THE STUDY OF VIBRATION MOTION OF HONEY KUIH LOYANG MOLD FRAME

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DECLARATION

This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree.

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ABSTRAK

Kuih Loyang madu semakin terkenal dalam kalangan rakyat tempatan dari masa ke semasa untuk rasa kemanisan dan kerangupannya. Permintaan untuk biskut semakin tinggi terutamanya pada musim perayaan. Pengeluaran biskut yang perlahan telah menjadi satu masalah untuk memenuhi permintaan. Mesin separa automatik telah direka untuk menyelesaikan masalah pengeluaran yang lambat. Bagaimanapun, mesin yang direka itu tidak dapat berfungsi sebagaimana mesin tradisional berfungsi. Untuk mereka mesin separa automatik yang dapat berfungsi seperti mesin tradisional, pergerakan getaran bingkai acuan mesin tradisional hendaklah dikaji dan difahami. Frekuensi semulajadi dan bentuk mod gerakan getaran harus diketahui. Dengan menggunakan simulasi jenis modal analisis dan syarat sokongan tetap, 10 frekuensi semulajadi dan bentuk mod gerakan getaran dinilai. Lingkungan frekuensi semulajadi adalah dari 165.97 Hz hingga 740.06 Hz. Bentuk mod terdiri daripada getaran lentur-torsional dan lenturan paksi. 3 bahan yang berbeza yang juga mempunyai ciri-ciri mekanik yang berbeza, dianalisa menggunakan model rangka acuan yang sama. Ia adalah sebagai alternatif untuk mengesahkan bahawa simulasi yang dibuat adalah betul. Hasil perbandingan daripada semua bahan menunjukkan bahawa simulasi yang dilakukan mempunyai persetujuan yang sama dengan hasil carian sastera yang tersedia. Simulasi yang dijalankan telah disahkan.

ABSTRACT

Honey Kuih Loyang is getting famous from time to time for its crunch and sweetness. The demand for the biscuits are getting higher mostly during the festive day. The slow production of the biscuits has become as problem to meet the demand. A semi-automatic machine had been designed to solve the problem of late production. However, the designed machine cannot work as effective as the traditional machine. In order to design a semi-automatic machine that can work as effective as the traditional machine, the vibration motion of the mold frame of the traditional machine is studied. The natural frequency and mode shape of the vibration motion should be known. By using modal analysis simulation and fixed support boundary conditions, the first 10 inherent natural frequencies and mode shapes of the vibration motion are evaluated. The natural frequencies are ranging from 165.97 Hz to 740.06 Hz. The mode shapes consists of lateral-torsional and axial bending vibration. 3 different materials which have different mechanical properties are analyzed for the same solid model of mold frame as an alternative to verify the simulation. The results of the simulation from comparing for all the materials shows a good agreement with the available literature results. The simulations are verified.

CHAPTER I

1 INTRODUCTION

1.1 Overview

Kuih Loyang is also known as kuih ros, kuih bunga durian, kuih cap, and kuih goyang. It is one type of Malay traditional biscuit which made of rice flour and egg mixture and fried in cooking oil. As an initiative to increase the sweetness of the biscuit, honey is added into the biscuit's mixture which also makes the mixture become stickier compared to other usual mixture. The biscuit that considered to be compatible with various ages has its own taste and appearance. This sweet fried biscuit is shaped like a rose complete with holes to represent layers of petals. Figure 1.1 shows a picture of Kuih Loyang which is ready to be eaten and its rose-shape mold. This biscuit traditionally come originating from India, especially South India (Tamil Nadu and Kerala), where cookies known as 'Achu murukku' or 'Achappam', it was also sweet.

Figure 1.1: Kuih Loyang and its mold

In the past, this sweet biscuit can only be get and enjoyed during the festive season, but now it is easier to get at any given time since it has been commercialized. The crunchy and sweet taste of this biscuit is love by Malaysian. Kuih Loyang has become one of the favorite festival biscuit for Malaysian. Therefore during the festival season like Deepavali, Hari Raya Aidilfitri and Chinese New Year, there will be a huge demand for this biscuit. The price of this biscuit range from RM30 to RM40 per 100 pieces. The way to produce this biscuit is dipping the mold of the biscuit into the biscuit mixture and fried until it turns golden brown in color. The preparation process to make this biscuit is not only complicated but also time-consuming. Even a skillful person sometimes have to face such as imperfect biscuit problem.

Generally, the whole process can be divided into few section which are dipping process in the mixture and also in the frying oil and then finally put into biscuit container. In current technology, the mold is manually controlled by skillful operator. The operator use a metal bar to dipped the mold into cake mixture and transfer the mold to frying container for frying. The entire process is only depending on the operator. The operator able to create a unique motion of mold after the frying process that cause the cake to fall off from the mold rather than stick to the mold. Figure 1.2 shows a picture of the operator handling the mold during the production of the biscuit.

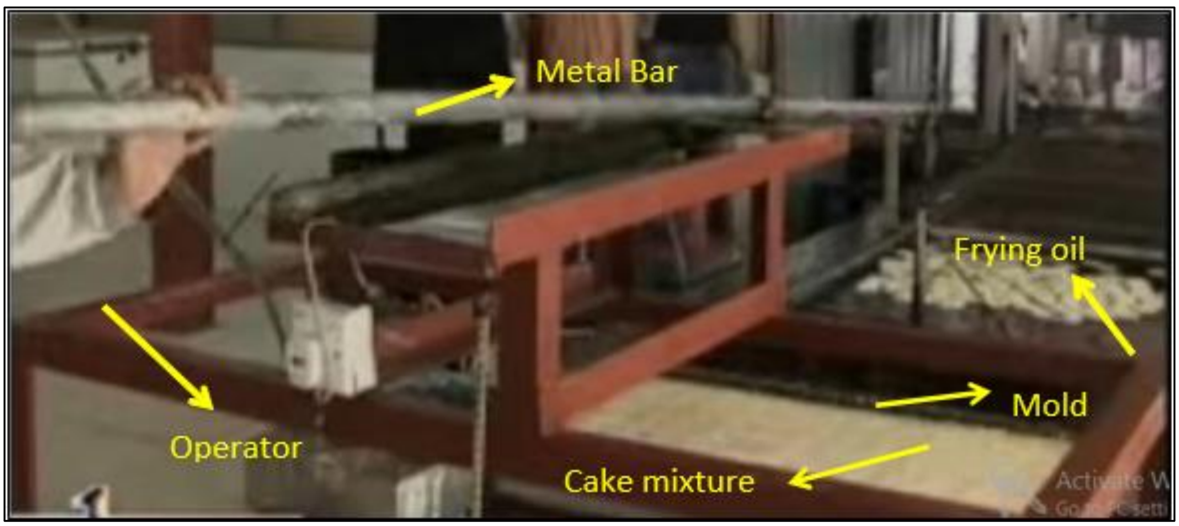


Figure 1.2: Operator handling the mold to produce Kuih Loyang.

The production of this cake is very slow as it has to be dipped and fried batch by batch. The company has to prepare the stock months earlier in order to fulfil the demand. There are some disadvantages if the stocks prepared so early. Sometimes, the Kuih Loyang might loses its tastiness and crunchy. As a solution for the slow production, a semi-automatic machine for dipping process of the biscuit is designed. Unfortunately, the designed machine does not work as effective as the traditional method. The vibration motion of the designed machine produced is not the same as the vibration motion produced when the mold handled by the operator.

1.2 Project background

The unique motion that produced by the mold handled by the operator is a kind of vibration motion. The mold oscillating in order to fall off the fried biscuit from the mold. There are different approaches that can be made to studied vibration motion such as numerical, experiment and simulation [1]. Numerically, the vibration motion is analyzed by calculating parameters using equations or formulas. While experimentally, the analysis process is done by testing the subject normally, in situ testing is done on the site of the experiment. And for simulation, suitable software is used to analyze the vibration motion of sample.

E. Alexandr and I. Alexandr [2] said that FEA method is widely used to solve problems that involve an estimation of natural frequencies of all elements of turbines. ANYSY software is one of the software that suitable to use to analyze the vibration motion of the sample. ANSYS software has high potential in analysis varies in structural, thermal, magnetic and vibration analysis [3]. While SOLIDWORK software can provides good solid modelling. Solid model is prepared by using SOLIDWORK software before transferred to ANSYS software for analysis. By studying the natural frequencies and mode shapes of the motion produced by mold handled by operator, a semi-automated machine that can produced the same motion can be design and the whole production process can be done at faster rate.

1.3 Problem statement

The main problem which needs to be addressed is the sticky mixture of the biscuit's mixture. The mixture of this honey Kuih Loyang is stickier compared to other usual mixture. The company decided to use the same mold rather than design a new one. The size and the weight of the mold is big and heavy. The heavy mold is in size of 10x10 mold which can produce 100 biscuits each time. Currently the Kuih Loyang company handled the mold traditionally which handles by a skillful operator. The production of the biscuits are slow and consume a lot of man power. A semi-automated machine is designed as a solution to increase the production rate. However the designed machine does not work as effective as traditional method. Sometimes, biscuits are attached to the mold after being fried and not fall off from the mold. Other than that, the rose-shape mold detached from the mold frame after the machine is run a few times. The vibration motion of the designed semi-automated machine does not the same with the vibration motion produced when the mold handled by the operator.

1.4 Objectives

The objectives of the project are:

1. To study and analyze the vibration motion of the honey Kuih Loyang mold frame when handled by the operator
2. To investigate the vibration motion produced when the mold frame is made from different materials
3. To help the company in designing a semi-automated dipping machine that can work as effective as traditional method

1.5 Scope of project

The traditional method used is slow and low in efficiency. In order to improve the process, observation must be made on the whole process of traditional method. Identify the steps included in the whole process, type of movement and equipment used to produce the biscuits. The company required that all the biscuits should be able to fall off from the mold and they insists to use their own mold and biscuits' mixture. The whole motion during the production by using the traditional method is observed and studied.

The important parameters such as the weight and the material type of their mold is determined for future improvement for the machine. The measurement of the mold frame is taken for simulation. Natural frequencies and mode shapes are important parameters that should be simulate to study the vibration motion. Simulation is done by using ANSYS software but the solid modelling for the whole frame is done by using SOLIDWORK software. The simulation is analyzed for future improvement of the designed semi-automated machine.

Different materials such as stainless steel, grey cast iron and alloy are set as a new material of the mold. Simulation with the same setup of the original mold is set for the new simulation. The new natural frequencies and mode shapes are collected and compared with the original natural frequencies and mode shapes to study the effect of different material on the vibration motion produced. The collected data and comparison are made for the company guidance in designing a better semi-automated machine for Kuih Loyang production that can work as effective as original method but at faster rate.

CHAPTER II

2 LITERATURE REVIEW

This chapter will discuss about the traditional method of Kuih Loyang production and the motion involved during the process. The motion produced during the whole process which is a vibration motion will be elaborated more in this chapter. Besides that, this chapter will also discuss on methods that exist to analyze a vibration motion.

2.1 Traditional method of Kuih Loyang production

Kuih Loyang is one of the traditional biscuits that remains as one of the favored biscuits until now. Before commercialized, locals made the biscuits as a snacks of a free time. Figure 2.1 shows a picture of a lady making a Kuih Loyang manually. At that time, the production of Kuih Loyang is one by one. The taste of the biscuits are less variety and the color of the biscuits are always the same which is in gold color.

Figure 2.1: A picture of a lady making Kuih Loyang in a small quantity

After the biscuits are commercialized, the production of the biscuits in the food industry grow rapidly. Kuih Loyang are easier to find at any given time after commercialized rather than only on specific festivals. The taste and the color of the biscuits also changed depend on the creativity of makers. Despite the growth of Kuih Loyang industries, the technologies used in the production are quite left behind. Some companies are still using the traditional method in producing Kuih Loyang for certain reason such as the mixture of the biscuits are stickier compared to other usual mixture and the designed semi-automatic machine cannot work as effective as traditional method. As an initiative to produce the biscuits faster, a mold that consists of a lot of rose-shaped mold is designed. Figure 2.2 shows a picture of the mold that has been designed that can work better with a stickier mixture which result for a sweeter and crunchy Kuih Loyang. However, the mold become bigger and heavier. The dipping process of the heavy mold in the biscuit’s mixture and the frying oil is handled by a skillful operator step by step.

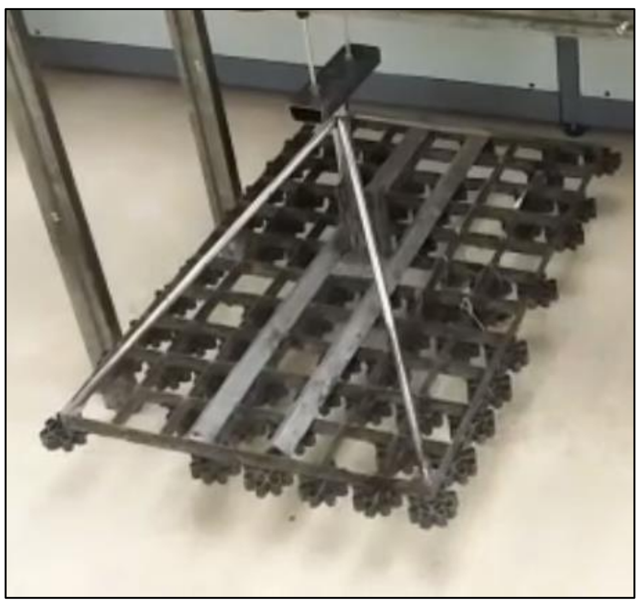


Figure 2.2: The designed mold that consists of 100 rose-shaped mold

2.2 Vibration motion

Vibration is a mechanical phenomenon of oscillation that occur about a point. There are 2 types of vibration which are free and forced vibration. Free vibration is when the object is put in a rest condition and allowed to move without any restraint. While forced vibration is when the system is added with external force while moving which lead to resonance. Resonance is a phenomenon in which the external force frequencies approach the natural frequencies of the system. Resonance can cause the natural frequencies of the system to excite higher, lower or destroyed. Resonance can cause a poor working condition and gave impact on the strength and stability of a system [4]. Vibration can give a desirable and non-desirable effect on the system. Usually, the direct cause of damaged of a mechanical structure is from vibration [5].

Commonly, vibration has 2 measureable quantities which are amplitude and frequency. Amplitude of a vibration represent the strength of the vibration in term of displacement. Frequency of a vibration represent the speed of the oscillation from the stationary point. The number of cycles that vibrating object completes in one second is called frequency. There are many wave form of displayed that used as an illustration for easier understanding of vibration. The most common used is in time domain and frequency domain. Figure 2.3 shows the comparison of a time domain and frequency domain. Time domain graph consist of the amplitude of the vibration in Y-axis versus the time in second in X-axis. While frequency domain consist of the amplitude of the vibration in Y-axis versus the frequency in X-axis.

Natural frequencies and mode shapes are important parameters that should be known in order to study the vibration motion and avoid failure [3]. Each natural frequencies is associated with specific mode shapes. Mode shape is a unique pattern of motion in which part vibrating with fixed natural frequency.

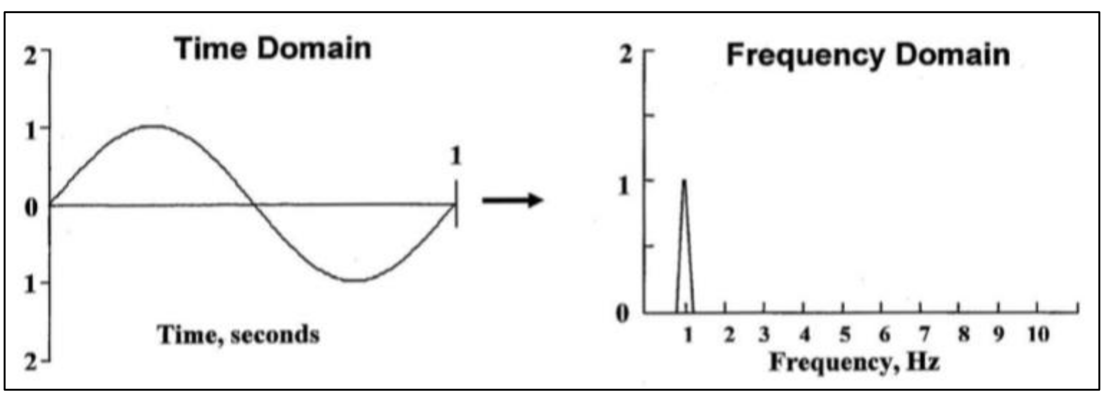


Figure 2.3: Example of a time domain graph and frequency domain graph

2.3 Numerical analysis of vibration

There are 3 different approaches that can be made to study vibration and one of them is by using numerical approach. Nikkah Bahrami, Khoshbayani Arani and Rasekh Saleh [1] presented a modified wave approach in calculating natural frequencies and mode shapes of a non-uniform beams. They claimed that analytical solution for the vibration with variable cross-sections are complex and in many cases are impossible. By using a modified wave approach, the non-uniform beam is divided into several continuous segments for which there exists an exact analytical solution when each segments have uniform cross-section. The method presented has higher accuracy because it has a benefit of calculating all natural frequencies and mode shapes compared to other approximate method which has limited in number of natural frequencies that can be calculated.

In complex structures, non-uniform beams are likely to be used in effort to achieve a better strength and weight distribution and sometimes to satisfy special architectural and functional requirements. In [6], a systematic theoretical development of the vibration response of non-uniform beam is presented with a general elastically restrained boundary conditions. They discovered the relations between the fundamental solutions of the governing fourth order differential equation with variable coefficients, the characteristic equations for the free vibration and Green function for the forced dynamic response. If the exact closed form fundamental solutions of the system are available, then the natural frequency and forced dynamic response can be shown in exact closed form. But if vice versa, a simple and efficient numerical method can be used to find the approximate fundamental solutions and the dynamic response of the system. The present analysis can also be applied to the vibrational analysis of beam with viscous and hysteretic damping.

E. Alexandr and I. Alexandr [2] presented an approach to solve a problems in calculating natural frequencies and mode shapes of a Francis turbine by using coupled of finite and boundary elements method. Methods of estimation of natural frequencies of all elements are very important in designing a turbine. Numerical approaches are made to determine the natural frequencies and mode shapes of the turbine in 2 conditions which are in air and water. The developed method also used for comparison of numerical and experimental parameters of natural vibration for different types of hydraulic machine which is in this case is Kaplan turbine. The results of calculation and comparison for both Francis and Kaplan turbine showed good agreement with experimental data.

2.4 Experimental analysis of vibration

Another approaches that can be made in analyzing a vibration is by using an experimental analysis. To understand the characteristics of the vibration, a device named accelerometer is used. Accelerometer is a device used to measure the acceleration forces. The collected data is analyzed with a software that performs the fast Fourier transform (FFT) analysis. The accelerometer is attached to the observed part, data are collected over time and digitally store as acceleration values in the computer. The analysis of the raw data using the Logger Pro Software is performed to get a set of sine wave frequencies and respective amplitude that create the raw data [7]. Figure 2.4 shows the time domain data collected for speaker of a single frequency source and Figure 2.5 shows the data transformed into frequency spectrum.

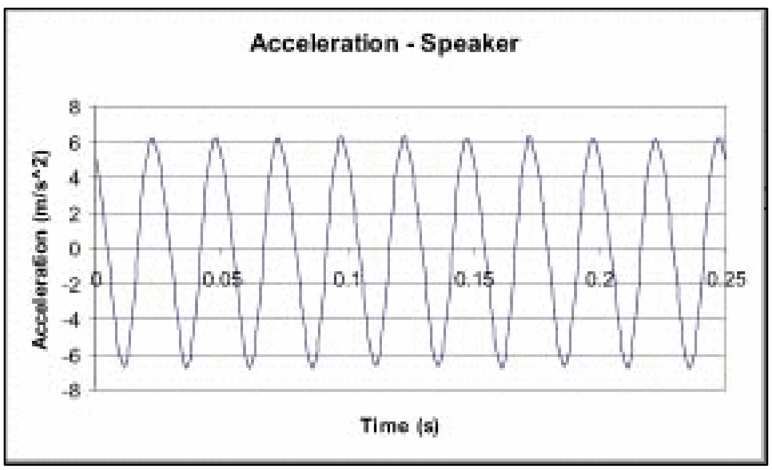


Figure 2.4: Example data for acceleration-time data for speaker of a single frequency source

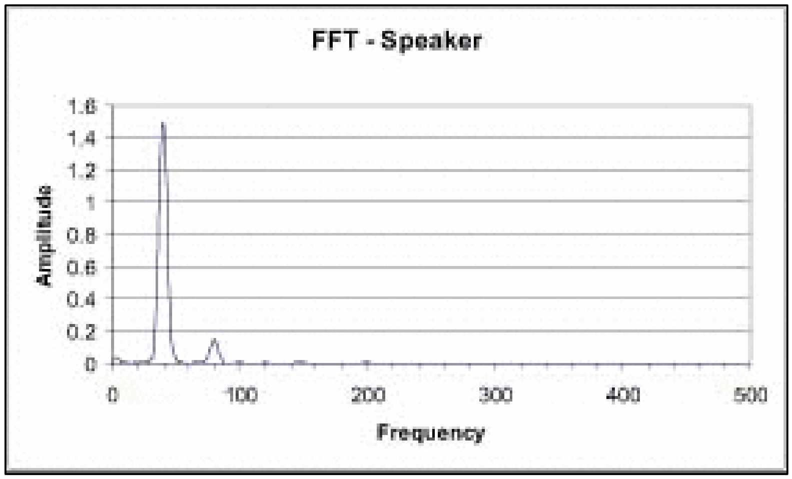


Figure 2.5: Example results of the FFT analysis of the acceleration-time data for speaker of a single frequency source

Accelerometer is widely used in an effort to study vibration and reduce damages of a mechanical structure. In [8], accelerometers are used to do modal testing on the offshore rock lighthouses around the British Isles. Some conventional techniques of forced and ambient vibration testing were used along with some unusual excitation methods. For a big structure like lighthouses, a small hammer is not suitable to produce an excitation forced. Shaker is needed to produce an excitation forced so that the vibration characteristics can be studied. Often, shaker is related with logistic challenges due to the need to deploy heavy shakers that also need mains power or heavy battery capacity.

The main aim of [9] is to reduce the logistics complexity of such modal tests, the study is aiming to evaluate the capacity of lightweight portable wireless MEMS accelerometer for synchronous acceleration measurements at multiple locations on a footbridge and of force generated by a human jumping to generate dynamic response. Instead of using a heavy shakers, a wireless inertial measurement units (IMUs) is carefully located on footbridges and successful to recover ground reaction force (GRFs) in open space conditions on full-scale structures. The developed procedure is useful for testing footbridges with modal frequencies in the range of the first and second harmonics of jumping and which likely to suffer from vibration serviceability problems.

In 2017, Brownjohn, Au and Li et al [10] improved the design of vibration field tests and structural health monitoring projects so that they can produce optimally reliable modal parameters data with pre-defined precision and uncertainty. Forced vibration testing provides the best modal parameters estimate but is technically unfeasible for long span and tall structure which have to rely on less reliable modal parameters from ambient vibration tests. The study showed that with good planning, good results of field vibration testing can be obtained even though with a small set of sensors not of the best quality.

2.5 Simulation analysis of vibration

Other than numerical and experimental approaches, simulation approach also another way of analyzing vibration and it is the most widely used to solve vibration problems [2]. Kumar, Jaiswal, Pandey and Patil [3] had analyzed a vibration motion of a truck transmission housing by using ANSYS 14.5 software based on Finite Element Analysis (FEA) method. They claimed that noise and vibration are the main reason for transmission housing failure. In order to prevent failure, they required to reduce the level of noise and vibration which also required them to find the natural frequency and natural mode shapes. The transmission housing motion is constrained by fixed-fixed motion supported by boundary conditions which lead them constraining the displacement of bolt holes. The analysis results shows that the transmission housing is subjected to axial bending vibration, torsional vibration and axial bending with torsional vibration.

To differentiate the effect of fixed and unfixed constraint, [11] study the relation between dynamic vibrations of transmission and fixed constraint of vehicle frame. The simulation is done for two conditions and each condition material property and boundary condition was same. One condition is set for zero displacement of all bolt holes and another one condition is set for one bolt loosened or unconstraint condition. Simulation results shows that one bolt unconstraint condition reduce the natural frequency.

Other than constraint, different type of materials also give effect on the vibration of a mechanical structures. Kumar, Jaiswal and Jain et al [12] study the effect of mechanical properties of materials on natural frequency and mode shapes of heavy vehicle gearbox transmission casing. A fixed-fixed constraint based boundary condition was used by constraining the connecting bolts hole but different materials which are grey cast iron, structural steel, aluminum alloy and magnesium alloy are taken into discretion. Mechanical properties that are taken into considerations for the modal analysis are elastic modulus, poisons ratio and material density. In the end, they found out that the mechanical properties taken into considerations are directly related with natural frequency and vibration mode shapes.

From all above three research [3,11,12], the step taken in order to study the vibration motion are all the same. The only different is the boundary condition of the simulation. Finite Element Analysis (FEA) methods are widely used in estimating the natural frequencies and mode shapes of the vibration. ANSYS software is used for simulation and a solid modelling software such as SOLIDEDGE is used for modelling. Modal analysis is a technique used to determine, improve and optimize dynamic characteristics of engineering structures [13].

2.6 Verification of data

At the end of the study, verification of data is an important step to ensure the research done is right and the boundary conditions taken into consideration are not wrong. Most of the research are verifying their data by comparing with an experimental data. For an example of numerical analysis, the results of calculations for Francis turbine and Kaplan turbine in [2] showed good agreement with the experimental data. For simulation analysis, in [13] modal analysis using experimental approach is planned to be done in order to verify their study. Other than comparing with an experimental approach data, comparison with available literature results is also another way in verifying research data. It can be observed in [12] that the simulation results are in agreement with available literature results and in [11] that the simulation results were verified with the experimental result available in literature.

2.7 Summary of literature review

Based on the literature study, can be said that there are 3 available approaches in analyzing a vibration motion which are numerical, experimental and simulation analysis. Simulation approaches are the one widely used in solving problems involving vibration motion [2]. Numerical approaches are hard to be done since many boundary conditions that had to be taken into considerations. While experimental analysis involved logistics challenges in conducting the experiment varying from the tools and location requirement [9]. By using simulation, modal analysis type of simulation based on FEA methods are suitable in analyzing a vibration motion. Natural frequencies and mode shapes are important parameters in order to study the vibration motion [3]. ANSYS software is the most common used software for the simulation and any suitable solid modelling software can be used for solid modelling of the mechanical structures. The collected data must be verified either by comparing with experimental data or any literature results available.

CHAPTER III

3 METHODOLOGY

The methodology are fully done based on the knowledge gained from the literature study. Generally, the study of the vibration motion of honey Kuih Loyang mold frame will be simulate by using ANSYS software. The mechanical properties of the mold frame will be varied to study the effect of mechanical properties on the vibration motion. Figure 3.1 shows the flow process of the whole steps taken for the simulation of the mold frame from the measurement of the mold frame to the verification of the data.

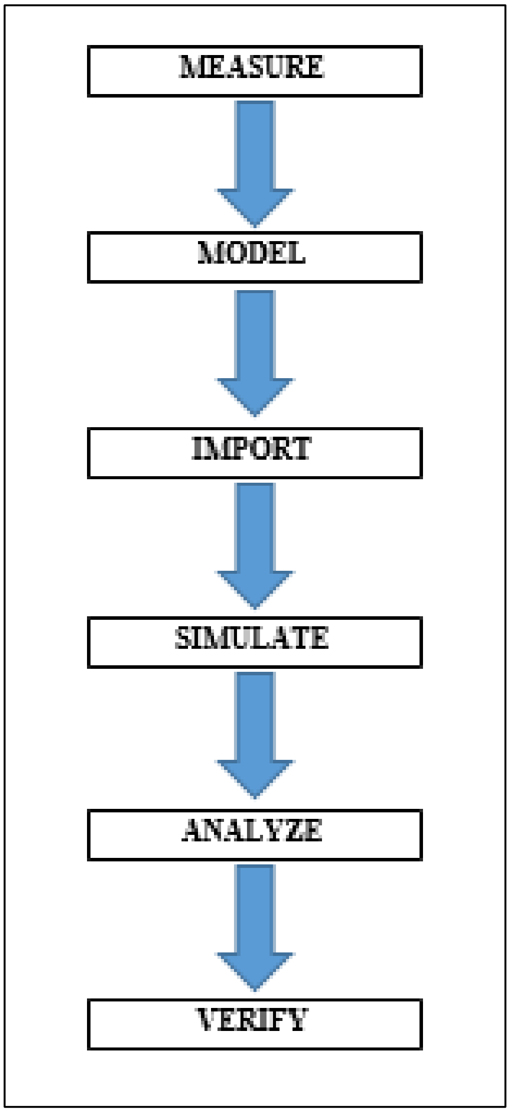


Figure 3.1: Flow process for the whole vibration analysis of the honey Kuih Loyang mold frame

3.1 Establishment of 3D model

The traditional machine model was constructed by using SOLIDWORKS (2014) software. SOLIDWORKS software have good modelling features so it is selected for solid modelling of the traditional machine. Before modelling the traditional machine through software, the measurements of the whole part of the traditional machine is taken. The design model of the traditional machine of honey Kuih Loyang is a complex design which consists of the main mold frame, 100 rose-shaped mold, holding bar, its stand holder and few types of steel support. Figure 3.2 shows the solid modelling of the traditional machine complete with its stand holder which constructed by using SOLIDWORKDS (2014) software.

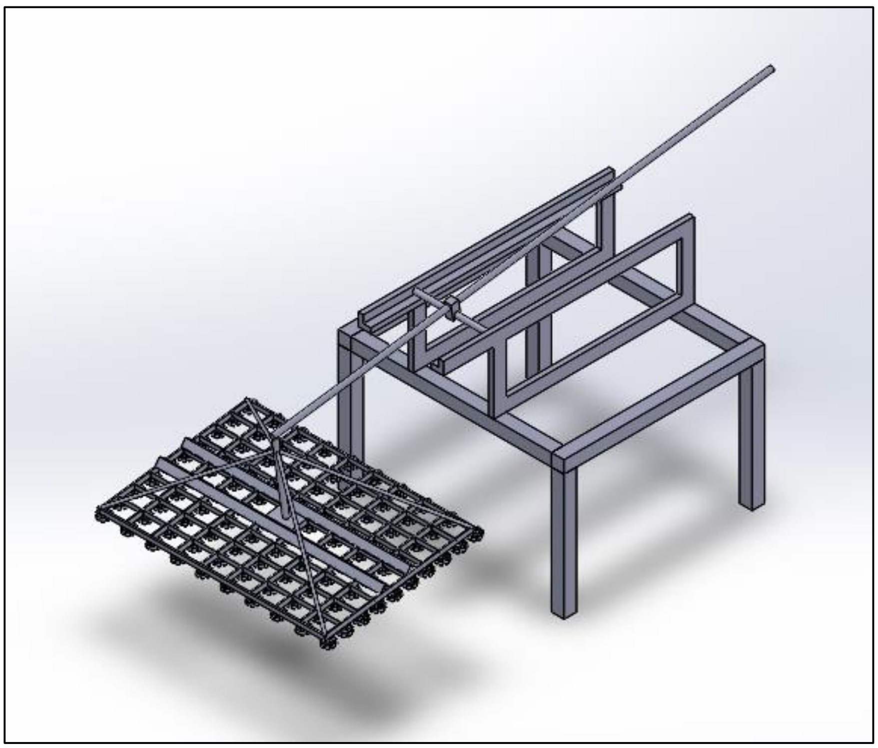


Figure 3.2: The complete solid modelling of the traditional machine of honey Kuih Loyang

The complex model required a lot of Random Access Memory (RAM) of computing device during simulation which leads to a limitation for the simulation process to be done. So necessary simplification is inevitable for the model [5]. To make the results less differ from the actual, a few parts of the traditional machine that does not gave effect on the vibration motion are reduced. Figure 3.3 shows the solid model of the traditional machine after a few parts are reduced to avoid limitation. The model is focusing more on the mold frame.

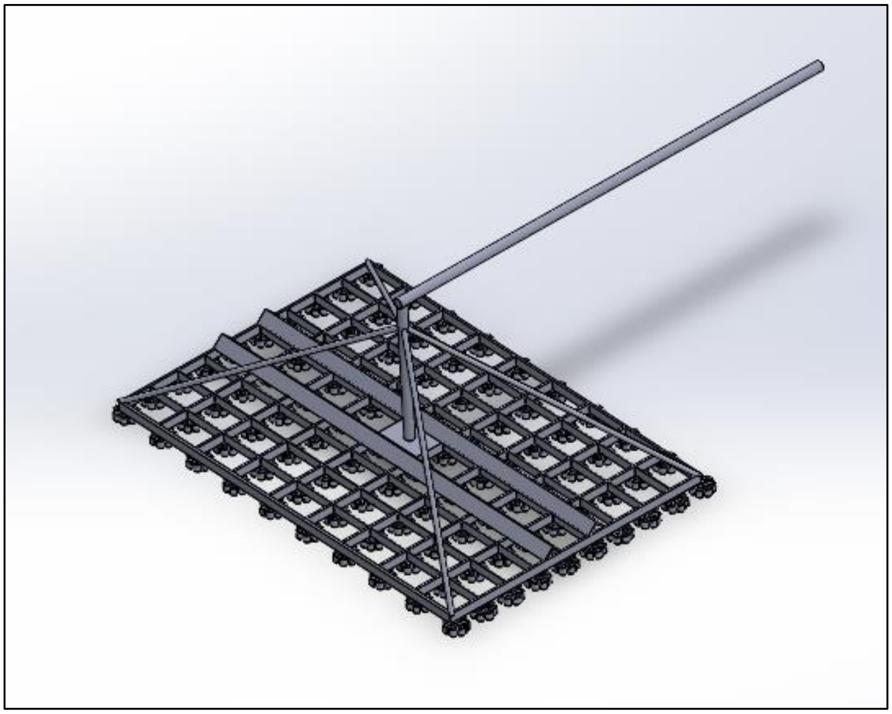


Figure 3.3: The model of the mold frame of honey Kuih Loyang

3.2 Modal analysis of mold frame

For the free vibration analysis, this study used a large commercial finite element software ANSYS to establish the simulation of the model. ANSYS software is a FEA based analysis tool for structures which works on nodes and elements concept. Elements are connected at a point known as node. This process is known as meshing. The fine meshing ensures more accurate results but increases calculation time [11]. Modal type of simulation is chose for the simulation in order to see the natural frequencies and mode shapes that exist for the free vibration of the mold frame. The solid mold frame model in Initial Graphics Exchange Specification (IGES) file is imported to ANSYS software. The complete mesh of the solid model is obtained by using automatic mesh generation with fine size. Figure 3.4 shows the complete mesh of the solid model in ANSYS software which have 325445 nodes and 150489 elements. Modal simulation required to define and apply the boundary conditions. All the support and the holding bar are set as fixed support while the main mold frame and the rose-shaped mold are left for free vibrating. The maximum number of the mode shapes is set to be 10.

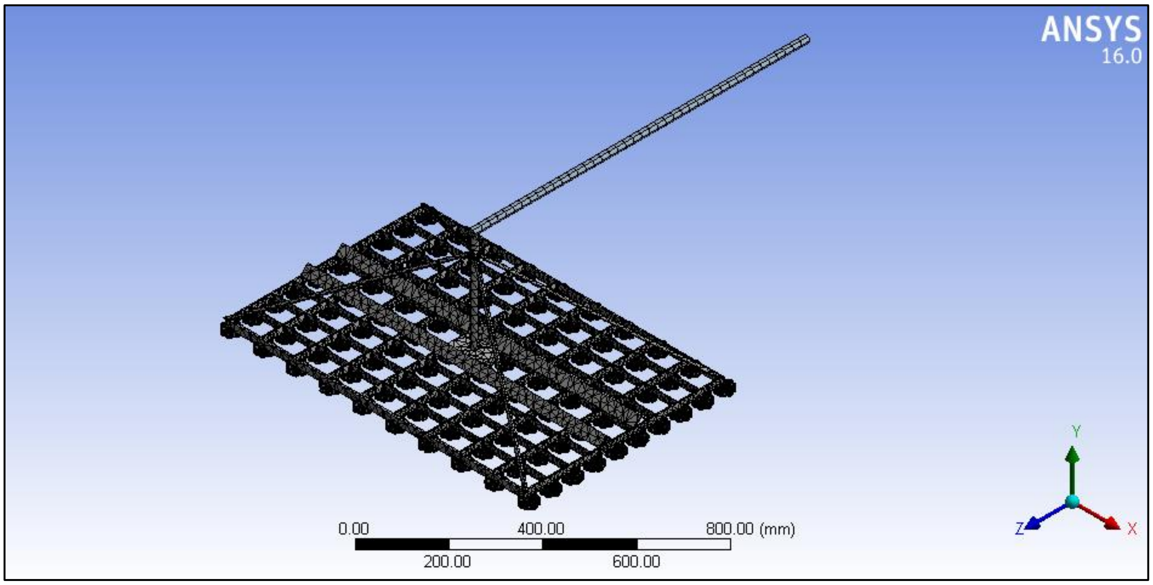


Figure 3.4: The complete meshed of the solid model in ANSYS software

3.3 Mechanical properties of different materials

In order to study the effect of other mechanical properties on the vibration of the mold frame, grey cast iron, aluminum (Al) alloy and magnesium (Mg) alloy are selected for comparison with structural steel. To simulate the same environment for the mold frame, fixed support constraint based boundary condition was used. Figure 3.5 shows the fixed support constraint based boundary condition. The blue color shows the fixed support constraint condition. The meshing of the solid model for all the materials used shows the same amount of nodes and elements. The complete meshing of the model contain 325445 nodes and 150489 elements. Mechanical properties of materials used for the modal analysis are elastic modulus, poisons ratio and material density. Table 3.1 shows the mechanical properties of the materials used including structural steel [12].

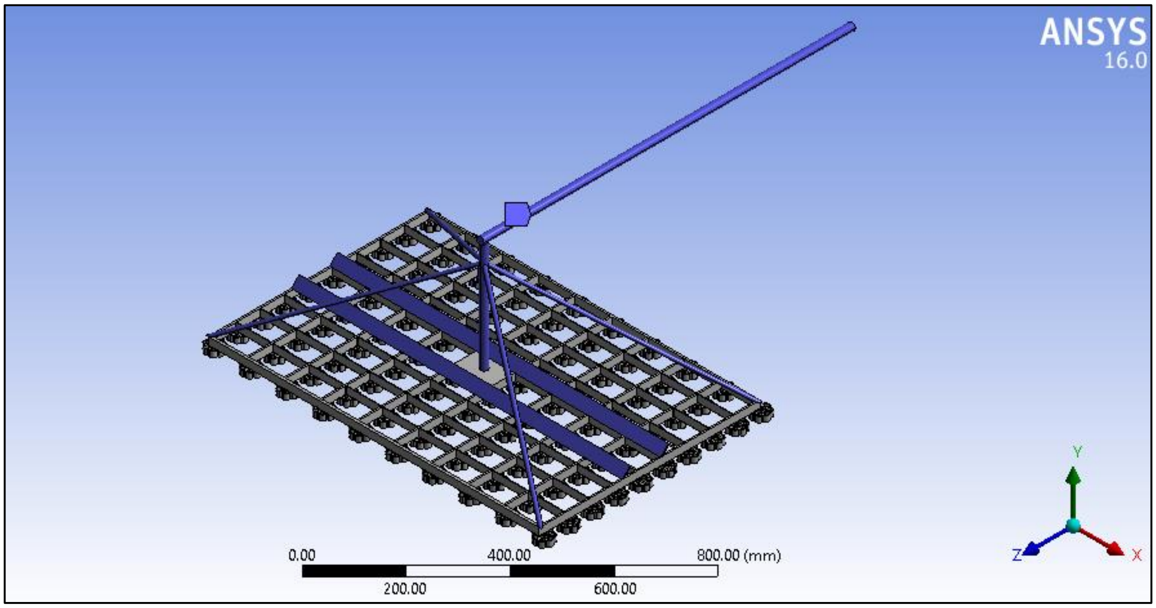


Figure 3.5: Fixed support constraint boundary condition

Table 3.1: The mechanical properties of selected materials

MATERIALS	MECHANICAL PROPERTIES		
	Young's Modulus (Pa)	Poisson's ratio	Density (kgm^-3)
Structural Steel	2.00E+11	0.3	7850
Grey Cast Iron	1.10E+11	0.28	7200
Al Alloy	7.10E+10	0.33	2770
Mg Alloy	4.50E+10	0.35	1800

3.4 Verification of data

This paper concern with the vibration motion of the mold frame. The act of studying the effect of mechanical properties influences on natural frequencies is as an alternative to find other suitable material that can form the mold frame. Other than that, the act of comparing the natural frequencies collected on different materials is as an alternative to verify the simulation. The simulation is verified by compare it with available literature results in [12].

CHAPTER IV

4 RESULTS AND DISCUSSION

4.1 Free vibration analysis of structural steel mold frame

In modal analysis the load is applied by the program automatically [11], by applying the suitable boundary conditions. The simulation was done for structural steel material and for fixed support boundary condition. The FEM based software ANSYS provides the first 10 natural frequencies and mode shapes. The results obtained from the simulation were tabulated. Table 4.1 represents the first 10 natural frequencies and deformation effects for the structural steel mold frame according to their mode shapes. The natural frequencies are ranging from 160Hz to 740Hz. Figure 4.1 shows the pattern of the natural frequencies of the structural steel mold frame against the mode number. The natural frequencies increase as the mode number increase. For mode 9 there is an abrupt increase in frequency value of structural steel mold frame. Figure 4.2 shows the deformation pattern of structural steel mold frame according to their mode number.

Table 4.1: The natural frequency and deformation effects according to their mode number for structural steel mold frame

MODE	NATURAL FREQUENCIES (Hz)	DEFORMATION (mm)
1	165.97	36.836
2	173.74	34.408
3	256.8	33.244
4	285.07	30.849
5	384.84	23.609
6	439.3	31.726
7	442.17	24.799
8	492.38	28.861
9	671.13	26.431
10	740.06	25.023

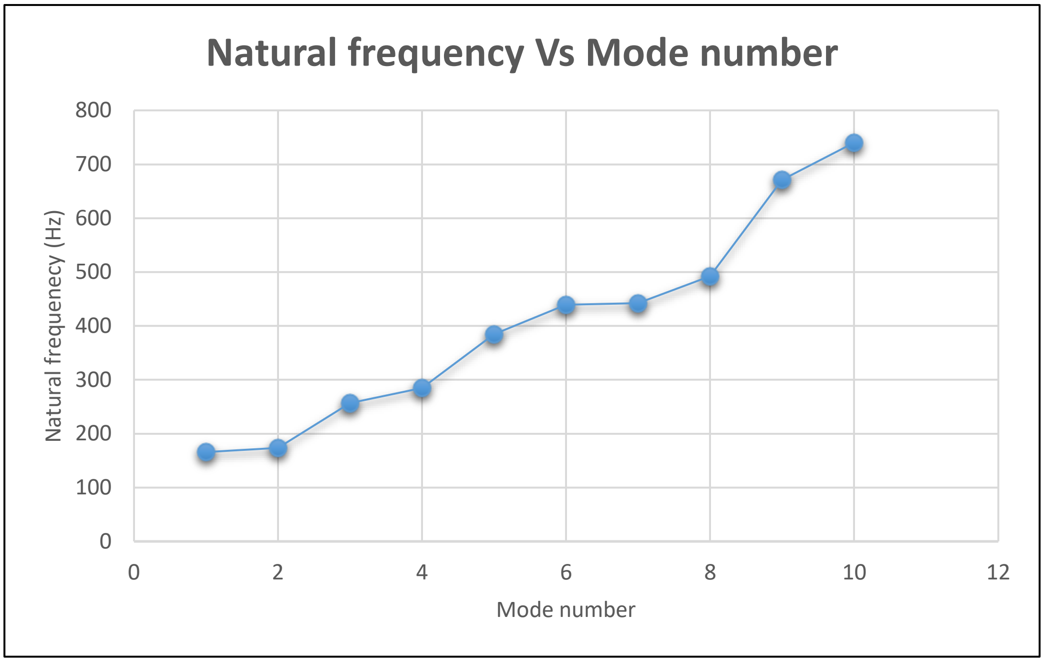


Figure 4.1: The pattern of the natural frequencies of structural steel mold frame corresponding to their mode shapes

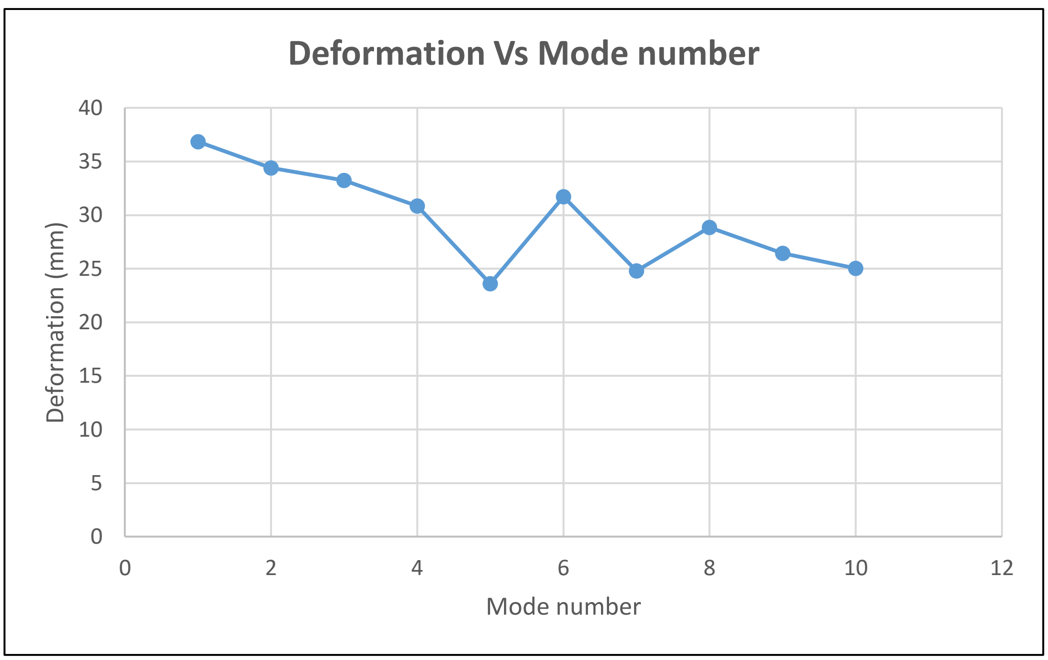
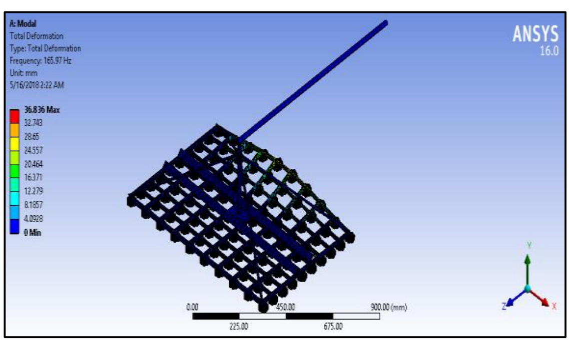


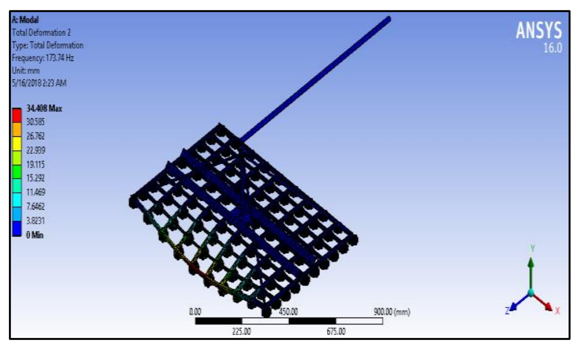
Figure 4.2: The deformation pattern of structural steel mold frame according to its mode number

Every corresponding natural frequencies are followed by mode shapes. Mode shapes are unique pattern of movement that represent how the mechanical structures move with specific natural frequencies during vibrating. From the simulation, the deformation effect of the mold frame is decreasing as the natural frequencies increase except for mode 5 and

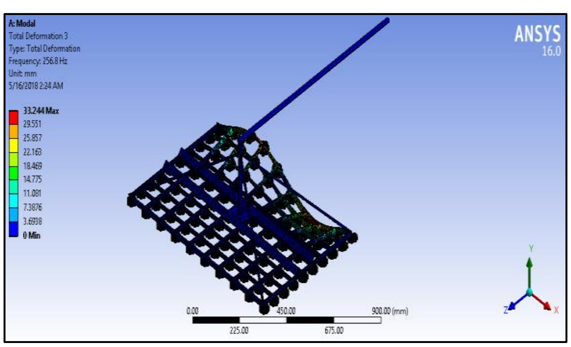
7. Mode 1 shows the highest deformation effect with 36.836mm while mode 5 shows the lowest deformation effect with 23.609mm. From figure 4.3, the mode shapes of the mold frame consists of lateral-torsional and axial bending vibration. This lateral-torsional bending vibration is performed at mode number 1,2,3,4,6,8,9 and 10 while the axial bending vibration is performed at mode number 5 and 7. Both bending vibration happen at front and back side of the mold frame. The average frequency of axial bending vibration is lower compared to average frequency of lateral-torsional bending natural frequency. The average deformation of lateral-torsional bending vibration is higher than the average deformation of axial bending vibration. The lateral-torsional bending vibration causes damage to the mold frame. The area region of the mold frame that effected by the vibration are divided into 2 area, the front part and the backside of the mold frame. The vibration motion are divided by 2 L-shapes steel support that present at the middle of the mold frame. It seem that the 2 L-shaped steel support really give a rigid support on the mold frame structure. Figure 4.3 shows the different mode shapes and corresponding natural frequency of the structural steel mold frame.



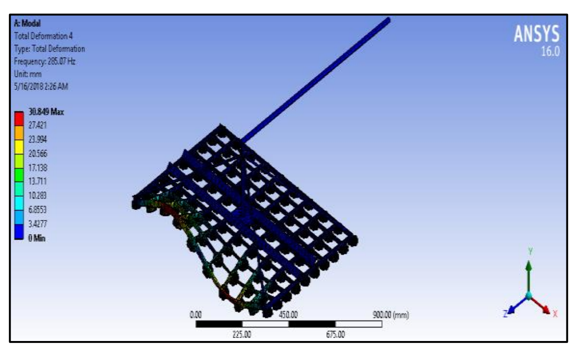
Mode 1 f_1=165.97 Hz



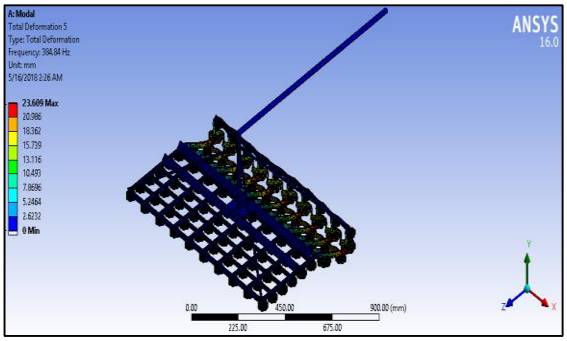
Mode 2 f_2=173.74Hz



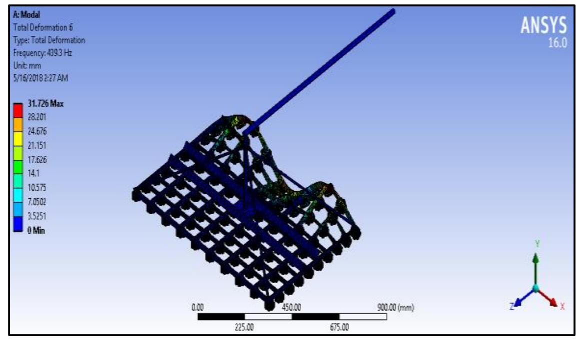
Mode 3 f_3=256.8 Hz



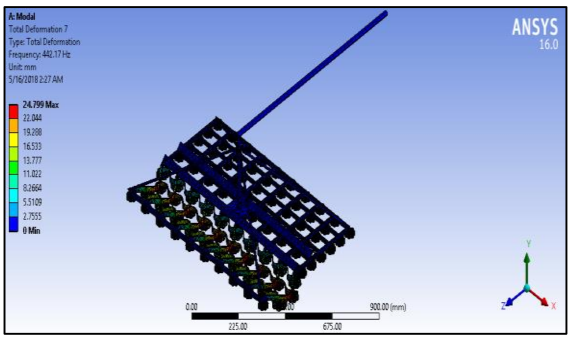
Mode 4 f_4=285.07 Hz



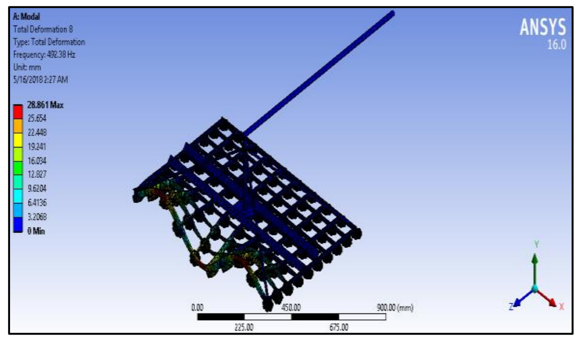
Mode 5 f_5*=384.84 Hz*



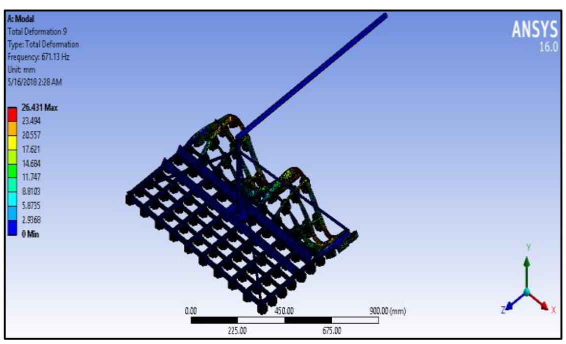
Mode 6 f_6*=439.3 Hz*



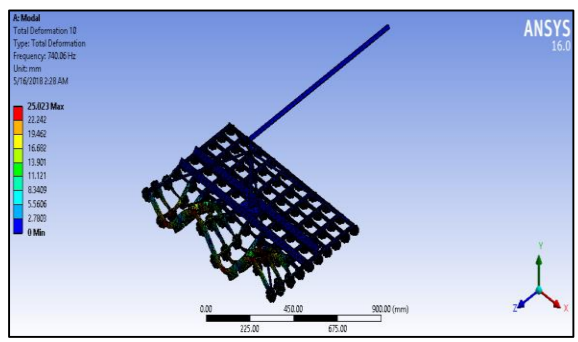
Mode 7 f_7*=442.17 Hz*



Mode 8 f_8*=492.38 Hz*



Mode 9 f_9*=671.13 Hz*



Mode 10 f_{10}*=740.06 Hz*

Figure 4.3: Mode shapes of corresponding natural frequency of structural steel mold frame

4.2 Free vibration analysis of different materials

The simulation was done for grey cast iron, aluminum alloy and magnesium alloy material and for fixed support boundary condition. The results obtained from the simulation were tabulated. Table 4.2 represents the first 10 natural frequencies for all different materials mold frame according to their mode shapes.

Table 4.2: Natural frequency according to their mode number for different materials of mold frame

MODE	NATURAL FREQUENCIES (Hz)			
	STRUCTURAL STEEL	GREY CAST IRON	ALUMINUM ALLOY	MAGNESIUM ALLOY
1	165.97	128.42	166.74	164.9
2	173.74	134.45	174.51	172.56
3	256.8	198.76	257.86	254.92
4	285.07	220.66	286.2	282.91
5	384.84	297.2	388	384.84
6	439.3	340.02	441.08	436.01
7	442.17	341.65	445.47	441.62
8	492.38	381.09	494.38	488.7
9	671.13	519.44	673.87	666.15
10	740.06	572.81	743.06	734.53

Figure 4.4 shows the mode shapes and the corresponding natural frequency of the grey cast iron mold frame. The mechanical properties of grey cast iron are elastic modulus 1.1e11 (Pa). Poisson ratio 0.28 and density $7200(kgm^{-3})$. Based on table 4.2, there are huge differences in term of average natural frequency between structural steel mold frame and grey cast iron mold frame. However, the corresponding mode shapes of grey cast iron mold frame shows no different to the mode shapes of structural steel mold frame. Mode for grey cast iron causes higher deformation compared to structural steel. Mode 1 shows the highest deformation effect with 38.458mm while mode 5 shows the lowest deformation effect with 24.636mm. From figure 4.4, the mode shapes of the grey cast iron mold frame