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TOOL WEAR AND SURFACE ROUGHNESS PREDICTION USING ANN IN CNC MILLING OPERATIONS

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ABSTRACT- The paper presents the state of art of review on tool wear and surface roughness prediction using artificial neural networks in CNC milling operations. In manufacturing industries milling is widely used metal removal processes. Milling is the basic machining process to produce flat surface by progressive chip removal. The surface roughness parameter ids most important factor to analyze the performance of machining properties like creep life, corrosion resistance and also fatigue behavior. However, proper selection of cutting conditions and parameters for achieving a desired surface finish is very difficult task, because the mechanism behind the occurrence of surface roughness is very dynamic, complicated and process dependent. An experiment was conducted using computer numerical controlled milling machine to train the data and to check the performance of the network. The basic factors like speed, depth of cut and feed were taken in an experiment.

KEYWORDS – Artificial neural networks, surface roughness, tool wear, CNC milling operations

I. INTRODUCTION

Milling is commonly used as a machining process to remove the unwanted material from the workpiece. The basic equipment's required for machining is milling machine, fixtures, jigs and the workpiece. The shape of work piece is of pre shaped which is fitted in a fixture and attached to the base of milling machine. The milling machining can be used in making tools or fabricating the tools for other like making molds in 3-D, also used in post machining operations to make desired shape that is secondary processes. In the milling operations the surface finishing quality is very high which helps in adding precision features in the operations [1]

II. MILLING OPERATIONS

- Plain or slab milling
- Face milling
- Angular milling
- Straddle milling
- Form milling
- Gang milling

a) Plain or slab milling**:** Machining of a flat surface which is parallel to the axis of the rotating cutter.
b) Face milling: Machining of a flat surface which is at right angles to the axis of the rotating cutter.
c) Angular milling: when the machining of a flat workpiece at an inclined angle or at right angle, with respect to the revolving axis of a cutter.
d) Straddle milling: when machining of simultaneously two parallel vertical faces of the work-pieces by a pair of side milling cutters.
e) Form milling: The machining of irregular shape and the shape of teeth of the form milling cutter corresponds to the profile of surface being produced.
f) Gang milling: the combination of vertical and horizontal milling machines are used to produce the desired surfaces.

CNC MILLING MACHINE

A program is required to operate the machine tool, can be generated manually or using Computer Aided Design/Computer Aided Manufacture (CAD/CAM) software **[2]**. To achieve the finished part the CNC milling machinist professionals undertake a sequence of essential activities **[3]**. To follow the specifications and interpret the drawings of engineering.

III. Specification of Computer Numerical Controlled Milling Machine

The HurcoVM CNC vertical milling machines offer powerful machining with a compact footprint, and absolutely the best value on the market. These type of small CNC machining centers gives the perfect combination of functionality and size. The design of machine in less space with possible footprint. **[6]**.

Table 1 Specification of CNC milling machine (Hurco VM10)

Sr. No.	Specification	Description
1	Machine Control	Hurco Max CNC Control
2	Spindle Drive	15HP
3	Machine Travels (X/Y/Z)	26" x 16" x 20"
4	Table Size	30"x14"
5	Spindle Taper	Cat 40
6	Spindle Speeds	10,000 RPM
7	Transmission	Direct Drive
8	Rapid Traverse Rate (X/Y/Z)	945 IPM
9	Tool Changer Capacity	20 Stations
10	Power Requirement	230 Volt 3 Phase
11	Tool Changer Style	Side Mount tool Changer

IV. ANN structure

An ANN model consists of three layers namely input layer, hidden layer and output layer repectively. Each layer consists of specific number of nodes which mimics the human neurons and they are linked with other nuerons and thus shares information with each other. These nuerons consists of infromation of weighted process variables. The nodes in the output layer depicts the value of response variable.The input and output layers are exposed to the environment and hidden layers do not have any contact with the environment. ANNs are characterized by their topology, weight vectors, and activation function that are used in hidden and output layers of the network. A neural network is trained with a number of data and tested with other set of data to arrive at an optimum topology and weights**[7]**. Fig.1 represents a neural network structure having one hidden layer.

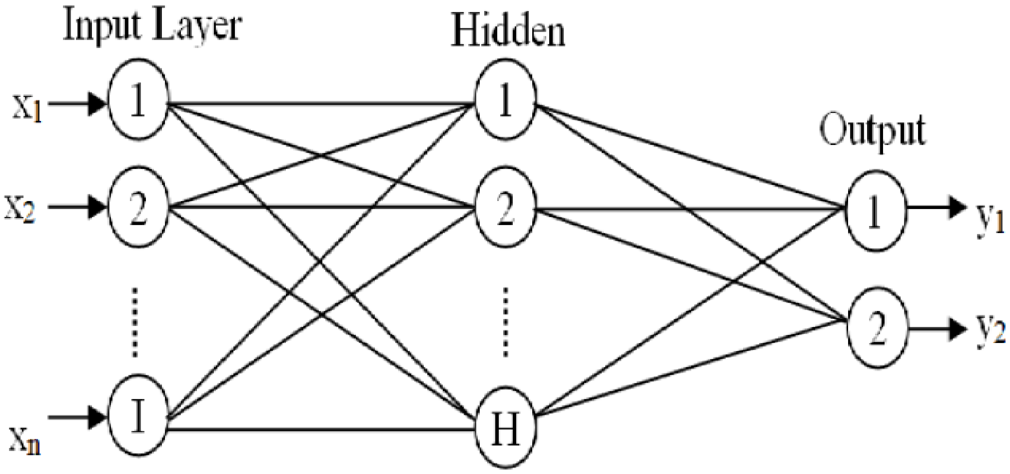

Fig.1 A typical neural network structure

V. WORKPIECE MATERIAL

The workpiece material used for present study were:-

1. AISI 1050
2. Grey Cast Iron (ASTM A48)
3. Incoloy 800

AISI 1050 steel with dimensions (length of 100 mm, width of 100 mm and thickness of 100 mm) was used for present study. AISI 1050 is an unalloyed medium carbon steel. It is easily machinable and possesses high tensile strength and is used in manufacture of brackets, brake discs, clips, clutches, springs, washers, automotive and general engineering components etc. The composition of material was tested on Spectrometer. The chemical composition and mechanical properties of AISI 1050 are listed below in Table 2 and Table 3.

Table 2 Chemical composition of AISI 1050 steel

Element	**Fe**	**C**	**Mn**	**P**	**S**
Percentage	98.46-98.92	0.48-0.55	0.60-0.90	0.030	0.035

Table 3 Mechanical Properties of AISI 1050 steel

Properties	**Tensile strength (MPa)**	**Yield strength (MPa)**	**Poisson's ratio**	**Elongation**	**Hardness (BHN)**
Values	690	580	0.27-0.30	10%	197

Grey cast iron (ASTM A48) is characterized by its graphitic microstructure, which causes fractures of the material to have a grey appearance. It is the most commonly used cast iron and the most widely used cast material based on weight and having good casting property, shock absorption, wear-resisting property and machining performance.

Table 4 Chemical composition of Grey Cast Iron

Element	**C**	**Si**	**Mn**	**P**	**S**
Percentage	3.2-3.5	1.8-2.4	0.5-0.9	0.2 max	0.2 max

Table 5 Physical and Mechanical properties of Grey Cast Iron

Properties	**Tensile strength (MPa)**	**Compressive strength (MPa)**	**Density (g/cm3)**	**Hardness (BHN)**
Values	151.68	55.15	7.15	210

Incoloy 800 is nickel iron-chromium alloys with good strength and excellent resistance to oxidation and carburization in high-temperature exposure. Incoloy 800 is a widely used material for construction of equipment requiring corrosion resistance, strength and heat resistance up to 1500°F (816°C). Alloy 800 offers general corrosion resistance too many aqueous media and, by virtue of its content of nickel, resists stress corrosion cracking. At elevated temperatures it offers resistance to oxidation, carburization, and sulfidation along with rupture and creep strength**[14]**.

Table 6 Chemical composition of Incoloy 800

Element	**Ni**	**Cr**	**Fe**	**C**	**Mn**	**Al**	**Ti**
Percentage	30-35	19-23	39.5 max	.10 max	1.5 max	0.15-0.60	0.15-0.60

Table 7 Mechanical properties of Incoloy 800

Properties	**Temperature (^{o}C)**	**Tensile strength (MPa)**	**Yield strength (MPa)**	**Hardness (BHN)**
Values	25	590	250	138

VI. 3.1.2 TOOL INSERTS

APKT 09T308R-EM TT9080 PVD coated titanium Carbide inserts were taken for the experimentation purposes. These type of inserts are used for generally machining of alloy steels with optimum wear resistance and for high interrupted machining of cast irons. Detailed specifications of the inserts are shown in Table 8**[11]**.

Table 8 Detailed Specifications of the Inserts

S.no.	ISO Designation	Grade	Shape	Material	Cutting edge angle (α)	Edge Length (l)	Thickness (t)	Nose radius (r)
1	APKT 09	TT 9080	90^0Rectangle	Titanium carbide	90^0	9 mm	3.97 mm	0.8 mm

VII. EXPERIMENTATION

Experiments were conducted on HURCO vertical CNC milling machine in the workshop of Department of Mechanical Engineering at National Institute of Technical Teachers Training and Research, Chandigarh.

The face milling of AISI 1050, Grey Cast iron (ASTM A48) and Incoloy 800 were carried out in dry environment using CNC vertical milling center. A numerical control (NC) code which was prepared to execute the CNC program for machining.

VIII. SURFACE ROUGHNESS MEASUREMENT

The surface roughness of machined component was measured using surface roughness tester SURFTEST (Mitutoyo American Corporation). SURFTEST instrument is a portable, self-contained instrument for the measurement of the surface profile. Evaluation of parameters is based on a processor. The surface roughness was measured thrice for a componentand the average value was taken to determine the surface roughness value of the specimen.

MEASUREMENT OF RESPONSE PARAMETERS

After conducting the experiments for face milling the surface roughness and tool wear were measured and shown in table 9.

Table 9 Experimental design matrix (actual factors)

	Parameters				Responses				
Run	Cutting Speed (rpm)	Feed Rate (mm/min)	Depth of Cut (mm)	Material Hardness	Surface Roughness (µm)				Tool Wear (µm)
					R_1	R_2	R_3	Avg.	
1	2250	400	0.8	0	2.55	2.59	2.44	2.53	363.12
2	2250	450	0.8	-1	1.1	1.16	1.04	1.1	177.34
3	2250	450	0.6	0	2.19	2.13	2.24	1.59	273.80
4	2000	450	0.4	0	1.96	1.85	1.92	1.91	188.79
5	2250	400	0.4	0	1.6	1.49	1.55	1.55	172.96
6	2250	450	0.6	0	2.23	2.15	2.17	2.18	277.88
7	2500	500	0.6	0	2.32	2.43	2.37	2.37	305.12
8	2000	500	0.6	0	2.27	2.34	2.23	2.28	313.47
9	2250	500	0.6	1	1.1	1.15	1.18	1.14	437.72
10	2500	450	0.6	1	1.08	1.11	1.14	1.11	387.65
11	2250	450	0.4	1	0.96	0.94	0.92	0.94	305.34
12	2000	450	0.8	0	2.7	2.68	2.72	2.7	356.12
13	2500	450	0.4	0	1.76	1.85	1.75	1.79	198.32
14	2250	450	0.6	0	2.25	2.17	2.19	2.2	274.78
15	2250	400	0.6	1	1.09	1.06	1.04	1.06	330.32
16	2250	450	0.6	0	2.19	2.18	2.24	2.2	276.88
17	2000	450	0.6	1	1.09	1.08	1.11	1.09	350.86
18	2250	450	0.6	0	2.19	2.13	2.27	2.2	278.31
19	2250	400	0.6	-1	0.82	0.86	0.78	0.82	107.34
20	2250	450	0.8	1	1.21	1.31	1.26	1.26	333.69

21	2000	450	0.6	-1	0.93	0.97	0.88	0.93	138.73
22	2250	500	0.6	-1	1.02	0.97	1.05	1.01	165.76
23	2500	450	0.8	0	2.62	2.65	2.67	2.65	367.82
24	2500	400	0.6	0	1.98	2.05	2.02	2.02	232.57
25	2250	450	0.4	-1	0.8	0.82	0.75	0.79	116.58
26	2250	500	0.8	0	2.86	2.82	2.92	2.87	388.00
27	2250	500	0.4	0	2.05	2.1	2.01	2.05	207.98
28	2000	400	0.6	0	2.08	2.14	2.03	2.08	225.13
29	2500	450	0.6	-1	0.93	0.83	0.88	0.88	145.57

The surface roughness is varying from 0.79 µm to 2.87 µm and tool wear from 116.58 µm to 437.72 µm respectively as depicted from table 9.

The neural network model

After the collection of data from the experimentation the artificial neural network is created using MATLAB version 9.5 R 2018b. The diagram used for neural network is shown in the figure 2.

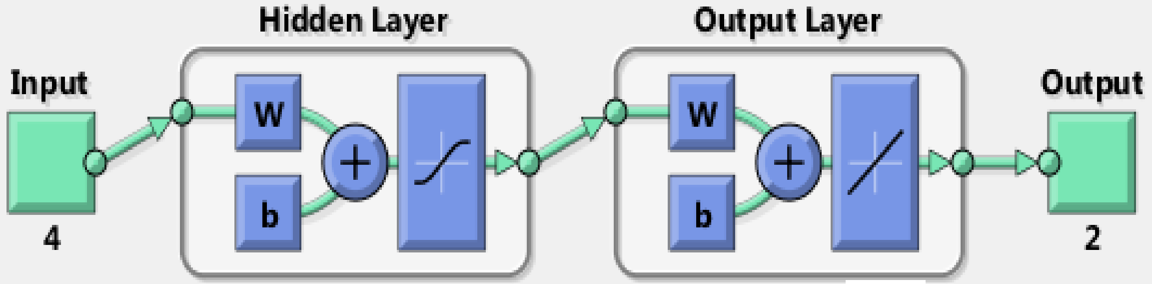

Fig. 2: Artificial Neural Network

As shown in above figure there are four input parameters (viz cutting speed , feed rate , depth of cut and work material) which are used to predict the surface roughness and tool wear. The number of layers, neurons, selection of activation function and the training algorithm are very important factors to be considered in the network architecture or topology which determines the functionality of the networks and capability of networks. ANN uses three type of training algorithm as shown in figure 2 i.eLevenberg- Marquardt, Bayesian Regularization and scaled conjugate Gradient. ANN was trained using these three techniques. The Levenberg – Marquardt algorithm was selected for training the ANN.

Correlation Coefficient

The correlation coeffiecient hav value between -1 to +1. And it tells how strong the relation between two variables is:

- 1indicates a strong positive relationship.
- -1 indicates a strong negative relationship.
- A result of zero indicates no relationship at all

The coefficient of correlation between the predicted values and actual values during the training and testing of the data is shown in the Figure 3 below. The data is taken by the software in random order.

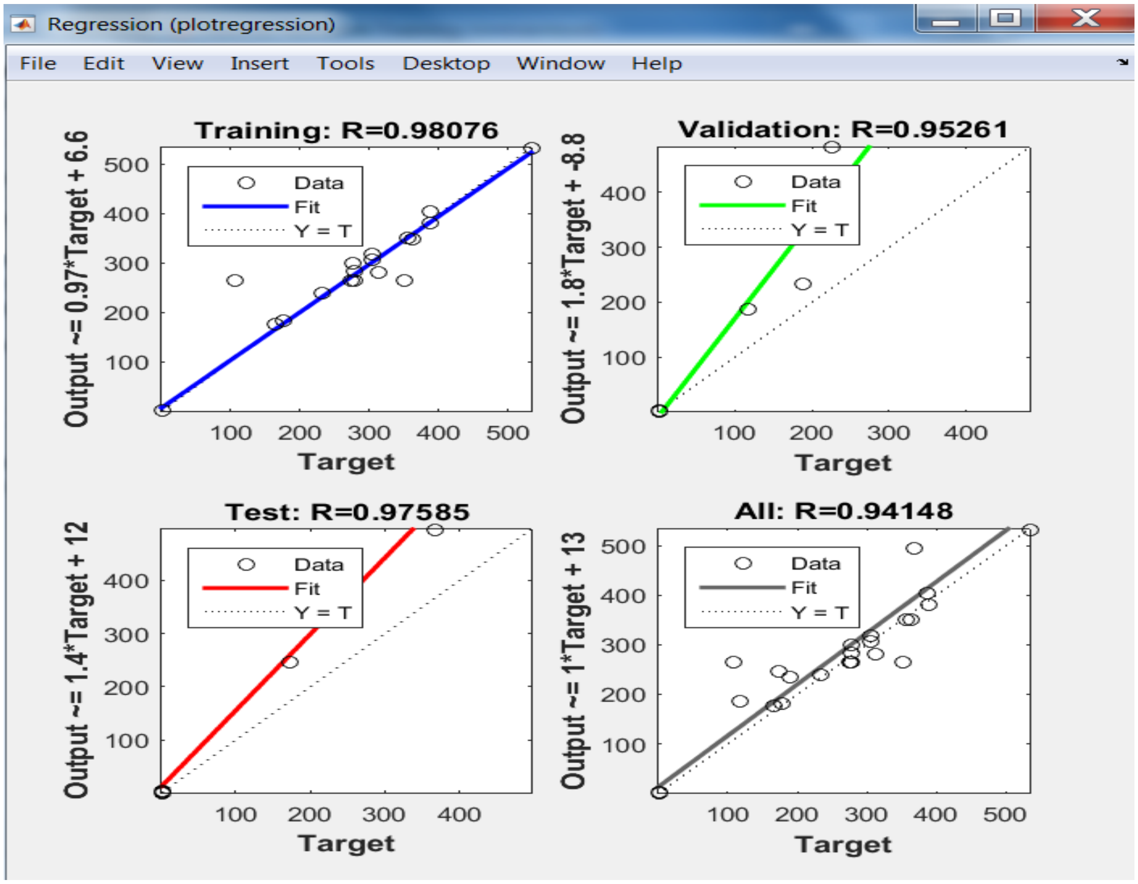

Fig. 3 Training and testing correlation coefficient

IX. CONCLUSIONS

ANNs are a powerful tool, easy-to-use in complex problems where not all of the parameters are straightforwardly engaged. For the given the accuracy that was achieved it is safe to conclude that all the significant factors were included in the DoE process. The most influential were found to be: depth of cut and the feed rate.The experimental results showed that the depth of cut and feed rate influences the surface roughness and tool wear. The value of surface roughness increases with the increase in depth of cut and feed rate. The maximum and minimum values of surface roughness *i.e.*2.87 µm and 0.79 µm andtool wear from 116.58 µm to 437.72 were attained respectively.Depth of cut and feed rate were found to be the most dominant parameters whereas cutting speed has very less effect on surface roughness and tool wear. Increase in cutting speed increases surface roughness but opposite trend was observed for tool wear.

X. FUTURE SCOPE OF THE WORK

The present research can be extended towards two different directions. Firstly, by investigating more cutting tool and workpiece material combinations thus building a database of trained ANNs for the variety of cases. Secondly, the reverse problem is also worthy of consideration. Given a desired value of surface roughness as well as the cutting tool and workpiece material, it is necessary to determine the optimum cutting conditions that must be used in order for that value to obtain. The ANN developed in the present research can deal with this by a trial-and-error process but it is by no means the optimum way to cater for this problem.

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