VIBRATION ON MILLING TOOL DURING MILLING OF CURVES

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Abstract- Machining processes such as milling, which is characterized by interrupted cutting, are often susceptible to problems involving due to vibration of the machine-tool-workpiece device system because of the proximity between their natural frequency and the frequency of tool entry on the workpiece. Tool vibration further lowers the component quality and reduces tool life. This paper reviews the state of the art in vibration-based condition monitoring with particular emphasis on milling machine during working with ball nose end mill tool.

Keywords- Milling machine, Vibration analysis, Ball nose end mill tool, Machine Condition Monitoring, damage detection.

I. INTRODUCTION

Vibration is a mechanical phenomenon whereby oscillations occur about an equilibrium point. Vibration is undesirable, wasting energy and creating unwanted sound in many situations. Vibrations could be caused by imbalances in the rotating and reciprocation unbalanced forces and couples. Careful designs usually minimize unwanted vibrations. Dynamic loading causes fatigue and vibration which leads to the development of various faults in machinery e.g. crack, unbalance, misalignment etc. Such problems can be resolved by vibration testing and analysis. Machine Condition Monitoring (CM) helps in ensuring the reliability and low-cost operation of industrial facilities. Condition monitoring can provide early detection of machine faults so that appropriate action can be taken before that fault cause early breakdown.

Continuous CM allows a machine repair and maintenance to be planned, which should improve economical operation and reduce possible harmful effects. Many technologies have been used to enhance the applicability, accuracy, and reliability of CM systems. Monitoring vibration amplitude of milling machine during working with ball nose end mill tool is one of the methods to reduce the machine failure.

II. Terminologies in Vibration analysis

- **Amplitude:**

The maximum displacement or distance moved by a point on a vibrating body or wave measured from its equilibrium position. It is equal to one-half the length of the vibration

path. The vibration data can be collected in three form, they are as follows.

1. Displacement - the amount of movement from one point to another.
2. Velocity - the rate of movement.
3. Acceleration - The rate of change of velocity.

These terms form the basis for the amplitude of vibration. Any measurement of vibration is normally denoted in the above three terms only.

- **Frequency:**

Frequency is the number of occurrences of a repeating event per unit of time. It is also referred to as temporal frequency, which emphasizes the contrast to spatial frequency and angular frequency. The period is the duration of time of one cycle in a repeating event, so the period is the reciprocal of the frequency. This denotes how frequently something occurs. Certain features appear at regular intervals or they are made to appear at regular intervals based on their relative motion. We do have a small mathematical formula for rotating members to know their frequency, it is

Frequency (Hz) = speed in rpm/60

The Hz denotes Hertz, the unit for frequency

Critical frequency is the highest magnitude of frequency above which the mechanical system fail. Its value is not fixed and it depends upon electron density of the system. The mechanical system fails when the actual frequencies match with the natural frequencies which cause resonance.

III. Vibration Causes, Elimination and Types

Vibration problems occur where there are rotating or moving parts in a machinery. Apart from the machinery itself, the surrounding structure also faces the vibration hazard because of this vibration machinery. Main causes of vibration are as follows.

1. Unbalanced forces in the machine.
2. Dry friction between the two mating surface.
3. External excitation
4. Earthquakes
5. Winds

Elimination or Reduction of the undesirable vibration can be obtained by one or more of the following methods.

1. Removing the causes of Vibration.
2. Putting the screens if noise is objectionable.
3. Placing the machinery on proper isolators.
4. Using shock absorbers.
5. Using dynamic vibration absorbers.

There is two type of vibration.

1. Free vibration

When a system is initially disturbed by a displacement, velocity or acceleration, the system begins to vibrate with a constant amplitude and frequency depend on its stiffness and mass. This frequency is called as natural frequency, and the form of the vibration is called as mode shapes

2. Forced vibration

If an external force applied to a system, the system will follow the force with the same frequency. However, when the force-frequency is increased to the system's natural frequency, amplitudes will dangerously increase in this region. This phenomenon called "Resonance".

These two can be further divided into damped and un-damped vibration. There are a variety of different types of Vibration analysis corresponding to different vibration phenomena.

1. Long time duration but narrow bandwidth.
2. Short time duration but wide bandwidth such as impacts or transients.
3. Short time duration and narrow bandwidth such as decayed resonance.
4. Time-varying bandwidth such as an imbalanced shaft generating noise dependent on RPM or machine speed.

IV Type of Vibration Analysis

Harmonic Vibration Analysis The motion of a particle moving along a straight line with an acceleration which is always towards a fixed point on the line and whose magnitude is proportional to the distance from the fixed point is called simple harmonic motion(SHM). It includes the motion of simple pendulum as well as molecular vibration. It works on linear elastic restoring force given by Hooke's law {F = -kx}.

Modal Analysis It is the study of the dynamic properties of structures under vibrational excitation. It is the field of measuring and analyzing the dynamic response of structure and or fluids during excitation. Modal analysis system is composed of 1) Sensors 2) Data Acquisition System 3) Host PC. The analysis of the signals typically relies on Fourier analysis. The resulting transfer function will show one or more resonances, whose characteristic mass, frequency and damping can be estimated from the measurements.

Transient Analysis A transient event is a short-lived burst of energy in a system caused by a sudden change of state. A transient response or natural response is not necessarily tied to "on/off" event but to any event that affects the equilibrium of the system.

Frequency Analysis is the most commonly used method for analyzing a vibration signal. The most basic type of frequency analysis is an FFT, or Fast Fourier Transform, which converts a signal from the time domain into the frequency domain.

Order Analysis, when performing vibration analysis many sound and vibration signal features are directly related to the running speed of a motor or machine such as imbalance, misalignment, gear mesh, and bearing defects.

Time-Frequency Analysis, one of the drawbacks of frequency analysis was that, with no time domain data associated with the signal, it was only useful for static signals.

Wavelet Analysis is appropriate for characterizing machine vibration signatures with narrow bandwidth frequencies lasting for a short time period.

Model-Based Analysis compares the vibration signal to a linear model of the signal and returns the error between the two which makes it useful for detecting transients.

V. Vibration Testing and Equipment

Vibration testing is performed to examine the response of a device under test (DUT) device under test to a defined vibration environment. Vibration testing is accomplished by introducing a forcing function into a structure, usually with some type of shaker.

The measured response may be fatigue life, resonant frequencies or squeak and rattle sound output (NVH). Squeak and rattle testing are performed with a special type of quiet shaker that produces very low sound levels while under operation. The most common types of vibration testing services conducted by vibration test labs are Sinusoidal and Random. Sine (one-frequency-at-a-time) tests are performed to survey the structural response of the device under test (DUT). A random (all frequencies at once) test is generally considered to more closely replicate a real-world environment, such as road inputs to a moving automobile.

Equipment required for Vibration analysis are

1. Sensors such as transducers (typically accelerometers, load cells), or non-contact via a Laser vibrometer, or stereo photogrammetric cameras.
2. Data Acquisition System and an analog-to-digital converter frontend (to digitize analog instrumentation signals)
3. Host PC (personal computer) to view the data and analyze it.

V. Experimental design and Setup

5.1 Milling Machine

A EMCO 250 mill was used in the experiment. The detailed specification of the machine tool is as follows.

Main drive (motor spindle)	RPM range	Up to 24,000 min^{-1}
Workspace	Rapid traverse/federate	30min^{-1}
	Traverse path X/Y/Z	730/560/560 mm
Nc rotary table	Clamping surface Rapid	Ø 600 mm
	traverse/federate	40 min^{-1}
	Max. workpiece weight	500 kg
Workpiece	Controller	Heidenhain ITNC 530
	Dimensions	80 x 80 x 175 mm
	Material	Aluminium

Table 1. Specification of milling machine used

5.2 Accelerometer Setup

Sensor is used as the vibration measurement device or accelerometer. This sensor was calibrated to collect the vibration during machining in form of Acceleration (m/s2). Arduino Uno is used as the DAQ (Data acquisition) system and controller board for our sensor. Program code is loaded on the Arduino Uno board which control input and output of the sensor.

A To conduct CNC milling operation spindle speed, feed and depth of cut and ball end mill dia. are selected as input process parameters. The levels of the independent variable are shown in table below.

The levels were selected to cover the normal cutting operations. Material for workpiece was AISI 304N Stainless Steel with hardness of 25-32 hrc.

A fractional factorial design implementing an L9 Taguchi orthogonal array (OA) was established to conduct machining experiments with the use of a computer-aided manufacturing (CAM) software. Fractional factorial design specifics involve the statistical elimination of unimportant parameters, thus reducing experimental runs without the loss of useful information. The workpiece material was free cutting steel with the following specification.

Properties	Metric
Tensile strength	620 MPa
Yield strength	330 MPa
Elastic modulus	193-200 GPa
Hardness, Rockwell B	85
C	0.08
Cr	18-20
Fe	66.345-75
Mn	Max 2
Ni	8-10.5
P	Max 0.045
S	Max 0.03
Si	Max 1

Table 2. Workpiece material specification

5.4 Tool parameters

Selected tool material is Cemented Carbide for milling of selected work piece material. The specification of selected tools are in following tables. During our experimental work two type of milling tools were used, End mill tool and Ball nose end mill tool. End mill was used in roughing process and ball nose end mill was used in finishing operation.

In our experimental work 5 mm End mill was used in roughing process and 3mm, 5mm, 7mm ball nose end mill tool was used in finishing operation. The material of ball nose end mill tool was Cemented Carbide.

VI. Analysis Procedure

In this experimental work vibration measurement is done. The machining condition such as tool nose radius, feed, speed, depth of cut, workpiece length, workpiece dimension were selected to cover the normal machining condition.

Independent Parameters	Units	Levels of parameters		
1.Ball Mill Dia.	mm	3	5	7
2.Spindle Speed	rpm	4000	5000	6000
3.Depth of cut	mm	0.020	0.030	0.060
4.Feed	mm/rev	1000	1200	1500

Table 3. In Put Process Variables

6.1 Vibration measurement

Equipment required for Vibration analysis is

1) Sensors such as transducers (typically accelerometers, load cells), or non-contact via a Laser vibrometer, or stereo photogrammetric cameras.
2) Data Acquisition System and an analogue-to-digital converter frontend (to digitize analog instrumentation signals)
3) Host PC (personal computer) to view the data and analyze it.

The tool vibration level is measurement using a 3D accelerometer mounted on the small acrylic sheet and acrylic sheet was mounted near the tool on the workpiece using C-clamp. The accelerations, measured were saved using putty software on the laptop in the form of notepad file. The first was the acceleration in the time domain, and the other is the autocorrelation of the acceleration in the frequency domain. The frequency domain was obtained using DIAdem software. The acceleration data was the then put in excel file and separated in different columns.

VII. Existing Research

Percentage of work in the field of milling machine process and performance parameters optimization are listed below.

- Cutter Geometry - 47 %
- Tool Path Optimization - 30 %
- Feed rate Optimization - 19 %
- Toolpath /Feed rate Integration - 4 %

Following is the detailed literature review of some important work which has been carried out in the field of Vibration during Milling Operation.

Ball end milling of molds and dies made of hardened alloy steels is very often conducted as a finishing process, which consequently imposes restrictive requirements on machined surface's quality and tool's condition. The high popularity of curvilinear surfaces milling is mainly attributed to the lower machining costs, as well as higher efficiency in comparison to that obtained during electro-discharge machining EDM, ultrasonic and laser beam techniques [1]. Nevertheless, the primary problem occurring during the precise ball end milling is correlated with an excessive surface roughness [2] and form error [3] of the manufactured curvilinear surface. The reason of the surface's quality deterioration is usually the selection of the inappropriate machining parameters and strategies, resulting from the insufficient understanding of the physical phenomena occurring during the surface texture formation in the milling process. The better recognition of these phenomena can contribute to the development of the accurate process' models, enabling identification and selection of parameters significantly affecting the formation of surface texture during precise milling of curvilinear surfaces. Nevertheless, the problem of surface texture optimization constitutes the significant scientific and technological problem, requiring further studies.

According to many types of research, the dimensional accuracy and surface roughness of the machined surfaces can be affected by the kinematic-geometric parameters [4], frictional effects in the tool-work material interface [5], process stability [6, 7, 8], plastic-elastic [9, 10], as well as the burr formation [11, 12]. However, one of the most significant factors affecting surface quality is tool-workpiece relative displacement. Furthermore, the excessive dynamic forces and displacements (vibrations) during machining can also lead to the catastrophic tool's failure. According to Becze et al. [13], the primary wear mechanism of tool materials during high-speed milling of hardened steel is chipping induced by milling process dynamics, related to the generation of vibrations.

The vibrations during machining are mainly induced by cutting forces and depended on the machine-tool holder-tool-workpiece system's dynamical properties, as well as the selected machining parameters and tool's slenderness. Lopez de Lacalle et al. [14], stated that the excessive cutting force values generated during ball end milling of complex surfaces significantly affect tool's displacements and thus workpiece dimensional errors. Furthermore, research carried out by Wojciechowski et al. [15] showed that cutting force oscillations during end milling of hardened steel affect so-called tool displacement envelope, and thus surface roughness height. Therefore, the identification of critical input parameters, affecting machining process dynamics is of high importance. One of the parameters, significantly influencing ball end milling dynamics is surface inclination angle α [16]. Investigations carried out by Chen et al. [17] showed that during ball end milling of P20 die steel, surface inclination angle had a non-monotonic effect on the mean values of cutting forces. In addition, the highest mean force values were obtained for the milling with α = 0°. According to Wojciechowski et al. [18] during finish ball end milling of hardened steel, tool's maximal displacements were higher during the slot milling, in comparison to those obtained for the upward ramping with α = 60°. Furthermore, the research conducted by Shan et al. [19] reveals that tool's orientation significantly affects the deformation of the thin-walled parts in multi-axis CNC machining. Therefore, the selection of cutting parameters and ball end milling strategy which enable the reduction of forces and vibrations is a significant task. In order to achieve it, the machining process optimization procedure can be applied.

The state of the art reveals that machining process' optimization objectives include mainly surface roughness [20], cutting forces [21], tool life [22], tool wear [23] and machining vibrations [24]. The popular optimization approaches are mainly based on the Taguchi method and determination of signal to- noise ratio, grey relational analysis (GRA), as well as the response surface methodology. Durakbasa et al. [25] applied the Taguchi method for the optimization of process parameters and different coating materials, combined with different tool radiuses to obtain the minimum surface roughness values during end milling process of AISI H13 hot work steel in dry cutting conditions. Khanna and Davim [26] studied the effect of control factors, as the cutting speed and feed rate on cutting forces, feed forces and the cutting tool temperature during turning of titanium alloys by using the Taguchi techniques. Masmiati and Sarhan [27] applied Taguchi optimization method regarding surface integrity after ball end milling of S50C steel. Through the analysis, it was found that milling strategy had a significant influence on microhardness and residual stress in the feed direction. The same approach was applied by Kivak [20] for the evaluation of the machinability of Hadfield steel with PVD TiAlN- and CVD TiCN/Al2O3-coated carbide inserts under dry milling conditions. Zhou et al. [28] used the grey relational analysis to the optimization of multi-axis ball-end milling of Ni-based superalloy Inconel 718. The aim of their research was to simultaneously obtain minimum surface roughness and maximum compressive residuals stress by the selection of optimal inclination angle, cutting speed, and feed. The grey relational analysis has been also applied by Kuram and Ozcelik [29] to multi-objective optimization for micro-milling of the Al7075 alloy. The carried out research allowed the obtainment of optimal milling parameters affecting the simultaneous minimization of forces, tool wear, and surface roughness. Subramanian et al. [24] optimized the end mill's geometry during machining of Al7075-T6 alloy with the application of response surface method. They found that vibration amplitudes are decreasing with the growth of the end mill's nose radius. Kark also et al. [30] applied the response surface method to predict the surface quality of the workpiece and identify optimal cutting parameters, that lead to minimum surface roughness during peripheral milling of Ti-6Al-4V ELI alloy. It was observed that surface roughness is increasing for the simultaneous increase in depth of cut and feed rate.

From the open literature, it can be seen that ball end milling process optimization procedures are not focusing on the relations between the process dynamics (including the simultaneous effect of cutting forces and vibrations) and the machined surface texture. In addition, these works are usually not considering the variations of surface inclination angle during the milling. Therefore, the purpose of this study concentrates on the optimal selection of surface inclination angle α and tool's overhang l, in order to minimize the vibrations, cutting forces, and consequently machined surface roughness. The proposed optimization procedure is carried out by the minimization of process responses with the application of a signal to noise ratio and grey relational analysis. The obtained results can be applied to the improvement of machined surface's quality, elongation of tool life and maintaining milling stability.

VIII. CONCLUSION and RESULT

1. Optimization through Taguchi method
   (Ball dia. = 5mm, Speed = 5000, DOC = 0.030 and feed =1500).
2. Optimization through ANOVA method
   (Ball dia. = 5mm, Speed = 5000, DOC = 0.030 and feed = 1500).

Both process give same answer. Hence the experiment is optimized. On the basis of the carried out review, the following conclusions have been formulated. Very less significant efforts have been made to provide optimization infrastructure using machining modeling environment and intelligent system to calculate vibration response amplitude of milling operation working with ball nose end mill tool. During milling operation, tool and workpiece come in contact much time, so there is a vibration in tool and workpiece. Different vibration measurement devices such as NI accelerometer, SLAM stick and other devices can be used to measure the vibration amplitude of milling tool during the milling operation. Techniques such as the implementation of FEM can be applied to simulate the vibration behavior.

After surveying variously related literature it can be concluded that there is the very limited amount of work is done in the field of analysis of vibration of the tool during the milling machining.

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