International Journal of Pure and Applied Mathematics
Volume 118 No. 20 2018, 1-9
ISSN: 1314-3395 (on-line version)
url: http://www.ijpam.eu
Special Issue

ijpam.eu

Prediction of Turning Tool Life and Surface Roughness with Optimal Cutting Parameters Based on MOGA Approach

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ABSTRACT:
Modern manufacturing industries needs to manufacture the product with better quality in a short time span. Machining parameters like cutting speed, feed rate, and depth of cut which influences the surface roughness (Ra), tool life (T_L) and material removal rate (MRR). The critical machining conditions leads to increase in machine tool chatter and temperature, causing in a poor surface finish, high noise and accelerated tool wear which in turn reduces machine tool life, reliability and safety of the machining operation. With CNC turning records, regression models has been developed in MINITAB for vibration, temperature, surface roughness and MRR in terms process parameters. Genetic algorithm multi-objective tool box has been used in MATLAB to predict the optimal conditions of machining variables. Finally the optimized set of parameters further reexamined and that has been considered for evaluating tool life.

Keywords: Dry turning, Surface roughness, Tool life, Material removal rate, Multi-objective optimization, Genetic algorithm.

I.INTRODUCTION

Turning is one of the most common machining process in metal cutting operations. The machining of metals is regularly associated with a ferocious relative motion between machine tool and workpiece which is called chatter vibration. In machine tools, three different types of mechanical vibrations such as free, forced and self-excited vibrations are present due to a lack of dynamic stiffness/rigidity is enunciated [1]. Free and forced vibrations can be easily predictable and eradicated. But self-excited chatter vibrations are still not fully understood owing to its complex nature. It is furthermost harmful for any machining process including turning, milling and drilling etc. The effects of machining parameters, including cutting speed, feed rate, depth of cut and cutting tool vibration on the resulting surface roughness in the dry turning operation was investigated [2,3].

Most of the researchers observed in machining process are, first is the cutting conditions, i.e. cutting velocity, feed, depth of cut. The second is mechanical and physical parameters of the cutting tool, i.e. tool material composition, strength, hardness and thermal properties. As the temperature is a function of the velocity, the excess amount of heat accelerate the wear. The influence of the temperature gradient in the cutting tool, on the tool life and mainly on the wear behavior [4]. Tool life enhancement is important to diminish the cost of production as much as possible. It was possible to proliferate tool life substantially, reducing the cutting tool wear by 30% with an appropriate variation of feed rate during the cutting process maintaining constant material removal rate (MRR) [5].

The unconventionality in cutting velocity (V), feed (S) and depth of cut (D) influences a major role on tool life. Taylor's has proposed a modified tool life equation by considering these parameters as [6]

$$V\,T^{n}F^{a}D^{b} = C$$

Where, n, a, b are Taylor's tool life exponent and C is constant. These value are depends upon mainly the tool - workpiece materials and the cutting environment (cutting fluid application).

The empirical regression models was developed for predicting the surface roughness, vibration, and material removal rate in terms of in cutting velocity, feed and depth of cut. The optimized cutting conditions are studied for minimizing the above surface roughness and vibration and maximizing material removal rate by multi objective optimization [8-10].

II.EXPERIMENTAL WORK

Fig.1 Setup of experiment

Fig.2 Surface Roughness Measurement

A series of turning test was done using CNC Turning Centre -Uniturn 300. The tool chosen for turning is Coated Carbide Inserts -CU35 of 0.2 mm nose radius, Style – TCMT. The workpiece material is mild steel with initial length and diameter of 170mm and 25mm respectively. Turning is performed on the work material by keeping two machining parameters are constant and varying other parameter [11], under dry conditions. The values of machining vibrations, surface roughness and cutting temperature are recorded, then MRR is calculated. Machining Vibrations are recorded using Accelerometer sensor-MPU6050 in terms of acceleration in g, temperature was measured using HTC Temperature Gun in Fig.1 and surface roughness was measured using SURFCOM 14008 in Fig. 2. Experiments was carried out by varying d, f and N between the range of 0.1 mm to 1 mm, 0.02 mm/rev to 0.1 mm/rev and 600 rpm to 1500 rpm respectively. The empirical regression analysis support is used for creating statistical relations between machining parameters and surface finish, temperature, vibration and material removal rate. These relations are taken for multi-objective optimization with aid of genetic algorithm.

S.No	Feed Rate (f) (mm/rev)	Depth of Cut d(mm)	Spindle Speed N (rpm)	Vibration V (Hertz)			Temperature t (^{o}C)			Surface Roughness Ra (µm)	Material Removal Rate MRR (mm^3/min)
				Trail I	Trail 2	average	Trail I	Trail 2	average		
1	0.06	1	1500	10.24	10.45	10.345	184.4	94.7	139.55	2.466	6.95196
2	0.06	0.9	1500	10.4	10.34	10.37	184.5	92.3	138.4	1.7743	6.256764
3	0.06	0.8	1500	10.56	10.42	10.49	110.7	73.1	91.9	1.7901	5.561568
4	0.06	0.7	1500	10.49	10.38	10.435	112.33	67.9	90.1	1.2994	4.866372
5	0.06	0.6	1500	10.46	10.41	10.435	109.1	62.47	85.715	1.147	4.171176
6	0.06	0.5	1500	10.56	10.48	10.52	103	58	80.5	1.9596	3.47598
7	0.06	0.4	1500	10.28	10.51	10.395	93.7	72.6	83.15	1.4977	2.780784
8	0.06	0.3	1500	9.92	10.4	10.16	72.7	62.43	67.565	1.0691	2.085588
9	0.06	0.2	1500	8.57	10.41	9.49	60.6	50.47	55.535	1.012	1.390392
10	0.06	0.1	1500	9.64	10.37	10.005	73.9	48.43	61.165	0.7914	0.695196

Table.1 Variation in depth of cut, feed rate and spindle speed are constant

S.No	Feed Rate (f) (mm/rev)	Depth of Cut d(mm)	Spindle Speed N (rpm)	Vibration V (Hertz)			Temperature t (^{o}C)			Surface Roughnes s Ra (µm)	Material Removal Rate MRR (mm^3/min)
				Trail I	Trail 2	average	Trail I	Trail 2	average		
1	0.01	0.6	1500	10.22	10.37	10.295	32.9	29.7	31.3	0.4986	0.695196
2	0.02	0.6	1500	9.8	10.18	9.99	29.7	27.7	28.7	0.3945	1.390392
3	0.03	0.6	1500	10.23	10.49	10.36	35.72	25.6	30.66	0.5796	2.085588
4	0.04	0.6	1500	10.37	10.62	10.495	43.2	39.1	41.15	1.1803	2.780784
5	0.05	0.6	1500	10.34	10.36	10.35	44.7	33.7	39.2	0.6606	3.47598
6	0.06	0.6	1500	10.21	10.48	10.345	42.6	37.1	39.85	0.8166	4.171176
7	0.07	0.6	1500	10.31	10.42	10.365	41.9	36.6	39.25	0.6723	4.866372
8	0.08	0.6	1500	10.46	10.32	10.39	38.7	33	35.85	0.6539	5.561568
9	0.09	0.6	1500	10.33	10.28	10.305	51.5	34.9	43.2	0.6784	6.256764
10	0.1	0.6	1500	10.81	10.25	10.53	49.1	30.9	40	0.7636	6.95196

Table.2 Variation in feed rate, depth of cut and spindle speed are constant

S.No	Feed Rate (f) (mm/rev)	Depth of Cut d(mm)	Spindle Speed N (rpm)	Vibration V (Hertz)			Temperature t (^{o}C)			Surface Roughness Ra (µm)	Material Removal Rate MRR (mm^3/min)
				Trail I	Trail 2	average	Trail1	Trail2	average		
1	0.06	0.6	600	10.68	10.43	10.555	30.4	36.2	33.3	1.1552	1.66847
2	0.06	0.6	700	10.24	10.39	10.315	27.4	32.1	29.75	1.1974	1.946549
3	0.06	0.6	800	10.23	10.44	10.335	28.4	32.7	30.55	0.9162	2.224627

4	0.06	0.6	900	10.26	10.4	10.33	29.3	33.9	31.6	0.9266	2.502706
5	0.06	0.6	1000	10.18	10.35	10.265	28.8	35.2	32	0.7963	2.780784
6	0.06	0.6	1100	9.6	10.32	9.96	28.8	37.2	33	1.8006	3.058862
7	0.06	0.6	1200	9.8	10.34	10.07	32.7	36.2	34.45	1.6067	3.336941
8	0.06	0.6	1300	9.67	10.14	9.905	29.6	40	34.8	1.193	3.615019
9	0.06	0.6	1400	9.2	11.35	10.275	31.5	44.5	38	0.9229	3.893098
10	0.06	0.6	1500	10.12	11.46	10.79	39.9	47.9	43.9	1.1138	4.171176

Table.3 Variation in spindle speed, feed rate and depth of cut are constant

II. FORMULATION OF OPTIMIZATION PROBLEM FOR TURNING

For a turning operation with single pass, we visualize to optimize the cutting speed, and feed rate and depth of cut, in order to minimize the surface roughness, vibration , temperature and maximize material removal rate. We execute constraints related to the machining parameters. Objective functions are developed using statistical modeling regression analysis in MINITAB 2017.

OBJECTIVE FUNCTION REGRESSION MODELS

SURFACE ROUGHNESS (Ra) = 0.188 + 4.62*f + 1.128*d - 0.000003*N

VIBRATION (V) = 9.732 + 2.24*f + 0.671*d + 0.000031*N

TEMPERATURE (T) = -66.1 + 267*f + 68.3*d + 0.0475*N

MRR = -8.342 + 69.52*f + 6.952*d + 0.002781*N

CONSTRAINTS FUNTIONS

The surface roughness, vibration and temperature are directly reflects the machining quality. The most preponderant factors influencing the objective functions are cutting speed, feed rate and depth of cut. Therefore the machining conditions are considered as constraint equations.

$600 \leq N \leq 1400$

$0.02 \leq f \leq 0.1$

$0.1 \leq d \leq 0.9$

IV. MULTI OBJECTIVE OPTIMISATION

To solve optimization problem using GA, fitness value is required. Fitness values, in fact, are the objective function values. The developed mathematical model was converted into a MATLAB R2017a function. This function was input to the GA Toolbox of MATLAB a as the objective function. Upper and lower bounds were specified as per the levels of the machining parameters and the number of variables was set at 3. The objective function values are obtained for minimization of surface roughness, vibration and temperature with maximization of MRR in turning. The Pareto-optimal solutions (along with corresponding performance measure values) are reported in table.4. Being a population-based approach, GA are well suited to solve multi-objective optimization problems. A generic single-objective GA can be modified to find a set of multiple non-dominated solutions in a single run. The ability of GA to simultaneously search different regions of a solution space makes it possible to find a diverse set of solutions for difficult problems with non-convex, discontinuous, and multi-modal solutions spaces. The crossover operator of GA may exploit structures of good solutions with respect to different objectives to create new non-dominated solutions in unexplored parts of the Pareto front [12].

OPTIMISATION PARAMETERS

Population type : Double vector
Population size : 60
Elite count : Default
Crossover fraction : 0.8
Pareto fraction : []
Migration direction : forward
Migration interval : 20
Migration fraction : 0.2
Generations : 100
Creation fcn : @Nonlinear Feasible population
Selection fcn : @tournament
Crossover fcn : @crossover scattered
Mutation fcn : @adaptive Feasible
Display : diagnose
Vectorized : off
Use parallel : never

Diagnostic information:

Fitness function : @ alltest
Number of variables : 3

S.No	Vibration V (Hertz)	Temperaturet (^{o}C)	Surface Roughness Ra (μm)	MRR (mm^3/min)	Feed Rate (f) (mm/rev)	Depth of Cut d(mm)	Spindle Speed N (rpm)
1	9.8401	-28.1	0.3452	-5.283	0.01	0.1	600
2	9.840740375	-27.12069803	0.345140486	-5.225654885	0.010000083	0.100001724	620.6139384
3	9.8401	-28.1	0.3452	-5.283	0.01	0.1	600
4	9.840771792	-27.07137686	0.345135994	-5.222770059	0.010000102	0.100000431	621.6540321
5	9.840389567	-27.65664744	0.345172442	-5.257039753	0.010000047	0.100000198	609.3331882
6	9.840587031	-27.35445232	0.34515387	-5.239342083	0.010000133	0.1000003	615.6945608
7	9.840474934	-27.52596768	0.34516433	-5.249388589	0.010000043	0.10000034	612.0841598
8	9.840551511	-27.40896167	0.345157447	-5.24253147	0.010000172	0.100000258	614.5468354
9	9.84074959	-27.10496926	0.345137551	-5.224741114	0.010000034	0.10000021	620.9475224
10	9.840682049	-27.20898872	0.345144801	-5.230826823	0.010000096	0.100000557	618.7567919
11	9.840631017	-27.28734958	0.345149941	-5.235414408	0.01000009	0.100000752	617.1068452
12	9.840414819	-27.61959579	0.345172027	-5.254865904	0.010000036	0.100001943	610.1107748
13	9.840230602	-27.90029539	0.345187876	-5.271306382	0.010000004	0.100000416	604.2036871
14	9.840643615	-27.267385	0.345147857	-5.234249673	0.010000042	0.10000022	617.5281851
15	**9.840790673**	**-27.04202422**	**0.345133581**	**-5.221055819**	**0.010000034**	**0.100000212**	**622.2726754**
16	9.840263374	-27.85011741	0.345184786	-5.268366751	0.010000043	0.100000325	605.2599766
17	9.840719697	-27.15218294	0.345142244	-5.227498676	0.010000087	0.100001504	619.9513918
18	9.840609552	-27.3197544	0.34515139	-5.237314368	0.010000061	0.100000339	616.4253906
19	9.840318706	-27.76522832	0.345179276	-5.26339822	0.010000016	0.100000303	607.0472966
20	9.840279211	-27.82611028	0.345183591	-5.26695969	0.010000059	0.100000543	605.7649863
21	9.840450977	-27.56235761	0.345166221	-5.251521679	0.010000007	0.100000126	611.3185644

22	9.840150757	-28.02276333	0.345195762	-5.278475946	0.010000009	0.100000528	601.6252243
23	9.840296841	-27.79857405	0.345181189	-5.265351322	0.010000009	0.100000162	606.3455242
24	9.84069438	-27.19003638	0.345143521	-5.22971806	0.010000081	0.100000545	619.1558904

Table.4 Pareto optimal solution obtained from multi objective optimization GA

V.RESULT AND DISCUSSION

The least surface roughness value 0.345133581µm has been chosen as the optimized value from pareto optimal solutions which has values of cutting parameter of feed rate (f) of 0.010000034 mm/rev, depth of cut (d) of 0.100000212 mm and spindle speed (N) of 622.2726754 rpm and it is validated by conducting turning experiments based on the receptive obtained optimum cutting parameters. The error percentage obtained for vibration, surface roughness and temperature are 0.018 %, 0.69% and 0.048% respectively shown in table.5. For this tool life is calculated using modified Taylor's tool life equation is 242 minutes.

Parameters	**Optimal values**	**Validation values**	**Error %**
Feed Rate (f) (mm/rev)	0.010000034	0.01	-
Depth of Cut d(mm)	0.100000212	0.1	-
Spindle Speed N (rpm)	622.2726754	622	-
Vibration V (Hertz)	9.840790673	9.66	0.018
Temperature t (^{o}C)	-27.04202422	27.6	0.69
Surface Roughness Ra (µm)	0.345133581	0.5856	0.048
MRR (mm^3/min)	0.04805	0.04807	0.0041

Table.5 Comparison of optimal and experimental validation results

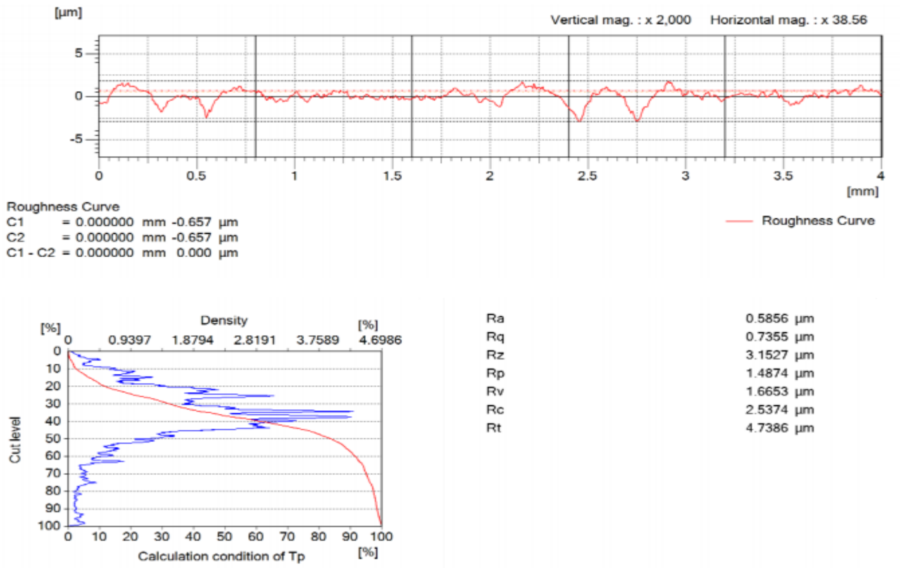

Fig. 3. Experimental measure of surface roughness

VI. CONCLUSION

The proposed work delivers multi-objective solution of the cutting parameters for the minimization of machining vibration levels, surface roughness and tool tip temperature. Based on the optimized numerical values and experimental studies the following conclusions were made.

- The mathematical model developed in this work gives the noble co-relation between the process parameters and the objective functions. In addition, the pareto front based MOGA model can obtain good solutions in short time and are suitable for the multi-objective environment due to its population based nature.
- The confirmatory tests are conducted for validation for the correctness of the optimized process parameters. Optimal values are compared with experimental results in terms of error percentage obtained for vibration, surface roughness, temperature and the maximum material removal rate is shown in table.5.

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