

## **ABSTRACT**

High Speed Milling (HSM) is a processing technology that finds numerous applications in manufacturing industry. It is a manufacturing technology to many industries where machining time is a significant fraction of the total product manufacturing cycle time. The other benefits of HSM are reduced cost, better surface finish, low residual stress and less work piece distortion. A better understanding and control of the machining process is necessary to satisfy the increasing demand, higher productivity and product quality. Process monitoring and its control will help in development of automated control of process and thereby improve productivity and product quality. Milling and in particular high-speed milling owing to the high complexity, only limited understanding of the process has been achieved till today. In HSM, tool wear occurs quickly and reaches unacceptable level resulting in poor surface finish and dimensional accuracy. Delivery of consistent quality is a challenge as far as HSM is concerned. Therefore studies related to tool wear monitoring in HSM forms a major part of this research work.

Tool wear monitoring encompasses two major domains- breakage detection and wear detection. In the current work, wear detection is targeted. Tool wear detection can be used to avoid production of parts out of tolerance, narrow down tolerance in design and also predict the useful life of tools. In the existing shop floor practice, cutting tools are replaced at the end of pre-determined machining time based on past tool life data or sometimes during

catastrophic tool failure. Dimensional accuracy and surface quality are influenced by tool wear. In Computer Numerical Controlled (CNC) machines, in order to compensate for tool wear, a tool offset is made manually in the NC program, whenever the component dimensions are found deviating. Therefore on-line tool wear prediction and estimation are essential for enforcing automatic, real-time control of HSM process.

The main objective of this study is to develop methods to get closer to the quality target both in terms of dimensional accuracy and surface finish. A study on optimisation of process parameters along with development of process monitoring and adaptive control system would result in significantly improvement. In order to accomplish the above objectives, four modules of work are carried out. In the first two modules, experimental studies on tool condition monitoring for wear prediction using Artificial Neural Network (ANN) and optimisation of process parameters for better surface quality are carried out. The third and fourth modules are on development of self-adjusting on-line tool wear compensation system and adaptive control systems respectively for real-time control of process.

A CNC 3-axis vertical machining centre, fitted with a 5 kW; 40000-rpm integral motorized spindle is taken up for the study. A two-flute solid coated carbide square end milling cutter ( $\phi$  6 mm) and aluminium alloy LM6 (grade 6550), widely used in manufacture of aerospace components are used in the experimental study. Acoustic emission based indirect tool condition monitoring technique which has already proved to be a better tool wear monitoring method in conventional machining is employed in HSM.

In the first module, indirect tool wear monitoring and estimation are attempted. The experiments are conducted as per ISO 8688-2 (E) (1989); standards for tool wear study in end milling cutters. A partial factorial experiment for tool wear study using AE signals are carried out using Taguchi's L9 orthogonal array. The experimental data are used to develop a correlation between tool wear and acoustic emission signals. An ANN model using back propagation algorithm is developed in C<sup>++</sup> for tool wear prediction. The ANN model has been trained to predict tool wear with less than four percentage deviation. In the second module optimisation of process parameters for improved surface finish were carried out. The cutting parameters namely cutting speed, feed rate and depth of cut are varied and the response parameters like cutting force, vibration and surface finish are observed. Analysis of variance (ANOVA) is carried out to optimise the process parameters and identify the influence of individual parameters on various responses like cutting force, vibration and surface finish. An experiment to observe the change in resultant cutting force with respect to progressive tool wear is carried out. The above experiments are conducted to study the feasibility of implementing on-line control of resultant cutting force by varying cutting speed to improve surface finish. The results of these studies are used in the fourth module in developing the adaptive control system.

The experimental results obtained in module one i.e., tool wear prediction using acoustic emission technique is used to develop a self-adjusting on-line tool wear compensation system. The necessary hardware

and software development forms a part of this work. A process capability study is carried out for verification of new process. The study shows significant improvement in the process capability index and process capability ratio and also shows a reduction in standard deviation.

The experimental outcome of the second module is used in the development of Adaptive Control based on Constraints (ACC). In this work the spindle speed is varied in order to maintain a constant resultant cutting force. The resultant cutting force is taken as an indirect measure of surface finish. A process capability study is carried out to study the improvement in new process. The study shows significant improvement in the process capability index and process capability ratio.

Summarizing, an experimental setup to investigate the high-speed milling of aluminium alloy for on-line tool condition monitoring and wear estimation have been accomplished. Taguchi's DoE has been used for optimisation of cutting parameters. On-line, self-adjusting tool wear compensation and Adaptive control system have been developed. The experimental work, mathematical models and soft computing tools used will be of immense help to modern manufacturing industries. This work also suggests new and better methods of sensor interface, signal processing, indirect tool condition monitoring, tool wear compensation and adaptive control in HSM. The above work will be laying a stepping-stone for development of low cost smart CNC machines and reliable intelligent self-adaptive CNC machines. A number of add-on modules for lean CNC machines can be developed using the above approaches.