software 11. The minimization objective is selected for all three objective functions (Fx, Fy and Fz) with equal importance and weight equal to 1. The optimization results are shown in Figure 5. The cutting force components reach the minimum value Fz=43. ,9 N and Fy=341.7 N and Fx=57.2 N when machining with a concentration of 2.24% MoS2 nanoparticles, a cutting speed of 89.6 m/min and a feed rate of 0.147 mm/rev.

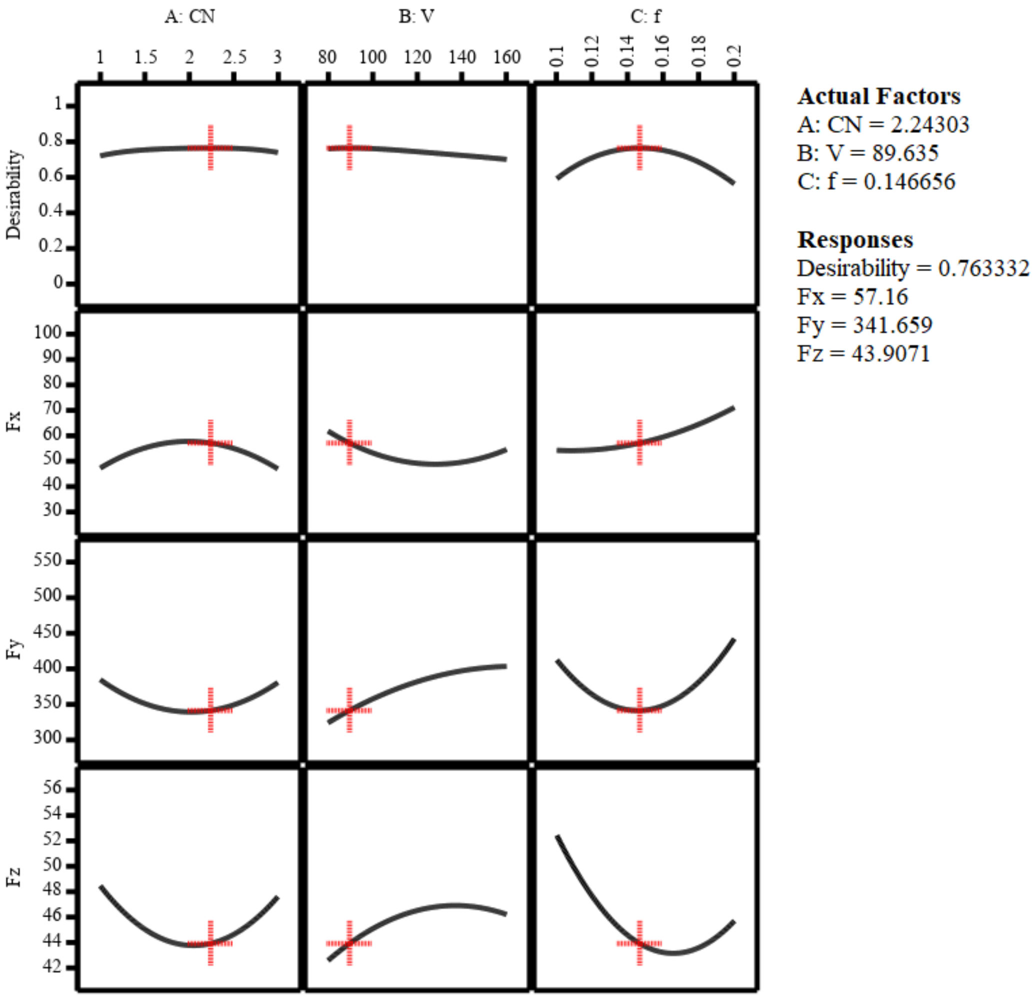

Figure 5. Multi-objective optimization Fx, Fy and Fz

IV. CONCLUSION

The efficiency of the 9XC steel hardening process using the MQL method mixed with MoS_2 nanoparticles was analyzed using the Boxken experimental model. An experimental matrix of 30 experiments was built to analyze the effect of solution concentration, cutting speed and feed rate on the cutting force components. The results of ANOVA analysis show that a second order model is suitable to analyze and predict the influence of the survey parameters on the cutting components in this study.

The study performed the Multi-objective optimization Fx, Fy and Fz and determined the optimal set of technological parameters. The cutting force components reached the minimum value Fz=43.9 N and Fy=341.7 N and Fx=57.2 N when machining with the concentration of MoS_2 nanoparticles 2.24%, cutting speed 89.6 m/min and feed rate 0.147 mm/rev.

ACKNOWLEDGMENT

The authors acknowledge the device support under Thai Nguyen University of Technology

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