Surface Roughness Model when Hole Turning SAE 420 Steel

Le Hong Ky

***Abstract*—In this paper, a study on surface roughness model when hole turning SAE 420 steel has been done. This study has been presented with three main contents. The first content is to determine the influence of some parameters on the surface roughness. The second content is to build a quadratic model showing the relationship between surface roughness with cutting velocity, depth of cut, feed rate and nose radius. The third content is to evaluate the accuracy of surface roughness model by comparing the roughness value when estimating and roughness value when testing. The development directions for further studies are also mentioned in this study.**

***Index Terms*—Hole Turning, SAE 420 Steel, Surface Roughness Models.**

I. Introduction

Turning is the most commonly used machining method in cutting machining methods. In a mechanical workshop, the group of lathes usually accounts for about 25 to 35% of the total machine-tools, the workload done by turning method is about 40% [1]. The roughness of the hole surface when machining has a great influence on the workability and life service of the products, thus, it is often chosen as an indicator to evaluate the efficiency of the machining process. Therefore, many studies have been published to determine the influence of machining process parameters on surface roughness as well as develop roughness models to predict the roughness of machining hole surface under different conditions. El-Axir et al. [2] tested the rough turning for 6061-T6 aluminum alloy. Dejan Tanikić et al. [3] tested the rough turning for Cold Rolled Alloyed - type Č.4732. Nguyen Hong Son et al. [4] used PVD coating to test the process of turning SCM400 steel holes. In another study, Nguyen Hong Son et al. [5] studied a test of turning SKD11 steel. Amrifan Saladin Mohruni et al. [6] studied the process of turning AISI D2 steel with CBN cutting pieces. Salah Gasim Ahmed [7] used carbide-coated cutting pieces to test the aluminum alloy turning process. Dilbag Singh et al. [8] tested the AISI 52100 steel turning with ceramic-coated cutting pieces. Feng et al. [9] used a cutting tool coated with Ti (C, N) - Al2O3 - TiN mixtures in the test process of turning two materials, 8620 steel and 6061T aluminum. Doniavi [10] et al. tested to turn AISI 1060 steel by cutting pieces coated with K10 bits. Taraman et al. [11] used a cutting piece coated with tungsten bits to carry out the test of turning steel ASE 1018. Manan Kulshreshtha [12] carried out the test of turning EN 36 steel. Shahabi et al. [13] tested the process of turning AISI 304 steel with cutting pieces coated with Cemented bits with symbol CNGP-12-04-04_H13A. Maohua Xiao et al. [14] used cutting pieces with symbol 41305A to carry out the test of turning 1Cr18Ni9Ti stainless steel. Dinesh et al. [15] carried out the test of turning EN 24 alloy steel by cutting pieces coated with cemented bits. Nitin Ambhore et al. [16] carried out the test of turning AISI 52100 steel with coated cutting pieces bearing symbol CNMG120408-MF5.

SAE 420 steel is a commonly used steel for manufacturing parts in shipbuilding, oil and gas, chemical technology, food processing and medical industries. Up to now, the documents of studies and surveys on the influence of machining process parameters on surface roughness when turning such steel are still quite limited. Therefore, the study on turning SAE 420 steel should be done.

In this paper, the influence of cutting speed, feed rate, depth of cut and nos radius on the roughness when hole turning SAE 420 steel will be studied. The RSM method based on a CCD test matrix will be applied to develop a surface roughness model.

II. Turning Test

A. Testing material

The testing material used in this study is SAE 420 steel. The equivalent symbol of such steel according to some standards is presented in Table I. Before the test, the steel sample is heat-treated to achieve a hardness of 56HRC. The dimensions of outside diameter, inside diameter and height of the sample are 80mm, 50mm and 22mm, respectively. The chemical composition of the sample is analyzed spectroscopically and shown in Table II.

B. Cutting machine and tool

The tests are performed on CNC Doosan Lynx 220L lathe. The cutting tool used in this study is PVD-coated cutting pieces form Korloy (South Korea) with five different values of the nose radius: 0.1mm, 0.2mm, 0.3mm, 0.4mm and 0.5mm . Four cutting pieces with corresponding symbols are DNC250 1EA19C28 0.1R, DNC250 1EA19C28 0.2R, DNC250 1EA19C28 0.3R, DNC250 1EA19C28 0.4R and DNC250 1EA19C28 0.5R.

Published on June 11, 2020.

L. H. Ky, Lecturer, Vice Rector, Vinh Long University of Technology Education, Vietnam.

(e-mail: lehongkydhspktvl.vn@gmail.com, kylh@vlute.edu.vn)

TABLE I: EQUIVALENT SYMBOL OF SAE 420 STEEL IN SOME COUNTRIES

USA	Germany	Japan	France	England	EU	Italia	Spain	China	Poland
SAE	DIN	JIS	AFNOR	BS	EN	UNI	UNE	GB	PN
420	1.4028	SUS420J2	410F21	420S45	1.4028	GX30Cr13	F.3403	3Cr13	3H13

TABLE II: CHEMICAL COMPOSITION OF SAE 420 STEEL

C	Si	Mn	Cr	S
0.44	1.12	1.05	12.00	0.008

TABLE III: VALUE OF INPUT PARAMETERS AT THE LEVELS

Parameters	Units	Symbol	Value at levels				
			-2	-1	0	1	2
Cutting velocity	m/min	v	100	140	180	220	260
Feed rate	mm/rev	f	0.02	0.04	0.06	0.08	0.1
Depth of cut	mm	t	0.05	0.1	0.15	0.2	0.25
Nose radius	mm	r	0.1	0.2	0.3	0.4	0.5

TABLE IV: TEST MATRIX AND RESULTS

No.	Code value				Actual value				Ra (μm)	Ra* (μm)
	v	f	t	r	v (m/min)	f (mm/rev)	t (mm)	r (mm)		
1	-1	-1	1	-1	140	0.04	0.2	0.2	1.12	1.393
2	1	1	1	1	220	0.08	0.2	0.4	4.08	3.901
3	-1	-1	-1	1	140	0.04	0.1	0.4	2.88	3.276
4	1	-1	1	1	220	0.04	0.2	0.4	1.4	1.553
5	0	0	0	0	180	0.06	0.15	0.3	2.18	2.207
6	0	0	0	0	180	0.06	0.15	0.3	2.34	2.207
7	1	-1	-1	-1	220	0.04	0.1	0.2	1.7	2.143
8	1	1	-1	-1	220	0.08	0.1	0.2	2.16	2.151
9	1	-1	1	-1	220	0.04	0.2	0.2	1.24	1.956
10	0	0	0	0	180	0.06	0.15	0.3	2.18	2.207
11	1	1	1	-1	220	0.08	0.2	0.2	3.32	3.275
12	-1	1	1	1	140	0.08	0.2	0.4	5.22	5.128
13	0	0	0	0	180	0.06	0.15	0.3	2.2	2.207
14	-1	-1	1	1	140	0.04	0.2	0.4	2.08	2.119
15	-1	1	1	-1	140	0.08	0.2	0.2	3.04	3.371
16	-1	1	-1	-1	140	0.08	0.1	0.2	2.84	3.038
17	1	1	-1	1	220	0.08	0.1	0.4	2.88	2.958
18	-1	1	-1	1	140	0.08	0.1	0.4	5.66	4.974
19	-1	-1	-1	-1	140	0.04	0.1	0.2	2.16	2.369
20	1	-1	-1	1	220	0.04	0.1	0.4	2.22	1.919
21	-2	0	0	0	100	0.06	0.15	0.3	2.8	3.013
22	0	2	0	0	180	0.1	0.15	0.3	3.94	4.689
23	2	0	0	0	260	0.06	0.15	0.3	1.44	1.559
24	0	-2	0	0	180	0.02	0.15	0.3	2.09	1.672
25	0	0	-2	0	180	0.06	0.05	0.3	1.92	3.015
26	0	0	2	0	180	0.06	0.25	0.3	2.32	2.982
27	0	0	0	-2	180	0.06	0.15	0.1	2.66	2.149
28	0	0	0	2	180	0.06	0.15	0.5	2.84	3.683
29	0	0	0	0	180	0.06	0.15	0.3	2.22	2.207
30	0	0	0	0	180	0.06	0.15	0.3	2.12	2.207

C. Measuring tool

The SJ-201 roughness tester (Mitutoyo - Japan) has been used to measure the roughness in this study. At each sample, measuring at least three times. The surface roughness value at each test is the average of successive measurements.

D. Design of experiment

The tests are designed in RSM format based on CCD test matrix. According to the planning form of this test, each input parameter will receive five coding values including –α. -1, 0, 1 and α. Of which $\alpha = (2^k)^{1/4}$, with k is the number of input parameters. The value of input parameters at testing levels is shown in Table III. The test matrix will consist of 2^k original test points (at the coding levels -1 and 1), 2k axial test points (at the levels -α and α) and select 6 central test points (at the coding level 0), as shown in Table IV.

III. Influence of Parameters on Surface Roughness

The testing process is carried in the order shown in Table IV, the surface roughness after measuring for each sample was also included in this table. The results of ANOVA analysis and regression model information for surface roughness were analyzed and obtained as shown in Table V.

TABLE V. ANOVA Analysis and Regression Model Information For Surface Roughness

Multiple R	0.9397	R Square	0.8831
Adjusted R Square	0.7740	Standard Error	0.4948

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	14	27.7436	1.9817	8.0930	0.0001
Residual	15	3.6730	0.2449		
Total	29	31.4166			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	2.2067	0.2020	10.9232	0.0000	1.7761	2.6373	1.7761	2.6373
v	-0.3633	0.1010	-3.5971	0.0026	-0.5786	-0.1480	-0.5786	-0.1480
f	0.7542	0.1010	7.4664	0.0000	0.5389	0.9695	0.5389	0.9695
t	-0.0083	0.1010	-0.0825	0.9353	-0.2236	0.2070	-0.2236	0.2070
r	0.3833	0.1010	3.7951	0.0018	0.1680	0.5986	0.1680	0.5986
v^2	0.0198	0.0945	0.2095	0.8369	-0.1816	0.2212	-0.1816	0.2212
f^2	0.2435	0.0945	2.5776	0.0210	0.0422	0.4449	0.0422	0.4449
t^2	0.0198	0.0945	0.2095	0.8369	-0.1816	0.2212	-0.1816	0.2212
r^2	0.1773	0.0945	1.8764	0.0802	-0.0241	0.3787	-0.0241	0.3787
v*f	-0.1650	0.1237	-1.3338	0.2022	-0.4287	0.0987	-0.4287	0.0987
v*t	0.1975	0.1237	1.5965	0.1312	-0.0662	0.4612	-0.0662	0.4612
v*r	-0.2825	0.1237	-2.2836	0.0374	-0.5462	-0.0188	-0.5462	-0.0188
f*t	0.3275	0.1237	2.6473	0.0183	0.0638	0.5912	0.0638	0.5912
f*r	0.2575	0.1237	2.0815	0.0549	-0.0062	0.5212	-0.0062	0.5212
t*r	-0.0450	0.1237	-0.3638	0.7211	-0.3087	0.2187	-0.3087	0.2187

The data in Table V shows that:

– The cutting velocity, feed rate, nose radius are the parameters that greatly affect the surface roughness. Of which, feed rate is the parameter with greatest influence on the surface roughness, followed by the influence of nose radius and cutting velocity. The depth of cut has a negligible influence on the surface roughness. As the value of cutting velocity increases, the surface roughness decreases. The surface roughness value will increase as the value of feed rate increases. When the nose radius increases, sometimes the roughness value increases or decreases. Observing Fig. 1 on the influence of parameters on surface roughness will shed more light on these statements.

– Regarding the interaction influence between parameters on surface roughness: the interaction between feed rate and the depth of cut has the greatest influence on surface roughness, followed by the influence of interaction between cutting velocity and nose radius. The interaction between other factors has a negligible influence on the surface roughness. However, if considering in detail, the influence of interactions on the surface roughness decreases gradually according to the order of interaction between feed rate and nose radius, the interaction between cutting velocity and depth of cut, the interaction between the cutting velocity and the amount of tool, the interaction between depth of cut and nose radius. Observing Fig. 2 on the interaction influence of parameters on surface roughness will shed more light on these statements.

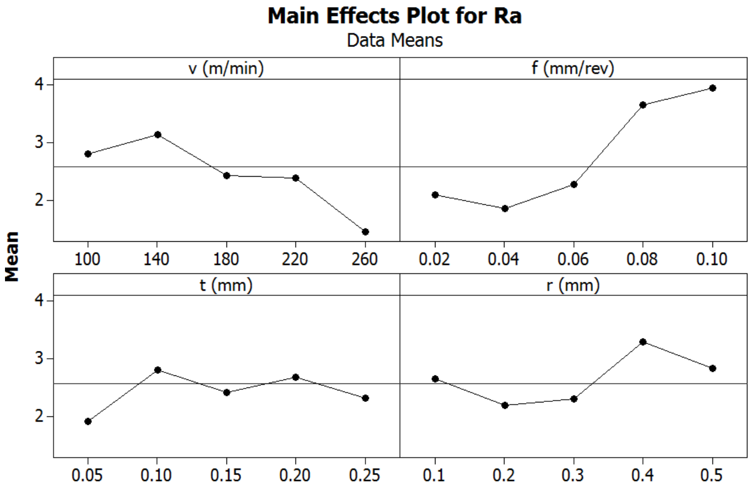
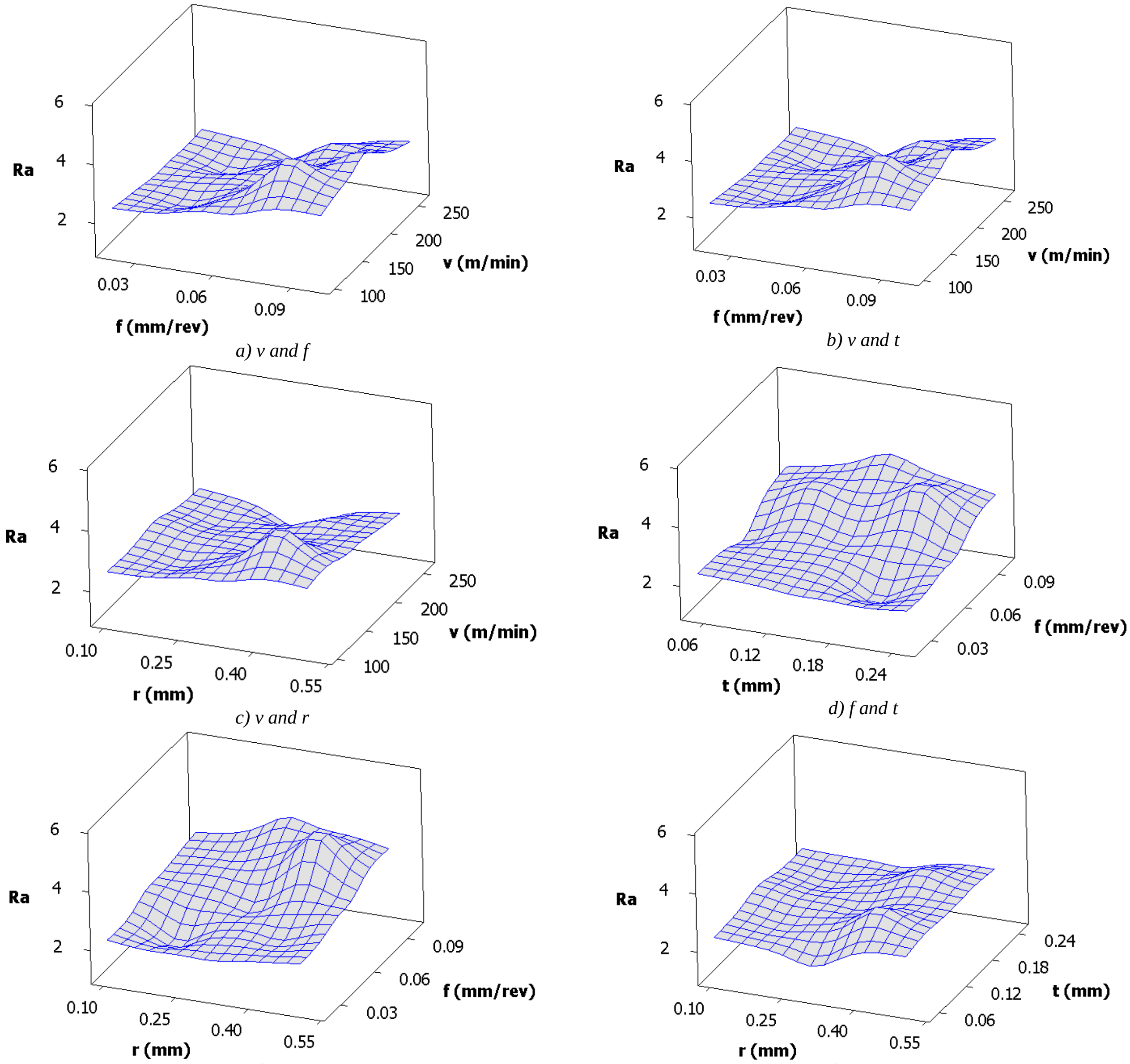


Fig. 1. Influence of parameters on surface roughness



a) v and f

b) v and t

c) v and r

d) f and t

e) f and r

f) t and r

Fig. 2. Interaction influence between parameters on surface roughness

IV. Surface Roughness Model

From the data in Table V, the regression equation describing the relationship between surface roughness with cutting velocity, feed rate, depth of cut and nose radius is presented as in equation (1). This model is used to predict the surface roughness from the data of input parameters as shown in Table IV. The predicted roughness value (Ra *) was also included in this table.

$$\begin{aligned} Ra = {} & 2.2067 - 0.3633 * v + 0.7542 * f - 0.0083 * t + 0.3833 * r \\ & + 0.0198 * v^2 + 0.2435 * f^2 + 0.0198 * t^2 + 0.1773 * r^2 - 0.1650 * v * f \\ & + 0.1975 * v * t - 0.2825 * v * r + 0.3275 * f * t + 0.2575 * f * r - 0.0450 * t * r \end{aligned} \quad (1)$$

Fig. 3 and Fig. 4 show the comparison of the two data sets, the roughness of the test and the roughness predicted by formula (1). Fig. 1 shows that the roughness value when predicting is greater than the roughness value when testing, but the difference between these two quantities is very small. This parameter is also shown clearly in Fig. 4, the average value of surface roughness when testing is 2.57 µm while the average value of surface roughness when predicting is 2.718 µm.

Regarding the standard deviation of these two data sets, it is also quite close, the surface roughness set when testing has a standard deviation of 1.04 while the surface roughness set when predicting has a standard deviation of 0.989. Regarding the standard error of these two value sets, it is also quite close, the standard error of surface roughness when testing and the standard error of surface roughness when predicting have values of 0.19 and 0.18, respectively. In particular, with the assumption that these two data sets are not equal (*vs not*) but the value of probability P-value = 0.589, much greater than the significance level (the significance level is often selected by 0.05) . Therefore, the assumption that two data sets are not equal has been removed. This affirms that the two data sets are equivalent. In other words, the surface roughness model presented in formula (1) is very consistent with test data.

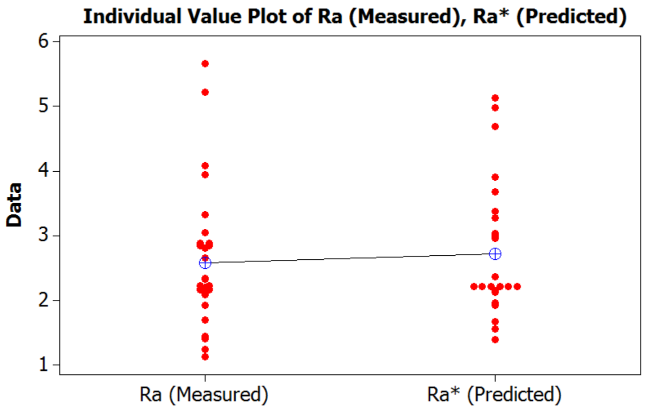


Fig. 3. Comparison chart of the surface roughess when predicting and testing

Two-Sample T-Test and CI: Ra (Measured), Ra* (Predicted)

```
Two-sample T for Ra (Measured) vs Ra* (Predicted)

                  N   Mean  StDev  SE Mean
Ra (Measured)    30   2.57   1.04     0.19
Ra* (Predicted)  30  2.718  0.989     0.18

Difference = mu (Ra (Measured)) - mu (Ra* (Predicted))
Estimate for difference:  -0.143
95% CI for difference:  (-0.667, 0.382)
T-Test of difference = 0 (vs not =): T-Value = -0.54  P-Value = 0.589  DF = 57
```

Fig. 4. Comparison of the Surface Roughness when Predicting and Testing

V. Conclusion

Some conclusions are drawn from this study when turning steel SAE 420 as follows:

- Cutting velocity, feed rate and tip radius are parameters that greatly affect surface roughness. In particular, the feed rate is the parameter that affects the roughness to the greatest extent, followed by the influence of the radius of the tip, and the degree of influence of the cutting velocity. Cutting depth is a parameter that does not significantly affect surface roughness.
- The interaction between the feed rate and the depth of cut has the greatest effect on the surface roughness, followed by the degree of interaction between the cutting velocity and the tip radius. The interaction between other factors has a negligible influence on the surface roughness.
- A model of surface roughness was proposed in this study. This model has been shown to be able to predict surface roughness very closely compared to the test. Using this model it is possible to predict surface roughness in each specific case of cutting speed, feed rate, cutting depth and tip radius.
- Research to determine the optimum value of the cutting velocity, the feed rate, the depth of cutting and the radius of the tip to ensure surface roughness with a minimum value is the research direction to be carried out in the next period.

Acknowledgement

The work was supported by Vinh Long University of Technology Education (http://vlute.edu.vn/).

References

[1] Tran Van Dich, Nguyen Trong Binh, Nguyen The Dat, Nguyen Viet Tiep, Tran Xuan Viet, Manufacturing technology, Science and Technics Publishing House, Ha Noi, 2003.

[2] M. H. El-Axir, M. M. Elkhabeery, M. M. Okasha, Modeling and Parameter Optimization for Surface Roughness and Residual Stress in Dry Turning Process, Engineering, Technology & Applied Science Research Vol. 7, No. 5 (2017) 2047-2055.

[3] Dejan Tanikić, Velibor Marinković, Modelling and Optimization of the Surface Roughness in the Dry Turning of the Cold Rolled Alloyed Steel Using Regression Analysis, J. of the Braz. Soc. of Mech. Sci. & Eng., Vol. XXXIV, No. 1 (2012) 41-48.

[4] Nguyen Hong Son, Hoang Xuan Thinh, Nhu-Tung Nguyen, and Do Duc Trung, Experimental Investigation of the influence of the Cutting Conditions on the Surface Roughness in Hole turning the SCM400 Steel, European Journal of Engineering Research and Science Vol. 4, No. 8, (2019) 11-14

[5] Nguyen Hong Son, Hoang Xuan Thinh, Nhu-Tung Nguyen, Do Duc Trung, Influence of Cutting Conditions on the Surface Roughness

When Hole Turning Heat-Treated SKD11 Steel, Proceedings of the International Conference on Engineering Research and Applications, LNNS 104 (2020) 426–435.

[6] Amrifan Saladin Mohruni, Muhammad Yanis, Edwin Kurniawan, Development of surface roughness prediction model for hard turning on AISI D2 steel using Cubic Boron Nitride insert, Jurnal Teknologi, Vol. 80, No. 1 (2018) 173–178

[7] Salah Gasim Ahmed, Development of a Prediction Model for Surface Roughness in Finish Turning of Aluminium, Sudan Engineering Society Journal, Vol. 52, No.45 (2006), 1-5.

[8] Dilbag Singh, P. Venkateswara Rao, A surface roughness prediction model for hard turning process, Int J Adv Manuf Technol, Vol. 32 (2007), 1115-1124.

[9] C. X. (Jack) Feng, X. Wang, Development of Empirical Models for Surface Roughness Prediction in Finish Turning, Int J Adv Manuf Technol, Vol. 20, (2002) 348–356.

[10] A. Doniavi, M. Eskandarzade, M. Tahmasebian, Empirical modeling of surface roughness in turning process of 1060 steel using factorial design methodology, Journal of applied sciences, Vol. 7, No. 17 (2007), 2509-2513

[11] K. Taraman, B. lambert, A surface roughness model for a turning operation, International Journal of Production Research, Vol. 12, No. 6, (1974) 691-703.

[12] Manan Kulshreshtha, Analysis of the Effect of Machining Parameters on Surface Roughness of EN 36 Nickel Steel, International Journal of Advanced Information Science and Technology, Vol.16, No.16, (2013), 1-7.

[13] H. H. Shahabi, M. M. Ratnam, Prediction of surface roughness and dimensional deviation of workpiece in turning: a machine vision approach, Int J Adv Manuf Technol, Vol. 48, (2010) 213–226.

[14] Maohua Xiao, Xiaojie Shen, You Ma, Fei Yang, Nong Gao, Weihua Wei, Dan Wu, Prediction of Surface Roughness and Optimization of Cutting Parameters of Stainless Steel Turning Based on RSM, Mathematical Problems in Engineering, Volume (2018),

[15] S. Dinesh, K. Rajaguru, V. Vijayan, Investigation and Prediction of Material Removal Rate and Surface Roughness in CNC Turning of EN24 Alloy Steel, Mechanics and Mechanical Engineering, Vol. 20, No. 4 (2016) 451–466.

[16] Nitin Ambhore, Dinesh Kamble, Satish Chinchanikar, Prediction of cutting tool vibration and surface roughness in hard turning of AISI52100 steel, MATEC Web of Conferences, Vol. 211, No. 03011 (2018), https://doi.org/10.1051/matecconf/201821103011.

PhD. Le Hong Ky was born in Vietnam in 1963. He obtained a Engineer in Mechanical Engineering in 1987 from Ho Chi Minh University of Technology and Education, Vietnam. In 1996, he received Master of Mechanical Engineering from Ho Chi Minh University of Technology and Education, Vietnam. In 2016 he got Doctor in Mechanical Engineering at National Research Institute of Mechanical Engineering (NARIME), Vietnam. Now He is a Lecturer and works as an Vice Rector at Vinh Long University of Technology Education, Vietnam. His current research focuses on optimization in machining processes such as grinding, EDM machining etc. and optimum design of gearboxes. Reviewer for the ICERA 2019, ICMSET 2019 and MEAE 2019..