Condition Monitoring of Single Point Cutting Tool Wear

Mr. Shailendra Narayan More
OPJS University, India

Abstract— Metal cutting plays an important role in the present day manufacturing. Over the years, the manufacturing industry has matured by introducing new materials and processes. Superior manufacturing facilities, with the state of the art technology processes are now available, catering to the stringent product requirements, like form, fit and function. They generate surface finishes that produce the right texture enhancing the products aesthetic appeal or satisfying the designer's functional requirements. The product quality has been built into the product, with every aspect of the process studied, monitored and excelled. With the advent of computer technology and its allied growth in the software industry, newer computing techniques and algorithms push the technology to its limits and application engineers are curious to study the impact of these in various situations that may interest them. As manufacturing brings to life the various abstract designs, there exists a huge potential to create newer and newer products by various processes. This moots the study of the implication of such algorithms and techniques on these processes with a goal to manufacture better products in a shorter time, keeping the cost aspects low and complying with the quality requirements. This also opens up another related domain called condition monitoring. Condition monitoring studies are carried out on processes, machines, tools and the like. It is the periodic or continuous measurement of various parameters that indicate the condition of the tool, stability of the process or condition of the machine. The focus is to avoid producing parts that are out of tolerance or those which are in non-conformance with the specified finish and to avoid surprise breakdown of the machine itself. Some of the methods by which diagnosis is carried out include studying and analysing the wear debris, sound and acoustic emission, and vibration signals. Signals are acquired and processed in time domain, frequency domain and time-frequency domain. Amongst these conventional techniques, Fast Fourier Transform (FFT) is simple and commonly used in industries. While the vibration signature is used as basis for FFT based techniques, there are several pre-processing methods by which noise and unwanted signals can be separated. Machine learning techniques (feature extraction, feature selection and feature classification) are recent methods used to perform machine condition monitoring. However there are different features and different algorithms that are used to classify the signals. This gives the basic motivation to study tool wear monitoring in turning operation using machine-learning techniques with an objective of finding the best possible feature-classifier combination. In addition, prediction of the surface quality using various parameters through different regression techniques is also of concern. Thus, this study has set out to classify tool wear and to predict the surface roughness from the features extracted from the vibration signals obtained during turning operation.

Key words: Condition Monitoring, Single Point, Cutting Tool Wear

I. Introduction

Manufacture of products undergoes different processes before they are assembled to serve their intended function. Over the years, many new materials and processes have been introduced. Latest machines have better process capability and are competent of achieving the right fit between mating parts. Today's industries are equipped with the state of the art technology machines, with processes catering to the specific needs of the product requirements, like form, fit, function. Some products demand stricter tolerances and better surface quality. Designers demand specific surface finishes that produce the right texture enhancing the products aesthetic appeal or satisfying the manufacturer's assembly requirements. So one can say that, in today's scenario, where manufacturing processes have matured and quality of products need to be built into them, every aspect of the process requires to be studied, monitored and be perfected. With the availability of computer technology and its allied growth in the software industry, newer computing techniques and algorithms push the technology to its limits and application engineers are curious to study the impact of them in various situations that may interest them. As manufacturing brings to life the various abstract designs, there exist a huge potential to create newer and newer products by various processes. This moots the study of the implication of new algorithms and techniques on these processes with a goal to manufacture better products in a shorter time, keeping the cost aspects low and complying with the quality requirements. This also opens up another related domain called condition monitoring. Condition monitoring studies are carried out on processes, machines, tools and the like.

II. Literature survey

1) Paper 1. Cutting Forces

It is one of the most capable techniques that have been adopted for tool wear detection and breakage. It involves the measurement of cutting forces using dynamometers. The three components of cutting forces are the vertical components Fy, the horizontal (feed) component Fx, and the radial component Fz. The cutting force signals are supposed to change with respect to time, according to the tool load. The tool load is a function of tool condition. If the tool condition is good (sharper), then the load on the tool will be minimum. On the other hand, if the tool is blunt or broken then it needs more force for the cutting action. This causes the required force to perform cutting action to rise [8, 25-27, 43]. This is the basic idea on which the works were carried out.

2) Paper 2. Temperature

Masory [44] performed single point curing tool experiments, measured and recorded the tool tip temperature, the true root mean squared value (RMS) of the AE signal, and the three components of the cutting forces. Five sensor signal pattern vectors and two binary inputs representing tool type were presented to an MLP network. Three neural network architectures were trained and based on obtained results, the best one was selected. The desired output sought by Masory was estimated values of flank and crater wear. He claimed the wear estimations to be very accurate but never quantified.

3) Paper 3. Optical

A tool wear-land on a single point cutting tool appears clearly because of the higher reflectivity compared with the unworn surface. Optical and electro-optical methods can be used to analyse the image of the illuminated wear zone when the cutting tool is not continuously in contact with the workpiece [45]. Change in the light intensity that is reflected and sensed between the cutting tool and the diameter of the workpiece is believed to be a simple, reliable, on-line tool wear signal [46-50]. An optoelectronic sensor along with multi-layered neural network uses gap sensing system consisting of a laser source, a bifurcated optic fibre and a photodiode circuit. The change in the workpiece dimension is correlated with the flank wear on the cutting tool. Fibre optic sensors are used during in process measurement of tool flank wear [51]. An optoelectronic method has been proposed for on-line monitoring of the flank wear of cutting tools [52].

Sensors for measurement of parameters can be classified either online or offline depending on the type of monitoring. When the reading from the sensors are taken continuously when the cutting process is going on, they are called on-line sensors and when the readings are taken intermittently after the process is stopped, they are called offline sensors. They can also be classified as direct measurement sensors or indirect measurement sensors based on whether they measure the direct size of wear area or, whether they measure the process parameters that can be correlated to predict the wear

However, there are some researchers who have used a combination of an online, indirect technique (by using tool fracture identification based on vibration signals) [13] with an offline, direct measurement technique (wear area measurement through Closed Circuit Digital camera).

4) Paper 4. Vibration

A review of the work carried out in the area of vibration analysis for tool condition monitoring was presented by many researchers [20-24]. There are number of techniques based on fast Fourier transform and pattern recognition are widely reported. To name a few, Artificial Neural Networks (ANN) [24-28], fuzzy [28], Neuro-fuzzy [29], FFT and Power spectral density [30]. It is important to note that there are numerous articles published in the area of tool condition monitoring using ANN. The main difference among them lies in the different configuration and network paradigms. To name a few paradigms, Multi-layer perceptron (MLP) [31-33], Radial Basis Function (RBF) [34], Adaptive Resonance Theory (ART) [35-37] etc. These are used in indirect methods during the measurement of vibration signals. They contain one or more peizo-electric crystal elements, either made of natural quartz or man-made ceramics. These crystals produce voltage when stressed in tension, compression or shear called as peizo-electric effect, which is proportional to the force applied. There are many types of transducers available to measure acceleration like capacitance type, strain gauge type, piezo-electric type etc. The piezo-electric accelerometer has wide frequency and dynamic range, good linearity throughout the ranges as it has no moving parts which may get worn out due to friction. It is the widely used transducer for vibration measurements. Piezoelectric materials such as quartz, Rochelle salt, barium titrate, lead zirconate etc., and generate electric charge when subjected to mechanical strain. Amongst them, barium titrate is poly crystalline in nature and can be formed into a variety of shapes. It has to be polarized before it can exhibit the piezoelectric effect.

Piezoelectric accelerometers rely on the self-generating, piezoelectric effect of either quartz crystals or ceramic materials to produce an electrical output signal proportional to the acceleration. The piezoelectric effect is that which causes a realignment and accumulation of positively and negatively charged electrical particles, or ions, on the opposed surfaces of a crystal lattice, when that lattice undergoes stress. The number of ions that accumulate is directly proportional to the amplitude of the applied stress or force.

III. PROBLEM STATEMENT

The problem consists of two phases of study; a tool status classification problem using supervised learning method.

IV. FUTURE SCOPE

- During the experimental study, in order to create the different tool wear conditions, it was decided to have 0.3 mm as tool blunt low and 0.6 mm as tool blunt high. The intention was to create two representative classes. This study can be extended to continuous monitoring of the progressive wear of the tool.
- The study has been carried out using C 4.5 algorithm for dimensionality reduction and feature selection. However, there are many other ways like PCA, Linear discriminant analysis, factor analysis, fisher's linear discriminant analysis, feature subset selection, Minimum Description Length Method, Probability of Error and Average Correlation Coefficient method, Koller and Sahami's method etc., that can be tried out.

V. CONCLUSION

Here, different sets of features were extracted from the time-domain signal obtained during the experiment. The experiment consisted of collecting the vibration signals for different tool wear states and classifying them. The four classes were, Good, Tool Blunt low (TB1), Tool Blunt high (TB2) and Tool tip loose (TTL). C4.5 algorithm was used as it is simple and good in feature selection. The various kinds of features that were considered for study are

- Statistical Features
- Histogram Features
- Discrete Wavelet Transform Features The comparative study between ID3 algorithm and PCA on feature reduction using statistical features showed that ID3 is better than PCA in feature reduction. From the results and discussion in section 5.2 we find that among the 11 statistical features that were considered, only two features, namely. Standard Deviation and Kurtosis contribute towards enhancement of classification accuracy while keeping the computational effort low. Similarly, among the twenty histogram features that were

defined, only four features namely, h9, h10, h13 and h14 were found to be contributing to the classification accuracy. (Refer section 5.2). Online prediction of surface roughness has been attempted in many ways and by using different parameters like, cutting tool parameter variations, geometry variations, coating of inserts with different materials, study using different signals like, acoustic signals, vibration signals etc. From the literature study, it was found that prediction of surface roughness using cutting parameters and mean value of the amplitude of the vibration signals are generally studied. However, a machine learning approach to using the statistical features extracted from vibration signals, along with the other cutting parameters and flank wear have not been attempted by researchers, especially in a single point cutting tool environment

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