FLUID STRUCTURAL INTERFACE ANALYSIS OF FORCE EXCITATION ON STRAIGHT PIPELINE

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ABSTRACT

This research focused on fluid structural interface analysis of force excitation on straight pipeline. Fluid Structural Interface (FSI) is the analysis of problem that involves fluid flows interacting with structures or solid body. The pipeline is one of the phenomenon that will contribute to the FSI existence. The pipeline has been use in conveying fluid for more than 100 years ago. Dynamic characteristics of the pipeline will define how pipeline will react towards the force been exerted by the fluid that flow inside it. This thesis aim are to determined the dynamic characteristics and to observe the fluid flow inside the straight pipeline The dynamic characteristics, such as mode shape and natural frequency can be determined by the most fundamental of all dynamics analysis that is modal analysis as well as the simulation done by using ANSYS Software. Furthermore, the response of the pipe wall when there is the fluid flow exist inside the pipe been observed through FSI simulation by ANSYS Software. It can be comprehend that that the dynamic characteristics were obtained to verified the pipe sustainability and the behaviour of the pipe when the fluid flow exist is observed and studied through the FSI simulation. The operating deflection shape application is highly recommended to study the fluid structural interface.

ABSTRAK

Kajian ini memberi tumpuan kepada analisis antara muka cecair struktur pengujaan berkuatkuasa pada saluran paip lurus. Muka Struktur cecair (FSI) adalah analisis masalah yang melibatkan aliran cecair berinteraksi dengan struktur atau badan yang kukuh. Perancangan adalah salah satu fenomena yang akan menyumbang kepada kewujudan FSI ini. Sistem paip telah digunakan dalam cecair menyampaikan lebih daripada 100 tahun yang lalu. Ciri-ciri dinamik sistem paip akan menentukan bagaimana saluran paip akan bertindak balas terhadap pasukan yang telah dikenakan oleh cecair yang mengalir di dalamnya.Matlamat tesis ini adalah untuk menentukan ciri-ciri dinamik dan untuk melihat aliran cecair di dalam saluran paip yang lurus Ciri-ciri dinamik, seperti bentuk mod dan frekuensi semula jadi boleh ditentukan oleh yang paling asas semua analisis dinamik iaitu analisa modal serta simulasi dilakukan dengan menggunakan Perisian ANSYS. Tambahan pula, reaksi dinding paip apabila terdapat aliran cecair wujud di dalam paip diperhatikan melalui simulasi FSI oleh Perisian ANSYS. Ia boleh memahami bahawa ciri-ciri yang dinamik telah diperolehi untuk mengesahkan kemampanan paip dan tingkah laku paip apabila aliran cecair wujud diperhatikan dan dikaji melalui simulasi FSI ini. Pesongan operasi permohonan bentuk amat disyorkan untuk mengkaji struktur muka cecair bagi tujuan mengurangkan kadar kegagalan yang berlaku didalam proses pengaliran.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Figure No. **Page**

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION AND BACKGROUND STUDY

According to Andersen *et al.* (1983) a safe and reliable mode of transportation are pipelines, it can transport fatalities per ton kilometers much lower than any other means of transportation. However, pipelines involve large capital cost, and any pipeline failure will contribute to economic impact because of the cost of repair and the loss of transportation capacity.

Modal analysis is the technique used to determine the structure's vibration characteristics for example natural frequency, mode shapes and mode participates in a given direction. It is the most fundamental of all the dynamic analysis types.

According to Brian and Mark (1999), experimental modal analysis has grown steadily in popularity since the advent of the digital FFT spectrum analyzer in the early 1970's.

1.2 PROBLEM STATEMENT

Piping system is one of the technologies that help to provide the quality of human life. It offers the basic need for humankind such as for washing, petrol station and cooking. As the piping is very important in daily life, it is important to determine the vibration characteristics of the piping system. Piping system be used widely in various industries and has many purpose. As the wrong piping system may cause a lot of waste and might be dangerous too.

The design of the piping system may lead to the efficiency and the pipe endurance towards the load that the pipe will experience. Without the right vibration characteristics the design may fail.

1.3 OBJECTIVE OF PROJECT

1. To determine the dynamic structure for straight pipelines using Modal Analysis.
2. To model the simulation for Fluid Structure Interface.

1.4 SCOPE OF STUDY

Modal Analysis has been a physical phenomenon in the engineering fields. Ignoring the. It could contribute to failure of the several systems. Through the pipeline the Modal Analysis is one of the main factors that will determine the effectiveness of the system. The methods that will be choose is by comparing the result from the software with the experimental which is to determine the load profile for straight pipeline.

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

1. Design the drawing for pipelines using SOLIDWORK.
2. Simulation using ANSYS Software.
3. Do Modal Analysis as experimental method.
4. Compare the result from Modal simulation with Modal Analysis.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Liquid filled pipelines exist in many fields, as in marine engineering, biological engineering, electrical industry, petroleum energy industry, nuclear industry, ships, aircraft device and daily life. In earlier studies, the fluid–structure interaction (FSI) in pipelines was neglected. But it has been widely accepted at present that in dynamic analysis of liquid-filled pipe systems, neglecting FSI may sometimes lead to unrealistic predictions. Therefore, FSI in liquid-filled pipe systems has been investigated widely, and many new results have been obtained over the last three decades.

A model which is widely used considering FSI is the FSI four-equation model, described by a set of coupled linear first- order partial differential equations. In this model, researchers have done a lot of work. It has obtained a solution for the model in time domain by the method of characteristics (MOC) and also presented an analytical solution in time domain for it, and the results shows from the analytical solution were proved by experimental measurements and numerical solutions determined by MOC. However, four-equation model can only consider simple straight pipeline. It has no means when the direction of pipeline changed, such as L-shaped pipe and so on, let alone complex pipeline system (Gongmin and Yanhua, 2011).

2.2 FLUID STRUCTURE INTERFACE OF PIPELINE

It has been a broad application background for problem of vibration on pipeline conveying fluid. Its research results can be directly or indirectly applied in the engineering fields, such as, nuclear plant, aviation, cosmonautics, oil transportation, municipal water supply, heat exchanger devices, etc. However, the coupling effects between fluid and structure often caused pipe vibration and even rupture. Thus, many research scholars are interested on how to get the natural frequency of the pipeline conveying fluid.

According to Chen *et al.* (2007) has stated that Fluid Structure Interaction (FSI) is defined as the analysis of problems that involve fluid flows interacting with structures, or solid bodies. Thus, FSI problems are varying and include large scale engineering problems. When there is a fluid flow that will interact with the solid body, for example in pipeline system the fluid filled is contacting the wall pipe and this will lead to FSI. The importance of knowing the FSI is to avoid any failure that will occur in the future, the force distribution that will also exerted towards the pipeline will also contribute to the failure.

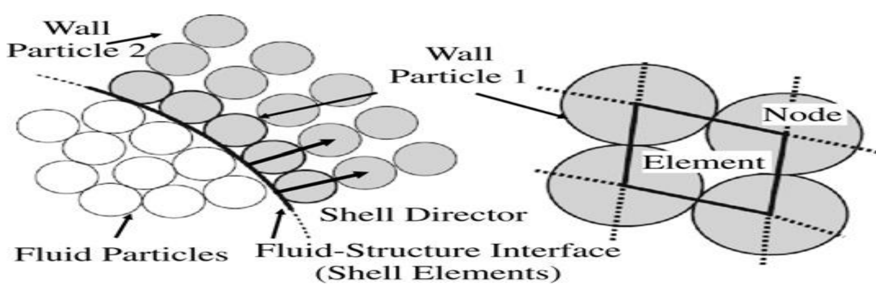


Figure 2.1 Fluid Structure Interface

Source: Jian et al. (2007)

The work of pipeline conveying fluid has been applied to more than 100 years ago, and its main research result is the classic water hammer equations. But it did not consider the inertia and axial motions of pipe. Since the complex systems of pipeline conveying fluid were applied widely in engineering fields, the work of fluid–structure interaction of pipeline conveying fluid has a high development.

According to Skalak *et al*. (1956) was studied the effect of Poisson coupling between the pipe and fluid. They considered the radial and axial motions of pipe in there researches. According to Wiggert *et al.* (1987) later has added the transverse vibration into their previous pipe dynamic equations.

According to Paidoussis and Issid (1974) has stated that from their studies, the transverse vibration equations do not contain any internal fluid-related terms. The transverse vibration equation of pipeline conveying fluid which using Euler–Bernoulli beam model with neglecting the gravity, internal damping and pressurization effects was presented, and it is reflected that the elastic restoring force, centrifugal force, Carioles force and inertia force are the several major factors of affecting the vibration of pipeline conveying fluid. A more general transverse vibration equation with considering the gravity, pressurization effects, material damping and viscous damping was presented.

According to Heinsbroek (1996) transients in fluid-filled pipeline systems are affected by wave propagation phenomena both in the fluid and in the pipe wall. Pressure waves in the fluid, also known as water hammer, interact with axial, bending, shear and tensional stress waves in the pipe wall. The interaction between axial stress waves and fluid pressure waves takes place via the radial expansion and contraction of the pipe wall. Due to the radial expansion and contraction of pipe wall may caused several phenomenon or pressure waves such as water hammer, interact axial, bending, shear and tensional stress waves in the pipe wall.

Keramat *et al.* (2011) who studied that fluid–structure interaction (FSI) due to water hammer in a pipeline which has viscoelastic wall behavior. It has been stated that there are four important items that may affect which may affect classical water-hammer results; there are unsteady friction (UF), column separation (CS), fluid–structure interaction (FSI) and viscoelasticity (VE).

Fluid Structure Interaction (FSI) deals herein with the transfer of momentum and forces between a pipeline and its contained fluid. This matter has been investigated widely for elastic pipes and various experimental and numerical researches have been reported (Wiggert and Tijsseling, 2001). In the numerical researches (most of which are in the time domain as opposed to the frequency domain), solutions based on the Method of Characteristics (MOC), the Finite Element Method (FEM), or a combination of these, are predominant. It has been presented two different procedures for computing FSI effects: full MOC uses MOC for both hydraulic and structural equations and in MOC–FEM the hydraulic equations are solved by the MOC and the structural equations by the FEM. (Lavooij and Tijsseling, 1991)

Acccording to Ahmadi and Keramat (2010), using the MOC–FEM approach, investigated various types of junction coupling. In has been stated by Heinsbroek (1997) compared MOC and FEM for solving the structural beam equations for the pipes and his conclusion for axial vibration was that both full MOC and MOC–FEM are valid methods that give equivalent results. In the current research, these two approaches were selected and developed for transients in pipes with viscoelastic walls.

2.2.1 Pipeline Conveying Fluid with Both Ends Supported

According to Sreejith *et al.* (2004) stated that, when both ends supported and cantilever is different so the equation is taken the dynamic equations are different between the pipes when the pressurization effects were considered. Lately, it has been introduced a finite element formulation to the fully coupled dynamic equations of motion to include the effect of fluid–structure interaction, and it can be applied to a pipeline system used in nuclear reactors. By utilizing Fourier series and Galerkin methods the critical velocity of pipeline conveying fluid was computed. (Chellapilla and Simha, 2007). According to Huang and Liu (2010) the natural frequency of fluid–structure interaction in pipeline conveying fluid was investigated by eliminated element-Galerkin method, and the natural frequency equations with different boundary conditions were obtained.

According to Kubenko *et al.* (2011) has stated that an exact wave solution was used to analyze the original four equation model of pipeline conveying fluid by taking the dynamic effects of fluid into account. It shows that, quasistatic and dynamic were studied by an elastic cylindrical shell of finite length under external static loading are the two qualitatively different instability modes of fluid-conveying pipeline.

It has been established via the finite element method that the dynamic equation of Timoshenko pipeline conveying fluid with considering the fluid–structure interaction and the effect of shear deformation (Zhai and Wu, 2011).

Huang Yi-min *et al.* (2012) has stated that when the fluid–structure interaction give effect, the mechanical model of coupling system exist asymmetric item. Thus, even in a simple case, the coupling analysis is also very complex and has massive difficulties in mathematical decoupling. Most research scholars used different methods to get the dynamic response's approximate solution, such as finite element method, Galerkin method, wave method, and the method of characteristics, transfer matrix method and others; however the analytical solution is less published. It also been studied that a direct method was used to obtain the analytical solution of pipeline conveying fluid with both ends supported. The dynamic equation of pipeline conveying fluid with two variables was obtained by Hamilton's variation principle based on Euler–Bernoulli Beam theory. The separation of variables method was used firstly to change the binary partial differential equation to a monadic partial differential equation. Second, the derived method of Descartes' method or Ferrari's method can be used to dispose the equation after separation. Lastly, the natural frequency equations and the critical flow velocity equations of pipeline conveying fluid with both ends supported were obtained via fixed the boundary conditions.

2.2.2 Fluid-Structure Interaction in Non-rigid Pipeline Systems

Water hammer theory for the fluid coupled with beam theory for the pipe has modeled the fluid-structure interaction in non-rigid pipeline system. Two different beam theories and two different solution methods in the time domain have been studied and compared. The fluid equations are solved by the method of characteristics and the pipe equations are solved by the finite element method in combination with a direct time integration scheme, in the first method. For second method, by using the method of characteristics for all basic equations (fluid and pipe) are solved. The solution methods are applied to a straight pipeline system subjected to axial and lateral impact loads and to a one-elbow pipeline system subjected to a rapid valve closure. In comparing the beam theories, the effects of rotator inertia and shear deformation for practical pipe geometries and loading conditions are investigated. The significance of fluid-structure interaction is demonstrated. The fluid-structure interaction computer code FLUSTRIN, developed by DELFT HYDRAULICS and which solves the acoustic equations using the method of characteristics (fluid) and the finite element method (structure), enables the user to determine dynamic fluid pressures, structural stresses and displacements in a liquid filled pipeline system under transient conditions. To validate FLUSTRIN, experiments are performed in a large scale 3D test facility consisting of a steel pipeline system suspended by wires. Pressure surges are generated by a fast acting shut-off valve. Dynamic pressures, structural displacements and strains (in total 70 signals) are measured under well determined initial and boundary conditions (Heinsbroek, 1996).

2.3 PIPELINE

Pipelines transportation through regions of high seismic activity are either buried under the ground in order to avoid aesthetic and safety problems and to minimize economic and environmental burdening, or constructed on an above-ground supporting system location of the piping system is also will bring effect to the pipeline itself. As pipeline is conveying the high pressure fluid that will contribute to vibration and the outer surrounding of the pipeline might as well vibrates. As which part of the pipeline will be sustain critical force from the fluid that has to be conveyed also have to be determined so that the location can be determine wisely (Baniotopoulos, 1994).

A normal pipeline structure, extended over a long range of ground surface, usually has lots of intermediate constraints. The constraints may vary in type from place to place according to local surface conditions. Too many compatibility conditions that must be satisfied at constraints make the attempt to look for exact solutions extremely difficult. The response analysis of pipeline structures with extensive lengths, therefore, has mainly relied on approximation techniques, such as the finite element method j and the decomposition method t2 in which displacement components are split into quasistatic and a dynamic part (Yong, 1996).

In the seismic activity the pipelines crossing regions are either buried under the ground in order to avoid aesthetic and safety problems and to minimize economic and environmental burdening, or constructed on an above-ground supporting system. The position of the pipelines also will bring the great impact to the system. Thus, the nature will naturally give many kinds of force towards the pipeline from the external that will eventually cause failure too (Baniotopoulos, 1994).

Sreejith *et al.* (1994) have stated that the when the pipes used for transporting the high pressurized fluids often operate undertime-varying conditions that is due to existence of pump and valve operation. These can contribute to vibration problems to the pipe.

Therefore, the accurate analysis of structural vibrations and fluid transients in piping requires formulation of FSI mechanism by which fluid and piping are coupled.

According to Skalak (1956), the modification has been used traditionally in the prediction of water hammer and oscillatory flows in fluid filled lines where pipe motion is insignificant. For valve closure, on a straight pipe has coupled the longitudinal wave equations of the fluid and the pipe to predict the presence of a tension wave in the piping material, which is a precursor to the primary water hammer, or acoustic wave. In this type of analysis pipe motion considered is primarily in the axial direction and is due to elastic elongation have formulated a one-dimensional symmetric system of six equations that included the radial and axial equations of motion of the pipe wall, two constitutive equations for the pipe wall, and the equations of motion and continuity of the liquid.

The method is most suitable for fast transients where the pressure pulse occurs in several milliseconds; the classical water hammer equations are adequate for longer pulses. The effect of Poisson coupling between the pipe wall and the fluid column has been recognized in these studies. However, these studies were limited to transient flows in a single straight reach of pipe.

The high velocity pressurized fluids that been convey using the pipes will contact the wall of the pipes and also many other internal and external forces due the vibrations that has to be determine. As for the study the FSI may involved. Many studies have been involve in analyzing the coupled between the fluid and the pipe wall. However, these studies are limited to transient flows in a single straight reach of pipe (Walker and Phillips, 1977).

The figure below shows the example of the pipeline systems which involved the straight pipelines and elbow pipelines that consists of many valve closure excitations. These pipelines systems have been analyzed to see the pressure history through that valve.

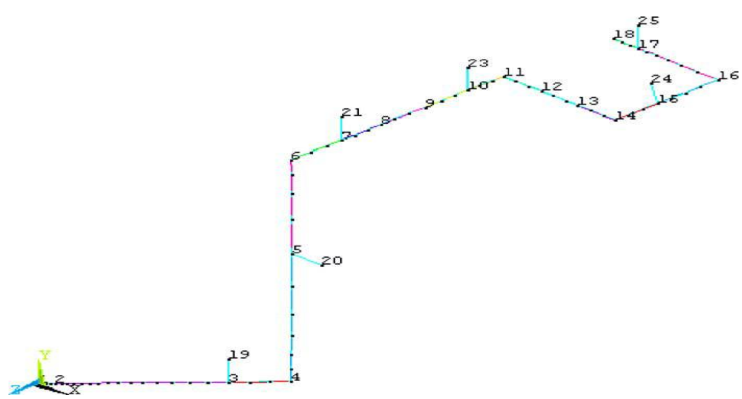


Figure 2.2 Secondary Sodium piping geometry

Source: Sreejith et al. (2003)

The calculated pressure–time histories of the system near the valve and bends without FSI effect and considering FSI are shown in figure below

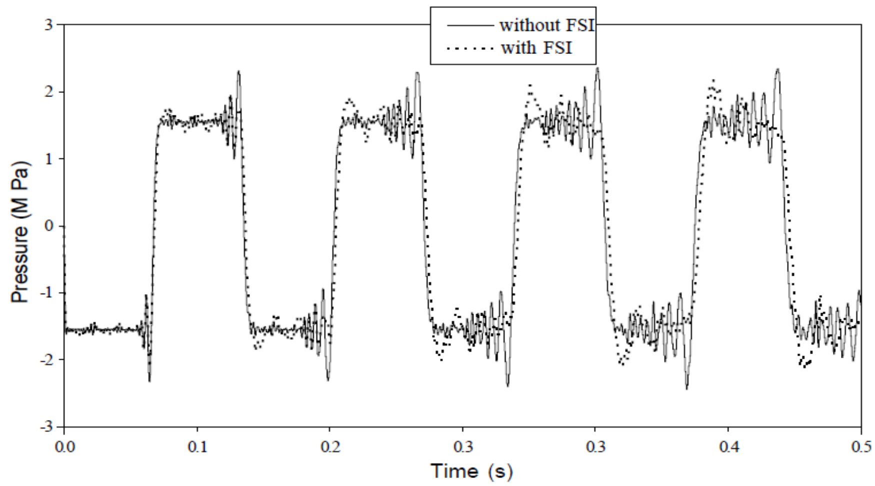


Figure 2.3: Pressure history, near valve location, for valve closure excitation.

Source: Sreejith et al. (2003)

According to Barry *et al*. (2012), there are three options have been implemented for constraint of the dependent node in the local axial directions of the pipeline:

i. Pipeline attached defined speed: The dependent nodes progress along the pipeline at a speed dictated by a predefined field and the length of the path segments. Any applied or inertial forces on the dependent nodes in the axial pipeline directions are transmitted to the pipeline. For example, in a riser (vertical pipe) the weight of the fluid is carried by the pipe.

ii. Ground attached defined speed: The dependent nodes progress along the pipeline at a speed dictated by a predefined field and the length of the path segments. Any applied or inertial forces on the dependent nodes in the axial pipeline directions are transmitted to ground. For example, in a riser the weight of the fluid is not carried by the pipe but is reacted to ground.

iii. Axially free: No constraints are applied in the pipeline axial direction and the dependent nodes can slide freely along the pipe.

2.4 OPERATING DEFLECTION SHAPE (ODS)

Richardson (1997) stated that an ODS has been defined as the deflection of a structure at a particular frequency. Moreover, an ODS can be known more generally as any forced motion of two or more points on a structure. Thus, the motion of two or more points defines a shape. Stated differently, a shape is the motion of one point relative to all others. Motion is a vector quantity, which means that it has location and direction associated with it. This is also called a Degree Of Freedom, or DOF. An ODS can be defined from any forced motion, either at a moment in time, or at a specific frequency. Thus, an ODS can be obtained from different types of time domain responses, be they random, impulsive, or sinusoidal. An ODS can also be obtained from many different types of frequency domain measurements, including linear spectra (FFTs), cross and auto power spectra, FRFs (Frequency Response Functions), transmissibility, and a special type of measurement called an ODS FRF.

Furthermore, mode shapes and operating "deflection" shapes are related to one another. The fact that one is always measured in order to obtain the other. However, they are quite different from one another in a number of ways.

2.5 MODAL ANALYSIS

Modal analysis is known as the study of the dynamic characteristics on a mechanical structure according to Dave *et al.* (1984). The dynamic characteristics of a mechanical structure such as natural frequencies and mode shape can be determined by doing modal analysis on the mechanical structure. Thus, for complex system assembles, the modal parameter can be identified by using the method of experimental modal analysis. But, all the modes of interest can be determined accurately depends on several factors involved, there are including how and where the excitation is applied, how and where measurement data is acquired and how boundary condition or other environmental condition are simulated (Andrew and Mark, 1998).

In order to study the dynamic behavior of structures, modal testing has become a well known means of study. Bruel and Kjaer (1945) has committed in supporting high quality modal testing systems for solving problems and for optimizing resources in the engineering community.

Bruel and Kjaer (1945) have stated that in modal testing, there are number of different measurement and analysis techniques of varying sophistication. The choice of techniques depends on;

I. The type and size of the structure
II. The extent to which the structure behaves linearity
III. What the test will be use for
IV. The time and resources available

2.5.1 Impact Testing

Impact testing is one of the modal testing methods that could save time, easy to be applied and conserve cost too, when finding the modes of machines and structures. There are equipments required to perform impact test;

i. An impact hammer with a load cell attached to its head to measure the input force.
ii. An accelerometer to measure the response acceleration at a fixed point and direction.
iii. A 2 or 4 channel FFT analyzer to compute FRF's.

iv. Post- processing modal software for identifying modal parameters and displaying the mode shapes in animation.

The size of the hammers are depends on the structures that need to be analyzed, different size of structures will need different size of hammer that is compatible to the structures itself (Brian and Mark, 1999)

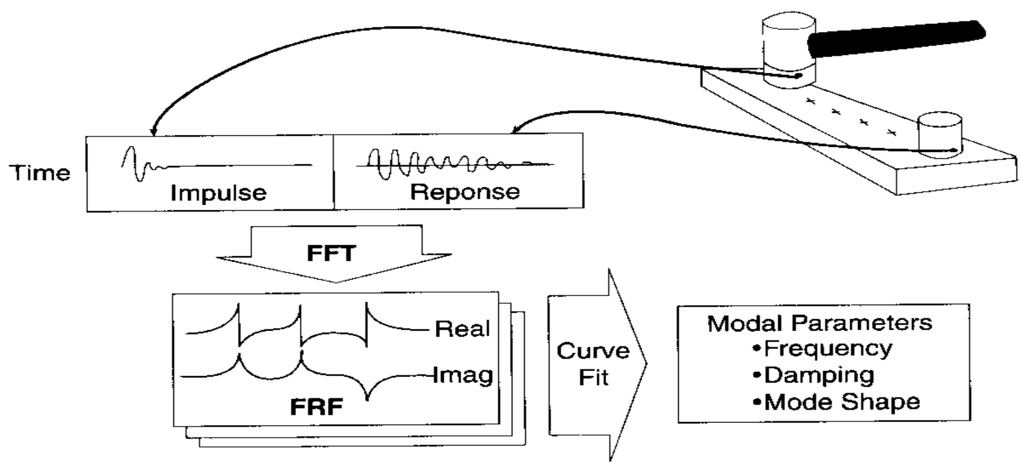


Figure 2.4: Impact Testing.

Source: Brian and Mark (1999)

2.5.2 Frequency Response Function (FRF)

According to Brian and Mark (1999), the Frequency Response Function (FRF) is the measurement that the function is to isolate the inherent dynamic properties of mechanical structures. From a set of FRF, the experimental modal parameter can be obtain such as, mode shape, frequency and damping.

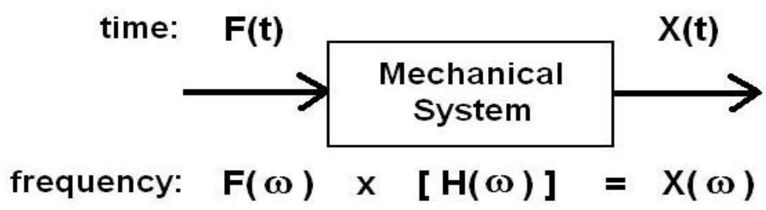
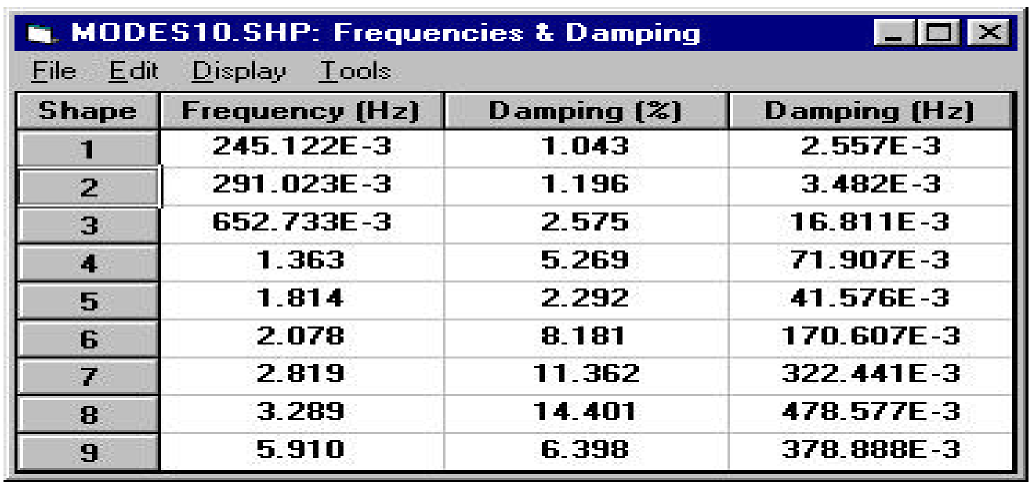


Figure 2.5; Block Diagram of a FRF

Source: Brian and Mark (1999)


MODES10.SHP: Frequencies & Damping

File Edit Display Tools

Shape	Frequency (Hz)	Damping (%)	Damping (Hz)
1	245.122E-3	1.043	2.557E-3
2	291.023E-3	1.196	3.482E-3
3	652.733E-3	2.575	16.811E-3
4	1.363	5.269	71.907E-3
5	1.814	2.292	41.576E-3
6	2.078	8.181	170.607E-3
7	2.819	11.362	322.441E-3
8	3.289	14.401	478.577E-3
9	5.910	6.398	378.888E-3

Figure 2.6: Frequency & Damping Estimates of Fundamental Modes

Source: Andrew and Mark (1998)

2.5.3 Accelerometer sensors

Accelerometer sensors used to measure acceleration experienced by the structure that is directly attached to it. Much application can be use by using accelerometer; the most common commercial application is impact sensors (Brian, 2000). For impact detection, it is for determine severity of impact, or to log when an impact has occurred.