Optimization of cutting parameters for surface roughness prediction using artificial neural network in cnc turning

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Abstract— **Turning is carried out on a lathe that provides the power to turn the work piece at a given rotational speed and to feed the cutting tool at a specified rate and depth of cut therefore, three cutting parameters, i.e. cutting speed, feed rate, and depth of cut, need to be determined in a turning operation. Surface roughness is an important index to evaluate cutting performance. The influence of cutting speed, feed rate and depth of cut on the surface roughness is examined. The model for the surface roughness, as a function of cutting parameters, is obtained using ANN in MATLAB7. The main objective of this paper is to carry out the experiments by selecting different variables and their levels, applying artificial neural network (ANN) and then analyzing the results obtained. The results obtained conclude that ANN is reliable method and it can be readily applied to different metal cutting processes with greater confidence.**

Keywords- Optimization ; Surface roughness ; ANN ; Regression analysis ;

I. INTRODUCTION

1.1 ANN Model

1.2 A formal description of ANN

This study was undertaken to investigate the performance of finish hard turning of TITANIUM (Ti-6Al-4V, HRC 37- 38). Various cutting speeds:25,45,100,135,150 m/min and various feed rate : 0.05,0.075,0.1,0.125,0.135 mm/rev and depth of cut : 0.08,0.05,0.1,0.125,0.16 mm were employed. Turning was done under wet cutting condition. Cutting forces, surface Roughness and tool life were investigated. The cutting forces, tool life and surface roughness models were developed using the five level full factorial designs

1.3 Equipment for experiment

1.3.1 Daewoo (Doosan) - Puma 300LCNC Lathe

This machine motor horse power is 35 HP (2 speed gear) and the spindle rotation ranges from 3500rpm. Spindle nose A2-8

Work piece material – TITANIUM

1.3.2 CHEMICAL COMPOSITION OF MATERIAL:

Table-1:- Composition of the material

N, Nitrogen	0.03 %
C, Carbon	0.08 %
H, Hydrogen	0.0125 %
Fe, Iron	0.25 %
O, Oxygen	0.13 %
Pd, Palladium	--
Al, Aluminum	5.5-6.5 %
Mo, Molybdenum	--
V, Vanadium	3.5-4.5 %
Ni, Nickel	--
Ti, Titanium	Bal

Phase II SRG-1000 Surface Roughness Tester

This equipment used to measure surface roughness of the work piece machine during experiment. The surface roughness was measured at three locations around work piece circumferences. The value of the surface roughness is the average of three points taken for each measurement

Conventional **DCMT 070204** insert which is Cubic boron nitride (CBN) was used in the machining study to finish turn Titanium with a hardness ranging from HRC 37 to 38.

ANNs are one of the most powerful computer modeling techniques. It is based on statistical approach, and

Currently being used in many fields of engineering for modeling complex relationships, which are difficult to Describe with physical models (Ezugwua et al., 2005).

STRUCTURE OF A SINGLE NEURON:

The structure and basic elements for designing artificial neural networks is shown in Figure 1. The nonlinear model of a neuron shows that there are three basic elements of a neuron (*X*), which consists of a set of connecting links or synapses, a summation function, and an activation function. Neuron is the fundamental of an ANN operation, which is an information processing unit (acts as a simple processor). Each link has a numeric weight (*W*) associated with it that determines the strength and sign of the connection corresponds to the importance of the information coming from each neuron. The weights control the effects of the inputs on the neuron. Summation function calculates the net input readings from the processing elements. Activation function (*F*) determines the output of the neuron by accepting the net input provided by the summation function. Each input has its own weight plus there is an additional weight, which is termed as bias. The use of a nonlinear transfer function makes a network capable of storing nonlinear relationships between the input and the output. Any differentiable function (e.g. sigmoid function, hyperbolic tangent function, sine or cosine function, linear function) can qualify as an activation function in an ANN model. Output accepts the result of the activation function and presents them either to the relevant processing element or to the outside of the network.

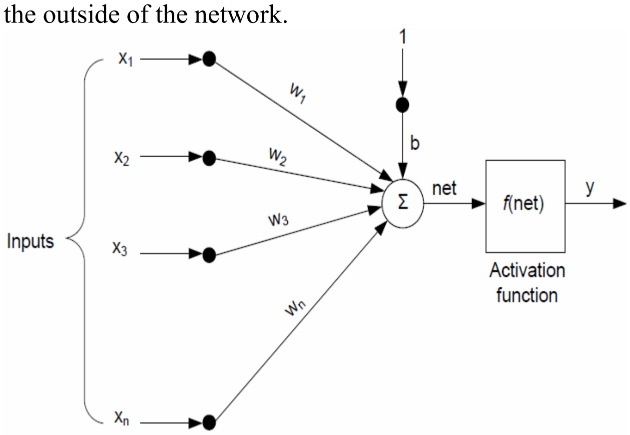


Figure-1:- A Single Neuron with its Elements

II LITERATURE SURVEY

Since turning is the primary operation in most of the production processes in the industry, surface finish of turned components has greater influence on the quality of the product. Surface finish in turning had been found to be influenced in varying amounts by a number of factors such as feed rate, work material characteristics, work hardness, unstable built-up edge, cutting speed, depth of cut, cutting time, tool nose radius. According to these parameters, a detailed literature survey is carried out as follows. David et al. (2006) described an approach to predict Surface roughness in a high speed end-milling process and used artificial neural networks (ANN) and statistical tools to develop different surface roughness predictors. [1]

Neural networks are simplified models of the biological nervous system and therefore have drawn their motivation from the kind of computing performed by a human brain. An NN, in general, is a highly interconnected network of a large number of processing elements called neurons in an architecture inspired by the human brain. An NN can be massively parallel and therefore is to set to exhibit parallel distributed processing.[2]

Neural network exhibit characteristics such as mapping capabilities or pattern association, generalization, robustness, fault tolerance, and parallel and high speed information processing.[1]

Neural networks learn by examples. They can therefore be trained with known examples of a problem to ‘acquire’ knowledge about it. Once appropriately trained, the network can be put to effective use in solving ‘unknown’ or ‘untrained’ instances of the problem[3]

Neural networks adopt various learning mechanisms of which supervisor learning and unsupervised learning methods have turned out to be very popular. In supervised learning, a ‘teacher’ is assumed to be present during the learning process, that i.e. the network aims to minimize the error between the target (desired) output presented by the ‘teacher’ and the computed output, to achieve better performance. However, in unsupervised learning, there is no teacher present to hand over the desired output and the network therefore tries to learn by itself, organizing the input instances of the problem.[4]

Though NN architectures have been broadly classified as single layer feed forward networks, multi layer feed forward networks and recurrent networks, over the years several others NN architectures have evolved. Some of the well known NN systems include back propagation network, perceptron, ADALINE (Adaptive Linear Element), associative memory, Boltzmann machine, adaptive resonance theory, self-organizing feature map and Hopfield network [1]

III NEURAL NETWORK DESIGN AND TRAINING

The network architecture/ topology or features such as number of neurons and layers are very important factors that determine the functionality and generalization capability of the network (Ezugwua et al., 2005). The selection of the activation function and training algorithm also play a significant role to obtain better forecast of response variable. In this work, standard multilayer feed-forward back-propagation hierarchical neural network has been considered for the prediction of and surface roughness in turning TITANIUM (Ti-6Al-4V) wet environment.

The neural network has been designed with MATLAB 7.1 software. The back propagation algorithm is a gradient decent error-correcting algorithm which updates the weights in such a way that network output error is minimized (Baskar and Ramamoorthy, 2004). The feed forward back-propagation network usually consists of an input layer (where the inputs of the problems are received, the inputs are the activity of collecting data from the relevant sources. These data are fed to the neural network), one hidden layer (where the relationship between the inputs and outputs are established represented by synaptic weights) and an output layer which emits the outputs of the network. The number of hidden layer may vary depending on the nature, complexity and non-linearity of the data at hand, but single hidden layer is sufficient to deal with most of the practical case. For the optimal network architecture, tangent of sigmoid (sigmoid function is of the form f(x) = (1/1+e-x)) transfer function 'tansig' has been used in the hidden layer and linear {linear function is of the form f(x) = (x)} transfer function 'purelin' has been used in the output layer**.** The ANN configuration is represented as 3-25-1 that is input layer consists of three input neurons; the hidden layer consists of twenty five neurons and the output layer consisting of one output neurons. The number of neurons in the hidden layer is determined by trial and error method after designing and investigating many networks which vary in their structure, transfer function, training algorithm etc

Training of an ANN plays a significant role in designing the direct ANN-based prediction. The accuracy of the prediction depends on how well it has been trained. The training of the neural network using a feed forward back propagation algorithm has been carried out in the work. The network performs two phases of data flow. First the input information is propagated from the input layer to the output layer and, as a result it produces an output. Then the error signals resulting from the difference between the networks predicted values and the actual values are back propagated from the output layer to the previous layers for them to update their weights accordingly. The update of weights continues until the network error goal is reached

The number of neurons in the hidden layer is intentionally chosen to start with 20 neuron and hidden neurons are added to the hidden layer incrementally. The addition of hidden neurons continues until there is no significant progress in network performance. The performance of the network was evaluated by mean squared error (MSE) between the experimental and the predicted values for every output nodes in respect of training the network. The feedback from that processing is called the "average error" or "performance".

Once the average error is below the required goal or reaches the required goal, the neural network stops training and is, therefore, ready to be verified. MATLAB 7.1 has been used for training the network architecture which has been developed for prediction surface roughness in wet environment. The training performance of the optimal network (consisting of twenty five hidden neurons) architecture is shown in Figure 4. A computer program was performed under this MATLAB version. The input-output dataset consisting of 36 patterns was divided randomly into two categories: training dataset consist of 75% of the data and test dataset which consist 25% the data. There are 27 training patterns considered for ANN modeling surface roughness. After the training, the weights are frozen and the model is tested for validation. In this work, the network is validated in terms of agreement with experimental results.

The momentum constant and learning rate used in this model is 0.5 and 0.1 respectively. The maximum number of training epochs that was set is 500 and the training error goal was 0.001. After the training is completed, the actual weight values are stored in a separate file. The value of R^2 and MAPE values between the network predictions and the experimental values using training and test dataset for different network architecture have been shown in below

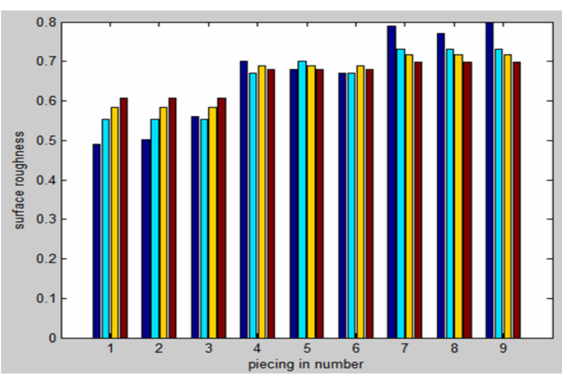
The summary of the proposed network architecture has been presented in Table As, the input and output vectors were supplied to the network, it was a supervised learning scheme. The back-propagation learning algorithm with LM versions was used at the training stage of the network. Gradient decent learning rule is used in this study. The learning rate and momentum constant used here are 0.1 and 0.5 respectively.

Table-2:- Regression values

Training Performance				Testing Performance		
Hidden Neurons	25	30	35	25	30	35
Regression	0.999	0.987	0.941	0.999	0.994	0.976

Table-3:- Comparison of roughness values with hidden neurons

S.No	Speed (rpm)	Feed (mm/rev)	DOC (mm)	Measured Roughness Ra (µm)	ANN Computed roughness Ra(µm) w.r.t hidden neurons					
					@25	% Dev	@30	% Dev	@35	% Dev
1	100	0.05	0.08	0.49	0.5534	11.4	0.5832	15.98	0.6063	19.18
2	100	0,05	0.05	0.501	0.5534	9.46	0.5832	14.09	0.6063	17.36
3	100	0.05	0.1	0.56	0.5534	-1.17	0.5832	3.97	0.6063	7.63
4	135	0.08	0.08	0.7	0.6995	-0.071	0.6894	-1.51	0.6801	-2.84
5	135	0.08	0.05	0.68	0.6995	2.78	0.6894	1.36	0.6801	0.0147
6	135	0.08	0.1	0.67	0.6995	4.21	0.6894	2.81	0.6801	1.48
7	150	0.1	0.08	0.79	0.7321	-7.329	0.7167	-9.2	0.6985	-11.58
8	150	0.1	0.05	0.77	0.7321	-4.92	0.7167	-8.22	0.6985	-9.2
9	150	0.1	0.1	0.8	0.7321	-8.48	0.7167	-10.41	0.6985	-13.12
	Total					5.88		8.87		8.9247



_______ measured surface roughness

_______@25 neurons surface roughness

_______@30 neurons surface roughness

_______@35 neurons surface roughness

Figure-2:- Comparison of surface roughness at different neurons

Table-4:- Data regarding the functions and layers

Object modeled	Surface Roughness
Input neuron	Speed(v), Feed (f), DOC (d)
Output neuron	Surface Roughness(Ra)
Network structure	
Network type	Feed-forward back-propagation
Transfer function	transig /purelin
Training function	Trainlm
Learning function	Learngdm
Error function	Mean square error
Learning conditions	
Learning scheme	Supervised learning
Learning rule	Gradient decent rule
Sample pattern vector	75% training,(27) ,25% (9) testing,
Number of hidden layer	One
Neurons in hidden layer	25, 30, 35
Learning rate	0.1
Performance goal	0.001
Minimum epochs	500

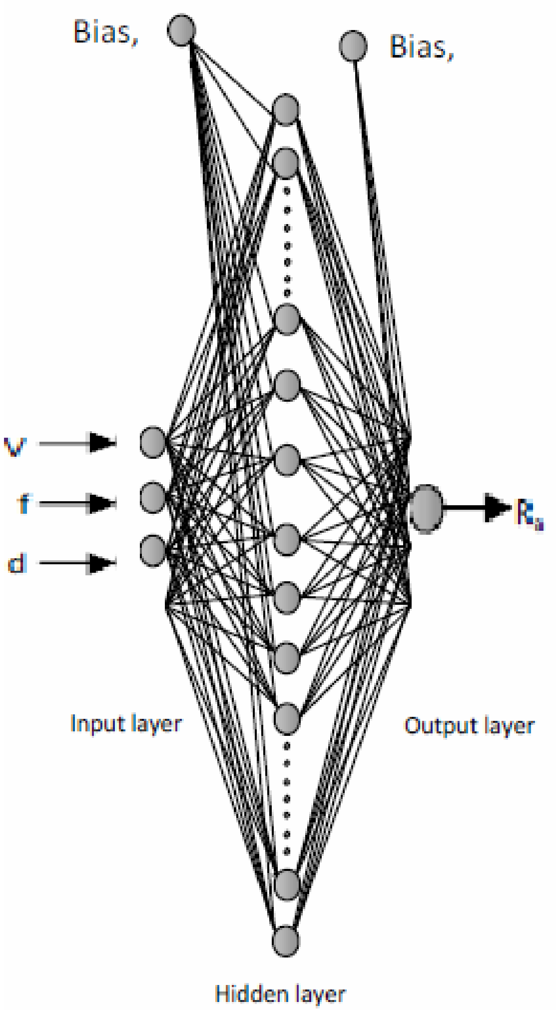


Figure-3:- Proposed ANN Structure

IV RESULTS AND CONCLUSIONS

Artificial neural network technique is adopted to simulate the machining conditions. In this technique 75% of data is trained, 25% data is used for testing. The results of artificial neural network reveals that regression value is R^2=0.99 for trained data and R^2= 0.99 for testing data performance , for which 4% of data is unexplainable.

It is observed that increasing the number of neurons from 25 to 30 has no significant improvement on the performance of the network. So, 3-25-1 network architecture was selected as the optimum ANN model

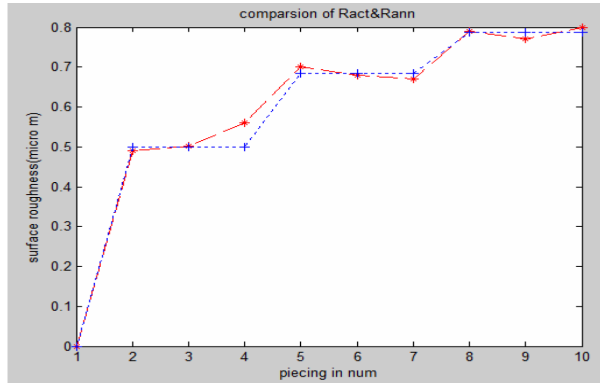


Figure-4:-Comparison of actual and predicted roughness values.

.... ACTUAL SURFACE ROUGHNESS
............MATLAB SURFACE ROUGHNESS

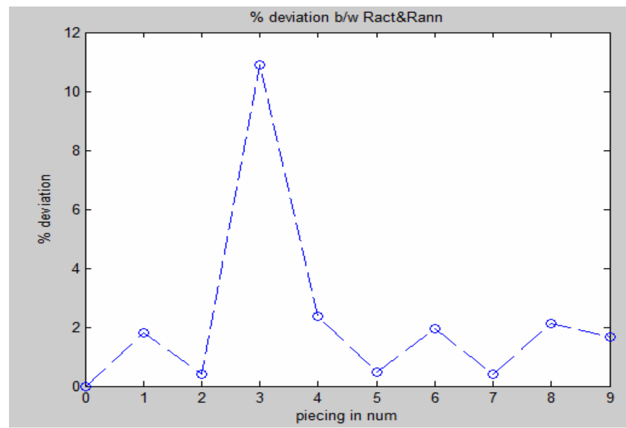


Figure-5:-Percentage deviation between actual and predicted roughness values.

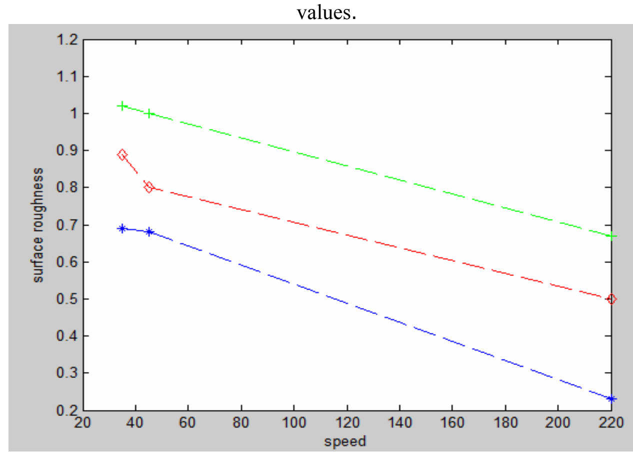


Figure-6:-Spindle speed vs surface roughness at DOC = 0.08 mm.

-------- 0.05mm/rev
--------0.075mm/rev
--------0.1mmrev

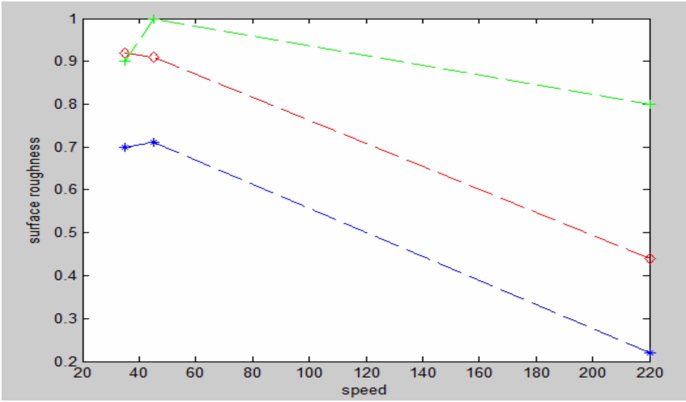


Figure-7:-Spindle speed vs surface roughness at DOC = 0.1 mm.

-------- 0.05mm/rev

--------0.075mm/rev

--------0.1mmrev

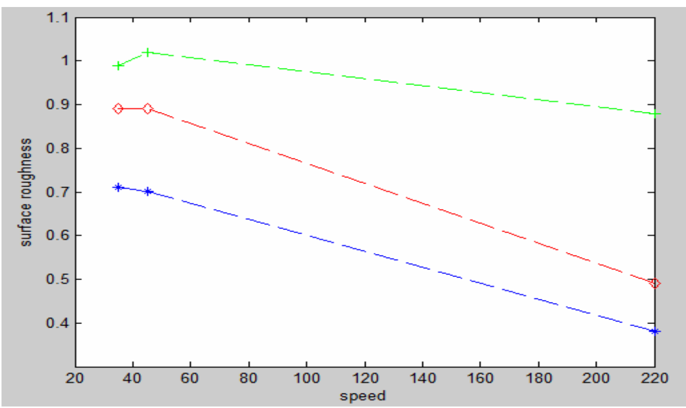


Figure-8:-Spindle speed vs surface roughness at DOC = 0.05 mm.

-------- 0.05mm/rev

--------0.075mm/rev

--------0.1mmrev

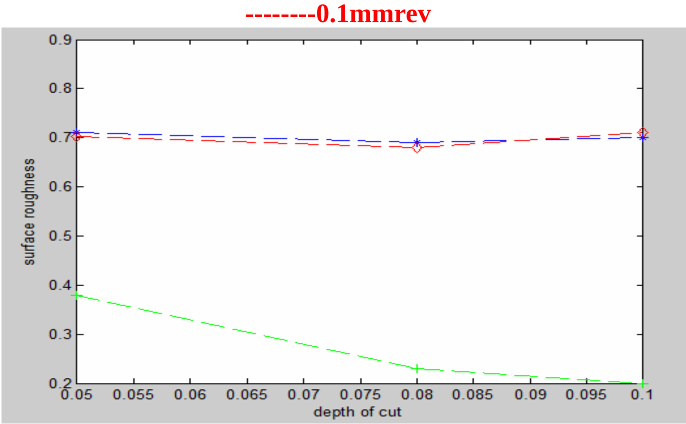


Figure-9:-Depth of cut Vs Surface roughness at feed rate = 0.05 mm/rev.

---------- 35 rpm

---------- 45 rpm

---------- 220 rpm

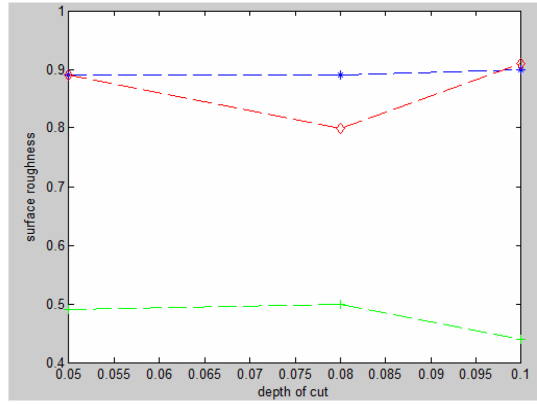


Figure-10:-Depth of cut vs surface roughness at feed rate = 0.075 mm/rev.

---------- 35 rpm

---------- 45 rpm

---------- 220 rpm

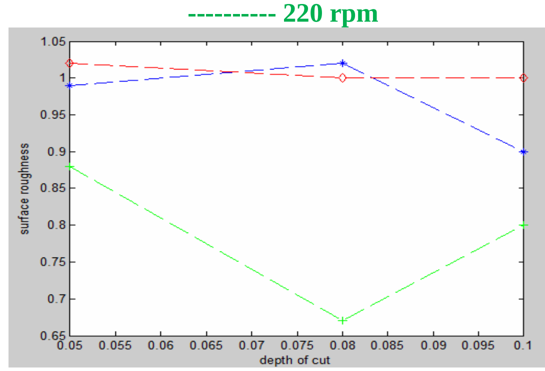


Figure-11:-Depth of cut Vs surface roughness at feed rate = 0.1 mm/rev.

---------- 35 rpm

---------- 45 rpm

---------- 220 rpm

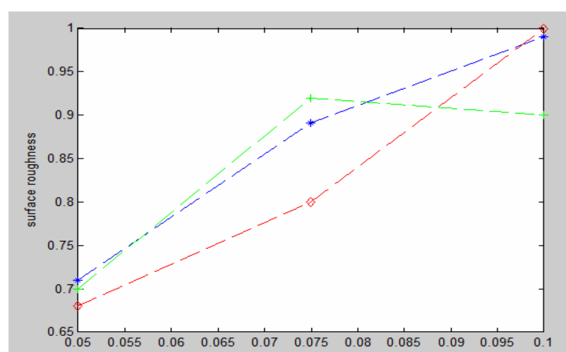


Figure-12:-Feed rate vs surface roughness at spindle speed = 35 rpm.

--------- 0.05mm

--------- 0.08mm

--------- 0.1mm

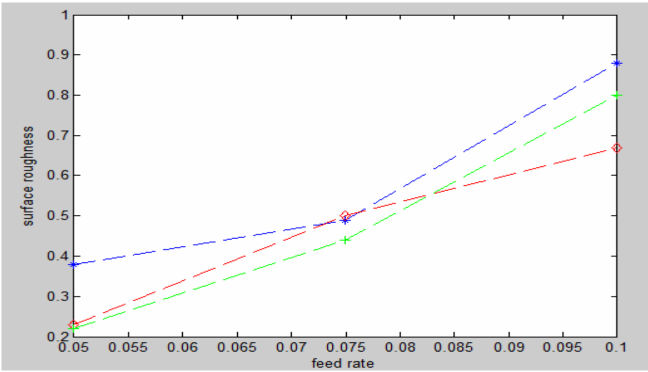


Figure-13:-Feed rate vs surface roughness at spindle speed = 220 rpm.

--------- 0.05mm
--------- 0.08mm
--------- 0.1mm

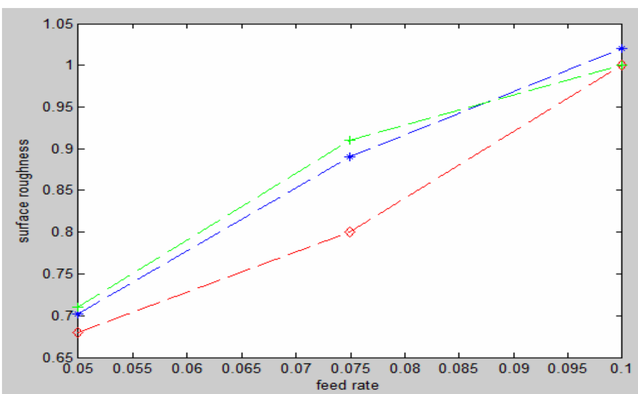


Figure-14:-Feed rate vs surface roughness at spindle speed = 45 rpm.

--------- 0.05mm
--------- 0.08mm
--------- 0.1mm

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