International Journal of Scientific Engineering and Applied Science (IJSEAS) – Volume-2, Issue-2, February 2016
ISSN: 2395-3470
www.ijseas.com

Estimation of Cutting Force Model Constants of Various High Speed Turning Tool Geometries

Pedro I. Ezeanyagu

Abstract**—**In this paper, an attempt has been made to estimate cutting force model constants of various HSS turning tool geometries. A cutting force data generated through experiment for HSS tool and EN-8 work piece using a 4-component piezoelectric dynamometer was extracted from literature and used in the study to estimate the model constants. A non-linear cutting force model that was made linear was used in fitting the cutting force data, according to their respective components for each of the tool geometry used. In the least-squares sense, it is found that the model constants generated decreases as the tool rake angles increases. Also the coefficient of determination R^2 at 0.9 for the various tool geometries used shows that the force model is suitable in predicting cutting forces in orthogonal turning process.

Keywords**—**Cutting forces, cutting force model constants, turning process

I. INTRODUCTION

Turning operation is one of the most important, frequently practiced and unavoidable machining processes for the components used in shaft design and fabrication [1]. For an orthogonal cutting operation in lathe turning, the force components can be measured in three directions, and the force relationships are relatively simple. The force component acting on the tool in the direction parallel with the direction of feed, i.e direction parallel to the axis of the workpiece is referred to as the feed force F_x . This force acts tangential to the main cutting force F_t, while the third component F_r is the radial force acting in the direction tending to push the tool away from the workpiece. A simple orthogonal turning operation is shown in Fig. 1.

Cutting force coefficient and its exponent are model constants that are experimentally predicted. They are ideally identified from direct cutting force measurements carried out with dynamometers [2]. These coefficients can later be used alongside modal parameters of the machine system for accurate evaluation of chatter stability lobes, which are useful in chatter prediction and adjusting the operating parameters for a higher production rate in turning process.

P. I. Ezeanyagu is with the Department of Mechanical Engineering, Nnamdi Azikiwe University, Awka, PMB 5025, Nigeria (phone: +2348030537514; e-mail: ezeanya77@yahoo.com).

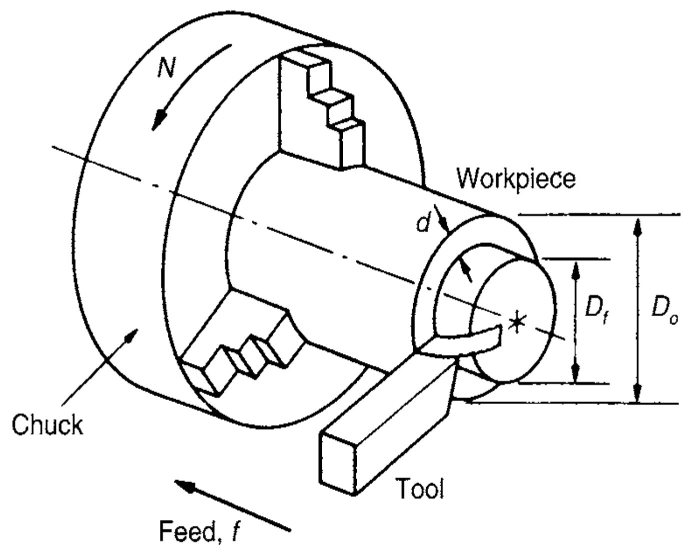

Fig. 1 Orthogonal turning process

Considerable amount of research has been undertaken to estimate these model constants from cutting force values which are the key factors to achieving efficient and accurate simulation of turning process. In the work of Budak, Altintas and Armarego [3] they developed a general approach that could fit the model with data extracted from orthogonal cutting tests. Yucesan and Altintas [4], Lee and Altintas [5], Engin and Altintas [6] presented general models that could be used for the reliable prediction of cutting forces for a general end mill. Fang and Wu [7] explained a detailed comparative turning study between Inconel 718 and Ti-6Al-4V, finding empirical relationships to predict cutting forces depending on cutting speed and feed rate. Also Ezeanyagu [8] in his work estimated these model constants at constant rake angle from feed cutting forces using the method of least squares in a simple dry orthogonal turning operation.

In this study, cutting force coefficients and its exponent of High Speed Steel (HSS) tool geometries were determined. These model constants were determined from cutting force values and parameters extracted from the work of Kosaraju, Anne and Ghanta [9] in TABLE I.

II. MATHEMATICAL MODEL

A. Cutting Force Model of Orthogonal Turning Process

A non-linear cutting force model used by Ozoegwu [1] as stated in equation (1) was used and F is the component of the cutting force.

$$F = Cwf^{\alpha} \quad (1)$$

C is the cutting force coefficient in the direction of the cutting force component, a workpiece-material dependent parameter, w is the depth of cut, f is the feed rate and α is the feed exponent that has a popular values of 3/4 [1]. The last value is termed the three-quarter rule. Equation (1) is a non-linear cutting force model, expressing it in logarithmic form in other to make it linear yields

$$\log F = \log (Cwf^{\alpha}) \quad (2)$$

$$\log F = \log C + \log w + \alpha \log f \quad (3)$$

Equation (3) is expressed as a linear form of equation (2) as given

$$Y_i = A_0X_0 + A_1X_1 + A_2X_2 \pm \varepsilon_i \quad (4)$$

Where Y_i is the logarithmic value of the cutting force component, A_i $(i = 0, 1 \ldots)$ to be calculated equation constants, X_0, X_1 and X_2 are the logarithmic values of C, w and f respectively and ε_i $(i = 0, 1 \ldots)$ is the error term. Using the method of least-squares, equation (4) is rewritten as

$$A = [X' \cdot X]^{-1} \cdot X' \cdot Y \quad (5)$$

III. METHOD

Experimental cutting force values and parameters extracted from the work of Kosaraju, Anne and Ghanta [9] was used in this work. In their work, EN-8 steel was used as the workpiece material. It is a material widely used in industries. For conducting their experiments hollow cylindrical bars with inner diameter of 19 mm and outer diameter of 24 mm were used. Prior to the experiments the specimens were turned with 1mm cutting depth in order to remove the outer layer, which could appear discontinuous or unexpected hardening distribution due to their extrusion production process. Without a coolant, the materials were turned at a constant speed of 490 rpm and constant depth of cut of 2.5 mm. The tangential, feed and radial cutting forces (*Fc*, *Ff*, and *Fr*, respectively) were measured. Parameters used during the turning test are shown in TABLE I.

TABLE I
PARAMETERS USED BY KOSARAJU, ET. AL [9] DURING TURNING OPERATION

Group No	Expt. No	f (MM/REV)	γ_0 (DEG)	F_x (N)	F_y (N)	F_z (N)
1	1	0.022	0	132.14	58.78	5.69
	2	0.044		220.36	101.32	10.14
	3	0.088		623.83	217.37	17.84
	4	0.108		819.48	262.82	22.36
	5	0.132		910.93	306.05	31.27
2	1	0.022	4	151.40	62.97	2.62
	2	0.044		332.40	125.99	1.33
	3	0.088		500.90	191.43	0.47
	4	0.108		604.00	222.93	2.66
	5	0.132		737.10	267.49	7.55
3	1	0.022	8	87.75	54.48	2.41
	2	0.044		187.38	111.20	3.99
	3	0.088		329.37	191.25	6.03
	4	0.108		414.29	228.97	8.70
	5	0.132		618.08	305.04	14.28
4	1	0.022	12	103.04	49.09	3.94
	2	0.044		183.77	93.22	8.18
	3	0.088		306.04	156.10	11.92
	4	0.108		371.81	189.30	15.10
	5	0.132		430.57	224.30	21.02
5	1	0.022	16	104.69	50.70	3.48
	2	0.044		184.41	90.28	5.51
	3	0.088		290.85	147.07	8.63
	4	0.108		345.62	177.14	9.75
	5	0.132		489.41	239.98	14.93
6	1	0.022	20	89.75	49.13	7.51
	2	0.044		147.88	86.21	12.9
	3	0.088		217.62	135.50	18.91
	4	0.108		243.77	157.40	19.44
	5	0.132		289.15	190.90	25.57

IV. RESULTS, VALIDATION AND DISCUSSIONS

The cutting force coefficients C and their respective exponents α at given cutting parameters in TABLE I were calculated for the cutting force components (F_c, F_f, and F_r, respectively) using Equation (5). Their respective standard errors which are the difference between the measured cutting force results and the calculated cutting force component results were gotten. The coefficient of determination R^2 used to control the developed model suitability to the observed values were gotten and tabulated in TABLE II to TABLE VII.

TABLE II
THE CUTTING FORCE COEFFICIENTS, FEED EXPONENTS, STANDARD ERRORS AND R^2 VALUES OF TOOL WITH 0.0 DEGREE RAKE ANGLE

Work piece material	: EN-8 steel			
µ	: 0.0			
Fi	*C*	α	ε_i	R^2
Fc	2137.9621	0.95	0.02	0.99
Ff	9772.3722	1.15	0.06	0.98
Fr	177.8279	0.91	0.04	0.99

TABLE III
THE CUTTING FORCE COEFFICIENTS, FEED EXPONENTS, STANDARD ERRORS AND R^2 VALUES OF TOOL WITH 4.0 DEGREE RAKE ANGLE

Work piece material	: EN-8 steel			
μ	: 0.0			
Fi	*C*	α	ε_i	R^2
Fc	1288.2496	0.78	0.03	0.99
Ff	4073.8028	0.84	0.04	0.98
Fr	143.4350	1.00	0.09	0.95

TABLE IV
THE CUTTING FORCE COEFFICIENTS, FEED EXPONENTS, STANDARD ERRORS AND R^2 VALUES OF TOOL WITH 8.0 DEGREE RAKE ANGLE

Work piece material	: EN-8 steel			
μ	: 0.0			
Fi	*C*	α	ε_i	R^2
Fc	1862.0871	0.92	0.03	0.99
Ff	4365.1583	1.02	0.04	0.99
Fr	67.6083	0.90	0.09	0.93

TABLE V
THE CUTTING FORCE COEFFICIENTS, FEED EXPONENTS, STANDARD ERRORS AND R^2 VALUES OF TOOL WITH 12.0 DEGREE RAKE ANGLE

Work piece material	: EN-8 steel			
μ	: 0.0			
Fi	*C*	α	ε_i	R^2
Fc	1230.2688	0.84	0.013	0.99
Ff	2137.9621	0.79	0.008	0.99
Fr	109.6478	0.86	0.05	0.98

TABLE VI
THE CUTTING FORCE COEFFICIENTS, FEED EXPONENTS, STANDARD ERRORS AND R^2 VALUES OF TOOL WITH 16.0 DEGREE RAKE ANGLE

Work piece material	: EN-8 steel			
μ	: 0.0			
Fi	*C*	α	ε_i	R^2
Fc	1174.8976	0.82	0.03	0.99
Ff	2238.7211	0.80	0.04	0.98
Fr	56.2341	0.74	0.06	0.96

TABLE VII
THE CUTTING FORCE COEFFICIENTS, FEED EXPONENTS, STANDARD ERRORS AND R^2 VALUES OF TOOL WITH 20.0 DEGREE RAKE ANGLE

Work piece material	: EN-8 steel			
μ	: 0.0			
Fi	*C*	α	ε_i	R^2
Fc	831.7638	0.74	0.014	0.99
Ff	1023.2930	0.63	0.014	0.99
Fr	89.1251	0.64	0.03	0.98

The turning process has been assumed to be a pure orthogonal process. For such an assumption only 3 components of force must exist in the orthogonal plane with the radial force having the lowest magnitude. Results gotten from regression equation (5) were tabulated as shown in Table II to Table VII.

From Table II to Table VII, it is clear that the cutting force coefficient *C* and its respective exponent's α decreases as the tool rake angle increases. This can be attributed to the overshadowing effect of cutting tools with higher rake angle on the cutting pressure, i.e there is a reduction in tool-chip contact area and less friction which allows chip flow easily in the cutting process. The developed model constants for the cutting forces in orthogonal turning process specifically can be said that the mean error for the tangential cutting forces (*Fc*) are less or equals 3%, that of feed force (*Ff*) and radial force (*Fr*) are less or equals 6.0% and 9.0% respectively. Also, their coefficients of determination R^2 values are above 0.9, which indicates the suitability of the model in estimating cutting forces for various tool geometries in turning.

V. Conclusion

Cutting coefficients and its exponents which are also the model constants of the tool-work piece pair were estimated from the cutting force model using the method of least-squares and tabulated.

It was found that the model constants decreases with the increase in rake angle of tool and that the value of the cutting force coefficient *C* in the radial component is very low as compared with that in the tangential and feed components respectively.

Also, with the mean error less or equals 3%, 6.0% and 9.0% for the tangential, feed and radial force components respectively and at coefficients of determination R^2 values above 0.9, it can be deduced that the cutting force model is suitable in predicting cutting forces in orthogonal turning process.

References

[1] C. G. Ozoegwu, "Chatter of plastic milling CNC machine", Master's Thesis in Mechanical Engineering, *Nnamdi Azikiwe University Awka, Nigeria 2011*.

[2] K. Dunwoody, "Automated identification of cutting force coefficients and tool dynamics on CNC machines". A thesis submitted in partial fulfillment of the requirements for the degree of master of applied science in the faculty of graduate studies (Mechanical Engineering) *University of British Columbia Vancouver 2010*.

[3] E. Budak, Y. Altintas, E. J. Armarego, "Prediction of milling force coefficients from orthogonal cutting data". *Transactions of the ASME Journal of Manufacturing Science and Engineering 1996*; 118:216–224.

[4] G. Yücesan, Y. Altintas, "Prediction of ball end milling force". *Transactions of ASME Journal of Engineering Industry, 1996*; 118: 95–103.

[5] P. Lee, Y. Altintas, "Prediction of ball-end milling forces from orthogonal cutting data". *International Journal of Machine Tools and Manufacture 1996*; 36:1059–1072.

[6] S. Engin, Y. Altintas, "Mechanics and dynamics of general milling cutters. Part 1: helical end mills". *International Journal of MachineTools and Manufacture 2001*; 41:2195-2212.

[7] P. I. Ezeanyagu, "Cutting force coefficients estimation and tool dynamics of turning process", Master of Engineering Thesis, *Nnamdi Azikiwe University Awka 2015*.

[8] N. Fang, Q. Wu, "A comparative study of the cutting forces in high speed machining of Ti-6Al-4V and Inconel 718 with a round cuting edge tool", *Journal of Materials Processing Technology, 2009*, (209) 4386-4389.

[9] S. Kosaraju, V. Anne, V. Ghanta, "Effect of rake angle and feed rate on cutting forces in an orthogonal turning process", *International Conference on Trends in Mechanical and Industrial Engineering* (*ICTMIE*) *Bangkok Dec., 2011*; 150-154.