Condition Monitoring and Fault Analysis of a Milling Tool
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Abstract:
Vibration based condition monitoring refers to the use of in situ non-destructive sensing and analysis of system characteristics—in the time, frequency or modal domains—for the purpose of detecting changes, which may indicate damage or degradation. Mechanical equipment is widely used in various industrial applications. Generally working in severe conditions. These apparatuses are exposed to progressive weakening of their state. The mechanical failures account for more than 74% of catastrophic failures of the machine. Hence, the identification of imminent mechanical fault is vital to avoid the system from breakdowns. This paper refers to the experiment carried out on a rotary milling machine for conditional monitoring and fault diagnosis of the milling tool. The advantages and disadvantages of condition monitoring are discussed. The review result shows the damage on the milling tool as well as the vibrational analysis. These data can be used for further experimentation.

Keywords: Condition Monitoring, Milling Tool, Vibrational Analysis, Waveforms, Spectroscopic Analysis.

I. INTRODUCTION
Kateris D et al. (2014) states that rotating machinery breakdowns are most commonly caused by failures in bearing subsystems. Consequently, condition monitoring of such subsystems could increase reliability of machines that are carrying out field operations [1]. G. Byrne et al. (1995), R. Teti et al. (1995) and K. Jemielniak et al. (1995) : The quest for automation is driven by the growing costs of human labour and quality demands which makes the monitoring of manufacturing systems inevitable. Therefore, extensive research work is taking place world-wide in the area of tool and process condition monitoring, which has been one of the most important focuses of research effort for more than twenty years [2 – 4].

Many approaches have been proposed to accomplish tool condition monitoring. In the nature of scientific research, there is a gap between science and technology. There is a time lag between research and commercialization and any new technology takes time to mature [5]. Jemielniak, Krzysztof et al. (1999) specified that one of the most significant developments on the manufacturing environment is the increasing use of tool and process monitoring systems. Many different sensor types, coupled with signal processing technologies are now available, and many sophisticated signal and information processing techniques have been invented and presented in research papers. However, only a few have found their way to industrial application [6].

Condition monitoring refers to continuous assessment of the well-being of the plant and equipment during its functional period. Condition monitoring and protection are closely related functions. The method to the implementation of each is, however, quite different. Condition monitoring can be extended to provide primary protection in many cases but its real function must always be to attempt to diagnose the progress of liabilities at an initial phase.

Larger electrical drives which supports generating, processing or production plant will benefit from monitoring if there is a higher margin of spare capacity that exists, although it does not continuously monitor. We can include induced and forced-draught boiler fan drives, boiler water feed pump drives, and cooling water pump drives in power stations in this category. It must be kept in mind that effective monitoring can allow a huge decrease in the requirement for on-site spare capacity. One should monitor when it is cost-effective to do so, or when there are overriding safety considerations to be observed. The valuation of cost-effectiveness can be a comparatively intricate issue but in general, monitoring is advisable when the total yearly funds are amplified by its usage.

There are 2 types of condition monitoring namely: Periodic monitoring and Continuous monitoring. Periodic Monitoring – It involves intermittent data gathering and analysis with portable, removal monitoring equipment. Occasionally this type of monitoring is utilised for data collection at specific intervals. Continuous Monitoring – Constant data collection or data collection at shorter intervals and the analysis of those data falls under this type of monitoring.

II. EXPERIMENTAL DETAILS
Monitoring the condition of cutting tools in any machining operation is very important to avoid unexpected machining trouble and improve machining accuracy. The use of vibration analysis of the cutting process in milling to indicate the presence and progression of damage incurred by an end mill. The metal cutting experiments were performed on a mild steel work piece without using any coolant to accelerate damage to cutter, and classical processing schemes in time and frequency domains were applied to the resulting vibrations of cutting process to obtain diagnostic information.

A. Experimental Setup –
A four-flute standard end mill, made of high-speed steel (HSS) with a cutting diameter of 14 mm, was used for the experiments on a conventional milling machine shown in Fig.1. The experiments were performed on a mild steel work piece without using any coolant to accelerate damage to the
cutter. The schematic diagram in Fig.2 shows the way the cutter movement through the workpiece.

![Cutter Movement Diagram](image1)

**Figure.1. Four-flute standard end mill**

A rotary encoder as shown in Fig.3, which produces 500 pulses per revolution, was attached to the end of ball-screw which had a pitch of 5 mm, and the output of which was then used to determine the amount of feed rate.

![Rotary Encoder](image2)

**Figure.3. Rotary Encoder**

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B. Experimental Parameters—
The various parameters during the conduction of the experiment were as follows:

- Spindle Speed = 600rpm
- Radial Depth of Cut = 5mm
- Axial Depth of Cut = 1.5mm
- Feed Rate = 0.3mm/sec

C. Visual observations during the course of the experiment—
By observing the tool at certain intervals at a macro level shows the advancement of tool wear from being a new tool to after 11.20 cm of cutting. Fig.5 below shows the advancement of tool wear.

![Tool Wear Progression](image3)

**Figure.5. Advancement of Tool Wear**

Fig.4 shows the milling machine used for the experiments and illustration of sensor locations placed in the machine which includes accelerometers, rotary encoder, spindle position sensor, ball-screw drive unit and spindle drive unit.
D. Observations from the above figures–

• The severity of tool wear is significantly influential upon the properties of chips such as shape, size, and colour.

• While the cutter is new in cut, the produced chips are usually bright, dimensionally large, and have continuously curved shapes.

• During the early phase of wear (i.e. at the end of 320mm cutting), the wear was firstly seen on the cutting edges which had been rounded off and consequently lost their sharpness.

• The chips obtained at this stage were still bright and had curved shapes, but much smaller in size compared with those of the sharp cutter.

• This kind of chip is called unstable or elemental chip whose formation shows a clear indication of tool chattering.

• Chatter is a form of relative structural self-excited vibrations between the cutter and work piece incurred at the cutting zone, and is highly associated with the interaction of the work piece and flank face wear of the cutter.

• When chatter occurs, the cutting edge no longer moves in the way as in stable cutting, but vibrates while it rotates. Thus, the cutting edge does not have constant contact with the workpiece, but jumps out of the workpiece completely when it shears away one elemental chip.

E. Time and Frequency domain analyses of Cutting Vibration–

During the experiments, vibration of cutting process was detected by two mutually perpendicular accelerometers located around the spindle bearing housing nearest to the cutter as seen in Fig.6.

Vibration measurements were carried out at the end of every 160mm cutting length. Both the vibration and positioning signals were sampled at 12.5 kHz, continuously collected over 40 cutter rotations, and then stored on a computer. Since the fault characteristics repeat themselves with the rotational frequency of the cutter, the resulting vibration signals were averaged over three cutter rotations to reduce noise content and to enhance repetitive signal components within the vibration. Fig.7 shows the spectra of the vibration accelerations of cutting process during the advancement of wear.

![Figure 7. Spectra of the vibration accelerations of cutting process during the advancement of wear](http://ijesc.org/)

**Figure 7. Spectra of the vibration accelerations of cutting process during the advancement of wear**

**OBSERVATIONS:**

• It can be seen that dominant frequency activities occur at relatively low and high frequency regions. The high frequency activities are seen around 3.4 kHz which is the reflection of the damped natural frequency of the tool-workpiece system. The other frequency activities occur at low frequency regions covering up to 1 kHz and contain the most condition indicating information about the cutting process.

• Figure illustrates the vibration acceleration signals of the cutting process detected at 160mm cutting intervals and their statistics (i.e. root-mean-square (rms), peak-to-peak (pp) value, and kurtosis) with respect to the cutting length are shown in Fig.7. During the very early phase of wear development (i.e. at the end of 160mm cutting), the amplitude of the vibration acceleration is slightly increased which is correspondingly reflected by the rms and pp values. Fig.8 and Fig.9 shows the time signatures of the vibration accelerations of cutting process during the advancement of wear and, RMS, peak-to-peak, and kurtosis variations for the raw (0) and filtered (▼) vibration accelerations of cutting process during the advancement of wear respectively.

![Figure 8. Time signatures of the vibration accelerations](http://ijesc.org/)

**Figure 8. Time signatures of the vibration accelerations**

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III. RESULTS AND CONCLUSIONS

• Vibration-based life monitoring of an end mill in dry cutting conditions has been examined and advancement of wear is assessed by visual observations of both the damaged section of tool and the produced chips.

• It was found that the wear initiates firstly on the cutting edges, develops gradually over the flanks with time, but later accelerates when the wear is fully developed. In addition, the severity of tool wear is significantly influential upon the properties of resulting chip such as size, shape, colour, and process temperature.

• The vibration of the cutting process in milling exhibits two dominant frequency activities clustered at relatively high and low frequency regions. The high frequency activities represent the damped natural frequency of the system, whereas a tool-related condition-indicating information is revealed by the frequency components located at low frequency region.

• It has been found that a very small section from the tip of a tooth is chipped off during the first tool–workpiece engagement. Since the vibration of the cutting process contains much noise, the presence of this tip breakage cannot be clearly revealed in the filtered vibration signals during the early phase of wear.

• Similarly, it is quite difficult to distinguish from the vibration waveforms any change signifying the development of wear until the medium stages of wear development. The amplitude of vibration signal considerably rises when the flank is severely damaged by wear and the resulting fault symptoms manifest themselves in the form of one per tooth error.

IV. ACKNOWLEDGMENTS

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V. REFERENCES


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