

MONITORING CATASTROPHIC FAILURE EVENT IN MILLING PROCESS USING  
ACOUSTIC EMISSION

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### **SUPERVISOR'S DECLARATION**

I hereby declare that I have checked this project and in my opinion, this project is adequate in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering.

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By the name of ALLAH, the Most Gracious and Most Merciful

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## ABSTRACT

This research focused on the monitoring catastrophic failure event in milling process using acoustic emission. Acoustic Emission (AE) is a naturally occurring phenomenon whereby external stimuli, such as mechanical loading, generate sources of elastic waves. AE occurs when a small surface displacement of a material is produced. This occurs due to stress waves generated when there is a rapid release of energy in a material, or on its surface. The wave generated by the AE source will be used to stimulate and capture AE in inspection, quality control, system feedback, process monitoring and others. In this thesis, the acoustic emission will be studied by carrying out experiments (milling) on the work piece and determine the material properties also dynamics of machines using acoustic emission detector. There are three cutting speeds and five conditions of depth of cut chosen for the experiments. The depths of cut and cutting speed are generated in the experiments and an acoustic emission sensor detects the acoustic emission signals and transfers it to the acoustic emission software. Then, the software generates the signals into RMS signal. Data taken from the software are plotted into a graph of RMS versus depth of cut. The experiment continued to determine the properties of materials using Inverted Microscopes (IM). Pictures of anomalies of the cutting tool, work piece and chipping have been taken from inverted microscope for observation and compared with acoustic emission graph (RMS). After that, the result of graph and figure are detail explained. Then, conclusion and recommendation has been made. Finally, a stable combination of machining parameter (spindle speed and depth of cut) is proposed and applied during milling process in order to reduce the failures in the milling process.

## ABSTRAK

Tesis ini difokuskan kepada pemantauan terhadap kegagalan yang berlaku di dalam proses pengisaran dengan menggunakan sinaran akustik. Sinaran akustik (AE) adalah sebuah fenomena yang berlaku secara semulajadi di mana rangsangan luaran, seperti beban mekanikal, menghasilkan sumber gelombang elastik. AE terjadi ketika peralihan permukaan kecil dari material yang dihasilkan. Hal ini terjadi kerana gelombang stres yang terhasil ketika ada pembebasan tenaga yang berterusan dalam suatu material, atau pada permukaannya. Gelombang yang dihasilkan oleh sumber AE dan akan digunakan untuk merangsang dan menangkap AE di dalam pemeriksaan, kawalan kualiti, maklum balas sistem, pemantauan proses dan lain-lain. Dalam tesis ini, sinaran akustik akan dipelajari dengan melakukan eksperimen (pengisaran) pada bahan kerja dan menentukan sifat material dan juga kedinamikan mesin menggunakan pengesan sinaran akustik. Tiga kelajuan pemotongan dan lima kedalaman pemotongan yang dipilih untuk eksperimen. Kedalaman pemotongan dan kelajuan pemotongan yang dihasilkan dalam eksperimen dan sensor sinaran akustik mengesan isyarat sinaran akustik dan memindahkannya ke peranti perisian sinaran akustik. Kemudian, perisian menghasilkan isyarat menjadi isyarat RMS. Data diambil dari perisian diplot ke dalam graf RMS melawan kedalaman pemotongan. Eksperimen dilanjutkan untuk mengetahui sifat-sifat bahan menggunakan Mikroskop Songsang(MS). Gambar anomali dari bahan, alat pemotongan dan cip akan diambil dari mikroskop songsang untuk diamati dan dibandingkan dengan graf sinaran akustik (RMS). Selepas itu, keputusan dan gambar anomali diterangkan secara terperinci. Seterusnya, penutup dan cadangan dibuat. Dan akhirnya, kombinasi parameter mesin yang stabil (halaju spindle dan kedalaman pemotongan) akan diperkenalkan dan dilaksanakan dalam proses milling bagi tujuan mengurangkan kadar kegagalan yang berlaku didalam proses pengisaran.

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**LIST OF ABBREVIATIONS**

AE	Acoustic Emission
ADC	Analog Digital Converter
AISI	American Iron and Steel Institute
ASTM	American Society for Testing and Materials
BUE	Build Up Edge
CS	Cutting speed
DB	Decibels
DoC	Depth of cut
DOE	Design of Experiment
HB	Brinell hardness
HSM	High Speed Machining
HSS	High Speed Steel
LAE	Lab assistant engineer
NDT	Non Destructive Testing
Ni	Nickel
RMS	Root Mean Square
RPM	Rotation per minute, spindle speed
Ti	Titanium

## **CHAPTER 1**

### **INTRODUCTION**

#### **1.1 INTRODUCTION**

The industrial demands for machining systems to increase process productivity and quality in milling of critical safety components requires advance investigations of monitoring techniques. Monitoring and analyzing of failures that happen the milling process will help researcher predict cutting tool life and breakage in the workpiece. This thesis is focused on the detection and prediction of the occurrence of process malfunctions at both of tool and workpiece surface integrity levels using Acoustic Emission. Acoustic emission (AE) has been employed predominantly for tool condition monitoring of continuous machining operations (e.g. turning, drilling), but relatively little attention has been paid to monitor interrupted processes such as milling and especially to detect the occurrence of possible surface anomalies. (Marinescu and Axinte, 2008).

The purpose of this thesis is to monitor catastrophic failure event in machining process (milling) using acoustic emission. The research focused to determine the failures that will occur in milling process and analyze them using Acoustic Emission (AE). Additionally, process monitoring is likely to reduce the number of scrap components via prevention and/or detection of tool and workpiece malfunctions before significant damaging events occur during the final machining operations.

## 1.2 PROJECT BACKGROUND

In recent years, research in the area of machining process has become very useful for industries that are considering improving their products and avoiding major losses in machining. For example, in manufacturing industries, manufacturers usually focused on the quality and productivity of the product.

In the production lines, problems that usually occur are malfunctioning of the machine and product defect. To increase the productivity of the product and lessen the manufacturing costs and times, manufacturing companies and researchers have done a lot of research in the process malfunctions at both of tool and workpiece. Several experiments and simulations had been made to decrease this failure event.

Manufactures control cutting speed during running their production. To get a best cutting speed, related formulas have been created. By using these formulas, some of product defect can be decrease but it is only occur on material that have low strength properties like aluminum and steel. Thus, for materials that have high strength properties, a new method should be created so that manufacturing industries can manufacture faster and produce high quality of product.

### 1.3 PROBLEM STATEMENT

With the demands for increasing the operating times of safety components while identifying routes for decreasing manufacturing costs and times, more emphasis is put on developing methods for on/off line supervision of key machining processes. These are challenging tasks due to the following main reasons:

- i. Geometrical complexity of the components that require complex tool paths in conjunction with a variety of machining techniques.
- ii. Use of notorious difficult-to-cut workpiece (Ni, Ti based) superalloys that can lead to rapid tool wear/chipping and the appearance of surface defects (e.g. white layers, material drags, pluckings, laps)
- iii. Difficulty to determine and establish relationships between sensory signals and process malfunctions (i.e. tool/workpiece) caused by the complexity of cutting tool geometries/paths.
- iv. Expensiveness of the components that implies the use of more conservative machining approaches to avoid scraps and/or additional machining.

Due to the hostile environment (temperatures over 650 °C and high cyclic loads) on which some components work in milling machine(e.g. cutting tool), surface damages generated during final machining operations that reach critical levels of intensity (e.g. material drag/strain over a specified limit) may have a significant impact on their fatigue performances and ultimately an effect on the workpiece or product.

In this context, most of milling machine manufacturers explored the possibility to employ process monitoring on key final machining operations and thus to “supervise” the conformity of these operations from both tool and workpiece integrity point of view so that malfunctioning of the machine and product defect can be avoided.

## 1.4 OBJECTIVES OF THE RESEARCH

In the view of implementing automated solutions for monitoring complex machining processes such as milling, the usage of acoustic emission (AE) in machining is regarded as a promising way for assessing machine tool condition and for in-process detection of workpiece malfunctions. Correlating AE signal events with the occurrence of workpiece surface anomalies (e.g. laps, material drag) can be a powerful method for scrap reduction of expensive components such as those employed in aerospace industry.

This paper proposes new methods for supervising cutting processes with end-mill cutting tool by using of AE signals data. This is done by taking into account signals patterns when cutting tool edge become wear or breaks when running the process. This situation often occurs in real milling applications. Moreover, detection of surface anomalies, such as folded laps that are generated by damaged cutting edges can be successfully identified in various milling conditions. This experiment demonstrates that RMS-DoC analysis of AE signals using acoustic emission method has great potential to be used and flexible and easily to implement in monitoring of milling process.

Therefore, the main objective of this experiment is to monitoring catastrophic failure event in machining process (milling) using acoustic emission method. The research focused to determine the failures that will occur in milling process and analyze them using the Acoustic Emission (AE) method. This thesis will also respond to the following technical requirement:

- i. To identify the characteristic of catastrophic failure event that will occur in milling process.
- ii. Monitoring AE sensor to detect workpiece surface defects (anomalies) as result of high energy transfer to the machined surfaces when abusive milling is applied.



## 1.5 SCOPE OF STUDIES

In order to achieve the objectives the following scope of studies are performed:

- i. Find out suitable cutting tool for related workpiece (mild steel).
- ii. Dimensioning the current workpiece using manual measured.
- iii. Conduct Acoustic Emission experiment on milling machine to get the data.
- iv. Determine the result that can get from AE sensor and analysis AE data by considering the total RMS value versus cutting depth graph.
- v. Record the anomalies that have occurred relate to the experiment by using high resolution microscope and analyze it.
- vi. Graph RMS-DoC is plotted to determine when the failure occur.
- vii. Graph and figure is compared to get the result.
- viii. Explanations about the result of graph and figure.
- ix. Conclusion and recommendation to be made.

## 1.6 OVERVIEW OF THE THESIS

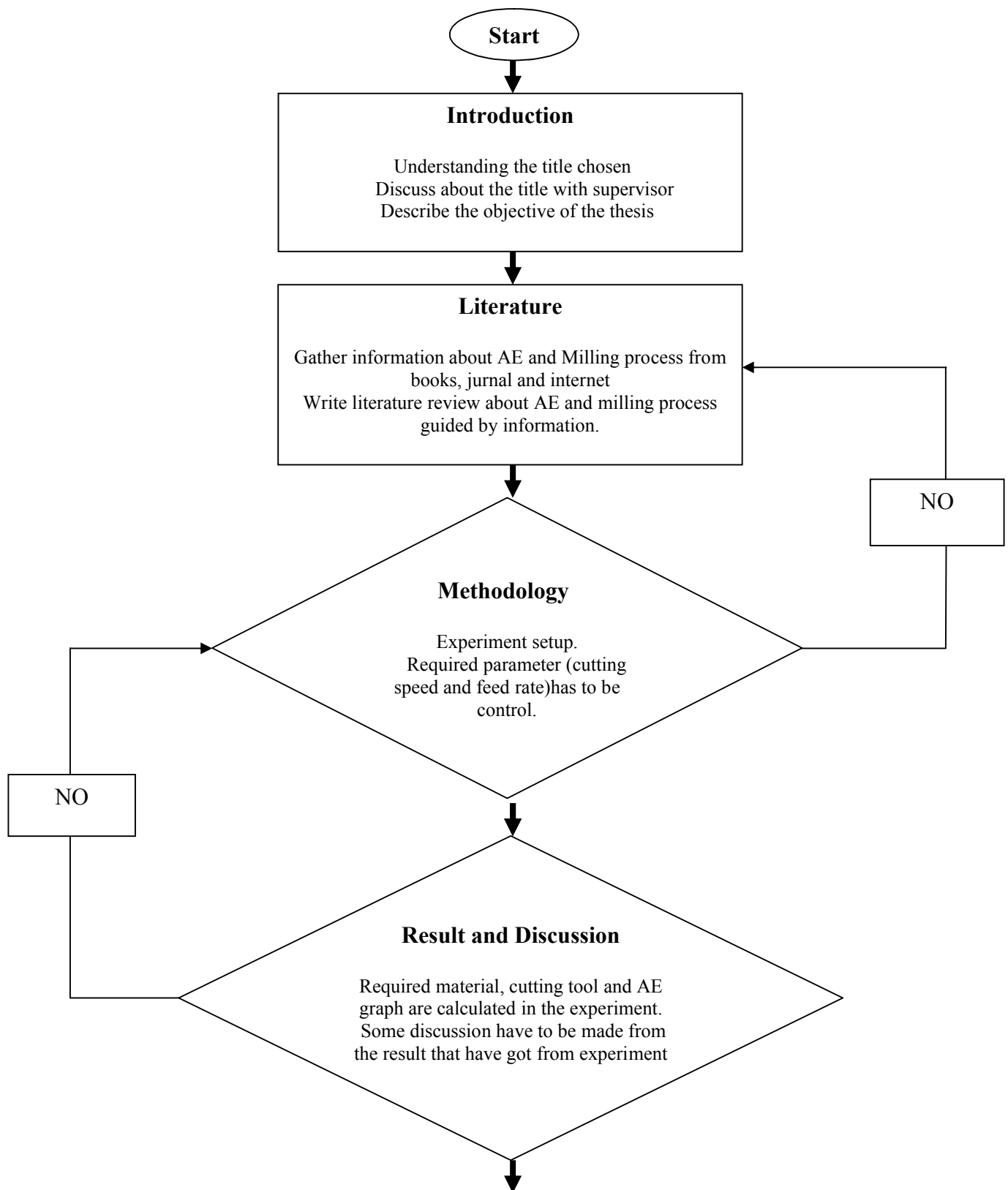
This report is divided into six chapters. Chapter one gives the brief the content and background of the project. The problem statement, objectives and scope of study are also discussed in this chapter.

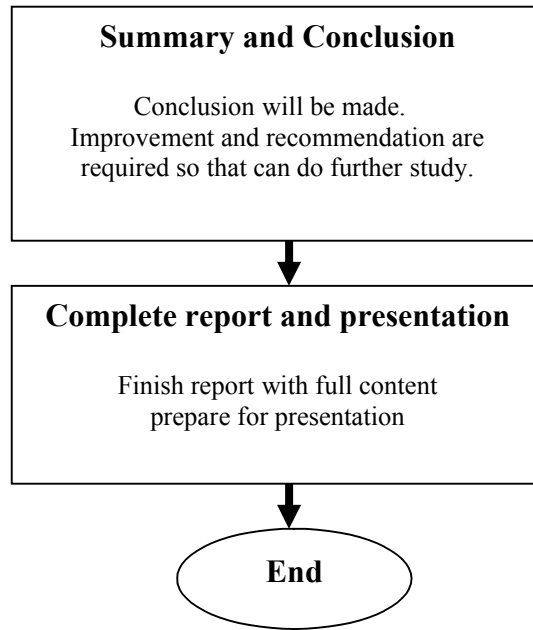
In chapter two, the literature review of the study is discussed. This chapter provided with introduction to Acoustic Emission (EA) method. Starting from the historical review of EA, Then, we will go deeper into various methods of EA, signal processing, time-frequency analysis and characteristic or behavior of the failure event that occur in the experiment. The second part of this literature will review about the machining process that used. For this thesis, milling process is used as major contributed process that will cause failure event. This thesis also exposed a little in milling process such as definition, operation, type of cutting tool and some parameter that will use and the last part is the catastrophic failure event that will occur in milling process.

For chapter three, methodology of the experiment is reviewed. Flow chart is shown so that the time required for this thesis is on schedule. After that, the Acoustic Emission (EA) method and milling process are studied. Then, the thesis explained about the milling operation that used in this experiment. Some calculations for parameters given (cutting speed and feed rate) are required to get better result. Finally, the experiment will be run with supervised by laboratory assistant engineer (LAE). Their supervision is important due to avoid unnecessary things happen.

In chapter four, the result from the experiment and characteristics of cutting tool are shown for further analysis. In this chapter, the details of required calculation and discussion to be determined. Follow by graph analysis to determine root mean square (RMS) value. The analysis of microstructure also conducted to get the catastrophic failure event which happened in the workpiece, cutting tool and chip deformation.

Lastly, in chapter five, the conclusion and recommendation are to be made from the all the chapters that have stated above so that further analysis can be done in the future.

**PROJECT FLOW CHART**



**Figure 1.1:** Project flow chart

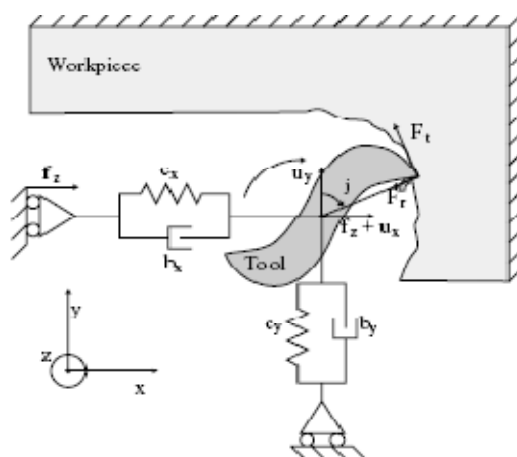
## CHAPTER 2

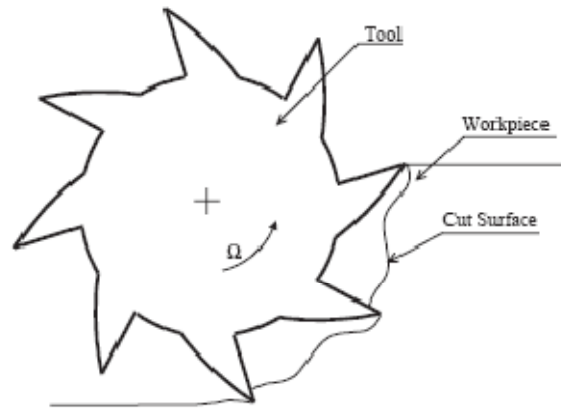
### LITERATURE REVIEW

#### 2.1 INTRODUCTION

In these recent years, metal cutting technology has grown rapidly and become one of the important aspects in the manufacturing industry, especially for the aerospace industry and also in producing high precision parts. In modern cutting technology, higher availability with more flexible cutting machines will be chosen as a priority in manufacturing. Milling is the most important and widely useful operation process for material removal compared to turning, grinding and drilling.

Milling can be defined as a machining process in which metal is removed by a rotating multiple-tooth cutting tool with each tooth removing a small amount of metal in each revolution of the spindle. Because both the workpiece and cutting tool can be moved in more than one direction at the same time, surfaces having almost any orientation can be machined. In accordance to (Denis R. Cormier, 2005), milling is a metal removal machining process for generating a machined surface by removing a predetermined amount of material progressively from the specimen. In the milling process, a milling cutting tool is held in a rotating spindle, while the workpiece clamped in the table is linearly moved toward the cutting tool (Altintas, 2000). A schematic representation of the milling process is shown in Figure 2.1.





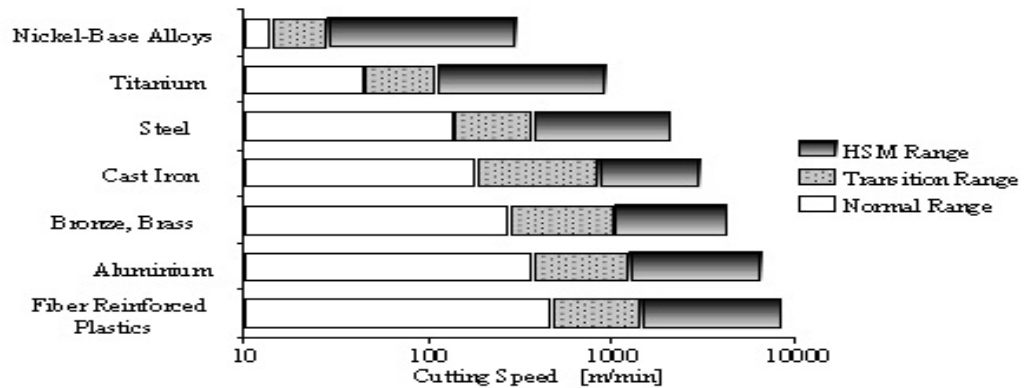
**Figure 2.1:** Schematic representation of milling process

Source: Altintas (2000)

## 2.2 APPLICATION OF HIGH-SPEED MACHINING

The term High-Speed Machining (HSM) commonly refers to end milling at high rotational speeds and high surface feeds. HSM has been applied to a wide range of metallic and non-metallic materials, including the production of components with specific surface topography requirements and machining of materials with hardness of 50 HB and above. With regard to attainable cutting speeds, it is suggested that the term HSM is standing for operating at cutting speeds significantly higher than those typically utilized for a particular material. The figure below indicated the attainable speeds in the machining of various materials.

But in practical definition, HSM is not simply high cutting speed. It should be regarded as a process where the operations are performed with very specific methods and production equipment. HSM is also not necessarily high spindle speed machining. Many HSM applications are performed with moderate spindle speeds and large sized cutting tools.



**Figure 2.2:** Attainable speed in machining for various materials

There are several factors for choosing High-speed Machining (HSM). The ever-increasing competition on the marketplace is setting new standards all the time. The demands on time and cost efficiency are getting higher and higher, forcing the development of new processes and production methods to take place. HSM usage will guarantee time saving nonetheless provide much in product quality and quantity compared to conventional milling operation. The other factor is the development of new; more difficult to machine materials which has underlined the necessity to find new machining solutions. The die and mold industry mainly has to face the problem of machining highly hardened tool steels, from roughing to finishing.

With regard to this problem, HSM has technically proved a better performance in finishing in hardened steel with high speeds and feeds, often with 4-6 times conventional cutting data. On the other hand, high-speed machining is a potentially unstable system, where the forces generated by the cutting process are coupled to the dynamic behavior (stiffness, damping, and inertia) of the machine structure, tool, and workpiece (Sims, 2004). These behaviors will generate a failure to workpiece several and also cutting tool after in the period of being used. Therefore, new software experiments have been developing due to avoid more failure from occurs. One of promising way to detect a failure is using Acoustic Emission Testing (AET) method.

## **2.3 ACOUSTIC EMISSION PHENOMENON**

Understanding the physical nature of acoustic emission in different materials is one of the important parts in the development of the acoustic emission technology. The success and the depth of the technology capabilities depend on the ability to determine the interconnection between characteristics of acoustic emission and sources it generated. However, establishing such interconnection for different materials and structures is a real scientific and technological challenge to machinists and researchers.

### **2.3.1 Sources of Acoustic Emission**

The main purpose of acoustic emission examinations in industrial applications today, are detection, location and assessment of flaws in structures made of metal, concrete or composites. In these materials, fracture development in form of crack propagation is a primary source of acoustic emission. Elementary crack jumps under static or dynamic loads are followed by a rapid release of energy. A part of this energy is released in form of stress waves as a result of fast redistribution of a stress field at the crack top. The stress waves generated are elastic waves mostly but inelastic waves can be generated also when stresses exceed yield limit. This occurs, for example, at the plastic zone of a crack developing in a ductile metal. Other primary sources of acoustic emission in materials that undergo fracture are:

- i. Plastic deformation development and fracturing of hard inclusions in metals;
- ii. Fiber breakage, matrix cracking and delamination in composites;
- iii. Aggregate fracture, voids closure and etc. in concrete.

Acoustic emission equipment is capable of detecting and analyzing acoustic emission sources of non-material origin, for instance, mechanical sources of friction, knocks, and leaks and so on. There are multiple applications in which acoustic emission technology is used for revealing leaks, machinery health monitoring, detection of dynamic stress events in structures and other using these capabilities.