Machines Condition Analysis Based on Output Machining Parameter and Vibration Signal Monitoring

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THESIS DECLARATION FORM

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ABSTRAK

Disertasi ini melaporkan siasatan mengenai keadaan mesin untuk sekumpulan mesin kisar yang sama berdasarkan isyarat getaran dan kualiti kekasaran permukaan. Kajian ini didorong oleh isu dalam bidang penyelenggaraan di mana teknik yang sesuai perlu digunakan untuk memantau prestasi mesin. Dalam projek ini, sistem mesin yang digunakan adalah sekumpulan mesin kisar yang terdapat di dalam makmal di Pusat Pengajian Kejuruteraan Pembuatan, Universiti Malaysia Perlis. Untuk lebih memahami subjek kajian, kajian yang luas telah dilakukan berkaitan dengan pemantauan keadaan, kemerosotan mesin, analisis getaran dan juga kesan kepada kekasaran permukaan. Penggunaan analisis tulang ikan dalam mengenal pasti kemungkinan punca masalah ini juga telah dimasukkan dalam kajian Dalam penyelidikan ini, getaran yang dihasikan telah direkodkan di tiga tempat yang berbeza daripada mesin ('ram', 'spindle' dan 'vertical head'). Getaran dianalisis untuk menentukan sebab-sebab kepada ketidaktepatan dalam kualiti pemesinan. Daripada keputusan ujikaji, didapati bahawa kualiti permukaan amat dipengaruhi oleh getaran. Mesin 2 ditemui dalam keadaan kritikal disebabkan tahap tertinggi getaran berbanding dengan mesin lain. Mesin 1 dan 8 telah menunjukkan keadaan yang luar biasa di mana tahap getaran adalah sederhana namun nilai kekasaran permukaan adalah tinggi dan tidak sinonim dengan getaran. Dalam kajian ini, punca untuk getaran dan kualiti permukaan yang rendah dilakukan dengan menggunakan analisis tulang ikan untuk mesin yang terjejas. Dapatan kajian dibincangkan dan kesimpulan yang dicapai dalam projek ini dan cadangan untuk kerja-kerja akan datang disertakan.

ABSTRACT

This dissertation reports an investigation on the machine condition for a group of similar milling machines based on vibration signal and surface roughness quality. This study is motivated by an issue in maintenance field where an appropriate technique has to be applied to monitor the condition of a machine. In this work, the machining system studied are the group of milling machines within the laboratory in the School of Manufacturing Engineering, Universiti Malaysia Perlis. To further understand the subject of studies, the extensive literatures has been done related to condition monitoring, vibration analysis and also the effect to the surface roughness. The application of fishbone analysis in identifying the possible causes of the problem also has been included in the review. In this work, the vibration level have been measured at three different points of the machines (ram, spindle and vertical head). These vibration level is then analysed to determine the causes of inaccuracy in the machining quality. From the experimental results, it is found that surface quality is strongly affected by the vibration. Machine 2 is found in critical state due to the highest level of vibration as compared to the other machines. Machine 1 and 8 have demonstrated the unusual condition where the vibration level is moderate however the surface roughness value is high and does not synonym to vibration trend. In the present work, the root cause for vibration and poor surface quality are performed by using fishbone analysis for the affected machine. The findings are discussed and the conclusions reached in this project and recommendations for future work are enclosed.

Chapter 1

INTRODUCTION

1.1 Overview

This chapter presents the motivation and rationale of the research undertaken. The aim, objectives and, problem statement of this project are addressed.

1.2 Research motivation and rationale

Milling are the common machining processes in the automotive, aerospace and other industries which covers a wide variety of operations and machines from small to large parts can be produced by milling process. This process is able to machine parts to a precise size and shapes. Thus, it is important that unwanted behaviour such as vibration of the machinery to be avoided during the operation. The phenomena is a significant issue and has been addressed by numerous authors previously [1-3].

Condition monitoring is desirable for increasing machinery availability, reducing consequential damage, and improving operational efficiency. It was found useful in predicting certain faults at early stages for ensuring the safe running of machines [4]. In today's practice, vibration analysis is one of the most preferred techniques in condition based maintenance. The vibration response provides useful information relevant to fault conditions. On the other hand, vibration spectrum can be collected for all machinery with rotating and moving parts make the method is widely used [5].

Monitoring the vibration characteristics of a machine provides understanding of the machine condition, in order to identify the root cause. Sources of vibration excitation are from the followings; i) in homogeneities in the work piece material, ii) variation of chip cross section, iii) disturbances in the work piece or tool drives, iv) dynamic loads generated by acceleration/deceleration of massive moving components, v) vibration transmitted from the environment, vi) self-excited vibration generated by the cutting process or by friction (machine-tool chatter) [5].

In machining operation, vibration is likely to happen (frequent problem) which influenced by many sources such as machine structure and work material which affects the result of the machining particularly surface finish. When a machine fails or breakdown, the consequences can vary from delaying the process, cost, and might cause personal injury. Thus, this research is to investigate the influence of the machine vibration on the resulting surface roughness in milling operation of mild steel which can be used to assess the machine condition of the studied machines.

1.3 Objectives

The objectives of this research are summarised as follows:

i. To investigate the correlation between vibration and surface roughness milling operation of mild steel.
ii. To identify root cause for critical machine(s) identified in objective (i) by using Fishbone analysis.
iii. To recommend the corrective actions to resolve the problems.

1.4 Research scope

The study was conducted in Manufacturing Lab in School of Manufacturing Engineering, Universiti Malaysia Perlis. Eight vertical milling machines have been used for the investigation purposes. The vibration level was recorded by using National Instruments Sound and Vibration Measurement Suite. The raw material used for slot machining was mild steel. The surface roughness was measured by using Mitutoyo Surftest SV-3100 Series. Fishbone analysis was utilised to investigate the possible root cause(s) on critical machine.

1.5 Dissertation outline

Chapter 2 reviews the condition monitoring, condition based maintenance the techniques of condition monitoring and milling machine vibration. The use of fishbone analysis in identifying the possible causes of problem are elaborated based the extensive literatures available. Chapter 3 describes the experimental equipment employed in this research work including the milling machines, analytical equipment and material characterisation methods. The experimental procedures were included. Chapter 4 details the experimental results and discussed the root causes for the problem of vibration and poor surface quality. The corrective actions were suggested to resolve the problem. Chapter 5 presents the conclusions of this research work and recommendations for future research.

Chapter 2

LITERATURE REVIEW

2.1 Introduction

This chapter reviews the condition monitoring of the machining process using various methods discussed in the literatures. The applications of Fishbone analysis also elaborated.

2.2 Condition monitoring

The growth of technology has facilitated the industry in monitoring and inspecting the 'health' or condition of the machinery with minimal intrusion. One of the technique that widely used is condition monitoring. Condition monitoring (CM) is a technique monitoring condition of machinery in order to identify a significant change of the machine which indicates fault. It is also allows maintenance to be scheduled and other actions for failure prevention and avoid its consequences [6]. The condition monitoring is normally applied to facilitate the detection of instabilities in the machining process [7, 8].

2.3 Condition-based maintenance

Machine maintenance is an important practice. It require a deep understanding of what maintenance is. Maintenance is the activities that is carried out to return the item to an acceptable working condition. The maintenance can be classified based on timings of action as shown in

Table 2-1 [9].

Table 2-1: Timings of action for maintenance [9]

Timings of action	Maintenance
Operating to failure	Shutdown or breakdown
Fixed time based	Preventive
Condition based	Predictive or diagnostic

The prevention of the possible damage to machinery is essential for reliable operation of plants as well as safety. When failures arise, the root cause investigation is a must as a prevention for future failure.

Condition-based maintenance was applied to reduce the uncertainty in the maintenance activities and was carried out based on the machine condition. The prognostic parameters can be identified and can be used to predict the possible failure for a component or a system. Condition based maintenance has been reported in many publications. Dieulle et al. [10] has applied condition based maintenance scheduling for a deteriorating system. Christer and Wang [11] has introduced the appropriate condition monitoring in a production plant which was regarded as cost effective.

Christer and Wang [12] also has developed model for condition monitoring for a component associated with wear. Wear accumulates over time and monitoring inspections was performed at chosen times to monitor and measure the cumulative wear. They have derived a model which able to minimise the expected cost per unit time over the time interval between the current inspection and the next inspection time.

2.4 Condition monitoring techniques

When a fault takes places, some of the machine parameters are subjected to change. The change in the machine parameters depends upon the degree of faults and the interaction with other parameters. In most cases, more than one parameter are subjected to change under abnormal condition. Condition monitoring can be carried out when the equipment is in operation, which known as on-line, or when it is off-line, which means when it is down and not in the operation [13].

While on-line, the critical parameters that are possible to monitor are speed, temperature, vibration, and sound. These may be continuously monitored or may be done periodically. Off-line monitoring is carried out when the machine is down for whatever reason. The monitoring in such would include crack detection, a thoroughly check of alignment, state of balancing, the search for tell-tale sign of corrosion and pitting. Most rotating machine defects can be detected by such a system much before dangerous situations occur. It allows the efficient use of stationary on-line continuous monitoring systems for condition monitoring and diagnostics as well [9, 14, 15].

Machine condition monitoring (MCM) is a vital component of preventive and predictive maintenance programs that seek to reduce cost and avoid unplanned downtime. It also contributes to health and safety by recognizing faults which may arise to pollution or health hazards, and also by indication of incipient faults which could produce danger conditions.

The condition monitoring techniques include the followings; visual inspection, vibration measurement and analysis, thermal analysis, wear and debris analysis

2.4.1 Visual Inspection

Visual monitoring can sometimes provide a direct indication of the machine's condition without the need for further analysis. The available techniques can range from using a simple magnifying glass or low-power microscope. Other forms of visual monitoring include the use of dye penetrants to provide a clear definition of any cracks occurring on the machine surface, and the use of heat-sensitive or thermographic paints. The condition of many transmission components can readily be checked visually. For example, the wear on the surfaces of gear teeth gives much information. Problems of overload, fatigue failure, wear and poor lubrication can be differentiated from the appearance of the teeth.

2.4.2 Vibration Analysis

The use of vibration analysis as one of the fundamental tools for condition monitoring has been developed extensively over a period of approximately 50 years. Vibration analysis in particular has for some time been used as a predictive maintenance procedure and as a support for machinery maintenance decisions. The state of a machine can be constantly monitored and detailed analysis may be made concerning the health of the machine and any faults which may arise or have already arisen. Vibration analysis is therefore, a powerful diagnostic and troubleshooting tool of major process machinery [3, 16-18].

It is very important to consider the type and range of transducers used as pickup for capturing vibration signal. Signature-based diagnostic makes extensive use of signal processing techniques involving one or more methods to deal with the problem of improvement in the signal to noise ratio. Vibration analysis is normally applied by using transducers to measure acceleration, velocity or displacement. The signals are normally processed and stored using spectrum analysis methods which takes incoming signal and breaks it into its individual frequencies. It relies on the ability to link particular frequencies to particular components [14, 19].

Source identification and fault detection from vibration signals associated with items which involve rotational motion such as gears, rotors and shafts, rolling element bearings, journal bearings, flexible couplings, and electrical machines depend upon several factors: (i) the rotational speed of the items, (ii) the background noise and/or vibration level, (iii) the location of the monitoring transducer, (iv) the load sharing characteristics of the item, and (v) the dynamic interaction between the item and other items in contact with it [20].

2.4.2.1 Vibration in machining

In machining, milling is one of the most common material removal process which able to create a variety features on part. In horizontal milling machine tool vibration occurs during machining process because of in homogeneous work piece material, disturbance in work piece or tool and variation of chip cross section. Effects of these vibration include reduction in tool life, improper surface finish and unwanted noise in machine tool [21, 22].

Extensive works have been published on development of vibration during machining and also fault detection from different method of vibration analysis. Bisu et. al [2] has introduced 3D envelope method for vibration analysis for an on-line monitoring of milling process quality. They proposed enveloped analysis to detect the capacity of the cutting tool with the optimization application of cutting parameters. Wright et. al [23] utilized Wireless Sensor Networks (WSNs) in monitoring machine tool vibration in end milling process. In their work a linear relationship was demonstrated between surface finish, tool wear and vibration of the machine tool. They found that WSNs shown to be an easily a deployable method for the identification of such correlation.

Mannan and Stone [24] in their work described a method in checking the spindle assembly by making vibration measurements. From these measurements they suggested that it is possible to determine which bearings are not at their design stiffness. This then allows appropriate adjustments to be made to ensure the assembled spindle is close to the design specifications.

2.4.3 Surface Finish Analysis

Surface finish is one of the cutting qualities which is commonly affected if the machine experiencing a problem. Surface roughness, in a form of average roughness, R_a is the most commonly used parameter for the quantitative representation of surface finishes. It is defined as the finer irregularities of surface texture, which results from the inherent action of the production process. Surface roughness greatly influence product quality as well as improves corrosion resistance, fatigue strength and creep life [25]. Surface roughness characterises the texture and quality of the cut surface. It appears in the form of irregularities of the surface profile. Several different profile roughness parameters are used to represent the roughness quality. However, average roughness, R_a is the most commonly used parameter for the quantitative representation of surface finishes.

To further understand the effect, a significant work have been done by previous researcher regarding the surface finish analysis in condition monitoring. Kassim et. al [26] in their work presented the workpiece surfaces that have been subjected to machining operations. Apart from standalone surface finish analysis, some researchers have coupled the surface finish analysis with vibration analysis. This is because in machining vibration is likely to happen (frequent problem) which influenced by many sources such as machine structure, tool type and work material which affects the result of the machining particularly surface finish.

A considerable amount of literature has been published on the effect of vibration towards surface roughness in machining. Selvam [27] in his work reported the effect of tool vibration towards surface roughness in turning. The author studied the frequency content of tool vibration and the surface profile in turning under normal cutting conditions by measuring the frequency spectra of tool vibration and the surface profile. On the other hand, Abouelatta and Madl [28] has developed a mathematical model in order to find the correlation between vibration and surface roughness. Venkata et. al [29] presented a work in estimating the effect of cutting parameters on work piece vibration, roughness on machined surface and volume of metal removed in boring of steel (AISI1040). According to Chang [30] the surface roughness and tool wear are strongly affected by the vibration amplitude and frequency. Improper tool geometry and the nose radius will produce more vibrations than the depth of cut.

2.5 Vibration issues in rotating machinery

Vibration in machinery is merely the back and forth movement or oscillation of machines and components, such as drive motors, driven devices (pumps, compressors), the bearings, shafts, gears, belts and other elements that make up mechanical systems. There are lot of issues have been discussed within the literatures regarding the vibration in machinery. This can be regarded as an important engineering problem. Vibration caused by mass imbalance if the principal axis of inertia of the rotor is not coincident with its geometric axis. It is important to control the vibration in order to improve the machining surface finish, achieving longer bearing, spindle, and tool life in high-speed machining, and reducing the number of unscheduled shutdowns. Apart from that, great cost savings can be realized if this issue can be controlled [31].

The most common causes of vibration in rotating machinery include [32]:

i. Imbalance – Imbalance of the machinery is due to the rotating component with the unbalance weight rotating around the axis of the machine which creates a centrifugal force. Such imbalance might be cause from the machining errors, dirty fan blades which cause to a missing balance weights. The effect of imbalance will be greater when the machine speed is increases. This effect can severely affect the bearing life and lead to machine vibration.

ii. Misalignment or shaft run-out – When the machine shaft is out of line, this can be a source of vibration. Angular misalignment happen when the axes for a pump and a motor are not parallel. This might be due happen during assembly and it is possible to develop over time due to several reasons such as thermal expansion, improper reassembly after maintenance and also components shifting. Improper alignment of the adjoining shafts will cause abnormal loads transmitted through the bearing and resulted additional bending stress to the shaft and reduce the shaft's fatigue life.

iii. Wear – Wear of the roller bearings, gears and drive belts may cause vibration. Roller bearing for instance, when the race becomes pitted, vibration will occur each time the bearing rollers travel over the damaged area. On another example, if a gear tooth is heavily worn, vibration will occur.

iv. Looseness – Looseness may excite any vibration present to a damage. The looseness of the bearing or loose the attachment to its mounts may develop the vibration level.

Another causes of machinery vibration are rubbing, aerodynamic/hydraulic problems in fans, blowers and pumps, electrical problems (unbalance magnetic forces) in motors, resonance and eccentricity of rotating components such as "V" belt pulleys or gears

2.5.1 Milling machine vibration

In machining process such as milling, the process involves material removal from the workpiece with the generation of chips. The machining process was controlled by various parameters, such as spindle speed, feed rate, depth of cut, cutting speed and more. The machine itself include a particularly complicated system which includes electrical, control systems, power drive mechanisms, measurement systems, gears, lubrication systems, coolant systems and etc. Different kind of failure could happen during the processes. The most common issues of the aforementioned processes is vibration which relatively affect cutting tool life, tool wear, cause chipping and breakage and the effect towards surface quality and the product quality [6].

There are literatures available reporting the failure of milling machines specifically due to the vibrations. Altintas and Chan [33] has reported that the failure of the machine resulted the oscillated spindle speed where the vibrations can be suppressed and subsequently affect the process.

Rantatalo et al. [34] also studied the lateral vibrations in a milling machine spindle for a better milling performance. They also stated that this type of vibration could result in poor surface finishes and in some cases it would damage the materials as well as the machine.

Huang et al [35] through the milling Ti–6Al–4V with variable pitch end mill of investigated the milling forces due to machine vibration. The experimental results show that due to vibration, milling forces were found to increase dramatically by 61.9–66.8% in comparison with stable milling process. The machining surface texture was poor and and the surface roughness increases by 34.2–40.5% resulted to rough surface compared to the stable milling process.

It was found that adverse effects of vibrations in milling machine like the poor surface finish, noise and breakage of tools affect the process/ work in progress, financial effect, injury as well as loosing life. Due to this reason, early detection, identification and correction of machinery problem is important for the better productivity, cost and safety. The type of vibration level must be identify to understand the condition of the machine.

2.6 Cause and effect analysis (Fishbone Analysis)

Different tools have been used to for a systematic analysis of the root cause of any problem. One of the widely used tool is cause and effect analysis or known also as Fishbone analysis. It is known as a fishbone because of its structural outlook and appearance. It is a diagram-based technique that assist in identifying the possible causes for an effect or problem. To determine possible root causes, cause and effect analysis is very useful. It helps to identify, sort, and display causes of a specific