A PRELIMINARY STUDY OF TURNING OF COMPOSITES

NURHAFIZZAH HASSAN

M.Sc.(ENG) MECHATRONIC SYSTEM ENGINEERING

DEPARTMENT OF ENGINEERING
THE UNIVERSITY OF LIVERPOOL
BROWNLOW HILL, LIVERPOOL L69 3GH

2008

UNIVERSITY OF LIVERPOOL

Department of Engineering

ENGG600 : MSc(Eng) Final Dissertation Report

A Preliminary Study of Turning of Composites

Student : HASSAN, Nurhafizzah

School of Mechanical Engineering

5th September 2008

Supervisor : Dr. Huajiang Ouyang

Project No : 270

Department of Engineering
The University of Liverpool
Brownlow Hill, LIVERPOOL L69 3GH

DECLARATION

The work contained in this dissertation is my own and has not been submitted for any other qualification

SUMMARY

Most of the engineering parts are made from metal based materials. Composites have recently become an economic alternative to traditional materials like metals due to their considerable advantages especially in high specific strength and specific stiffness. But, turning of composites is different from turning conventional metals because of the inhomogeneity and anisotropic characteristics of composites. It also depends on the diversity of fiber and matrix properties, fiber orientation, and the relative volume of matrix and fibers. During a turning operation, vibration and noise are generated as a result of the interaction between the rotating work piece and moving cutting force. Therefore, there is a need to understand the dynamic behaviour of composites during machining particularly turning. In this project, the influence factors contributing to surface finish, vibration and noise during turning operation have been established. A mathematical model for the dynamic behaviour of the turning operation is constructed via Rayleigh beam theory and coded into MATLAB tool for simulation. A parametric study is also performed which involves several operational conditions and work piece characteristics to discover their effect on vibration of a work piece (hence the surface finish) through simulation. Results from the numerical simulation generated are found to be consistent with many experimental findings done by the previous researcher.

ACKNOWLEDGEMENT

This project was made possible through the generous help and support from my supervisor, Dr. Huajiang Ouyang whom from his undying commitment, assistance and direct contributions made this project a successful one.

I also owe a large thank you to my friends and families especially to my husband and my father for their advice, support and encouragement throughout the duration of this project and made me a better and stronger person.

Lastly, I would like to thank also the University of Liverpool especially the Department of Engineering for giving me the opportunity to study here for my MSc.

TABLE OF CONTENTS

NOTATION

R_a	Roughness	-
f	Feed rate	Millimetre (mm)/min
FRP	Fiber reinforced plastic	-
GFRP	Glass fiber reinforced plastic	-
MMC	Material matrix composite	-
GFR	Glass fiber reinforced	-
F_f	Feed cutting force	N/m^2
n	Revolution per minute	Revolution per minute
K_f	Feed direction	-
a_c	Width of cut	Meter (mm)
h (t)	Dynamic chip load	-
h_c	Intended cut	Meter (mm)
ρ	Mass density	kg/m^3
I	Moment area	m^4
Ω	Rotational speed	m/s
E	Young's Modulus	GPa
P_x	Axial force	Newton
ω	Frequency of vibration	Rad/s
Δt	Time step	Second
r	Radius of gyration	Metre (m)
ω_i	Frequency of beam	Rad/s
C	Cutting constant	N/m^2
A	Cross section area	m^2

LIST OF FIGURES

LIST OF TABLES

1.0 INTRODUCTION

Engineering is the most creative application of scientific principles to design or develop structures and it is also strongly involved during creation of new products or components. These products and components require satisfaction of several quality aspects including correct dimensions, correct finish and surface smoothness before being delivered to customers.

Manufactured products or components should have good surface finish for better quality, reliability, excellent performance and last but not least meet customer requirements. In most cases, excessive roughness is considered to be detrimental to performance and often a good predictor of poor quality of a mechanical component, since irregularities in the surface may form nucleation sites for cracks or corrosion.

There are many different ways in which a product or component can be manufactured. Manufacturing itself can be described as a process of converting raw material to finished product or parts. The conventional technique encompasses processes like metal forming, machining, injection molding, die casting, stamping and others. Machining is the most important of the manufacturing processes. It is the traditional method for material removal and it is being used as one of the methods to change other manufacturing processes like casting or forgings from unfinished work piece into required shape with size, dimension and surface finish to accomplish product design requirement.

There are three principal processes in machining which are turning, milling and drilling. Turning process is one of the oldest and most versatile conventional ways to produce parts in cylindrical shape using a single point cutting tool. Turning is performed on a machine called a lathe in which the tool is stationary and the part is rotated. The tool is fed either linearly in the direction parallel or perpendicular to the axis of rotation of the work piece, or along a specified path to produce complex rotational shapes.

Generally work pieces used in turning are made of metals due to their popular physical and mechanical properties in most engineering applications. In automotive industry for example, most of the parts are made from metals. Due to its homogeneity and isotropic properties, metals had been undergone numerous of researches particularly to optimize its machinability.

Lately, many studies have been conducted to replace metals due to its shortcomings especially as sometimes they are heavy and most metals suffered from bad corrosion if not painted or coated. Plastic materials especially composites has become the preferred choice and prominent to replace conventional materials particularly metals to avoid these drawbacks and it has been seen implemented in wide variety of applications such as aeronautical, aerospace, automotive, biomechanical and mechanical engineering, as well as in other industries.

2.0 BACKGROUND AND SIGNIFICANCE OF RESEARCH

Composite materials are engineered materials made from two or more constituent materials with significantly different physical or chemical properties and which remain separate and distinct on a macroscopic level within the finished structure (Hull and Clyne, 1996). Composites also have been considered as an advanced material in which they are characterized by a combination of light weight, very high specific strength, high modulus and a high stiffness. The principal advantage of these materials is the very high strength to weight ratio, which makes them attractive in aircrafts, spacecraft, cars, boats, and sport equipment.

Composites have been seen as early as 1940s where glass-reinforced resin matrix composites were first introduced (Komanduri, 1997). Since then, the use of composites is growing steadily in various industries including aerospace, aircraft, automobile, sporting goods, marine, off-shore drilling platforms, appliances, etc. Composite materials have gained popularity in high-performance products that need to be lightweight, yet strong enough to take harsh loading conditions such as aerospace components (tails, wings, fuselages, propellers), boat and scull hulls, bicycle frames and racing car bodies. Other uses include fishing rods and storage tanks. Carbon composites are a key material in today's launch vehicles and spacecrafts. They are widely used in solar panel substrates, antenna reflectors and yokes of spacecrafts. They are also used in payload adapters, inter-stage structures and heat shields of launch vehicles.

With regard to the increasing use of composites in the aeronautical, aerospace, nuclear, biomedical, and automotive industries, the need to machine the materials, adequately, increases. The final operation on their fabrication is a machining process in which the dimension precision and the surface finishing are determined.

Machining of composites predominantly using turning process has becomes an exciting subject in recent years since the use of composites has increased tremendously in various areas of science and technology due to their special mechanical and physical properties such as good corrosive resistance and high specific strength and stiffness. Machining of composites differs significantly in many aspects from machining of conventional metals and their alloys. In the machining of composites, the material behaviour is not only inhomogeneous, but it also depends on diverse fiber and matrix properties, fiber orientation, and the relative volume of matrix and fibers. The tool encounters continuously alternate matrix and fiber materials, whose response to machining can be entirely different.

The physical properties of composite materials are generally not isotropic in nature, but rather are typically orthotropic. For instance, the stiffness of a composite panel will often depend upon the orientation of the applied forces and/or moments. Panel stiffness is also dependent on the design of the panel. For instance, the fiber reinforcement and matrix used, the method of panel build, thermoset versus thermoplastic, type of weave, and orientation of fiber axis to the primary force. In contrast, isotropic materials such as aluminium or steel typically have the same stiffness regardless of the directional orientation of the applied forces and/or moments.

Due to this inhomogeneity and anisotropic characteristics, turning of composite is different from turning conventional metal. Furthermore, according to Ramkumar et.al (2004), there is a significant difference between machining of metal and composite materials since composites are anisotropic, inhomogeneous, and mostly it is prepared in laminate form before going through the machining process. Besides, machinability of composites is influenced by fiber and matrix properties, fiber orientation and the type of weave.

Several attempts have been made to eliminate machining operation via fabrication techniques like near net shape forming and modified casting, but the scope of these techniques is limited and therefore machining is still an integral part of the composites component manufacture (Basavarajappa, Chandramohan et.al, 2006). Even though composite parts may be produced by moulding process, they require further machining to facilitate dimensional control for easy assembly and control of surface quality of functional aspects.

Apart from the utilization of composites in most engineering application and its difficulties to machine, the knowledge on machining of composites is still insufficient and more investigations are needed to be done to optimize the machinability of composites. As a result, there is an essential need to stud y and understand questions associated with the machinability of these unique materials. Additionally, very little has been found in the literature concerning machining of composites.

3.0 PROJECT OBJECTIVES

Several objectives have been planned to achieve the aim of this research. The objectives of this research are as listed below:

(1) To establish the factors that influence the surface roughness in turned composite.
The surface finish of turned composites is believed to be far from good as that of metals parts and this is mainly due to good homogeneity and isotropy of metals in comparison with composite. Hence, identifying the critical aspects affecting the surface roughness of composites is necessary to produce a high quality component.

(2) To identify the reasons that will lead to vibration and noise in turning.
Since composites are non-homogeneous and anisotropic, their chance of vibration leading to chatter during turning process is high and it is higher than turning of metals. Thus, by identifying the factors that influence vibration and noise in turning of composites, it would help to improve the surface finish of turned composites and the working environment as well.

(3) To establish a mathematical model for turning and code it in MATLAB software
A mathematical model is going to be developed to model the behaviour of turning of composites before it could be coded into simulation packages. Simulation is then needed to imitate the dynamic behaviour of the turning process of composites prior to actual machining. One has to predict and visualize the effect of several cutting and machine parameters to the turned composite parts so that a good finished component can be achieved. It will involve a great deal of effort since the dynamic model for turning is very complicated in mathematics.

(4) To perform parametric studies
It is known that many parameters affect the surface roughness of a turned work piece. By means of the dynamic model established above, these operational conditions and work piece characteristics will be simulated to find out how they affect surface finish and vibration of a work piece and (partly) validate the dynamic model.

One of the original objectives included turning experiments of composites on a lathe. As the project proceeded, it was realized soon after submitting the Interim Report that that was not possible. The main reasons are as follows. First, as the construction of the New Department Building got delayed, there was no space available to site the lathe. The technical support required in operating te lathe for the special use of turning composites was not readily available. It also turned out that the mathematics of the established dynamic model was very difficult and complicated and hence learning it took time. Finally, coding in MATLAB proved to be a daunting task as the knowledge of MATLAB was very little at the beginning of this project.

So in the end, experiments were abandoned. However, there has not been a reduced quality of the project. The focus of the project has rightly changed to the mathematical aspect of coding and numerical simulation, after consultation with the supervisor.

4.0 INFLUENCE FACTORS CONTRIBUTING TO THE SURFACE FINISH OF THE TURNED PARTS

Quality of the surface finish and tolerances are among the most critical quality measures in many products and parts. As competition grows fiercer, customers now make higher demands on quality, making surface finish become one of the most competitive aspects in today's manufacturing industry. It reflects aesthetical value of the product besides its functionality.

In addition, the majority of engineering failures are caused by fatigue failure. Fatigue failure is defined as tendency of a mate rial to fracture by means of progressive brittle cracking under repeated alternating or cyclic stresses. Surface roughness of a machined part is vital fatigue endurance and corrosion resistance. Nishitani and Imai (1983) found that the fatigue strength is more strongly influenced by greater surface roughness. To that extent, it is important to do further research on what are the factors that influence surface roughness in turning of composite and afterwards compare it with turned metal.

Figure 4.1 shows the surface profile which can be divided into roughness, weaviness and form error. Waviness refers to variations in the surface profile with relatively long wavelength while roughness had wavelengths shorter than those characteristic of waviness. Theoretically, the ideal value of certain arithmetical mean roughness, (R_a) for a given feed rate (f) and tool nose radius (r) can be calculated by this formula,

$$R_a = \frac{f^2}{8r}$$

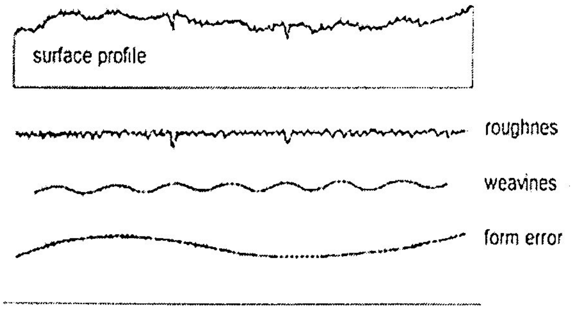

Figure 4.1 : Surface profile schematic by Dagnall (1986)

A considerable number of studies had been investigated the general effect of the cutting speed, feed rate, depth of cut, nose radius and other major factors on the surface roughness of turned metal. A representative summary of this study is shown below in Table 4.1.

Table 4.1 : Factors affecting surface roughness and major investigators

Investigators	**Major factors**	**Materials studied**
Karmakar (1970)	Speed, feed, depth of cut	Steel C-45
Bhattacharya et al.(1970)	Speed, feed, nose radius, work-piece hardness	Plain carbon steel
Rasch and Rolstadas (1971)	Speed, feed	Carbon steel
Selvam and Radhakrishnan (1973)	Speed, built-up edge, work-piece strain hardening	Steel
Lambert and Taraman (1974)	Speed, feed, Depth of cut	Steel SAE 1018
Petropoulos (1974)	Tool wear, surface roughness distribution	Steel
Boothroyd and Knight (1989)	Speed, feed	Mild steel
Selvam (1975)	Vibrations, chatter speed	Steel
Sundaram and Lambert (1981)	Speed, feed, nose radius, depth of cut	Steel 4140
Miller et al. (1983)	Speed, feed, tool condition, cutting fluid	Alloy, cast iron
Lambert (1983)	Speed, feed, nose radius	Steel D6AC

(Source : Feng and Wang 2002)

From the table shown, it is obviously concluded that the most factors contributing to give significant impact on surface roughness was cutting parameter in this case cutting speed and feed rate. Figure 4.2 show the schematic diagram of cutting parameters mentioned.

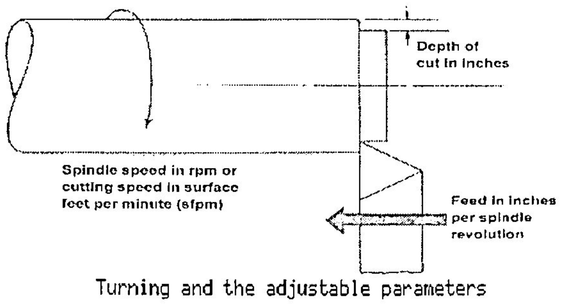

Figure 4.2 : Schematic diagram of cutting parameters

(Source : www.mfg.edu/.../trad/turning/turn.html)

Interest in turning of composites material is only a recent development in manufacturing. Understandably, there have been much fewer investigations into turning of composites than turning of metals. A literature survey has been conducted for several months well before the official start date of the MSc project until now and yields the following finding summarized in Table 4.2.

Table 4.2 : Factors affecting surface roughness and major investigators

Investigators	**Major factors**	**Materials studied**
	A) Inhomogeneous and anisotropic material	
1. Bhatnagar et al. (1995)	1. Fiber orientation angle	FRP Composite
2. Jahanmir (1998)		FRP Composite
3. Sakuma and Seto (1983)		GFRP Composite
4. Wang and Zhang (2003)		FRP Composite
1. Palanikumar and Karthikeyan (2006)	2. Fiber volume raction, V_f	Al/SiC-MMC Composite
2. Sonbaty et al.(2004)		GFR/epoxy Composite
	3. Manufacturing technique	
1. Davim and Mata (2005)	(i) Hand Lay up	FRP Composite
2. Palanikumar et al. (2008)		FRP Composite
1. Davim and Mata (2005)	(ii) Filament Winding	FRP Composite
2. Palanikumar et al. (2008)		FRP Composite
1. Jahanmir (1998)	4. Type of fiber	FRP Composite
	(B) Cutting parameter	
1. Birhan (2007)	1. Cutting speed	GFRP Composite
2. Palanikumar and Karthikeyan (2006)		Al/SiC-MMC Composite
3. Palanikumar et al. (2008)		FRP Composite
4. Ramulu et al.(1994)		FRP Composite
5. Sonbaty et al.(2004)		GFR/epoxy Composite
6. Takeyame and Lijima (1988)		GFRP Composite

Investigators	Major factors	Materials studied
1. Birhan (2007) 2. Hocheng et al.(1997) 3. Palanikumar and Karthikeyan (2006) 4. Palanikumar et al. (2008) 5. Sonbaty et al.(2004) 6. Spur and Wunsch (1988)	2. Feed rate	GFRP Composite Graphite/Aluminium Composite Al/SiC-MMC Composite FRP Composite GFR/epoxy Composite GFRP Composite
Less significant	3. Depth of cut	
	C) Tool	
1. Birhan (2007) 2. Bhatnagar et al. (1995) 3. Sakuma and Seto (1983)	1. Tool wear	GFRP Composite FRP Composite GFRP Composite
1. Birhan (2007)	2. Tool radius	GFRP Composite
1. Palanikumar and Karthikeyan (2006)	3. Built up edge	Al/SiC-MMC Composite

*1-*4 sequence of most importance factor influence surface roughness

According to Sonbaty et al (2004), increasing the volume fiber fraction, V_f of GFREC can improve surface roughness but in the same time cutting speed and feed have a vice versa effect. Wang and Zhang (2003) investigated unidirectional FRP composite and the result shown surface roughness is greatly influenced by the fiber orientation. In the mean time, Takeyama and Lijima (1988) had examined the surface roughness on machining of GFRP composites and found out that the higher the cutting speed, the rougher and the more damaged the machined surface is. Ramulu et al (1994) also achieved better surface roughness at high velocity whereas Birhan (2007) discovered that surface roughness will decrease of increase of cutting speed and increased with increase of feed rate. He also discovered that the surface roughness decreased with the increase of tool nose radius. In addition, Spur and Wunsch (1988) realized that during turning of GFRP composites, surface roughness increased with the increase of feed rate but it is not depends on cutting velocity.

A good surface finish is required for improving the physical properties, fatigue strength, corrosion resistance and aesthetic appeal of the product. It is vital to find out the factors that will influence surface roughness. From the literature survey that has been carried out, the major factors influencing surface roughness during turning of composites are feed rate, fiber orientation, hand layup technique and tool wear. The feed rate is the cutting parameter that has the highest influence on surface roughness. An increase in feed rate will increase the heat generation and hence, tool wears which results in higher surface roughness. Tool wear will decrease the cutting tool life and subsequently increase the cost of machining of the turned parts. In the mean time surface roughness will fluctuate for different angle of fiber orientation. The higher the orientation angle, the rougher the surface finish will be generated whereas for the manufacturing technique, hand layup process is proven to be producing better surface roughness than the filament winding process in machining of composites.

5.0 INFLUENCE FACTORS CONTRIBUTING TO THE VIBRATION AND NOISE

Vibration and chatter is one of the most important problems which arise in machining operations and is almost impossible to be avoided during machining operations. The presence of vibration can increase surface roughness of finished parts or components increase the cutting tool wear and produce unacceptable noise.

Referring to Khraisheh (1995), vibration in machining can be classified in two types which are forced vibration and self excited vibration. Force vibration is caused by cyclic variation in the cutting force while self excited vibration is caused by relative movement of the tool with work pieces. Vibration in turning process is self-generated and it is produced from the friction caused by the spindle rotation with work piece as well as from tool work piece relative motion. The usual cause of vibration during machining is the dynamic interaction between the cutting process and the machine tool structure which the source come from the variation of cutting force generated between the tool and work piece. This force strains the structure elastically and causes a deflection of the tool and work piece, which alters the tool-work engagement. A disturbance in the cutting process, such as a hard spot in the work material, causes a typical deflection which then alters the cutting force. This may then cause the initial vibration to be self-sustaining and to build up with the machine oscillating in one of its natural modes of vibration. Therefore, it is essential in the early stage of this research to investigate what factor influences the vibration and noise in turning of composites.

Sandvick Coromont (2005) suggest ones to choose a smaller nose radius less than the depth of cut and increase the feed to avoid the vibration from happening. The schematic diagram in Figure 5.1 represents the tool nose radius and depths of cut.

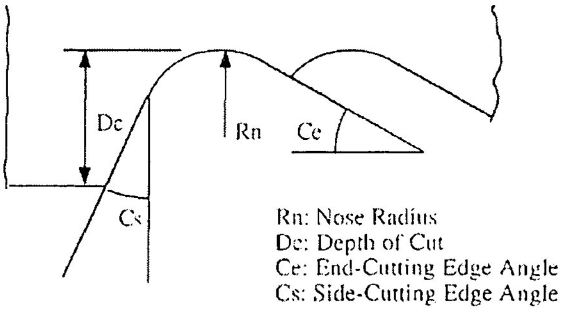

Figure 5.1 : Schematic diagram of tool nose radius by Lin and Chang, (1998)

In the meantime, Wiercigroch et al (2001) and Grabec (1988) discerned that friction between the tool and work piece can cause chatter. Wardle et al (1983) noticed that the choice of bearing supports and bearing setting as well as assembly related problems, such as insufficient pre-loading of bearings and their inadequate interference fitting to the shaft investigated by Lacey et al (1983) and Rahnejatet et al (1984) caused the out-of-balance rotations of spindle, which in many cases contribute significantly to the vibration of the spindle. In addition, Lin and Chang (1998) discovered that vibration is caused from unbalanced rotating masses and non accurate ball bearings at spindle.

It turns out that there are very few papers on vibration and noise in turning of composites. So this looks like an excellent area of research. The findings from a number of published papers are summarized in Table 5.1 below.

Table 5.1 : Factors affecting vibration and noise

Composites	
A) Tool	**(B) Cutting condition**
1. Nose radius Sandvick Coromont (2005)	1. Cutting speed Sandvick Coromont (2005)
2. The length and diameter of the tool holder Sandvick Coromont (2005)	2. Feed rate Sandvick Coromont (2005)
3. Clamping of the tool Sandvick Coromont (2005)	3. Depth of cut Sandvick Coromont (2005)
	4. Spindle speed Tarng et al. (1996)

*1-*4 sequence of most importance factor influence surface roughness

On the other hand, there are some additional papers found discussing the effect of vibration and noise during machining. According to Andren, Hakansson et al (2003), the vibration during a cutting operation affects the accuracy of the machining, which in turn affects the surface finish. Severe noise is also an important factor which is induced by tool holder vibration. Meanwhile, Petersson, Hakansson et al (1999) had mentioned that the stochastic chip formation process usually induces vibrations in the machine tool system. Energy from the chip formation process excites the mechanical modes of the machining, in particular the surface finish. Modes of the work piece may also influence the tool vibration. It is well known that vibration problems are closely related to the dynamic stiffness of the structure of the machinery and work piece material.

Besides, Heisel and Feinauer (1999) had discovered that the causes and effects of vibration mainly arise as a result of the acceleration of the axes and the speed dependent excitation of imbalance due to the lack of symmetries of rotating masses in regard to the rotational axis. Within this system, the single components have their own imbalances. It is evident, that the resulting excitation of imbalance depends to a large extent on the assembly tolerances. They also mentioned that vibrations in cutting process are caused by the chip forming frequency in which in milling process, an additional vibration results from the tooth contact impacts. It is also believed that the vibrations are caused by the acceleration movement. As for summary, the dynamic excitations in high speed machining are mainly caused by imbalance, tooth contact and axis acceleration. Furthermore, Pan and Su (2001) concluded that chatter is the self-excited vibrations which are caused by the hysteresis relationship between force and work piece deflection that ensure the system to gain energy necessary to maintain the vibration. Hysteresis is recognized as one of the factors that cause undesirable chatter, resulting in instability of oscillations, inaccuracy, etc.

Jang, Choi et al, (1996) had observed that the built-up edge and tool wear affect the roughness, as would the type of tool used. These process factors (including machine tool flexibility and work piece properties) have been shown to cause variations in cutting forces, which eventually generate relative vibrations between the tool and the work piece. Cutting parameters (i.e. speed, depth of cut and feed rate, chip loads and chip formations, dynamic characteristics of the tool-spindle structure, and non-homogeneous hardness distribution in the work piece) are generally considered to be major factors affecting this random relative vibration between the tool and work piece. As mentioned by Sexton, Milne and Stone metal removal rates on machine tools may often be limited by instability, commonly called chatter. This occurs because of an interaction between the forces which arise during metal cutting and the response of the machine tool structure to such forces.

Vibration may result from the variation of cutting forces generated during the machining process. The dynamic cutting force which excites the machine tool structure generates the tool vibration and as a consequence of self excited vibration. Cutting speed and spindle speed also exert a significant impact to vibration as increasing both speeds may well increasing the vibration and noise. Furthermore, the increase in feed rate during machining will increase the chance of chatter. Generally the influence factors of the vibration and noise can be categorized in two main sources, which are the machine tool for the likes of unbalanced rotating masses and non accurate ball bearings, and external causes such as the vibration of the foundation.

6.0 MANUFACTURING TECHNIQUES OF COMPOSITE

From the literature review that had been carried out, several fabrication processes are found used in manufacture of composites. Table 6.1 below indicated the investigators, type of composites and fabrication process used;

Table 6.1 : Summary table of several manufacturing techniques used in previous researches

No.	Investigator	Material Studied	Fabricating process	Type of Fiber	Type of resin	Fiber Orientation
1	Palanikumar, K (2006)	GFRP Composite	Filament Winding	E Glass	Epoxy	60°
2	Davim and Mata (2005)		Wet Filament Winding	Glass	Polyester	45°
		FRP Composite	Hand Lay Up	Glass	Polyester	90°
3	Palanikumar et al. (2008)	GFRP Composite	Wet Filament Winding	Glass	Polyester	45°
		GFRP Composite	Hand Lay Up	Glass	Polyester	90°
4	Aravindan, Sait and Haq (2008)	GFRP Composite	Filament Winding	Glass	Isophthalic and Vinylester	90°
5	Birhan (2007)	GFRP Composite	Pultrusion	E Glass	Polyester	90°
6	Palanikumar et. al (2006)	GFRP Composite	Filament Winding	E Glass	Epoxy	30°
7	Sonbaty et al.(2004)	GFR/Epoxy Composite	Hand Lay Up	E Glass	Epoxy	60°

The most common method to fabricate composite is filament winding. It is an effective fabrication process especially for composites pipe. It assures a precise alignment of fibre needed and also promising high directional strength. According to Hull and Clyne (1996), in most filament winding process, the filament winding apparatus passes unidirectional fibre through a resin 'bath', just before it touches the mandrel and the cured to achieve final strength. The schematic diagram of the process is shown below in Figure 6.1.

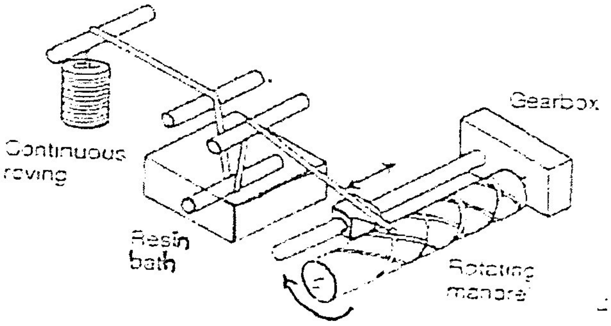

Figure 6.1 : Schematic diagram of the filament winding process by Hull and Clyne (1996)

The second famous manufacturing technique of composite is handy layup. The process start with resin applied to fibre by rollers or brushes that forces resin into the fabrics. Layers are built up by repeatedly placing fibres and applying resin. Then the laminates are left to cure under standard atmospheric conditions (Hull and Clyne, 1996). Figure 6.2 depicts the schematic diagram of the hand layup process.

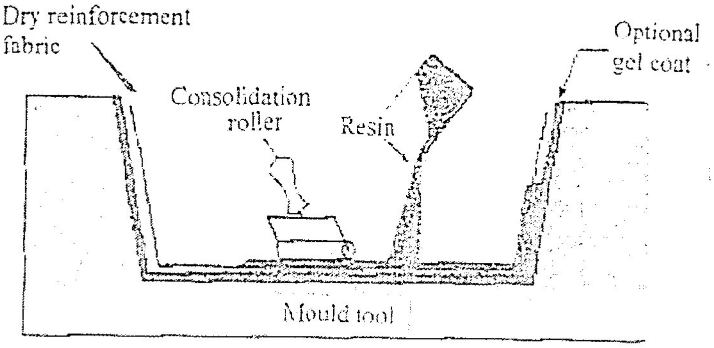

Figure 6.2 : Schematic diagram of the hand layup process by Hull and Clyne (1996)

In the mean time, Wang and Zhang (2003) found out that the surface roughness had increased sharply when the fibre orientation was at $\theta > 90°$ for a given depth of cut which is smaller than the fibre diameter but it will start to decrease again when θ is at 120°. In contrast, if the depth of cut becomes larger than fibre diameter, the surface roughness will increase constantly with the increasing of fibre orientation. Hypothetically, the ideal fibre orientation should be less than 90° because of at this angle; fibre is better supported by the material behind. At the same time it will help the force produced by the tool to create a tensile stress to make the fibre easier to break in the cutting zone. In addition, Santhanakrishnan (1990) had discovered that the glass fibre in the GFRP composites is brittle and less flexible hence a combination of plastic deformation, shearing, and bending rupture takes place during machining.

Unfortunately due to the time constraints, it is unlikely to manufacture the composites specimen using both of manufacturing techniques mentioned above. Alternatively, by using data such as Young's Modulus and mass density of several composites specimen from the previous researchers, it will be used in the programming code produced by the MATLAB tool.

7.0 THEORY AND METHODOLOGY

There are basically two schools of thought in modeling vibration of a turned work piece. The first school is formed by structural dynamicists. They model the problem as vibration of a shaft spinning about its longitudinal axis subjected to a moving load (Chen and Ku, 1992). Moving-load problems are more complicated in mathematics and more difficult to study. So is vibration of spinning bodies. When spinning and moving loads are both included, it presents a great challenge. The second school consists of mainly manufacture engineers. Their dynamic models tend to be simpler than those built by the first school of experts and in this sense are not as good. However, their models of cutting forces are more realistic.

The rotating work piece (usually a beam or shaft) can be modeled in more than one beam theory. In general, there are four beam theories which is Euler Bernoulli, Rayleigh, shear and Timoshenko. As more beam theories being implemented into the dynamic model of the work piece, the more accurate is the modelling will be. On top of that, to deal with many beam theories involved, the more difficult the mathematical will be since the more work load consumed during the computational modelling. In this project the work piece was modeled via Rayleigh beam theory. The following section is the work that has been done by previous researchers and the two following sections will describe both the methodologies briefly.

7.1 Rotating Shaft Subject to a Moving Load

The rotating work piece (usually a beam or shaft) which is excited by a force produced from the cutting tool that moves in the axial direction is a basic features of the dynamic model turning operation (Ouyang and Wang, 2007). The first study by Katz et.al (1988) has examined the Euler-Bernoulli, Rayleigh and Timoshenko beam theories for modeling the rotating shaft. The influence of parameters such as rotational speed of the shaft and the axial velocity of the load are discussed for each shaft model. The shaft, which is pinned-pinned, rotates at a constant rotational speed and subject to a moving load. Chen and Ku (1992) had studied the dynamic stability behaviour of a cantilever shaft-disc system subjected to axial periodic forces. Ouyang and Wang (2007) have investigated the effect of bending moment in the dynamic response of the shaft which is never been put into consideration from previous researchers.

7.2 Rayleigh Beam

It was recognized by the early researchers that the bending effect is the single most important factor in a transversely vibrating beam. The Euler Bernoulli model includes the strain energy due to the bending and the kinetic energy due to the lateral displacement. Love (1927) provides a marginal improvement on the Euler Bernoulli theory by including the effect of rotation of the cross-section.

7.3 One Degree of Freedom under a Regenerative Cutting Force

Most of the manufacture engineers used simplify dynamic model for the work piece and treated it as one degree of freedom or two degree of freedom and it is not good as dynamicists school. On the other hand the manufacture engineer's models of cutting forces are more realistic. In this section the generation of cutting force mentioned is described below.

A cylindrical turning process shown in Figure 7.1 can be used to illustrate one degree of freedom under a regenerative cutting force. The work piece is supported at one end by chuck and other end by tailstock. During turning process the work piece will rotate as it is being machined. The cutting tool movement is parallel to the longitudinal axes of the work piece and depending on the depth of cut. When the cutting tool makes contact with the work piece it will deflect. As the cutting tool move along its tool path, there will be a variation in the magnitude and the direction of cutting forces because of the previous removing material process leaves a wavy surface finish due to structural vibrations. The developing vibrations will lead to the increase of cutting force thus, resulting poor surface finish. (Altintas, 2000). This is self-excited vibrations. Balkrishna et al (1998) described how self-excited vibrations generate. They found that it is caused by the overlapping of successive cuts where the tool is subjected to the wavy surface produced during previous cuts.

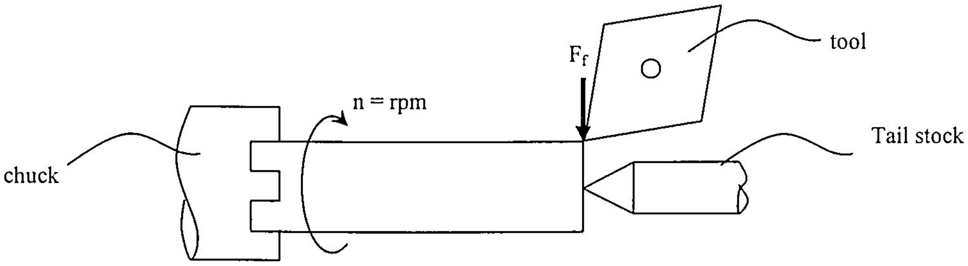

Figure 7.1 : Schematic diagram of turning process

From Figure 7.1 shown, the cylindrical work piece is positioned at the chuck and supported by tail stock at another end. This work piece is free to move in the feed direction and known that feed cutting force (F_f) applied causes the work piece to vibrate. Presume a single point cutter is fed perpendicular to the axis of cylindrical shaft. During the first revolution, the surface of the work piece is smooth which is without waves but due to the bending vibration of the work piece it will initially leave a wavy surface in the feed cutting force (F_f) direction. As a second revolution took place, the previous surface now has two waves which are inside and outside surface. The inside surface denoted as y(t) was originated from cut made by the tool whereas the outside surface, indicated by y(t-T) is the effect of the vibrations during previous revolution of cutting. This general mechanism can be represented as below;

$$h(t) = h_o - [y(t) - y(t-T)]$$

Assuming that the work piece is one single degree of freedom in the radial direction which consists of mass and spring system, the equation of motion can be written as below;

$$m_y\ddot{y}(t) + c_y\dot{y}(t) + k_y y(t) = F_f(t)$$

Figure 7.2 below illustrates the one degree of freedom mentioned;

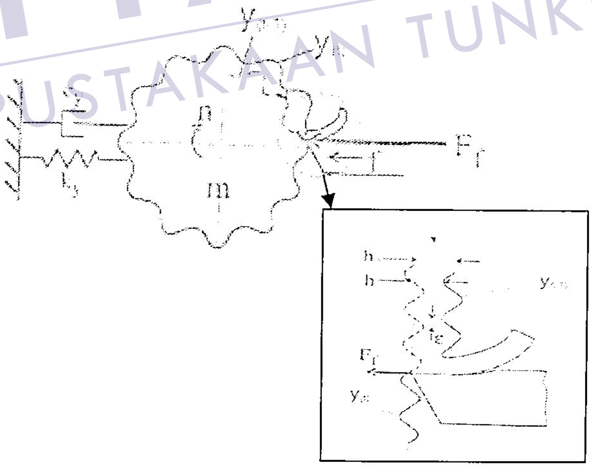

Figure 7.2 : Free body diagram of one degree of system by Altintas (2000)

On the other hand, Altintas (2000) has mentioned that the feed cutting force (F_f) is proportional to the cutting constant in the feed direction (K_f), width of cut (a) and the dynamic chip load h(t). The cutting force (F_f) can be expressed as below:

$$F_f(t) = K_f a\mathrm{h}(\mathrm{t}), \text{ and since } h(t) = h_o - [y(t) - y(t-T)],$$
$$F_f(t) = K_f a[h_o - [y(t) - y(t-T)]]$$

Figure 7.3 (a) shows the location of cutting tool before the cutting operations. h_c is the intended cut and there is no deformation occurred at this point. After one spindle revolution, the cutter will move inside and the work piece will deformed at a distance $x = l_b - v(t-\tau)$ at time $t-\tau$ and can be shown in Figure 7.3 (b). At any arbitrary time t the deflection location is $l_b - v(t)$ and illustrated in Figure 7.3 (c).

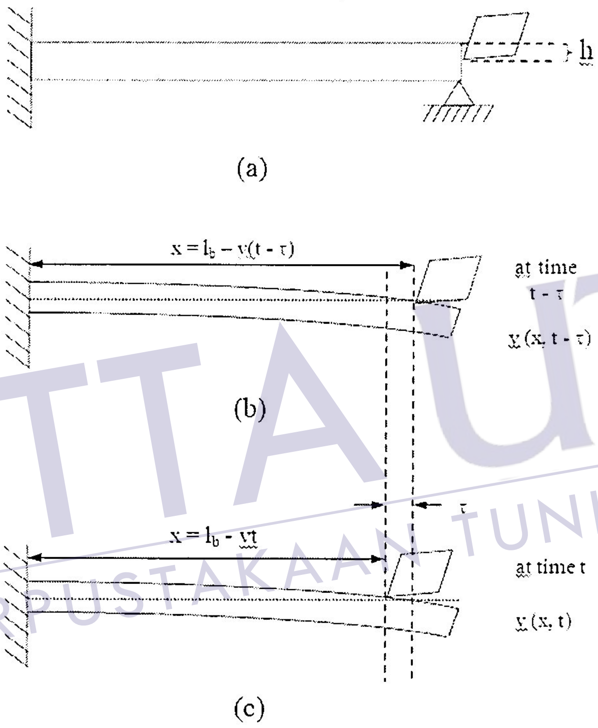

Figure 7.3 : (a) Location of the cutter before cutting operation (b) Location of the cutter after one spindle revolution (c) Location of the cutter after two times spindle revolution

Naturally, if the ideas from rotating shaft subject to a moving load will then combine he cutting force generated from the manufacturer engineers, an even better dynamic model nay be obtained. That will be a major objective of this research project.

8.0 MATHEMATICAL MODEL

A cylinder beam which is subjected to three directional force moving along the *x* axis is rotating about its longitudinal axis, *x* as shown in Figure 8.1. The deflections in the *y* and *z* directions are indicated by *v* and *w*. There are several partial differential equation involved with respect to time and distance generated from the *v* and *w* coordinate.

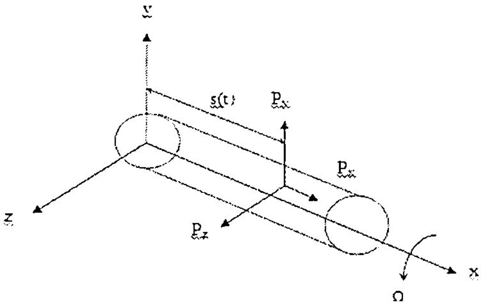

Figure 8.1 : Rotating shaft subjected to a moving load with three perpendicular forces (Ouyang and Minjie (2007)

It is assumed that the deflections of the beam can be characterized as equation (1). By doing partial differentiation with respect to time *t* and the derivation with respect to *x*, the results of the derivation are denoted as (2), (3) and (4) respectively.

$$v(x,t) = \varphi^T(x)\alpha(t)\,, \qquad w(x,t) = \varphi^T(x)\beta(t) \tag{1}$$

$$\frac{\partial v}{\partial t} = \varphi^T(x)\dot{\alpha}(t)\,, \qquad \frac{\partial w}{\partial t} = \varphi^T(x)\dot{\beta}(t) \tag{2}$$

$$\frac{\partial v}{\partial x} = \varphi'^{\,T}(x)\alpha(t)\,, \qquad \frac{\partial w}{\partial x} = \varphi'^{\,T}(x)\beta(t) \tag{3}$$

$$\frac{\partial^2 v}{\partial x\,\partial t} = \varphi'^{\,T}(x)\dot{\alpha}(t)\,, \qquad \frac{\partial^2 w}{\partial x\,\partial t} = \varphi'^{\,T}(x)\dot{\beta}(t) \tag{4}$$

According to Chen and Ku (1992) the kinetic energy, *T* of the shaft element including both the displacement under the assumption that the shaft rotates at a constant speed *Ω* is given by

$$T = \frac{1}{2}\int_0^l \Bigg\{\rho A\left[\left(\frac{\partial v}{\partial t}\right)^2 + \left(\frac{\partial w}{\partial t}\right)^2\right] + \rho I\left\{\left[\left(\frac{\partial^2 v}{\partial x\partial t}\right)^2 + \left(\frac{\partial^2 w}{\partial x\partial t}\right)^2\right] + 2\Omega\left(\frac{\partial^2 v}{\partial x\partial t}\frac{\partial w}{\partial x} - \frac{\partial^2 w}{\partial x\partial t}\frac{\partial v}{\partial x}\right) + 2\Omega^2\right\}\Bigg\}dx \tag{i}$$

By substituting (2), (3) and (4) into equation (i);

$$\begin{aligned} T = {} & \frac{\rho A}{2}\int_0^l \left[\left(\varphi^T(x)\dot{\alpha}(t)\right)^2 + \left(\varphi^T(x)\dot{\beta}(t)\right)^2\right] dx \\ & + \frac{\rho I}{2}\int_0^l \left[\left(\varphi'^T(x)\dot{\alpha}(t)\right)^2 + \left(\varphi'^T(x)\dot{\beta}(t)\right)^2\right] dx \\ & + \rho I \Omega \int_0^l \left[\left(\varphi'^T(x)\dot{\alpha}(t) \text{ x } \varphi'^T(x)\beta(t)\right) - \left(\varphi'^T(x)\dot{\beta}(t) \text{ x } \varphi'^T(x)\alpha(t)\right)\right] dx \end{aligned}$$

$$\begin{aligned} T = {} & \frac{\rho A}{2}\int_0^l \left[\left(\dot{\alpha}^T(t)\,\varphi(x)\right)\left(\varphi^T(x)\dot{\alpha}(t)\right) + \left(\dot{\beta}^T(t)\varphi(x)\right)\left(\varphi^T(x)\dot{\beta}(t)\right)\right] dx \\ & + \frac{\rho I}{2}\int_0^l \left[\left(\dot{\alpha}^T(t)\varphi'(x)\right)\left(\varphi'^T(x)\dot{\alpha}(t)\right) + \left(\dot{\beta}^T(t)\varphi'(x)\right)\left(\varphi'^T(x)\dot{\beta}(t)\right)\right] dx \\ & + \rho I \Omega \int_0^l \left[\left(\dot{\alpha}^T(t)\varphi'(x)\right)\left(\varphi'^T(x)\beta(t)\right) - \left(\dot{\beta}^T(t)\varphi'(x)\right)\left(\varphi'^T(x)\alpha(t)\right)\right] dx \end{aligned}$$

$$\begin{aligned} T = {} & \frac{\rho A}{2}\left[\dot{\alpha}^T(t)\int_0^l \varphi(x) \text{ x } \varphi^T(x)\,dx\;\dot{\alpha}(t) + \dot{\beta}^T(t)\int_0^l \varphi(x) \text{ x } \varphi^T(x)\,dx\,\dot{\beta}(t)\right] \\ & + \frac{\rho I}{2}\left[\dot{\alpha}^T(t)\int_0^l \varphi'(x) \text{ x } \varphi'^T(x)\,dx\,\dot{\alpha}(t) + \dot{\beta}^T(t)\int_0^l \varphi'(x) \text{ x } \varphi'^T(x)\,dx\,\dot{\beta}(t)\right] \\ & + \rho I \Omega\left[\dot{\alpha}^T(t)\int_0^l \varphi'(x) \text{ x } \varphi'^T(x)\,dx\,\beta(t) \right. \\ & \left. - \dot{\beta}^T(t)\int_0^l \varphi'(x) \text{ x } \varphi'^T(x)\,dx\,\alpha(t)\right] \end{aligned}$$

where

$$\boldsymbol{A} = \int_0^l \varphi(x) \text{ x } \varphi^T(x)\,dx\,, \quad \boldsymbol{B} = \int_0^l \varphi'(x) \text{ x } \varphi'^T(x)\,dx$$

the kinetic energy of the beam can be obtained as below;

$$\begin{aligned} T = {} & \frac{\rho A}{2}\left[\dot{\alpha}^T(t)\,\boldsymbol{A}\,\dot{\alpha}(t) + \dot{\beta}^T(t)\,\boldsymbol{A}\,\dot{\beta}\right] + \frac{\rho I}{2}\left[\dot{\alpha}^T(t)\,\boldsymbol{B}\,\dot{\alpha}(t) + \dot{\beta}^T(t)\,\boldsymbol{B}\,\dot{\beta}(t)\right] \\ & + \rho I \Omega\left[\dot{\alpha}^T(t)\,\boldsymbol{B}\,\beta(t) - \dot{\beta}^T(t)\,\boldsymbol{B}\,\alpha(t)\right] \end{aligned}$$

where ρ is mass density, A is the cross sectional area, I is the moment area of the beam in which $I = \frac{\pi r^4}{4}$, and Ω is the rotational speed of the shaft. In addition, Chen and Ku (1992) also had mentioned that the potential energy of the beam used can be represented in equation (ii).

$$v(x,t) = \varphi^T(x)\alpha(t)\,, \quad w(x,t) = \varphi^T(x)\beta(t) \tag{5}$$

$$\frac{\partial v}{\partial t} = \varphi^T(x)\dot{\alpha}(t)\ , \qquad \frac{\partial w}{\partial t} = \varphi^T(x)\dot{\beta}(t) \tag{6}$$

$$\frac{\partial v}{\partial x} = \varphi'^{\,T}(x)\alpha(t)\ , \qquad \frac{\partial w}{\partial x} = \varphi'^{\,T}(x)\beta(t) \tag{7}$$

$$\frac{\partial^2 v}{\partial x^2} = \varphi''^{\,T}(x)\alpha(t)\ , \qquad \frac{\partial^2 w}{\partial x^2} = \varphi''^{\,T}(x)\beta(t) \tag{8}$$

$$V = \frac{1}{2}\int_0^l EI\left[\left(\frac{\partial^2 v}{\partial x^2}\right)^2 + \left(\frac{\partial^2 w}{\partial x^2}\right)^2\right]dx - \frac{1}{2}\int_s^l P_x\left[\left(\frac{\partial v}{\partial x}\right)^2 + \left(\frac{\partial w}{\partial x}\right)^2\right]dx \tag{ii}$$

By substituting (7), (8), **C** and **B1(t)** into equation (ii);

$$V = \frac{EI}{2}\int_0^l \left[\left(\varphi''^{\,T}(x)\alpha(t)\right)^2 + \left(\varphi''^{\,T}(x)\beta(t)\right)^2\right]dx$$
$$-\frac{1}{2}\int_s^l P_x\left[\left(\varphi'^{\,T}(x)\alpha(t)\right)^2 + \left(\varphi'^{\,T}(x)\beta(t)\right)^2\right]dx$$

$$V = \frac{EI}{2}\int_0^l \left[\left(\varphi''^{\,T}(x)\alpha(t)\right)\left(\varphi''^{\,T}(x)\alpha(t)\right) + \left(\varphi''^{\,T}(x)\beta(t)\right)\left(\varphi''^{\,T}(x)\beta(t)\right)\right]dx$$
$$-\frac{P_x}{2}\int_s^l \left[\left(\varphi'^{\,T}(x)\alpha(t)\right)\left(\varphi'^{\,T}(x)\alpha(t)\right) + \left(\varphi'^{\,T}(x)\beta(t)\right)\left(\varphi'^{\,T}(x)\beta(t)\right)\right]dx$$

$$V = \frac{EI}{2}\left[\alpha^T(t)\int_0^l \varphi''(x)\ \mathrm{x}\ \varphi''^{\,T}(x)\,dx\,\alpha(t) + \beta^T(t)\int_0^l \varphi''(x)\ \mathrm{x}\ \varphi''^{\,T}(x)\,dx\,\beta(t)\right]$$
$$-\frac{P_x}{2}\left[\alpha^T(t)\int_s^l \varphi'(x)\ \mathrm{x}\ \varphi'^{\,T}(x)\,dx\,\alpha(t) + \beta^T(t)\int_s^l \varphi'(x)\ \mathrm{x}\ \varphi'^{\,T}(x)\,dx\,\beta(t)\right]$$

where

$$\boldsymbol{C} = \int_0^l \varphi''(x)\ \mathrm{x}\ \varphi''^{\,T}(x)\,dx\ , \quad \boldsymbol{B1(t)} = \int_s^l \varphi'(x)\ \mathrm{x}\ \varphi'^{\,T}(x)\,dx$$

the potential energy of the beam then can be formed as below:

$$V = \frac{EI}{2}\left[\alpha^T(t)\,\boldsymbol{C}\,\alpha(t) + \beta^T(t)\,\boldsymbol{C}\,\beta(t)\right] - \frac{P_x}{2}\left[\alpha^T(t)\,\boldsymbol{B1(t)}\,\alpha(t) + \beta^T(t)\,\boldsymbol{B1(t)}\,\beta(t)\right]dx$$

where E is Young's modulus of the beam material, I is the moment area of the beam in which $I = \frac{\pi r^4}{4}$, and P_x is the axial force.

13. LIST OF REFERENCES

Abouelatta, O. B and Madl, J., (2001), 'Surface roughness prediction based on cutting parameters and tool vibrations in turning operations', *Journal of Material and Processing Technology*, Vol. 118, pp.269-277.

Altintas, Y., (2000), 'Manufacturing Automation: Metal Cutting Mechanics, Machine Tool Vibration and CNC Design', University of Cambridge Press, Cambridge, pp. 97-99.

Andren, L., Hakansson, L., Claesson, I., (2003), 'Active control of machine tool vibrations in external turning operations', Proc. Instn Mech. Engrs Vol. 217 Part B : *Journal of Engineering Manufacture*, Vol. 217, pp. 869-872.

Basavarajappa, S., Chandramohan, G., Rao, K. V. N., Radhakrishanan, R., Krishnaraj, V., (2006), 'Turning of particulate metal matrix composites – review and discussion', *Proc. IMechE*, Vol. 220, pp.1189-1203.

Bhatnagar, N., Ramakrishnan, N., Naik, N. K., Komandur, R., (1995), 'On the machining of fiber reinforced plastic (FRP) composite laminates', *Int. J. Mach. Tools Manufacturing*, Vol. 35, No. 5, pp.701-716.

Bhattacharya, A., Faria-Gonzalez, R., and Ham, I., (1970) 'Regression analysis for predicting surface finish and its application in the determination of optimum machining conditions', *ASME Journal of Engineering for Industry*, Vol. 4, pp.711-714.

Boothroyd, G. and Knight, W. A., (1989), 'Fundamentals of Machining and Machine Tool', Marcel Dekker, New York.

Budak, E., (2006), 'Analytical models for high performance milling. Part II: Process dynamics and stability', *International Journal of Machine Tools & Manufacture,* Vol. 46, pp. 1489-1499.

Chen, L. W. and Ku, D. M, (1992), 'Dynamic stability of a cantilever Shaft-Disc System', *Journal of Vibration and Acoustic*, Vol. 114, pp.326-329.

Dagnall, H. M. A., (1986), 'Exploring Surface Texture', Leicester, UK, Rank Taylor Hobson.
Davies, M.A., Burns, T.J., Evans, C.J', (1997) On the dynamics of chip formation in machining hard materials, CIRP *Annals 46*, pp.25-30.

Davim, J. P and Mata, F., (2005), 'A new machinability index in turning fiber reinforced plastics', *Journal of Material Processing Technology*, Vol. 170, pp.436-440.

El-Sonbaty, I., Khashaba, U. A., Machaly, T., (2004) , 'Factors affecting the machinability of GFR/epoxy composites', *Composite Struc'tures*, Vol. 63, pp.329-338.

Faassen, R. P. H., Wouw, N. V. D., Oosterling, J. A. J., Nijmeijer, H., (2003), 'Prediction of regenerative chatter by modelling and analysis of high-speed milling', *International Journal of Machine Tools & Manufacture*, Vol. 43, pp.1437-1446.

Feng, C. X. J., Wang, X., (2002), 'Development of Empirical Models for Surface Roughness Prediction in Finish Turning', *International Journal Adv Manufacturing Technology*, Vol. 20, pp.348-356.

Gagnol, V, Bouzgarrou, B. C., Ray, P., Barra, C., (2007), 'Model-based chatter stability prediction for high-speed spindles', *International Journal of Machine Tools & Manufacture*, Vol. 47, pp.1176-1186.

Grabec, I., (1988), 'Chaotic dynamics of the cutting processes', *International Journal Machine Tools and Manufacture* Vol. 28, pp.19–32.

Hamdan, M. N., and Bayoumi, A. E., (1989), 'An approach to study the effects of tool geometry on the primary chatter vibration in orthogonal cutting' *Journal of Sound and Vibration*, Vol. 128, No. 3, pp.451–469.

Heisel, U., Feinauer, A., (1999), 'Dynamic Influence on Workpiece Quality in High Speed Milling', Annals of the CIRP, Vol. 48, No. 7, pp. 321-324.

Hocheng, H., Yen, S. B., Yen, B. K., (1997), 'Fundamental turning characteristic of a tribiology-favored graphite/aluminium alloy composite material', Composites Part A, pp. 883-890.

Hull, D., and Clyne, T. W., (1996), 'An introduction to composite materials', University of Cambridge Press, Cambridge, pp. 45-50.

Isik, B., (2007), 'Experimental investigations of surface roughness in orthogonal turning of unidirectional glass-fiber reinforced plastic composites', *Int J Adv Manuf Technology.*

Jahanmir, S., Ramulu, M., Koshy, P., (1998), 'Machining of ceramics and composites', Marcel Dekker Inc., New York, pp. 238-243.

Jang, D. Y., Choi, Y. G., Kim, H. G., Hsiao, A., 1996, 'Study of the correlation between surface roughness and cutting vibrations to develop an on-line roughness measuring technique in hardturning', International Journal of Machine Tools Manufacturing, Vol. 36, No. 4., pp. 453-464.

Karmakar, A, (1970), 'Factors influencing surface finish during fine turning' *Proceedings of 4th. All India Machine Tool Design and Research Conference*, pp.123-128.

Katz, R., Lee, C. W., Ulsoy, A. G., Scott, R. A. , (1988), 'The dynamic response of a rotating shaft subject to a moving load', *Journal of Sound and Vibration*, Vol. 122, No. 1, pp. 131-148.

Khraisheh, M. K., Pezeshki, C., Bayoumi, A. E., (1995), 'Time series based analysis for primary chatter in metal cutting', *Journal of Sound and Vibration,* Vol. 180, No. 1, pp.67-87.

Komanduri, R., 1997, 'Machining of fiber-reinforced composites', Machining Science and Technology, Vol. 1, No. 1, pp. 113-152.

Lacey, S.J., Wardle, F. P., Poon, S. Y.,(1983), 'High speed bearings for CNC machine tools spindles', Chart. Mech. Eng.

Lambert, B. K., (1983) 'Determination of metal removal rate with surface finish restriction', *Carbide and Tool Journal*, pp.16-19.

Lambert, B. K., and Taraman, K. (1974) 'A surface roughness model for a turning operation', *International Journal of Production Research*, Vol. 12, pp.691-703.

Lin, S. C., and Chang, M. F., (1998), 'A study of the effect of vibrations on the surface finish using a surface topography simulation modal for turning', *International Journal of Machine Tools and Manufacture*, Vol. 38, pp.763-782.

Lipski, J., Litak, G., Rusinek, R., Szabelski, K., Teter, A., Warminski, J., Zaleski, K., (2002), 'Surface quality of a work material's influence on the vibrations of the cutting process', *Journal of Sound and Vibration* , Vol. 252, No. 4, pp.729–737.

Litak, G., (2002), 'Chaotic vibration in regenerative cutting process', *Chaos, Solitons and Fractals*, Vol. 13, pp.1531-1535.

Miller, J. C., De Vor, R. E., Southerland, J. W., (1983), 'Surface roughness characteristics for turning 380 and 390 aluminum casting alloys' *Proceedings of North American Manufacturing Research Conference*, pp.282-288.

Nishitani, H., and Imai, R., (1983), 'Effect of surface roughness of heat-treatment materials for S45C and SCM435 steels on rotary bending fatigue strength', *Trans. JSME (A)* 49-442, pp. 693–698

Ouyang, H., Wang, M., (2007), 'Dynamics of a Rotating Shaft Subject to a Three-Directional Moving Load', Transaction of the ASME, *Journal of Vibrations and Acoustics*, Vol. 129, pp. 386-389.

Palanikumar, K. and Karthikeyan, R., (2006), 'Optimal machining conditions for turning of particulate metal matrix composites using taguchi and response surface methodologies', *Machining Science and Technology*, Vol. 10, pp.417-433.

Palanikumar, K., (2006), 'Cutting Parameters Optimization for Surface Roughness in Machining of Composites using Taguchi's Method', *Journal of Reinforced Plastics and Composites*, Vol. 25, pp.1739-1751.

Palanikumar, K., (2007), 'Modelling and analysis for surface roughness in machining glass fibre reinforced plastics using response surface methodology', *Material and Design*, Vol. 28, pp.2611-2618.

Palanikumar, K., Davim, J. P and Mata, F., (2008), 'Analysis of surface roughness parameters in turning of FRP tubes by PCD tool', *Journal of Materials Processing Technology*, Vol. 204, pp.469-474.

Palanikumar, K., Karunamoorthy, L., Karthikeyan, R., (2006), 'Assessment of factors influencing surface roughness on the machining of glass fiber-reinforced polymer composites', *Materials and Design*, Vol. 27, pp. 861-871.

Palanikumar. K., Mata, F., Davim, J. P., (2008), 'Analysis of surface roughness parameters in turning of frp tubes by pcd tool', *Journal of Materials Processing Technology*, Vol. 204, pp. 469-474.

Pan, J., Su, C. Y., 2001, 'Chatter suppression with adaptive control in turning metal via application of piezoactuator', Proceeding of the 40th. IEEE, Conference on Decision and Control, pp. 2436-2441.

Petropoulos, P. G., (1974), 'Statistical basis for surface roughness assessment in oblique finish turning of steel components', *International Journal of Production Research*, Vol. 12, pp.345-360.

Rahnejat, H.,(1984) 'Influence of vibration on the oil film in concentrated contact', Ph.D. thesis, Imperial College of Science and Technology and Medicine, University of London.

Ramkumar J, Aravindan S, Malhotra SK, Krishnamoorthy R., (2004) 'An enhancement of the machining performance of GFRP by oscillatory assisted drilling', *Int J Adv Manuf Technology, Vol.* 23, pp.240–244.

Ramulu M, Arola D, Colligan K., (1994), 'Preliminary investigation of effects on the surface integrity of fiber reinforced plastics', *Eng Syst Anal ASME PD*, Vol. 64, No. 2, pp.93–101.

Rao, B. C., Shin, Y. C., (1999), 'A comprehensive dynamic cutting force model for chatter prediction in turning', *International Journal of Machine Tools & Manufacture,* Vol. 39, pp.1631-1654.

Rasch, F. O., and Rolstadas, A., (1971), 'Selection of optimum speeds and feeds in finish Turning' *Annals of CIRP*, Vol. **19**, pp.787-792.

Regib, E. A., Ni, J., Lee, S. H., (2003) , 'Programming spindle speed variation for machine tool chatter suppression', *International Journal of Machine Tools & Manufacture*, Vol. 43, pp.229-1240.

Sakuma, K. and Seto, M., (1983), 'Tool wear in cutting glass fibre-reinforced plastics', *Bulletin of the JSME*, Vol. 26, No. 218, pp.1420-1427.

Sandvik Coromant, (2005),'How to reduce vibration in metal cutting', *Cutting tool instruction manual.*

Santhanakrishnan, G. (1990)., 'Investigations on Machining of FRP Composites and their Tribological Behaviour', PhD Thesis, IIT Madras, Chennai, India.

Selvam, M. S., (1975), 'Tool vibrations and its influence on surface roughness in turning, Wear,', Vol. 35, pp.149-157.

Selvam, M. S., and Radhakrishnan, V., (1973), 'Characteristics of a surface machined with a single point tool' *Tribology*, Vol. 6, pp.93-96.

Sundaram, R. M., and Lambert, B. K., (1981), 'Mathematical models to predict surface finish in fine turning of steel, Parts I and II,', *International Journal of Production Research*, Vol. 19, pp.547-564

Takeyama, H. and Lijima, (1988), 'Machinability of glass fiber reinforced plastics and application of ultrasonic machining', *Ann CIRP*, Vol. 37, No. 1, pp.93-96.

Tarng, Y. S., Hseih, Y. W. and Li, T. C., (1996), 'Automatic selection of spindle speed for suppression of regenerative chatter in turning', *International Journal of Advanced Manufacturing Technology*, Vol. 11, pp.12-17.

Tarng, Y. S., Kao, J. Y., Lee, E. C., (2000), 'Chatter suppression in turning operations with a tuned vibration absorber', *Journal of Materials Processing Technology,* Vol. 105, pp. 55-60.

Tarng, Y. S., Lee, E. C., (1997), 'A critical investigation of the phase shift between the inner and outer modulation for the control of machine tool chatter', *Int. J. Mach. Tools Manufacturing*, Vol. 37, No. 12, pp.1661-1672.

Wang, X. M., Zhang, L. C., (2003), 'An experimental investigation into the orthogonal cutting of unidirectional fibre reinforced plastics', *International Journal of Machine Tools & Manufacture*, Vol. 43, pp.1015-1022.

Wardle, F. P., Lacey, S. J., and Poon, S. Y.,(1983) 'Dynamic and static characteristics of a wide speed range machine tool spindle'. *Precision Engng* 5, Vol. 4 ,pp.175–183.

Wiercigroch, M., (2000) Nonlinear dynamics of orthogonal metal cutting,in: M. Wiercigroch, A. de Kraker (Eds.), Applied Nonlinear Dynamics and Chaos of Mechanical Systems with Discontinuities, World Scientific, pp. 361–401.

Wiercigroch, M., and Krivtsov, A. M., (2001), 'Frictional chatter in orthogonal metal cutting', Philosophical Transactions of the Royal Society of London 359 (A) pp.713–738.

Wiercigroch, M., Budak, E., (2001), 'Sources of nonlinearities, chatter generation and suppression in metal cutting', *Philosophical Transactions of the Royal Society of London 359 (A)*, pp.663–693.