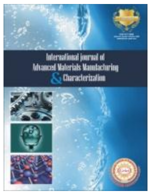

Advanced Materials
Manufacturing & Characterization

journal home page: www.ijammc-griet.com

Development of an ANN Model to Predict Surface Roughness During Cryogenic Machining Operation

Mandal K. K.

Assistant Professor: Department of Mechanical Engineering North Eastern Regional Institute of Science and Technology (DU)
Nirjuli – 791109, Itanagar, Arunachal Pradesh, India.

ARTICLE INFO

Article history:
Received 21 Oct 2012
Accepted 26 Dec 2012

Keywords:
High Speed Machining,
Surface Roughness,
Cryogenic Cooling,
ANN Model.

ABSTRACT

This research paper deals with the advanced manufacturing technique in addition to high speed machining which can be achieved by improving machining parameters through cryogenic cooling approach instead of conventional cooling system. Industrial growth and globalizationaim to increase the material removal rate maintaining very good surface finish and high machining accuracy even for harder, difficult to cut materials. Also, it should be possible at lower overall cost of manufacturing as well as maintaining an eco-friendly environment. Cutting tool fails due to high-elevated temperature and plastic deformation. Also the material is removed due to ploughing and rubbing instead of ideal shearing under conventional cooling method. Moreover, for ductile material cutting, heat causes a "stickiness" which produces material build-up on the edge of cutting tool known as "welding." This results a bad odor, smoke, health hazards and water penetration into the machine bearings. To improve the surface roughness i.e. to maintain the tool's form stability for longer time, cutting zone temperature is to be maintained low. Liquid nitrogen used as coolant can reduce the cutting zone temperature to a greater extent and thereby helps to retain the shape of cutting edge of cutting tool for a longer time. Also HSTR alloys, MMC may also be machined economically because of low tool wear rate and easy chip breakability. In this present problem, an ANN model has been developed to predict tool wear during cryogenic machining using back propagation feed-forward network algorithm and four hidden layers feed forward architecture.

Introduction

According to advanced technology, industrial growth and globalization, ouraim is to increase the material removal rate i.e. high speed machining, maintaining the consistency of very good surface finish and high machining accuracy. Definition of high speed machining depends on the work-tool combination [1]. Even for harder, difficult to cut materials this target is to be fulfilled at lower overall cost of manufacturing as well as maintaining an eco-friendly environment [1, 2]. Cutting fluid is used to extend tool life by reducing tool temperature and friction between the tool, the chip and the work-piece. However, conventional cutting fluids are environmental pollutants as well as health hazards as the bacteria and microbial organisms feed on the coolant base oils, rust inhibitors and emulsifiers [2].

- Corresponding author: Mandal K.K.
- E-mail address: kkm@nerist.ac.in
- Doi: http://dx.doi.org/10.11127/ijammc.2013.02.051

Cutting tool fails due to high-elevated temperature and plastic deformation under high speed machining of tough, very hard and difficult-to-cut material using conventional cooling methods. Also the material is removed due to ploughing and rubbing instead of ideal shearing as cooling as well as lubrication function of the cutting fluid reduces which inhibits adhesion, rubbing of the chips and welding-like seizure between the chip and the tool [3]. Also for machining most ductile materials, long continuous chips can scratch the finished surface [4]. The high elevated temperature increases the temperature dependent wear rapidly which affects on the finished surface. It also causes dimensionaldeviation and premature failure of cutting tools due to form instability. To improve the surface roughness i.e. to increase tool's form stability, basic conventional approach involves either heating the job or cooling the cutting tool. But these methods do not totally fulfill above mentioned needs of the high speed metal machining. Also these are uneconomical as this process needs more time [5]. During ductile materials cutting, the heat causes a "stickiness" which produces material build-up on the edge of the cutting tool known as "welding." It also creates long and continuous chips which often snarl and jam the automatic turning and too bulky for disposal [6]. Also, these chips may scratch the finished surface [7]. To eliminate the above mentioned limitations during metal cutting, cryogenic cooling is getting more importance nowadays. Cryogenic machining using liquid nitrogen (LN_2) as a coolant, is considered a viable option to conventional machining. With temperature as low as –196.7^{0}C at 1 atm, super cold LN_2 is a good coolant. It leaves no harmful residue to the environment. Therefore, it is considered naturally recycling and environmentally friendly. This economical cryogenic machining process improves the tool life up to five times when compared with state-of-the-art conventional emulsion cooling. This clean process also increases the productivity and lowers the production cost [2]. It helps to remove the material by ideal shearing and less by the ploughing, sliding and rubbing as the chips are irregular, very small and easily washable with the coolant. It improves chip breaking for low carbon steel and reduces the build-up edge [4]. In 1965, Grumman Aircraft Engineering Corporation reported safe and successful tool-life improvement when using LN_2 to cool high-speed steel end mills. This process emphasizes that only a small amount of the super-cooled LN_2 is supplied directly and only to the tip of the cutting tool to take advantage of the high exit velocity and low temperature of LN_2 as it streams from the nozzle aperture [8]. In a different approach, the temperature in the cutting zone can be reduced through cryogenic cooling in turning of stainless steel with diamond tool. It can reduce the cutting zone temperature from 1150^{0}C to 830^{0}C, i.e. 35% reduction at higher ranges of cutting parameters i.e. at higher material rate too. With the help of cryogenic cooling, harder materials, HSTR alloys and MMCs may be machined economicallymainly because of low tool wear rate as it retain its shape dropping the cutting zone temperature [9]. As tool wear is in the lower range under cryogenic cooling, so, surface finish and job accuracy is also improved a lot and thereby machining parameters as well as machining performances can be improved comparing to conventional cooling methods [10]. LN_2 machining provides lower tool wear, better surface finish and cutting forces. By injecting a small amount of liquid nitrogen to the chip–tool interface yield a noticeable (i.e. 43% to 67%) tool-life as well as surface roughness improvement compared to conven-tional cooling. It also improved machiningproductivity and reduced overall production cost [11].

There are some soft computing methods available to predict the surface roughness like design of experiment [12], Genetic algorithyms [13]. Also ANN model is used to predict the cutting performances (e.g. [14]). In the present problem, an ANN model has been developed to predict surface roughness during cryogenic machining using back propagation feed-forward network algorithm and single layer feed forward architecture.

Experimental planning

The experimental work, here turning operation is performed in a PL-4 Lathe of Laxvard Industries, Bangalore. The job material is high strength steel, technically known as hot die steel i.e. H_{11} is undergone a heat treatment process to achieve the required hardness (RC 58). To observe the effect of any machining parameter on the finished surface, tool is changed every time. For this purpose, replaceable tool inserts are used. The specification of tungsten carbide insert is CC MT 090304 TK 15/TN 200. Shape of these tool inserts is rhomboidal with an angle of 80^0. Experiments are performed under the cryogenic environment. Before starting the turning operation, job is slowly rotated and liquid nitrogen spray is applied over the job through a movable nozzle to lower down the ductility of the workpiece. This process is known as precooling the job surface tends to improvement of chip breaking and thereby avoiding scratching over the finished surface. The details of the experimental conditions selected to fulfill the criteria are given in Table 1. After each set of experiments, surface roughness is measured by Handy Surf Instrument.

Table1. Experimental conditions

ITEMS	DESCRIPTION
Cutting Speed	45, 50, 55 m/min
Depth of Cut	0.5, 0.75, 1.0, 1.5 mm
Feed Rate	Constant at 1 mm/rev
Length of Cut	25, 50, 75, 100 mm
Equipment to Measure Surface Roughness	Handy surf
Environment for Turning Operation	Liquid Nitrogen Flow

Cryogenic machining

With the advanced machining technology i.e. at much higher material removal rate, the heat build-up is greater and the cutting temperature is so high that cooling effects by the conventional cooling method is no longer effective to reduce the high temperatures. The method and apparatus of the present invention provide a practical solution for the improved machining of materials including high speed steel alloys, titanium, ceramics and composites. This invention has a special advantage in improving the chip breaking. The improvement of chip breaking especially for ductile material is obtained due to the following mechanisms:

a) Increasing the brittleness of the material by the application of cryogenic coolant.

b) Reducing the tendency of secondary deformation of chip which rubs on tool face.

c) Reducing the long tail in the grain structure of the chips which helps in breaking chips.

d) Avoiding self-welding of the bottom layer of the chip due to coldness.

e) Bending and curling the chip for breaking due to the pressure from the cryogenic fluid.

In this invention, however, the build-up edge formation is automatically prevented by injecting the super cold cryogenic fluid to the cutting tip area. This reduces the adhesion of the chip material to the tool tip which lowers the temperature in the cutting zone and prevents the welding phenomenon. Also, this invention can clean and remove the possible build-up edge with the cryogenic jet due to which the present invention also indirectly improves the finish of the machined surface. This provides a fluid cushion which reduces the friction of the chip rubbing on the tool face, and reduces the cutting force involved, as well as the abrasive wear. This will improve the penetration of coolant to the cutting zone. Thus friction between the chip and the tool face is greatly reduced and therefore, heat due to the frictional deformation is also reduced.

Development of the neural

Network model

Generally, an ANN is made of an input layer of neurons, one or several hidden layer of neurons and an output layer of neurons. These neurons are sometimes referred to as nodes or processing units. The neighboring layers are fully interconnected by different weights which are decided by the different transfer functions. The input layer neurons receive information from the outside environment (i.e. input parameters. Here these are cutting speed, depth of cut and length of cut) and transmit them to the neurons of the hidden layers without performing any calculation. The hidden layer neurons then process the incoming information and extract useful features to reconstruct the mapping from the input space to the output space (i.e. output parameters. Here this is surface roughness). The procedure for developing the model consists of two phases namely training phase and testing phase. In this method, back-propagation network is used to learn the forward relationship between the process inputs and process output. Actually the total development procedure for the proposed ANN model includes the following steps:

Step 1: Set the Learning rate, Momentum rate, Maximum allowed system error, number of iterations to optimize.
Step 2: Normalize all the inputs and output variables in the range of 0.0 to 1.0 based on their individual maximum value.
Step3**:** Initialize the number of hidden layers(here it is four) and that of neurons in each layer(here they are 30, 30, 30 and 1 respectively). Also set the model and output layers for 3 input and 1 output parameters.
Step 4: Initiate the connecting weights in normalized scale, bias values and coefficients of the transfer functions in random order.
Step 5: Update connecting weights, bias values and coefficients of transfer functions iteratively using a Back Propagation algorithm through batch mode of training.
Step 6: Set a goal during training process so that the iterations continuously go on until the termination criterion or goal is reached. Also the maximum numbers of epochs or cycles are mentioned to execute from the model during training process. When the model is properly trained then model output is noted and compared with actual output.
Step 7: After getting trained and optimized neural network model, it is tested with non-familiar sets of input values to get the output response and compare with the real value.
Step 8: Number of neurons in hidden layers and the transfer functions for each layer, are taken with different combinations of transfer functions as well as the number of neurons in each hidden layers for optimizing the model.

The Matlab program consists of two parts, one part can be used for continuous training of the model until the goal is reached and when the model gets optimized, having least MSE (mean square error) then the other part of the program used to compare surface roughness for unknown sets of input parameters. From the verification data a comparative study revealed that the mean difference between ANN output and experimental output is least when the Transfer function between the input layer, hidden layers and output layer is 'logsig','tansig', 'logsig' and 'purelin' respectively. Also the most suitable number of neurons in hidden layers are found to be 30, 30, 30, 1. Finally a feed forward neural network of type 3 – 30 – 30 – 30 - 1 was adopted to model the process as shown in Fig. 1 and the verification data set for optimized model for the training isillustrated in Fig. 2. All verification data set is also plotted as shown in Fig. 2 and Fig. 3.

Fig. 2 represents comparison between actual experimental outputs versus model output result for surface roughness when the model well trained. For the ideal case all points should lie on line drawn 45º to the both axis. On the other way it can be said that if all points are joned then then a firm solid line is seen. From Fig. 2 it is observed that there is very small deviation between actual experimental outputs and model output result for surface roughness which is represented by the wide line.

Fig. 3 shows slight deviation between actual experimental outputs and model output result for surface roughness when the neural network is tested for a set of unknown output data after the training. As data are collected through experimentation having manual error, so range of error by the model is acceptable.

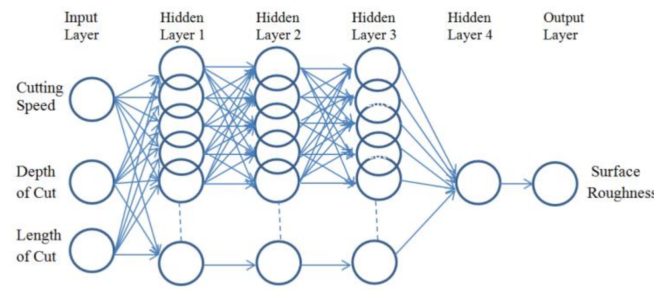

Figure 1: Configuration Of The Neural Network

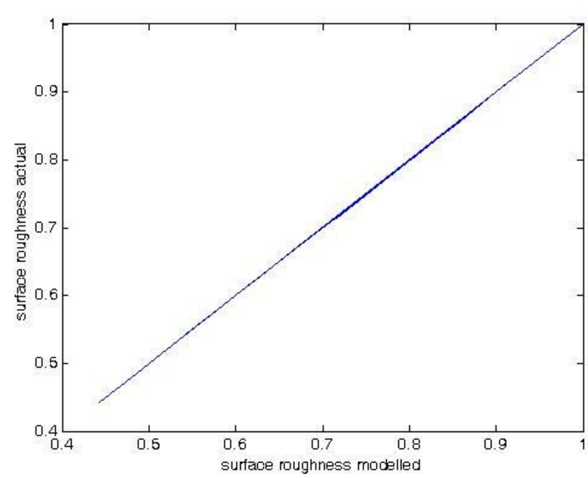

Figure 2: Experimental Outputs Versus Model Outputs For Surface Roughness For Training

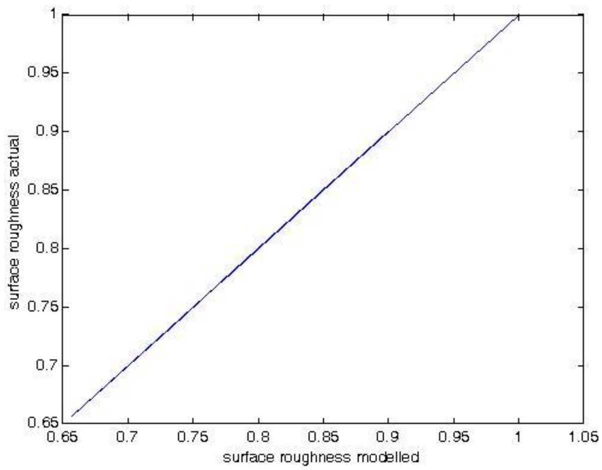

Figure 3: Experimental Outputs Versus Model Outputsfor Surface Roughness For Testing

Conclusion

The study conducted in this paper shows the feasibility of using a simple ANN model to predict the surface roughness as the output parameter during cryogenic machiningfrom a given sets of input parameters like cutting speed, depth of cut and length of cut. I have used linear output transfer function (purelin) and sigmoid transfer function to other layer like logsig – tansig – logsig which helps in fast converging, to reach the goal. The results indicate that with proper training, ANN can provide an alternative method for predicting surface roughness during cryogenic machining in cases where it is difficult to model the complex interaction among the multiple variable. Extrapolation over those limits would restrict the applicability of this model.

References

1. H. Schulz: Aspects in Cutting Mechanism in High Speed Cutting, Annals of the CIRP Vol. 38 (1989), p. 179-188.
2. Shane Y. Hong: Economical and Ecological Cryogenic machining, Journal of manufacturing Scienceand Engineering, ASME Vol.123 (2001), p. 331 – 338.
3. A. Bhattacharya: Metal Cutting Theory and Practice, Central Book Publishers (P) Ltd. (2000).
4. S. Y. Hong, Y. Ding, R. G. Ekkens: Improving Low Carbon Steel Chip Breakability by Cryogenic Chip Cooling, Int. J. Machine Tools and Manufacture, Vol. 39 (1990), p. 1065 – 1085.
5. C. Evans: Cryogenic Diamond Turing of Stainless Steel, Annals of the CIRP, Vol. 40 (1991), p. 571-575.
6. Y. Ding, S. Y. Hong: Improvement of Chip Breaking in Machining Low Carbon Steel by Cryogenically Precooling the Workpiece, Trans. ASME, Vol., p. 76-83.
7. S. Paul, A. B. Chattopadhyay: The Effect of cryogenic Cooling on Grinding Forces, Int. J. Machine Tools & Manufacture, vol. 36 (1996), p. 63-72.
8. S. Ravi, M. P. Kumar: Experimental investigations on cryogenic cooling by liquid nitrogen in the end milling of hardened steel, Cryogenics, Volume 51 (2011), p. 509-515 .
9. Z. Y. wang, K. P. Rajurkar, M. Murugappan: Cryogenic PCBN Turing of Ceramics (Si_3N_4), Wear, Vol. 195 (1996), p. 1 – 6.
10. K. Uehara, S. Kumagai: Surface Roughness and Cutting Forces in Cryogenic Machining, Annals of CIRP, VOL.17 (1969), P. 409.
11. K. K. Mandal, S. Mitra, B.Bhattacharya: Applying Liquid Nitrogen as the Coolant: An Index for Improving manufacturability, National Conference on Design for Product Life Cycle (2006).
12. A. Choudhury, M. A. El-Baradie: surface roughness prediction in the turning of high-strength steel by factoral design of experiments, Material Processing Technology, Vol. 67 (1999), p. 55-61.
13. P. V. S. Suresh, P. VentateswaraRao: selection of Optimal Machining Conditions for required surface finish using genetic algorithyms, Proc. Of 19^{th} AIMTDR (2000), pp. 439 - 444.
14. R. Banik, R. Pongen, A. Mandal and K. K. Mandal: Development of an ANN Model to Predict Tool Wear During Cryogenic Machining, Int. Conf. Advances in Materials and Manufacturing Technology, Mech. Engg. Deptt. Chitkara University, Punjab (2011), p. 28 – 30.