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A COMPARATIVE STUDY OF REGENERATIVE CHATTER AND CHATTER FREE ZONE USING SLD

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Abstract- Advanced production technology involves high speed milling, use of newer materials and machines. However, machine tool chatter due to self-excited vibration is always a hidden cause that controls the quality of the surface generated in machining. Occurrence of chatter, not only reduces tool life but causes a poor surface finish. The parametric conditions that provide chatter-free machining can be obtained from the stability lobe diagram.

Key words—chatter, vibration, stability lobe diagram.

I. Introduction

Advanced manufacturing technology requires high speed machining for achieving higher productivity. When high speed machining is combined with newer 'difficult-to-machine' materials, then there could be difficulties with cutting tool life and hence, the productivity. At the same time, when high speed machining is performed on thinner or slender work surfaces, the deflection of tool and work surfaces would lead to mechanical vibrations due to lack of stiffness. Normally, aerospace structural components are carved out of monolithic block involving huge, in excess of 90% of material removal. Many of the structural elements on these components are very thin in size and have complex to free form shapes.

A significant amount of research has been done by various investigators in these fields to detect, identify, avoid or suppress chatter. Guillem. [1] classified the current methods to ensure stable cutting by stability lobe diagram as out-of-process and in-process also, by system behaviour modification as passive and active changes. In 1907, Taylor stated that chatter is the "most obscure and delicate of all problems facing the machinist". Detection of chatter and thereby creating stability lobe diagram helps to calculate the optimum depths of cut and corresponding spindle speeds both analytically and experimentally [2]. Guillem. [3] performed experiments on inclined plane of workpiece to generate stability lobe diagram, first by operator using the sound emission analysis, second by computer application and finally compared both the results. Songlin Ding.[4] presented online chatter detection system based on analysis of cutting force signature and transformed it into frequency domain by applying Fast Fourier Transform (FFT). Armando. [5] also used the time and frequency domain of cutting force signature to study the influence of tool entering angle on the stability of the process. The selection of various cutting parameters on difficult to machine materials and their influence on tool wear, surface integrity and MRR is described with various experiments [6]. Fang. [7] made a comparative study of cutting forces on Titanium and Inconel alloys with extensive experiments based on various levels of cutting parameters like cutting speed, feed rates etc. Toh [8] analysed machining vibration by the use of cutting force signatures obtained on various cutter path orientation on rough and finish milling based on new and worn cutters. The occurrence of chatter is highly associated with the workpiece interaction, flank face wear of cutter and imposed cutting conditions.

II. Literature Survey

i. Vibration Analysis In Machining

It is observed that out of all the factors which produce vibration in machining, chatter is most obscure and needed to be handle carefully as it has a huge impact on material removal rate and surface finish. The whole idea of vibration analysis is detection, identifying, avoiding, preventing, reducing or suppression of chatter, enormous amount of research has been done on the same. Various approach towards the can be again classified as below:

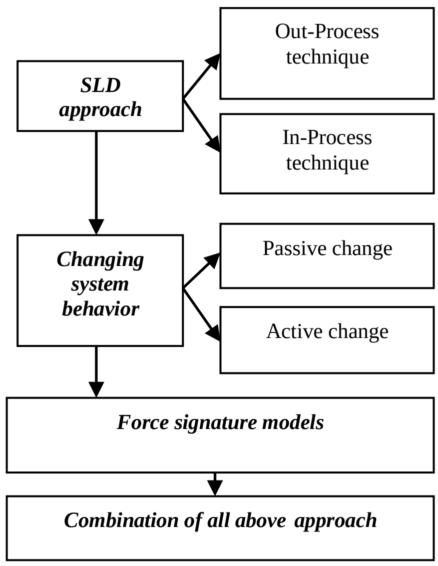

Fig:-Classification of literature research for stable machining techniques.

ii. Out- Process Technique

Out-process technique is the method of predicting the optimum cutting parameter in the stability region without changing the characteristics of the machine tool system composed of machine tool structure, tool, tool holder, drives, etc.
It is very important to note that in this process technique, the stability lobe diagram calculation is done before the actual manufacturing process starts and selection of desired parameter from SLD is done before the process starts [3] [9].

iii. In-Process Technique

It is the technique that involves the detection of chatter during the machining process and from there allowing the cutting parameters to change if required in order to migrate the process from unstable to stable zone. This technique requires skilled operator for monitoring the process and utilizing the modern equipments like microphone, sensors in order to get the chatter online and to make suitable adjustment to suppress it [4].

iv. Passive Change In System Behaviour

It is the technique that focuses on enlargement of stable zone in stability lobe diagram or by modifying the system behaviour. Passive technique is based on improving the design of the machine tool by carefully analysing the problem of vibration and acting against it. It also involves the usage of some extra devices that can absorb energy or disrupt the regenerative effect [10] [11].

v. Active Change In System Behaviour

Active chatter avoidance technique for chatter reduction and suppression are differentiated from the passive methods by their ability to monitor the dynamic state of the machine tool system, detection of a certain occurrence and actively executing those decisions that change the system to a more adequate situation [12].

vi. Force Signature Models

In this dynamometer is used to measure the cutting force coefficients in any cutting tests in most severe direction in terms of damping and force signature is captured by any data acquisition system. Further FFT analysis of force signature is done to analyze the system vibration effects [8] [13].

vii. Combination Approach

There are many approaches that make the use of two or more above mention techniques to analyze the chatter [14] [5].

viii. Sensors In Chatter Detection

It is observed form previous literature that in order to achieve highly efficient machining, unwanted phenomena called chatter must be detected, suppressed or eliminated. Out of all these, chatter detection is the most vital part and it can be achieved by using various signals from the machining process by the use of various sensors. Based on the process and response of particular operation sensor must be selected. Selection of sensors is also very important task as efficiency of detection of chatter depends on the effectiveness of the response signal from sensors. Several researchers have used various kind of sensors based on their application.

Process	**Physical Quantity**	**Sensor**	**Signal Processing**	**Chatter Identification Criteria**
Milling	Sound emission	Microphone	Power Spectral Density (PSD)	Energy threshold exceeded
Turning	Tool vibrations	Accelerometer	Cross coherence function between accelerations	Coherence function close to one at a certain frequency
Milling	Tool vibrations	Laser displacement sensor	Tool trajectory in time domain	Qualitative analysis
Milling	Spindle housing vibrations	Eddy current probes	Vibration and force signals trajectories in time and frequency domain (PSD)	Qualitative analysis
	Cutting forces	Plate dynamometer under the workpiece		
Turning	Cutting forces	Plate dynamometer under the workpiece	Coarse-grained entropy rate—CER of the force signals	CER below a threshold
Milling	Sound emission	Microphone	OPRS of the audio signal	OPRS variance above a limit
Milling	Workpiec e vibrations	Eddy current probes	OPRS, PS, PSD of tool trajectory	High OPRS variance, chaotic PS
Milling	Cutting forces	Plate dynamometer under the workpiece	FFT of cutting force signals	Anomalous distribution of spectral peaks
Milling	Tool vibrations	Laser displacement sensor	OPRS, PS, PSD of tool trajectory	High OPRS variance, chaotic PS, anomalous distribution of spectral peaks
Milling	Sound emission	Microphone	PSD of audio signal	Energy threshold exceeded

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Table:- Summary of chatter identification system research [8], [9]

III. METHODOLOGY

The work related with issue of chatter formation, detection and suppression was limited for end milling of thin structures and for hard to machine material irrespective of its wide usage in current industries.

The methodology adopted for the stability analysis is as shown in fig.

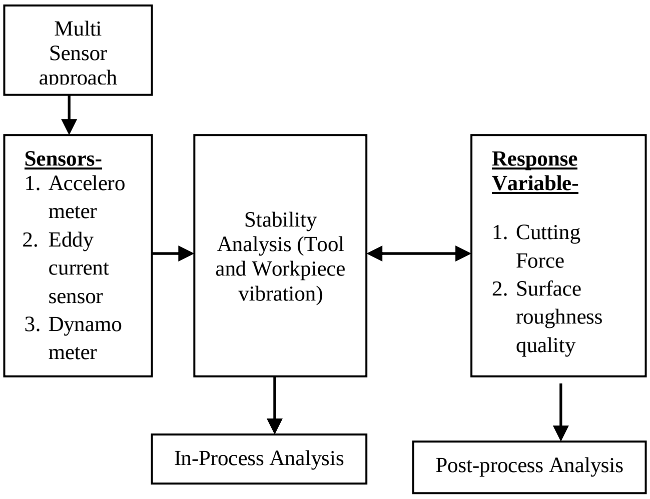

Fig.:- Methodology adopted for the stability analysis.

To correlate the in-process stability analysis parameters such as data obtained from various vibration sensors viz. a) Accelerometer b) Eddy current sensors c) Dynamometer, with the post process response variables viz. a) Cutting forces b) Surface quality.

The above work also serves some other objectives, which are as follows,

- To investigate the stiffness of the system formed by the machine-tool, tool holder, collet and cutting tool.
- To investigate cutting forces induced vibrations in the system and consequent effects on dimensional accuracy of feature machined and the quality of machined surfaces.
- To investigate the effect of cutting speed and tool – workpiece deflections on the stability of machining process.
- To investigate the compatibility of multi sensor system with the available milling machine and data acquisition system.

IV. SCOPE OF WORK

The parametric study on high-speed milling, in order to enhance the material removal rate, has been investigated extensively over past few decades. Nevertheless, analysis of machining stability brought on by vibration effects due to cutting process requires a deeper understanding to further aid the analysis. However, very few researchers have been addressed the issue of chatter occurrence in milling of thin structures irrespective of its wide use in the current industries. On this regard, the initial study is done to understand the process behind stability analysis and its impact on milling of thin structures. Under this initial work, experiments will be performed in order to decide the range of parameters, which significantly influence the stability of the machining process in milling of thin metal or alloy plates. The results obtained from the preliminary experiments will be used to decide the range of machining parameters and to decide the frequency range for accelerometers, eddy current sensors, data acquisition system etc. in order to design the experiments for successive chatter analysis.

The Present experimental work detects the chatter in high speed milling process with the use of multi-sensor system and correlated with the surface quality obtained and workpiece acceleration when chatter occurs. Chatter is an unwanted phenomena which restricts the material removal rate and impacts the surface quality. In this chatter boundaries occurred during machining is obtained, from that stable and unstable zone of machining is obtained to get the experimental stability diagram.

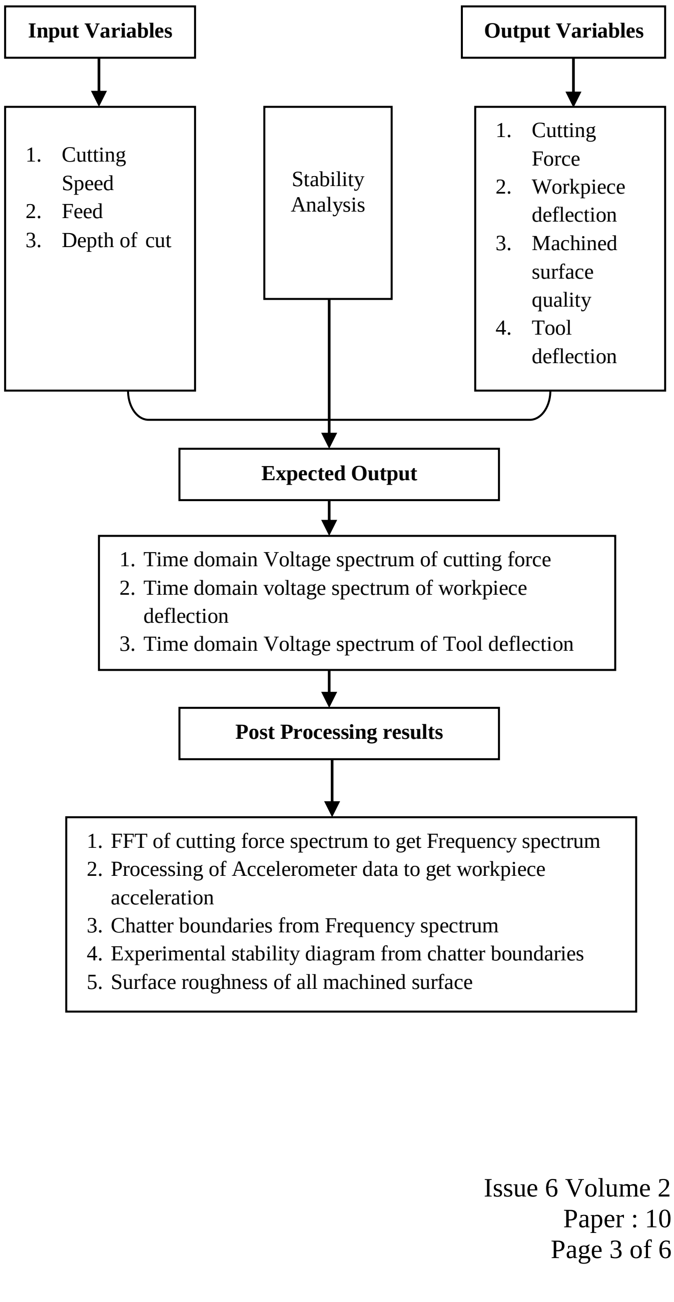

Fig:- Proposed theme of work.

V. PROPOSED EXPERIMENTAL SETUP

For experimental study, different types of sensors can be selected based on their usability for chatter detection during machining process. The proposed experimental setup along with data acquisition system is as shown in Fig. The cutting force dynamometer mounted on the milling machine bed. Then various chatter detection sensors placed on locations, where a lot of vibrations are expected during machining on the milling machine. The most vibration prone area would be tip of the cutting tool, however, it is impossible to attach a contact type sensor to detect the cutting tool vibration due to continuous rotations of the cutting tool during machining. Therefore, place a non-contact type eddy current sensor near the tool holder. Similarly, a contact type accelerometer can be used to detect the workpiece deflection in radial direction. The accelerometers and eddy current sensors are connected to specifically designed individual power source from where, an output is connected to data acquisition block. All the data must be simultaneously collected in one computer system from each individual sensor during the machining process. The data collection must be started before the beginning of milling process to avoid the time lag in the sensor.

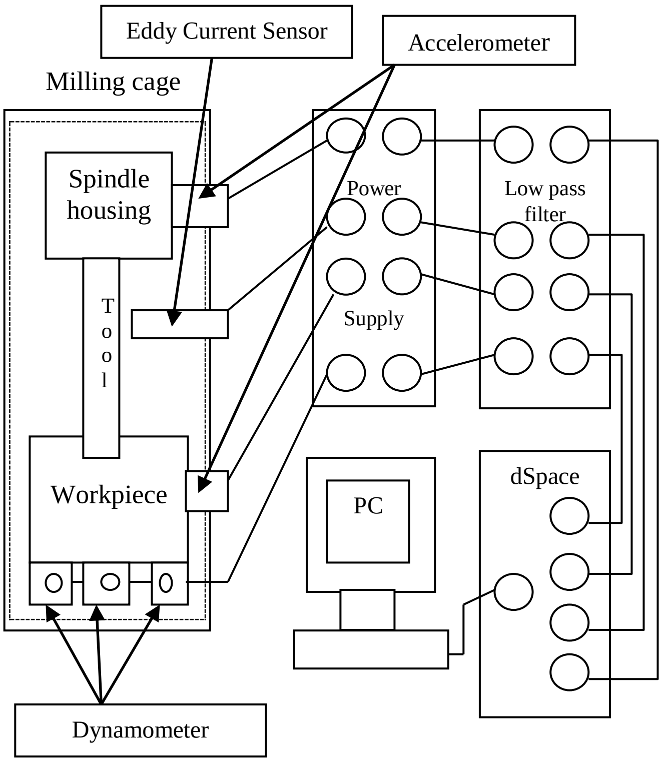

Fig:- Proposed schematic of experimental setup

VI. PROPOSED EXPERIMENTAL PROCEDURE

I. Mounting of Sensors

The accelerometer attached to the workpiece surface as well as tool holder casing and a non-contact type sensor near the tool holder system. The non-contact type eddy current sensor was properly mounted in such a way that it is perfectly rigid and perpendicular to the tool holder surface.

II. Sensors and data acquisition system

Suitable sensors are to be selected as per the requirement. Dynamometer can be mounted on the bed of milling machine below the workpiece surface to measure cutting tool forces in X-Y-Z directions. Eddy current non-contact type sensor can be mounted near a tool holder to capture the tool deflection. The contact type accelerometers can be mounted on the workpiece and the tool holder casing for capturing their deflections while machining. All the three sensors (dynamometer, accelerometer, eddy current sensor) are connected with some suitable input-output block. Further, a data acquisition system is connected to acquire the voltage data generated from various sensors. Suitable software can be used to acquire the entire signals simultaneously within the time domain.

III. Post Processing

After collecting all the data from various sensors during machining process, the data can be filtered using low pass filter in the Origin software to avoid the excess noise other than machining vibrations.

VII. CONCLUSION

The conclusion drawn from whole study has been put in below section.

- The cutting force data can be analyzed using FFT and the chatter frequencies can be distinguished from tool path and spindle frequencies. Further, chatter boundaries can be defined for each combination of process parameters selected for study. Thereby, the final stability analysis of milling process can be carried out.

- Multi sensor approach can be used, in which sensors like accelerometer, eddy current deflection sensor and dynamometer is used to give the output simultaneously while machining. The data obtained is post processed and analyzed to get the stability diagram.

- The detail analysis of formation of chatter and its transition from no-chatter to chatter can be done with the help of chatter boundary plot.
- The safer machining zone based on parametric selection is obtained experimentally.

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