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Optimization of Process Parameters by NSGA-II in CNC Milling of EN8 Mild Steel

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***Abstract*: In this paper, the algorithm is developed to investigate the optimal cutting parameters for minimizing the machining time, maximizing the material removal rate, minimizing surface roughness and maximizing the tool life with respect to constraints such as maximum machine power and available feed rate and spindle speed on machine tool in CNC milling operation. The Nondominated Sorting Genetic Algorithm-II (NSGA-II) is used for optimizing machining parameters selection.**

The algorithm searches for the best solution in terms of cutting speed, feed and depth of cut with the aim of optimizing the objective functions. In this work, a specific case in milling operation is taken and its process parameters are optimised using NSGA-II.

Mathematical models for objective functions are obtained using regression analysis in MINITAB. Optimization procedures based on the above algorithm have been developed and are successfully implemented.

Keywords: *Optimization, NSGA_II, CNC-Milling.*

1. INTRODUCTION

MILLING is one of the most common metal removing processes in manufacturing.The application of milling has been increased with the introduction of high speed machining (HSM).Optimal machining parameters is the key to economical machining operations. Operators usually select the machining parameters from handbooks or select the parameters based on their experience. The machining parameters so selected are usually conservative to avoid machining failure. The optimisation of machining parameters is multiobjective and non – linear with the constraints,so it is difficult for the traditonal optimisation algorithm to solve the problem.In this paper,Non traditional algorithm namely NSGA-II Algorithm is proposed to optimise the milling parameters.

2. LITERATURE REVIEW

Initially a number of researchers have dealt with the optimization of machining parameters, considering only turning operations and hand book recommendations to determine the optimum speed and feed. In [1], the author described the optimization system which determines optimum machining parameters for milling using method of feasible directions. In [2], the development and utilization of an optimization system which determines optimum machining parameters for milling operation using Genetic Algorithm is described. Recently different methods have been reported in the literature to optimize the machining parameters of milling operations using GA (Genetic Algorithm) [3], Ant colony Algorithm[3], and particle swarm optimization techniques[3]. All the above researchers consider only the minimization of the cost as an objective. In [4,5], the authors developed models for maximum MRR and minimum surface roughness are described for exploring optimized machining parameters in milling operation. In this paper, a computerised algorithm will be developed to optimize the cutting parameters for minimizing the machining time, maximizing the material removal rate, minimizing surface roughness and maximizing the tool life. It is also proposed to use the quality and advantages of non-traditional optimization technique NSGA-II.

3. OBJECTIVE

A typical optimization problem of a machining operation comprises one or multiple economic objectives with several machining constraints. In this paper

Objectives are:

- Minimize the machining time
- Maximize the material removal rate
- Minimize surface roughness
- Maximize tool life

In practice possible range of cutting speed and feed rate are limited by the following constraints:

1. Maximum machine power.
2. Available feed rate and spindle speed on the machine tool.

4. METHODOLOGY

Step1: A specific component is selected to be produced using CNC milling machine. Material chosen for the component is mild steel. Ten components of same dimensions are produced with the different combination of speed, feed and depth of cut.

Step2: Surface roughness is measured using Talysurf machine. Machining time is also observed. Material removal rate is calculated using the formula MRR=W_i-W_f/ρ*t. Density of Mild Steel is found to be 7.8 gm/cm^3. Tool life is calculated using the formula.T= $(C/V)^{1/n}$

Step3: Different combinations of speed, feed and depth of cut as well as corresponding Machining time, Tool life, Surface finish and Material removal rate are given as inputs to the MINITAB. Model for Machining time, Tool life, Surface finish, Material removal rate in terms of speed, feed and depth of cut is obtained from MINITAB.

Step4: Mathematical model for all objective functions obtained from MINITAB is given as input to the NSGA-II algorithm to optimize the parameters such as speed, feed and depth of cut. The code for NSGA-II algorithm is written using C language.

Step5:The optimum combination of speed, feed and depth of cut is obtained by compiling the C codes.

5. EXPERIMENTAL VERIFICATION

The experimental verification of the above algorithm in CNC milling machine is carried out at small scale industry in penia, Bangalore. The component shown in fig.5.1 is produced using a CNC Milling in Vertical Machining Centre (VMC). Specifications of machine, material and values of constants are given below.

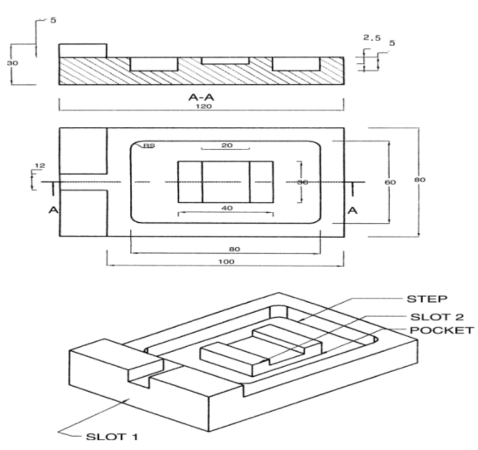

Fig. 5.1. Component for CNC Machining

Constants:

C=900m/min for carbide tools;
n=0.25 for carbide tools;

Machine tool data:

Type: Vertical Machining Centers

P_m =12 kw;

e =95%;

Material data:

Type: EN8 Mild steel

Hardness: 15HS

The work piece needs four types of features: Step, Pocket and Two slots. There are five milling operations to perform in the complete processing of this component to be completed namely Face milling, Corner milling, Slot milling1, Pocket milling and Slot milling2, out of which three operations has been considered in this paper for the optimization purpose.To obtain the optimum speed, feed and depth of cut for the respective operations a Nondominated Sorting Genetic Algorithm II (NSGA-II) is considered and turbo C is used as a work bench to calculate the optimum parameters.

First Mild Steel plate of cross section 125mm*35mm*1000mm is procured and cut at 100mm*80mm*35mm using Milling machine. Raw material and finished components are shown in Fig. 5.2

Fig. 5.2. Raw material and Finished Product

A. Face Milling

First operation to be carried out is face milling and the experimental values measured from face milling are given in Table.1.

TABLE 1: Experimental values taken from face milling.

Face Milling							
Si .No.	**Speed (rpm)**	**Feed (mm/min)**	**Depth of cut (mm)**	**Time (min)**	**Surface roughness(μm)**	**MRR (mm^3/sec)**	**Tool-life (min)**
1	1800	700	.2	.56	2.025	18.85	4018
2	1810	750	.22	.53	5.258	19.63	3930
3	1840	760	.24	.52	3.354	20.67	3680
4	1850	700	.3	.38	3.801	27.31	3601
5	1830	770	.2	.57	5.994	19.23	3761
6	1880	700	.27	.57	6.109	18.47	3377
7	1880	780	.3	.34	3.603	32.05	3377
8	1890	600	.4	.44	2.359	25.15	3306
9	1898	698	.39	.38	5.125	27.87	3250
10	1895	700	.35	.38	3.857	27.31	3271
Speed Range:1800-2000(rpm)							
Feed Range:600-800(mm/min)							
Depth of cut:0.2-0.4(mm)							

Experimental values analyzed using Minitab software and equations are generated for Time, Surface Roughness (SR), Material Removal rate (MRR) and Tool life in terms of speed, feed and depth of cut is given below.

Time = -719.9 +0.7163 v +0.2490 f -242.5 d -0.000161 v^2 +0.000051 f^2 +10.54 d^2 -0.000193 v*f +0.07876 v*d +0.1221 f*d

SR = 26517 -30.02 v -1.649 +13636 d +0.008176 v^2 -0.001334 f^2 +1432 d^2 +0.002270 v*f -6.946v*d -2.133 f*d

MRR = 44156 -44.21 v -14.80 f +15668 d +0.01018 v^2 -0.002644 f^2 -90.97 d^2 +0.01110 v*f -5.732 v*d -6.749 f*d

Tool life = 55799 -48.61 v -0.2655 f +569.5 d +0.01105 f^2 +0.000150 v^2 +33.63 d^2 +0.000010 v*f-0.3593 v*d +0.1040 f*d

Equations generated using Minitab are feed in to the Non Sorted Genetic Algorithm-II to optimize the parameters. Optimum values obtained from the NSGA_II Algorithm are given in Table 6.

B. Corner Milling

Second operation to be carried out is corner milling and the experimental values taken from corner milling are given in Table.2.

TABLE 2: Experimental values taken from corner milling.

Corner Milling							
Sl. No.	**Speed (rpm)**	**Feed (mm/min)**	**Depth of cut (mm)**	**Time (min)**	**Surface roughness(μm)**	**MRR (mm^3/sec)**	**Tool-life (min)**
1	1800	700	.3	30.29	2.983	25.40	4018
2	1810	760	.33	25.9	3.887	29.71	3930
3	1810	770	.34	24.49	4.223	31.50	3930
4	1850	700	.35	25.4	3.034	30.32	3601
5	1830	770	.2	40.53	4.425	19.02	3761

6	1800	700	.39	30.29	4.864	25.39	4018
7	1800	780	.38	21.37	3.888	36.00	4018
8	1890	680	.39	24.46	1.116	31.41	3306
9	1898	698	.4	22.32	2.492	34.52	3250
10	1895	700	.4	22.28	2.475	34.51	3271
Speed Range:1800-2000(rpm)							
Feed Range:600-800(mm/min)							
Depth of cut:0.2-0.4(mm)							

Experimental values analyzed using Minitab software and equations are generated for Time, SR, MRR and Tool life in terms of speed, feed and depth of cut for corner milling is given below.

TIME = 1037 -1.233 v +0.08321 f + 1080 d +0.000303 v^2 -0.000077 f^2 +260.7 d^2 +0.000192 v*f -0.2661 v*d -1.116 f*d

SR = 5038 -4.609 v -3.250 f +1899 d +0.001043 v^2 +0.000356 f^2 - 200.9 d^2 +0.001550 v*f -0.8847 v*d -0.2093 f*d

MRR = 1063 -0.6084 v -1.323 f -732.7 d +0.000161 v^2 +0.000319 f^2 -49.79 d^2 +0.000238 v*f -0.1428 v*d +1.463 f*d

Tool life = 46779 -38.80 v +1.690 f -3229 d +0.008362 v^2 -0.000100 f^2 +390.5 d^2 -0.000869 v*f +1.616 v*d +0.07271 f*d

Equations generated using Minitab is feed in to the NSGA-II to optimize the parameters. Optimum values obtained from the NSGA_II Algorithm are given in Table 6

C. Slot Milling1

Third operation to be carried out is slot milling1 and the experimental values taken from slot milling are given in Table.3.

TABLE 3: Experimental values taken from slot milling1.

Slot Milling1							
Si .No.	Speed (rpm)	Feed (mm/min)	Depth of cut (mm)	Time (min)	Surface roughness(µm)	MRR (mm^3/sec)	Tool-life (min)
1	2000	400	.2	4.22	.711	4.97	20343
2	2010	430	.23	3.35	2.963	6.12	19941
3	2015	432	.23	3.33	3.408	6.35	19744
4	2150	400	.25	3.31	3.090	6.25	15233
5	2200	400	.28	3.11	2.282	6.58	13894
6	2300	408	.26	3.17	3.809	6.55	11631
7	2100	415	.25	3.23	1.961	6.48	16736
8	2250	410	.22	3.56	2.834	5.75	12700
9	2180	430	.25	3.16	1.354	6.61	14411
10	2165	416	.27	3.13	2.516	6.61	14815
Speed Range:2000-2250(rpm)							
Feed Range:400-500(mm/min)							
Depth of cut:0.2-0.3(mm)							

Experimental values analyzed using Minitab software and equations are generated for Time, SR, MRR and Tool life in terms of speed, feed and depth of cut for slot milling1 is given below.
TIME = 148.2 - 0.04242 v - 0.3914 f - 127.0 d + 0.000009 v^2 + 0.000306 f^2 + 139.5 d^2 + 0.000029 v*f - 0.02933 v*d + 0.2808 f*d
SR = -3738 + 2.233 v + 8.934 f - 4166 d -0.000298 v^2 - 0.004518 f^2 -869.2 d^2- 0.002966 v*f + 1.204 v*d + 4.668 f*d
MRR = -3772 +1.641 v +10.83 f -1959 d -0.000337 v^2 - 0.009039 f^2 -900.5 d^2-0.001291 v*f +1.478 v*d -2.123 f*d

Tool life = 547229 -298.1 v -955.6 f +146592 d +0.05998 v^2 +0.8404 f^2 +89644 d^2 +0.09670 v*f -123.0 v*d +201.4 f*d

Equations generated using Minitab is feed in to the NSGA-II to optimize the parameters. Optimum values obtained from the NSGA_II Algorithm are given in Table 6.

D. Pocket Milling

Fourth operation to be carried out is pocket milling and the experimental values taken from corner milling are given in Table.4

TABLE 4: Experimental values taken from pocket milling.

Pocket Milling							
Se:No	**Speed (rpm)**	**Feed (mm/min)**	**Depth of cut (mm)**	**Time (min)**	**Surface roughness(µm)**	**MRR (mm^3/sec)**	**Tool-life (min)**
1	2000	400	.2	27.13	2.3076	11.12	20343
2	2010	430	.22	23.18	1.6197	12.89	19941
3	2015	436	.23	21.59	2.2924	13.92	19744
4	2150	400	.23	23.58	3.1659	12.68	15233
5	2200	400	.18	30.28	3.7390	9.85	13894
6	2200	409	.22	24.29	2.8453	12.18	13894
7	2100	415	.2	26.14	3.7766	11.5	16736
8	2230	405	.21	25.48	2.0677	11.67	13162
9	2180	418	.23	20.52	2.9893	14.63	14411
10	2165	400	.23	23.58	2.1037	12.74	14815
Speed Range:2000-2250							
Feed Range:400-500							
Depth of cut:0.2-0.3							

Experimental values analyzed using Minitab software and equations are generated for Time, SR, MRR and Tool life in terms of speed, feed and depth of cut for corner milling is given below.
TIME = -5134 +2.471 v +16.04 f -6148 d-0.000289 v^2 - 0.01581 f^2 -5377 d^2
-0.003362 v*f +0.5260 v*d +17.63 f*d
SR = -1949 +1.004 v +2.965 f +2863 d- 0.000232 v^2 - 0.007490 f^2 -3759 d^2
+0.000840 v*f -1.785 v*d +6.285 f*d

MRR = 3954 -1.774 v -12.32 f +3759 d +0.000206 v^2 +0.01246 f^2 +4501 d^2 +0.002348 v*f -0.2215 v*d - 12.62 f*d

Tool life = 190958 -168.5 v +231.8 f-99434 d +0.03511 v^2 - 0.2444 f^2 +5831 d^2 -0.03367 v*f +11.46 v*d +179.9 f*d

Equations generated using Minitab is feed in to the NSGA-II to optimize the parameters. Optimum values obtained from the NSGA_II Algorithm are given in Table 6.

E. Slot Milling2

Fifth operation to be carried out is slotmilling2 and the experimental values taken from corner milling are given in Table.5

TABLE 5: Experimental values taken from slotmilling 2

Slot Milling 2							
Se:No	**Speed (rpm)**	**Feed (mm/min)**	**Depth of cut (mm)**	**Time (min)**	**Surface roughness(µm)**	**MRR (mm^3/sec)**	**Tool-life (min)**
1	2000	400	.2	4.22	.711	4.97	20343
2	2010	430	.23	3.35	2.963	6.12	19941
3	2015	432	.23	3.33	3.408	6.35	19744
4	2150	400	.25	3.31	3.090	6.25	15233
5	2200	400	.28	3.11	2.282	6.58	13894
6	2300	408	.26	3.17	3.809	6.55	11631
7	2100	415	.25	3.23	1.961	6.48	16736
8	2250	410	.22	3.56	2.834	5.75	12700
9	2180	430	.25	3.16	1.354	6.61	14411
10	2165	416	.27	3.13	2.516	6.61	14815
Speed Range:2000-2250							
Feed Range:400-500							
Depth of cut:0.2-0.3							

Experimental values analyzed using Minitab software and equations are generated for Time, SR, MRR and Tool life in terms of speed, feed and depth of cut for corner milling is given below.

TIME = 879.4 -0.7319 v -1.062 f + 1047 d +0.000116 v^2 - 0.000141 f^2 +88.53 d^2
+0.000709 v*f -0.2378 v*d -1.403 f*d

SR = -4129 +0.4859 v +17.90 f -341.5 d +0.000064 v^2 - 0.01706 f^2 -7.846 d^2

-0.001906 v*f +0.03928 v*d +0.6475 f*d

MRR = 308.5 +0.5780 v -4.524 f -43.72 d -0.000124 v^2 +0.006072 f^2 -449.0 C^2

-0.000182 v*f +0.1645 v*d -0.1852 f*d

Tool life = 164239 -108.2 v +83.45 f -152953 d +0.02339 v^2 +0.01975 f^2 +2854 d^2 -0.06987 v*f +31.46 v*d +201.8 f*d

Equations generated using Minitab is feed in to the NSGA-II to optimize the parameters. Optimum values obtained from the NSGA_II Algorithm are given in Table 6.

TABLE 6: Results of NSGA-II

Optimum values Obtained from NSGA-II							
Operations	**Speed (rpm)**	**Feed (mm/min)**	**Depth of cut (mm)**	**Time (min)**	**Surface roughness(µm)**	**MRR (mm^3/sec)**	**Tool-life (min)**
Face Milling	1869	850	0.27	1.48	0.18	10.14	3444
Corner Milling	1833	700	0.2	34.4	0.48	28.28	3745
Slot Milling1	2044	414	0.24	5.14	0.93	9.23	18695
Pocket Milling	2034	443	0.3	5.7	0.4	21.6	19453
Slot Milling2	2017	438	0.28	2.94	0.17	15.04	19676

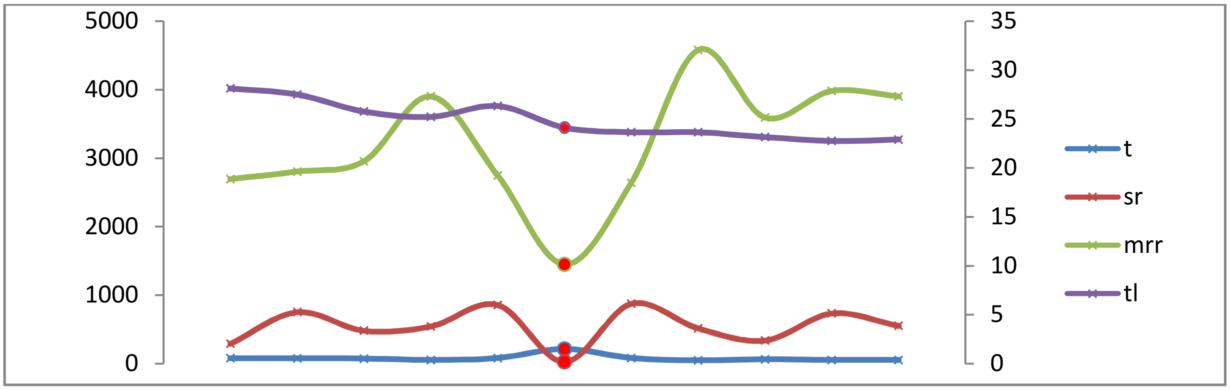

Fig.5.3.1 Face Milling

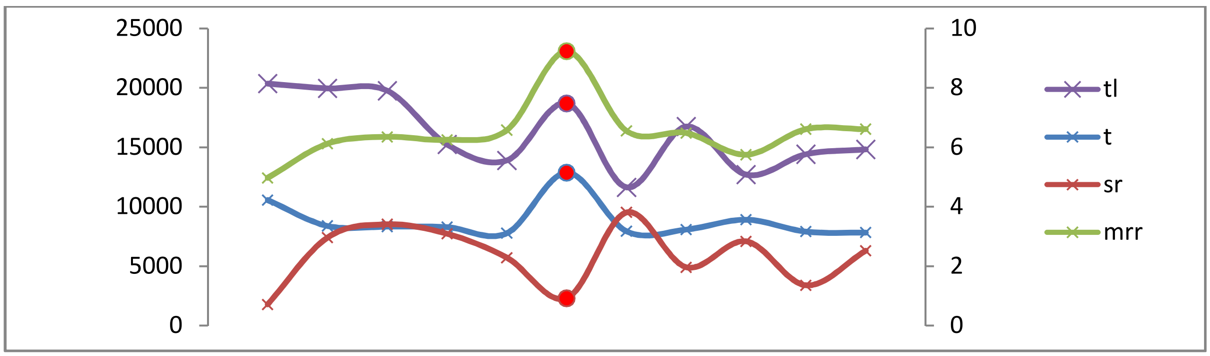

Fig.5.3.3 Slot Milling1

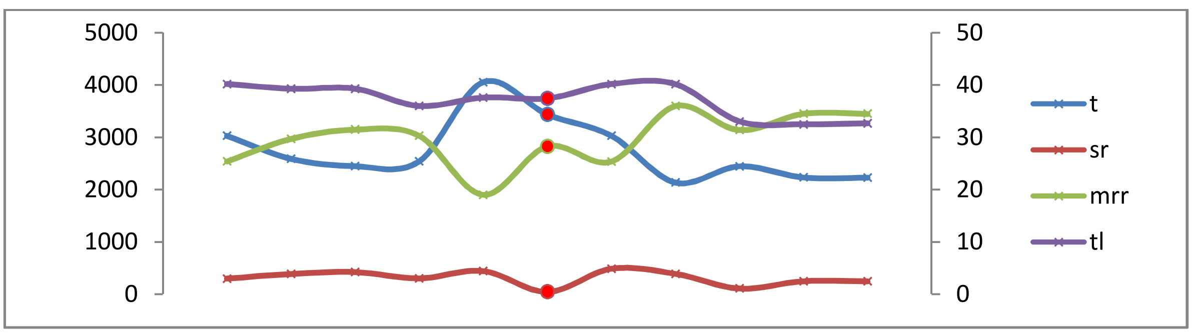

Fig.5.3.2 Corner Milling

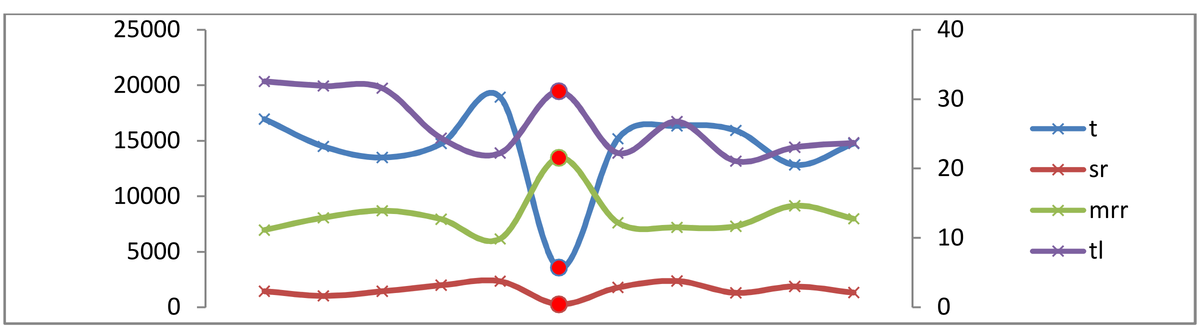

Fig.5.3.4 Pocket Milling

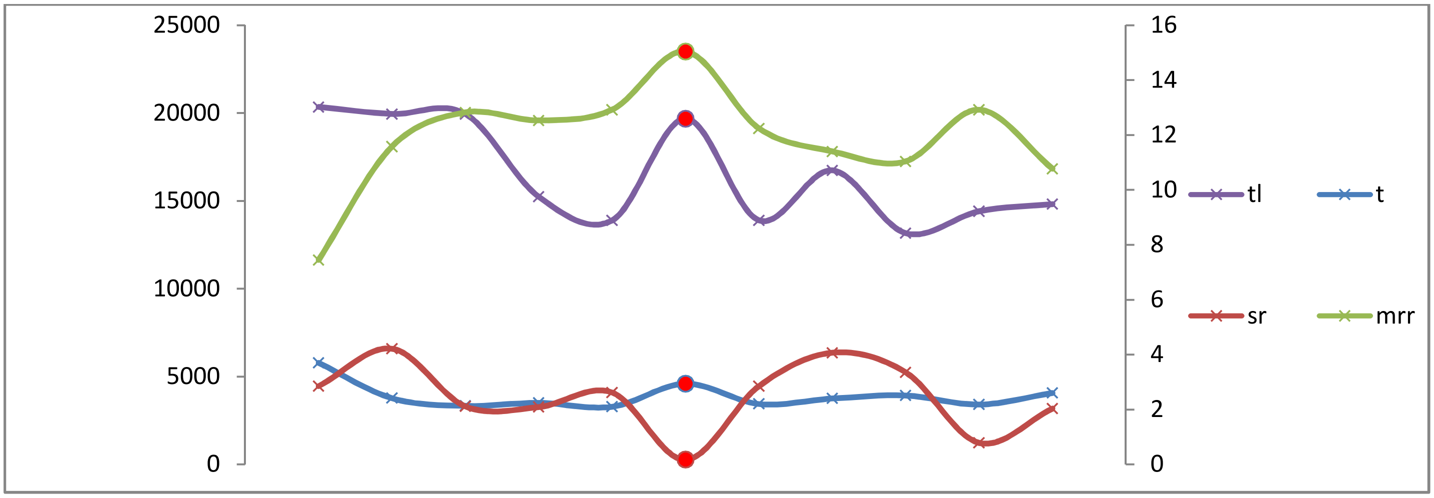

Fig.5.3.5 Slot Milling2

6. RESULTS AND DISCUSSIONS

The list of different combination of process parameters and the responses were analyzed using the graphs shown in fig 5.3. In the graph, the red points are used to specify the optimum values of objective functions obtained from the NSGA-II. It inferred that, NSGA-II gives the best combination of process parameters to optimize all the objectives. The enlisted values shown in Table.6 gives us the set of operating parameters for the optimum values of MRR, Surface Roughness, Time and Tool life for the precision machining of Mild Steel material.

7. CONCLUSION AND FUTURE ENHANCEMENT

The algorithm is developed to investigate the optimal cutting parameters with minimum machining time, minimum surface roughness, maximum MRR and maximum tool life.The NSGA-II is used for the optimisation of machining parameters in CNC milling operation and the results are analysed to get optimal values for the improved performance.This optimisation helps in optimising the machining parameters resulting in improved productivity of CNC machines. The algorithm is completely computerized so that it can be easily modified to optimize the other machining operations like drilling, turning, grinding etc. under various economic conditions. Inclusion of many other machining parameters and constraints may enhance the end result. The technique can also be implemented for the other branches of engineering like civil, Electronics etc. to solve the various optimization problems.

NOMENCLATURE

V Speed (rpm)

f Feed (mm/min)

d Depth of cut (mm)

MRR Material Removal Rate (mm^3/sec)

SR Surface Roughness (μm)

C, n Tool constants

P_m Maximum power (kw)

e Machine efficiency

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