

DYNAMICS ANALYSIS OF 3 AXIS GANTRY TYPE MULTIPURPOSE CNC  
MACHINE

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## ABSTRACT

The determination of the natural frequency and the resonance is important before the machine can be use. If the natural frequency is occur and the resonance will be occur also and it will make the damage to the machine when the machine is using. From this paper, modal analysis is used to determine the natural frequency. Modal analysis is a process whereby describe a structure in terms of its natural characteristics which are the frequency, damping and mode shape of its dynamic properties. From the experiment that was carrying out, the natural frequency is occur at 24Hz. From the result, when the machine is running with the speed of 50Hz or 100Hz, it doesn't meet with the natural frequency which is 24Hz. From the experiment that was carrying out, it was shows that the machine can be use as user to milling process. Most machines produce low levels of vibration when designed properly. During operation, all machines are subjected to fatigue, wear, deformation, and foundation settlement. These effect cause an increase in the clearances between mating part, misalignments in shafts, initiation of cracks in parts, and unbalances in rotors. All leading to an increase in the level of vibration, which cause additional dynamic loads on bearings. As time progresses, the vibration level continue to increase, leading ultimately to the failure or breakdown of the machine. So, the maintenance is needed for all the time the machine is use.

## ABSTRAK

Penentuan frekuensi semula jadi dan resonans adalah penting sebelum mesin boleh digunakan. Jika kekerapan frekuensi semula jadi berlaku dan resonans akan berlaku juga dan ia akan membuat kerosakan kepada mesin apabila mesin digunakan. Dari kertas ini, analisis modal digunakan untuk menentukan kekerapan frekuensi semula jadi. Analisis modal adalah satu proses di mana menggambarkan struktur dari segi ciri-ciri frekuensi semula jadi, redaman dan bentuk mod hatanah dinamik. Daripada eksperimen yang telah menjalankan, kekerapan frekuensi semula jadi berlaku pada 24Hz. Melalui hasil eksperimen, apabila mesin sedang berjalan dengan kelajuan 50Hz atau 100Hz, ia tidak akan bertemu dengan frekuensi semula jadi yang 24Hz. Daripada eksperimen yang telah menjalankan, ia menunjukkan bahawa mesin boleh digunakan sebagai panduan kepada proses pengilangan. Kebanyakan mesin menghasilkan tahap rendah bagi getaran apabila direka dengan betul. Semasa operasi, semua mesin adalah tertakluk kepada keletihan, kegunaan, ubah bentuk, dan asas penyelesaian. Kesan ini menyebabkan peningkatan dalam kelonngaran antara bahagian mangawan, ketidaksejajaran dalam aci, pemulaan retak di bahagian-bahagain mesin, dan tidak seimbang bagi motor mesin. Semua fakta ini menyebabkan peningkatan dalam tahap getaran yang menyebabkan beban dinamik tambahan di gelas. Lama kelamaam, tahap gegaran akan terus meningkat dan akan membawa kegagalan atau kerosakan mesin. Jadi, penyelenggaraan diperlukan untuk semua mesin semasa digunakan.

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## ABBREVIATIONS

Hz	Hertz
PC	Personal Computer
SIMO	Single-input, Multiple-output
MISO	Multiple-input, Single-output
MIMO	Multi-input, Multiple-output
FEM	Finite Element Method
CNC	Computer Numerical Controller
FRF	Frequency Response Function
FFT	Fast Fourier Transfer
DAQ	Data Acquisition
ODS	Operating Deflection Shape
ADC	Analog -To-Digital
DACs	Digital-To -Analog converters
rpm	Revolution per minute
$\omega_n$	Natural Frequency in rad s <sup>-1</sup>
$f_n$	Natural Frequency in Hz
E	Modulus of Elasticity/ Young's modulus
I	Moment of area about central axis parallel to width
b	Breath of the beam
h	Thickness of the beam
$\rho$	Density of the beam which 2700 kg m <sup>-3</sup> for Aluminum
m	Mass

## **Chapter 1**

### **Introduction**

#### **1.1 RESEARCH BACKGROUND**

Manufacturing process is a transformation process of raw material to form a final product. In the manufacturing process, includes milling, forming, casting, and turning process. This report focuses more on milling process. Milling process is a process which works on the principle of removing some material on the work piece to form designated products. The process can be achieved with two type of milling machines which are G or kneed type (movable table type) and fixed bed (gantry type) machines. Depending on which application the machines are intended to be used, both machines have their own advantages and disadvantages. Gantry type machine is chose as this machine has a capability of machining large and thin work piece such as sheet metal, plywood, polymeric material sheet, plastic sheets etc. The gantry type machine consists of 3 axes just like knee bed type milling machine. However, the gantry type employs moving spindle operation and this design requires very good dynamic stability. Modal analysis is use to test the dynamic properties of the structure that is under vibration excitation.

Modal analysis is use to test the natural frequency for all the thing. It is the measuring and analysis the dynamic response of the structures and or fluid when some of the input is come from outside. Modal analysis is use to know the structure of the natural frequency. Natural frequency is the frequency when the object is hits

or somehow disturb from outside input. All of the objects also have a natural frequency. When the natural frequency is happen, the resonance will be occurred, resonance is the condition when a vibration system responds with maximum amplitude to a periodic driving force. Resonance will be occurred when the driving force has same with natural frequency. For the mechanical systems it will have a number of possible frequencies that will be occur. This is just saying that resonance occurs when the driving force has the same value as one of the natural frequencies. Through the modal analysis will test the natural frequency and prevent the resonance happen.

## **1.2 Objectives**

The objectives of this research are as follow;

- To conduct fundamental studies on milling machine and more focus on gantry type machine.
- To determine natural frequency of the gantry type milling machine.

## **1.3 Research Performed**

The research is performed in two semesters as below:

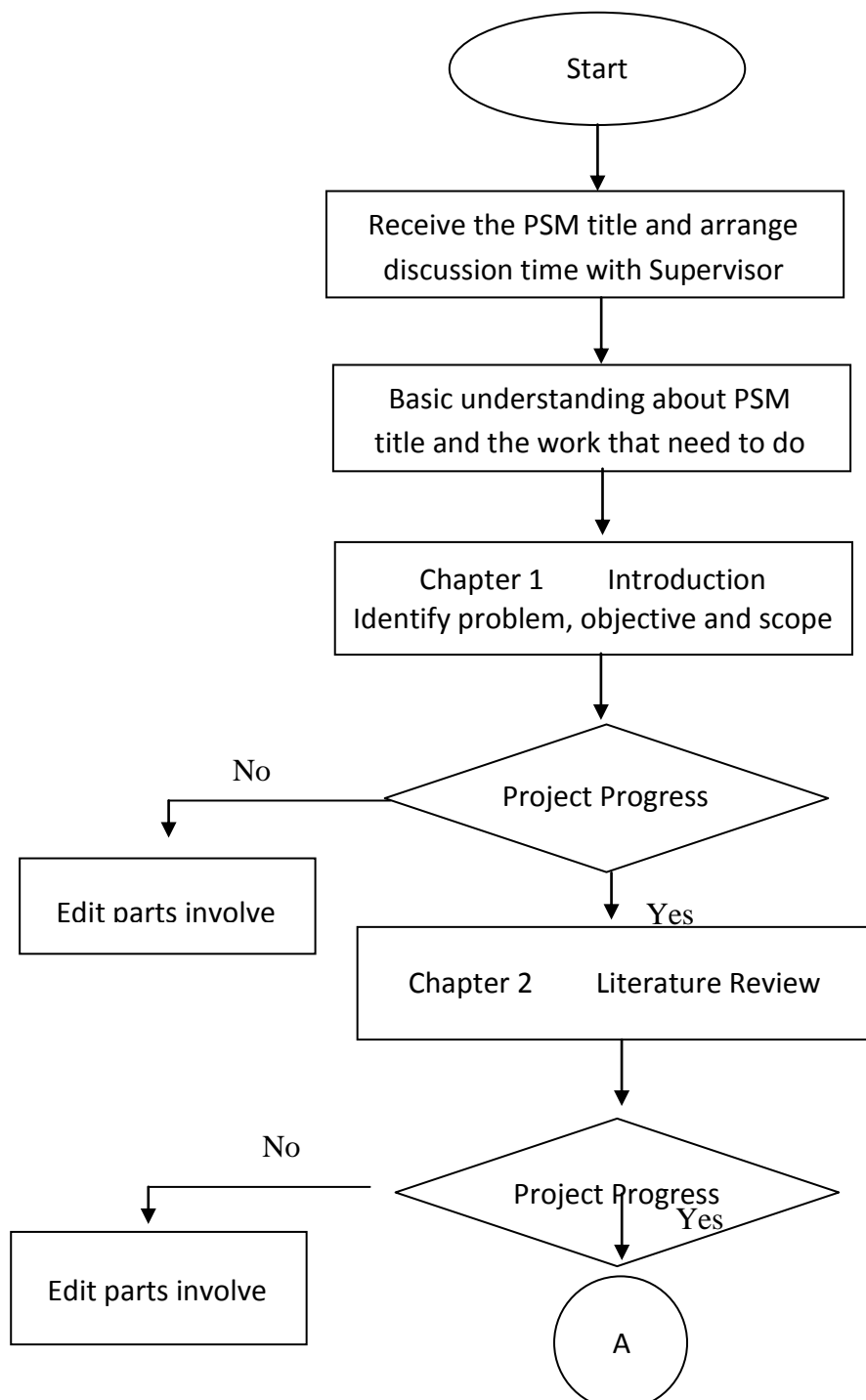
### *Semester1*

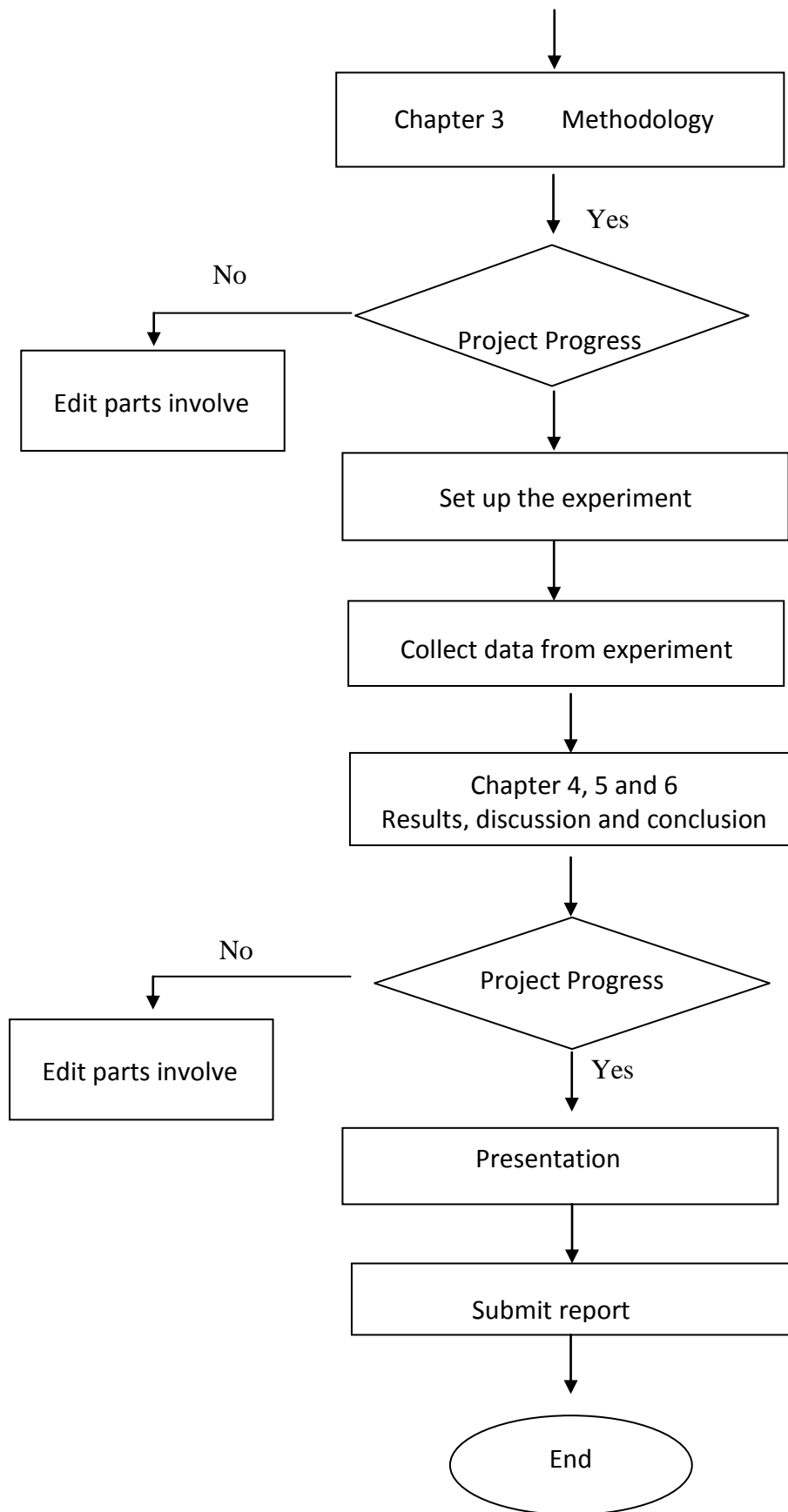
Research gap was identified and the objectives were defined. Fundamental studies on the milling machine and modal analysis were carried out in the Literature's chapter. The studies mainly focused on the gantry type milling operation and determination of natural frequencies of the machine. A dedicated hammer was used to stimulate vibration on the machine's frame and signal was recorded by a data logger. Testing procedures were derived based on several parameters and discussed further in the Methodology chapter.

### *Semester2*

Experiment of modal analysis was conducted to determine natural frequencies of the gantry type milling machine. Changes of spindle speed was manipulated to get the different result of the analysis and record the data into the result table and do the discussion about the result and do a conclusion.

#### 1.4 FLOW CHART / PROJECT FLOW FOR FYP





## **Chapter 2**

### **Literature review**

#### **2.1 Manufacturing Process**

Manufacturing process is the steps that through the raw materials that follow the product shape that needed for the final product. The process is begin with the creation of the material that come from the design that was made at the beginner before make the shape at the machine. When put the material at the machine will be modified through manufacturing processes to become the required part for the final product. The manufacturing process can included treating of a machine, or reshaping a material. This process also can be include in the tests and checks for the quality of the product that was make during or after the manufacturing. Modern manufacturing includes all the intermediate processes for the integration and the production of the product components[1].

##### **2.1.1 Examples of Manufacturing Processes**

One example of manufacturing processes is a forming process, which is the process make use of suitable stresses like compression, tension, shear or combined

stresses that cause the plastic deformation to the materials to produce required shapes. In the forming process, no material is removed, it is deformed and displaced. Another example of the manufacturing process is casting process which a liquid material usually poured into a mold that contains a hollow cavity of the desired shape, and then allowed to solidify. This solidified part is also known as casting, which is ejected or broken out of the mold to complete the process. Casting materials are usually metals or various cold setting materials that cure after mixing two or more components together; examples are epoxy, concrete, plaster and clay. The other process of the manufacturing are turning process that form of machining, a material removal process, which is used to create the rotational parts by cutting the unwanted material. The turning process requires a turning machine or lathe, workpiece, fixture, and cutting tool. Turning is also commonly used as a secondary process to add or refine features on parts that were manufactured using a different process. Turning can be done manually, in a traditional form of lathe, which frequently requires continuous supervision by the operator, or by using an automated lathe which does not. For the example of the milling process, it is most common form of the machining that removal the material. It can create a variety of feature on a part by cutting away the unwanted material. The milling process requires a milling machine, workpiece, fixture, and cutter. The workpiece is a piece of pre-shaped material that is secured to the fixture, which itself is attached to a platform inside the milling machine. The cutter is a cutting tool with sharp teeth that is also secured in the milling machine and rotates at high speeds. By feeding the workpiece into the rotating cutter, material is cut away from this workpiece in the form of small chips to create the desired shape. Milling is typically used to produce parts that are not axially symmetric and have many features, such as holes, slots, pockets, and even three dimensional surface contours. Parts that are fabricated completely through milling often include components that are used in limited quantities, perhaps for prototypes, such as custom designed fasteners or brackets. Another application of milling is the fabrication of tooling for other processes. For example, three-dimensional molds are typically milled. Milling is also commonly used as a secondary process to add or refine features on parts that were manufactured using a different process. On the other hand, it got another process that also use the manufacturing process that is engraving which is the practice of incising a design on to a hard, usually flat surface, by cutting grooves into it. It is also a historically important method of producing on paper, both in artistic printmaking, and

also for commercial reproductions and illustrations for books and magazines. Traditional engraving, by burin or with the use of machines, continues to be practiced by goldsmiths, glass engravers, gunsmiths and others, while modern industrial techniques such as photoengraving and laser engraving. For the others example of the process is routing process that selecting paths in a network along which to send network traffic. Routing is performed for many kinds of networks, including the telephone network, electronic data networks (such as the Internet), and transportation networks. It is a more a more narrow sense of the term, is often contrasted with bridging in its assumption that network addresses are structured and that similar addresses imply proximity within the network. Lastly, for the joining process it is recognized as a leading innovator in precision joining applications and laser additive manufacturing. From welding services and the component manufacturing to complete systems is delivered to the production floor[2].

## **2.2 Milling Process**

Milling process is a material removal process, which it can create a variety of features on a part by cutting away the unwanted material. The milling process requires a milling machine, workpiece, fixture, and cutter. The workpiece is a piece of pre-shaped material that is secured to the fixture, which itself is attached to a platform inside the milling machine. The cutter is a cutting tool with sharp teeth that is also secured in the milling machine and rotates at high speeds. By feeding the workpiece into the rotating cutter, material is cut away from this workpiece in the form of small chips to create the desired shape. Milling is a typically use to produce parts that are axially symmetric and it have many features, such as holes, slots, pockets, and even three dimensional surface contours. The parts that are fabricated completely through milling often include components that use in the limited quantity, perhaps for prototypes, like custom designed fasteners or brackets. Another application of milling is the fabrication of tooling for other processes. For example, three-dimensional molds are typically milled. Milling is also commonly used as a secondary process to add or refine features on parts that were manufactured using a different process. Due to the high tolerances and surface



finishes that milling can offer, it is ideal for adding precision features to a part whose basic shape has already been formed [3].

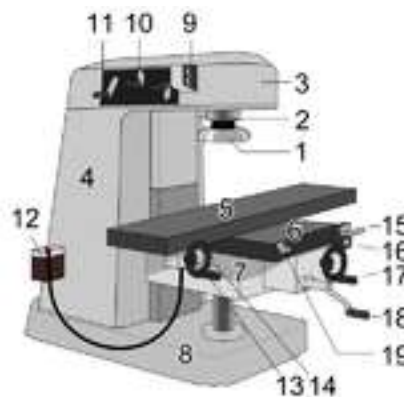
### **2.2.1 Milling Machine**

Milling machine is a machine tool that used to machine the solid materials. Milling machine can be classified into two basic forms, horizontal and vertical, which refer to the orientation of the main spindle. Milling machines may be manually operated, automatic or digital automated via computer numerical control. Milling machine can perform a vast number of operations, from simple to complex. The cutting fluid is often pumped to the cutting site to cool and lubricate the cut and to wash away material. Milling machine is the most common machine, which use to removal the material process, which can create a variety of features on the part by cutting away the unwanted part. The milling process requires a milling machine, workpiece, fixture, and a cutter. The cutter is a cutting tool with sharp teeth that also secured in the milling machine and rotates at high speeds. Milling is typically used to produce parts that don't have axially symmetric and have many features, such as holes, slots, pockets, and three dimensional surface contours. In milling, the speed and motion of the cutting tool is specified through several parameters. These parameters are selected for each operation based on the workpiece materials, tool material or size[4\_5].

### **2.2.2 Vertical Type Milling Machine**

For the plain that was vertical machines are characterized by a spindle that is located vertically, parallel to the column face, and mounted in a sliding head that can be move up and down by hand or using the electrical power. Modern vertical milling machines are designed so the entire head can be swivel to permit working on angular surfaces. In the vertical mill the spindle axis is vertically oriented. Milling cutters are held in the spindle and rotate on its axis. The spindle can generally be extended (or the

table can be raised/lowered, giving the same effect), allowing plunge cuts and drilling. There are two subcategories of vertical mills: the bed mill and the turret mill. A turret mill has a stationary spindle and the table is moved both perpendicular and parallel to the spindle axis to accomplish cutting. The most common example of this type is the Bridgeport, described below.



**Figure 2.1:** Milling machine (vertical type)

Source: Scientific Technincal, 2008

Vertical milling machine, 1: milling cutter, 2: spindle, 3: top slide

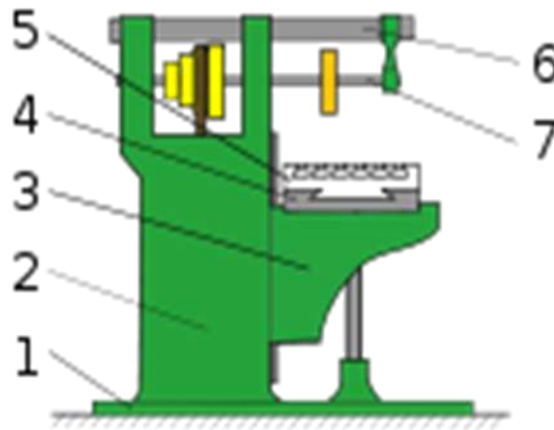
or overarm, 4: column, 5: table, 6: Y-axis slide, 7: knee and 8: base.

Turret mills often have a quill which allows the milling cutter to be raised and lowered in a manner similar to a drill press. This type of machine provides two methods of cutting in the vertical (Z) direction: by raising or lowering the quill, and by moving the knee. In the bed mill, however, the table moves only perpendicular to the spindle's axis, while the spindle itself moves parallel to its own axis. Turret mills are generally considered by some to be more versatile of the two designs. However, turret mills are

only practical as long as the machine remains relatively small. As machine size increases, moving the knee up and down requires considerable effort and it also becomes difficult to reach the quill feed handle (if equipped). Therefore, larger milling machines are usually of the bed type. Bed type are any milling machine where the spindle is on a pendant that moves up and down to move the cutter into the work, while the table sits on a stout bed that rests on the floor. These are generally more rigid than a knee mill. Gantry mills can be included in this bed mill category. The advantage of using the vertical milling machine can be categorized into seven, that is:

1. Vertical mill using the locally limited material bed to smash the principle of a vertical roller mill grinding efficiency, the system unit power consumption than the ball mill to save 20% – 30%.
2. Through the drying ability, make full use of the vertical mill, the kiln tail exhaust to dry the moisture of the raw meal can be as high as 20% or more, not like milling, drying mill specifications and production increases dry a reduced ability of the defects, roller press, as only the limitations of grinding dry materials.
3. Allowed to enter the vertical mill the material grain size up to 80mm, relaxed out of the crusher feed size, saving broken electrical energy consumption. Because the layer between the material bed big enough to crush efforts to feed less than 5% of the diameter of the grinding rollers, will still be effective to smash the job, unlike milling or roller press is less sensitive to changes in feeding efforts.
4. When vertical mill in operation, the noise is small, the distance of vertical mill of 1 m at the sound intensity is 80dB lower than the ball mill.
5. Vertical milling machine when process in pieces, grinding, drying, the powder pneumatic conveying of five unit operations in one less device. The system of the vertical mill is simple, small footprint, and the host can be placed in the open air.
6. Adaptable to a variety of performance materials, its grindability, abrasion resistance, feed moisture, particle size or the fineness in considerable changes within, can apply[6].

### 2.2.3 Horizontal Milling Machine:



**Figure 2.2:** Milling machine that horizontal

Source: Scientific Techincal, 2008.

Horizontal milling machine. 1: base 2: column 3: knee 4 & 5: table (x-axis slide is integral) 6: overarm 7: arbor (attached to spindle).

For the plain horizontal milling machine's column contains drive motor, gearing and a fixed position horizontal milling machine spindle. An adjustable overhead arm containing one or more arbor to supports the projects forward from the top of the column. The arm and arbor supports are used to stabilize long arbors. Supports can be moved with the overhead arm to support the arbor where support is desired depending on the position of the milling cutter or cutters. A horizontal mill has the same sort of x-y table, but the cutters are mounted on a horizontal arbor across the table. Many horizontal mills also feature a built-in rotary table that allows milling at various angles; this feature is called a universal table. While for the end mills and the other types of tools available to a vertical mill may be can used in a horizontal mill, their real advantage lies in arbor-mounted cutters, called side and face mills, which have a cross

section rather like a circular saw, but are generally wider and smaller in diameter. Because of the cutters have a good support from the arbor and have a larger cross-sectional area than an end mill, quite heavy cuts can be taken enabling rapid material removal rates. These are used to mill grooves and slots. Plain mills are used to shape flat surfaces. It have a several cutters may be ganged together on the arbor to mill a complex shape of slots and planes. Special cutters can also cut grooves, bevels, radii, or indeed any section desired. These specialty cutters tend to be expensive. Simple x mills have one spindle, and duplex mills have two. It is also easier to cut gears on a horizontal mill. Some horizontal milling machines are equipped with a power-take-off provision on the table. This allows the table feed to be synchronized to a rotary fixture, enabling the milling of spiral features such as hypoid gears.

### 2.3 Gantry Type Machine

Machines are available with the traditional floor plate and the mobile gantry, as well as special gantry mills with integral turntable providing heavy duty turning capabilities[7].



**Figure 2.3:** Gantry type machine

Source: Nicolás Correa S.A, (2007)

The milling head rides over two rails (often steel tubes) which lie at each side of the work surface.[7] For the gantry machine it have 5 performance:

- Gantry type structure provides highest structural rigidity and dynamic performance. X-axis travel can expand according to customer requirements, Y-axis can travel the equipped with patented as “ Crossbeam Adjustment Mechanism ”which it can reach maximum span at 7 m.
- X-axis has dual ball screws, dual servo motors and dual linear scale synchronous that controlled driving system to ensure ultimate dynamic accuracy.
- Extra high rigidity roller type linear guide ways for Y-axis combine the benefits of both box way and linear guide ways which make the machine can do a heavy duty cutting, fast movement and low abrasion capabilities.
- Z-axis have a extra-large size linear guide ways which along with larger saddle and high rigidity box structure headstock which provides best cutting rigidity.

## **2.4 Modal Analysis**

Modal analysis is a measuring and analysis a dynamic response of the structures and or fluid when some of the input is come from outside [8]. The resulting of the transfer function will show one or more resonances, whose the characteristic mass, frequency and damping can be estimated from the measurements. If see from the engineering, modal analysis uses the overall mass and stiffness of a structure to find various periods which it will naturally resonate. The periods of the vibration are very important to note in the earthquake engineering. As a building's natural frequency does not match with the frequency of expected earthquakes in the region in that building, it will be constructed. If a structure's natural frequency matches with an earthquake's frequency, the structure may continue to form the resonate and experience structural damage. Although modal analysis is usually carried out by using the computers, it is

possible to hand-calculate the period of vibration of any high-rise building through idealization as a fixed-ended cantilever with lumped masses. The natural frequency also can be test by using the Finite Element Method (FEM), the goal of modal analysis in structural mechanics is to determine the natural mode shapes and frequencies of an object or structure during free vibration. It can be used the finite element method (FEM) to test for this analysis because, like other calculations using the FEM, the object being analyzed can have arbitrary shape and the results of the calculations are acceptable. The types of equations that arise from the modal analysis are those seen in Eigen systems. Sometimes, only desired modes are the lowest frequencies because they can be the most prominent modes which the object will vibrate and will be dominating all the higher frequency modes[9].

The modal analysis can help to reduce the noise level that come out from the product, when the data from the modal analysis is take, the value of the natural frequencies can be know and can make sure that the speed of the spindle have to more than or less than the natural frequencies. Other than that, the modal analysis assists in pointing out the reasons of vibrations cause cracking issues of the components, when the data is take, can be see from the mode shape to get the most possible the place the material will crack.. The modal analysis can be using to improve the overall product performance in specific operating conditions[10]. Modal analysis is a process whereby describe a structure in terms of its natural characteristics which are the frequency, damping and mode shape which it is call as dynamic properties.

Modal analysis studies the dynamic properties or “structural characteristics” of a mechanical structure under dynamic excitation:

1. the method of modal analysis can let people know what is the natural frequency of the material that was test. From here then will know the resonant frequency
2. By using the modal analysis, can used the software to get the mode shapes of the product that maybe crack at the material.
3. Damping ratio is a dimensionless measure describing how oscillations in a system decay after a disturbance.

The measured amplitude can be vary depending on the frequency rate of the input force. The response amplifies that apply a force with a frequency rate that gets closer and

closer to the natural frequencies. The resonant frequency is the frequency that the excitation produces an exaggerated response. This is important to know since excitation close to a structure's resonant frequency that will be produce negative effects. For this generally involve excessive vibration leading to potential fatigue failures, damage to the more delicate parts of the structure or, in extreme cases, complete structural failure. For the example: when spinning, the washing machine's drum vibrations induce such a powerful resonant frequency, then the machine begins to actually move causing the door spring to open[10].



**Figure 2.4:** washing machine

Source: D. J. Ewins: Modal Testing: Theory, Practice and Application

Modal analysis is a process whereby that can be describe a structure in terms of its natural characteristics which are the frequency, damping and mode shapes which it is dynamic properties. The most simple to explain the modal analysis in terms of the modes of vibration is a simple plate.