Evolutionary Techniques for Process Modelling and Optimization in Turning Ti-6al-4v Alloy

Ambae Rakesh, D.Kondayya

Abstract: Turning of Ti6Al4V alloy presents a great challenge and opportunity for the machinist. In this paper, multi-target and process modelling advancement of a machining parameters in plain turning of Ti6Al4V alloy are presented using two evolutionary approaches namely Gene Expression Program (GEP) and Non-Dominated Sorting Genetic Algorithm II (NSGA II).The three controlling factors in turning namely, speed (N), feed rate (f)and depth of cut (Dc) are designed as a input parameters, while Material Removal Rate (MRR) and Surface Roughness(Ra) are the measured outputs. The data used in the GEP model is taken by doing several turning experiments within the experimental domain. As the responses MRR and Ra are conflicting in nature, so that NSGA-II has been used as it is a multi-objective optimization technique to obtain the optimal solutions.

Keywords: TI-6AL-4V; GEP; NSGA-II; Multi objective optimization.

I. INTRODUCTION

Titanium combinations are generally utilized in aerospace industries due to their high thickness elasticity, high consumption resistance and the ability to withstand decently high temperatures without crawling. The areas of application of these exotic alloys can be found in aircraft, armor plating, naval ships, spacecraft, and missiles. Ti6AL4V (Grade 5) is the most famous grade amongst the titanium alloys and records for practically 50% of the titanium utilized in industry. This alloys consists of almost 88.86% of Ti, 6.40% of Al, 4.33% of V, 0.25% (max) of Fe and 0.2% (max) of O2. Aluminum and vanadium addition in the pure metal expands the hardness of the material in the compound framework, improving its mechanical properties and machinability to the journal, rectification is not possible [1]. Metal Turning is undoubtedly an important primary machining process which involves gradual removal of material from the cylindrical work in order to reduce its diameter.

Turning of Ti6Al4V alloy is an important activity in industry as it presents a great challenge in achieving the required surface finish at the input parameters ie., feed, speed and depth of cut. Process modelling and optimization are therefore the most widely considered regions of machining, as this results in both lower cost of creation and improvement of product quality [2]. Moreover, Ti6Al4V alloy being a costly and precious metal it is even more required to carefully study, model and optimize the machining conditions.

In turned components the most vital performance indicators are MRR and Ra. While MRR indicates productivity of the process surface roughness is a pointer towards the process quality. Both these performance measures are conflicting in nature as it is always desired that MRR should be high while the minimal value of surface roughness is always desired.

The overall aim of the present work is to apply a novel approach for process modelling and to optimize the turning Ti6Al4V alloy. The turning process models are developed using an evolutionary technique called gene expression programming (GEP). Subsequently these accurate models are optimized using another global search algorithm ie., Non-Dominated Sorting Genetic Algorithm II (NSGA II).

II. EXPERIMENTAL PROCEDURE

The experiments were performed on Kirloskar Made Industrial Grade turning center (Turnmaster-35) using Sandvik make coated carbide inserts shown in fig 1. The turning center is equipped with a Cutting tool dynamometer system connected to DAS. A MQL system of Dropsa (Italy) make is also integral to the system.

The three prominent variables in any turning, which are Speed, feed and depth of cut are considered as the input variables. These variables are considered to control the responses MRR and the Ra. MRR is determined as the result of feed, cutting speed and depth of cut. For surface roughness, the standard arithmetic mean deviation parameter, Ra was found out using roughness tester of make Mitutoyo Surf Test 301.

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Fig no:1   Experiment set-up. (Lathe Machine)

The machining parameters for turning along with feasible range of input parameters are shown in table 1. The chemical composition of Ti6Al4V alloy used for experiments is given in table 2. Since GEP is a data driven modelling algorithm, a number of experiments were conducted in the experimental range to generate data for modelling. The data was segregated as training data and validation data, the former being used for developing the model expressions while later being used to test the validity of the models.

Table 1   Machining Parameters for Ti-6Al-4V turning test

Work Material	Rod,41.5mm diameter and 540mm length
Tool Holder	T-Max 25 X 25 RH (TNMG)
Cutting Tool Inserts	Coated Carbide
Rake Angles	7^0
Relief Angles	11^0
Cutting Speeds	36.50, 58.66, 92.56 and 146.02mm/min
Feed Rates	0.045,0.05,0.056 and 0.063mm/rev.
Cutting length/Test	40mm

Table 2   Chemical Analysis Report of Ti-6Al-4V(Grade-5)

Components	Al	V	C	Fe	Sn	Mo
Wt%	6.40	4.33	0.08	0.21	0.017	0.006

Components	Si	Cr	Ni	Nb	Ti
Wt%	0.019	0.015	0.020	0.036	88.86

III.   GEP MODELLING AND RESULTS

Gene Expression Programming is an evolutionary algorithm technique that emulates biological development in order to construct a computer program for modelling some occurrence. Gene expression programming (GEP) is, similar to genetic algorithms (GAs) and also same as genetic programming (GP), a genetic algorithm as it utilizes populations of different values, chooses them according to their fitness and adding genetic difference utilizing atleast one or many genetic operators [3]. The crucial distinction between the nature of individuals lies on three algorithms: in GPs the individuals have various size and shapes (parse trees) which are of non-linear strings; in GAs the individuals have a fixed length (chromosomes) which are of linear strings ; and in GEP the individuals having a fixed length (genome or chromosomes) which are of linear strings and

later it can be shown to be a non-linear strings of various shapes and sizes (representation of simple diagram or expression trees).[4] Evolutionary algorithms makes no earlier assumptions about the real model structure being a stochastic hunt strategy. The complexity and structure of the model develop consequently [5].

The paramees used in the GEP tool as shown in the below table.

Table 3   Parameters used in the GEP tool.

1. No. of genes	3
2. Size of Head	8
3. Linked function	Addition (+),
4. Function sets	$+, - \times, /$
5. No. of generation	1,000 -17,000
6. No. of Chromosomes	40
7. Mutation	0.00138
8. Inversion	0.00546
9. One-point and Two-point recombination	0.1
10. Genes transposition	0.1
11.Genes recombination	0.1

After doing the investigation for different elective models we have found that the following expression trees as shown in fig 3&4 are having the biggest fitness value. while building up above model the fitness measure is to be consider as correlation coefficient, so that R^2 produces an exact solutions in less generations to obtain the optimum models.

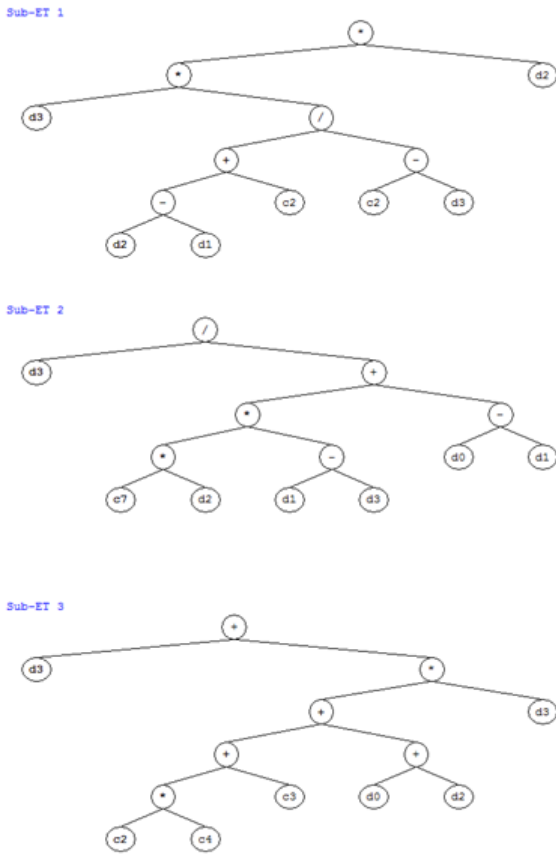**Fig no:2   View of Machining zone.**

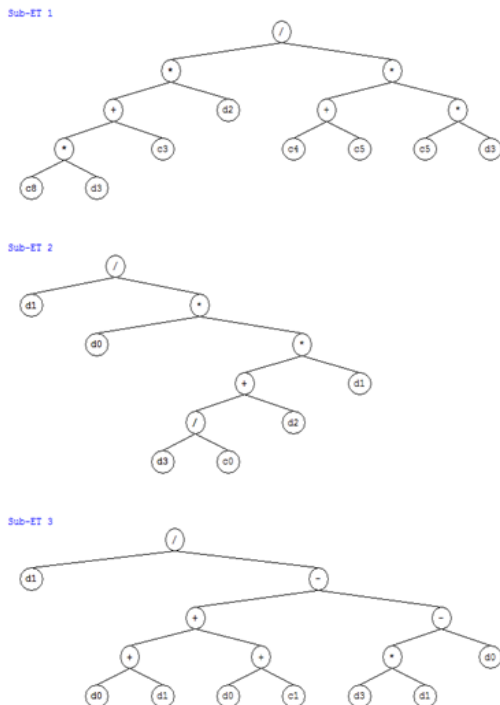Fig no: 3   ETs for MRR by models (expression trees).

Fig no: 4   ETs for Ra by models (expression trees).

By Comparing the anticipated models and the values from the experiment are taken from the validation dataset are MRR and Ra as shown in fig 5 & 6 respectively. The value of R^2 for MRR and Ra are obtained high values that are

found to be 0.94 & 0.89 respectively. This says that the models developed from the GEP are represent as outputs.
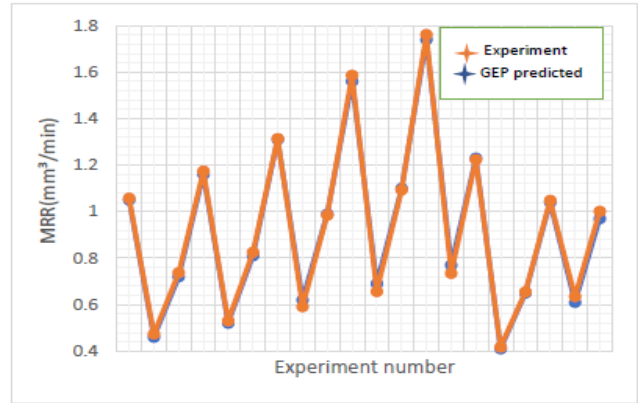

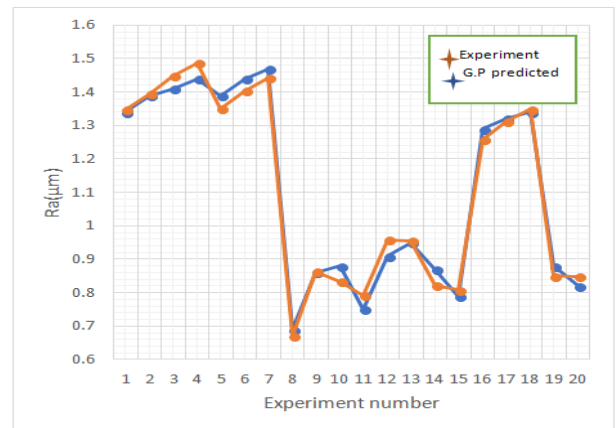Fig no:5   Comparison of the experiment value and the GEP model of MRR.

Fig no:6   Comparison of the experiment value and the GEP Model of Ra.

IV.   FORMULATION AND SOLUTION USING NSGA II

In this study two objective functions are considered as:
(i) Maximization of MRR and
(ii) Minimization of Ra.
The mathematical expressions for these objective functions were earlier obtained from the GEP expressions. The objective functions are functions of feed, speed and depth of cut. In this study maximization of MRR and minimization of Ra and the input variables are optimized subject to the feasible bonds. The optimized problem are defined as follows:
Maximize (MRR)
Minimize (Ra)
Subject to:
$450 \leq Speed \leq 1120$
$0.045 \leq feed \leq 0.063$
$0.1 \leq doc \leq 0.3$

V.   RESULTS AND DISCUSSIONS

Optimization techniques are Multi-objective evolutionary algorithms that are used to make the better use of the features of EAs of multipoint search, and also at the same time obtain Pareto optimal set [5].

Elitist Non-dominated Sorting Genetic Algorithm (NSGAII) proposed by Deb et al. [6] is a well-known and an exceptional implementation of MOEAs. In the present work the NSGA-II algorithm was utilized for getting the Pareto optimal solutions. The NSGA-II has a source code and it is implemented in the VC++ programming language on Windows stage. The typical nature of any heuristic techniques is being sensitive to algorithm parameters. So that it is essential to conduct repeated trials to search the appropriate values of the controlling parameters [7]. The following best results are chosen after 10 test runs: size of Population -50; no. of generations = 90; probability crossover – 0.90; probability mutation y – 0.10. NSGA-II gave great decent variety of results and provided the conflicting objective functions for a well populated pareto optimal front as shown in Fig 7.
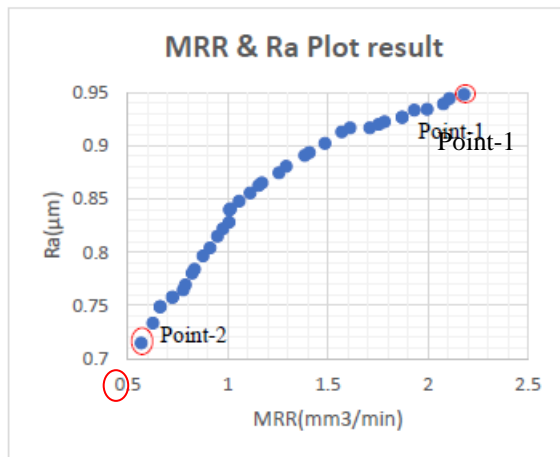

Fig no:7   Pareto optimal front

By the end of the process we have obtained 15 optimum results as of input variables and their related responses as shown in table 4.By analyzing the pareto front, it can use a decision maker to make specific decisions based on the process requirement For example at point-1 the turning process yields highest MRR but surface roughness will be on higher side. while at point-2 though the MRR is least, the best surface finish is obtained.

Table 4. Final optimal solutions through NSGA-II.

S.no	Speed (RPM)	Doc (mm)	Feed (mm/rev)	MRR (mm³/min)	Ra (µm)
1	391.72	0.21	0.047	0.46	0.88
2	627.46	0.29	0.046	1.14	0.87
3	558.17	0.23	0.051	0.86	0.93
4	940.06	0.23	0.054	1.54	1.01
5	447.59	0.26	0.047	0.81	0.84
6	292.55	0.23	0.045	0.36	0.79
7	717.77	0.22	0.054	1.19	0.97
8	1061.46	0.29	0.055	2.3	0.97
9	1074.17	0.23	0.052	1.73	1.01
10	826.06	0.27	0.057	1.64	0.97
11	1082.92	0.21	0.051	1.57	0.87
12	617.63	0.23	0.047	0.89	0.93
13	1083.34	0.27	0.056	2.26	0.98
14	522.17	0.23	0.052	0.87	0.91
15	993.6	0.23	0.058	1.82	1.01

Fig no:8   Surface Roughness (Ra) Tester.

VI.   CONCLUSIONS

Turning of Ti6Al4V alloy is an industrially important machining activity carried out for many critical applications. The said alloy being a costly and precious metal it is essential to optimize the process parameters in turning operation. The present work is a unique implementation for the optimization in which two evolutionary based approaches are used for process modelling and optimization. GEP is a proven observational displaying approach for understanding the precise relationships between the process parameters and outputs. This has been proved by the fact that the experimental data and GEP predicted has very close correlation for both MRR and Ra. These models were subsequently optimized uses the elitist NSGA II algorithm. The pareto-optimal set generated as output of the multi-objective optimization procedure gives the decision maker a wide choice of selecting the process parameters. The optimal values are essential for adaptive control of the turning process.
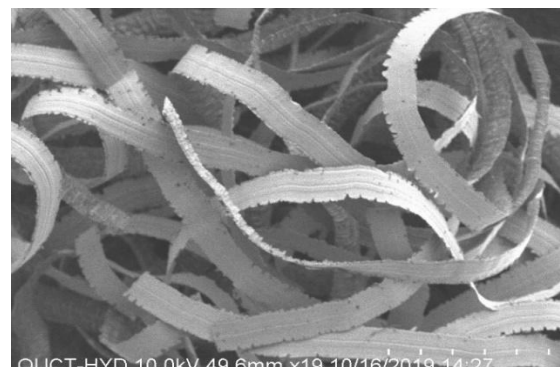

Fig no:9   SEM photograph of chips. Machining conditions:
x1=627.46RPM,x2=0.29mm,x3=0.046mm/rev, MRR=1.14mm³/min, Ra=0.87µm.

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AUTHORS PROFILE

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