A STUDY ON DETERMINATION MOMENT OF INERTIA OF REGULAR-SHAPED BODY USING TRIFILAR TORSIONAL PENDULUM

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ABSTRACT

The aim of this project is to study of the Trifilar Torsional Pendulum for the experimental determination of moment of inertia for a regular-shaped body. This is seen as a method that can be improved by adding computer communication ability to this apparatus. Given a rigid body and its mass, this method allows measuring moment of inertia with only a simple single test. Software is implanted in this experiment in order to record the data and calculate all the parameters that needed for determine the moment of inertia. The motion of the pendulum is recorded by accelerometer and transferred to the computer using microcontroller which is arduino. Then the transferred data will be displayed and calculated by the LabView. In this paper, only one type of the test object is used which is solid bar of cylinder. For the final step is comparison of the experimental result with the theoretical result.

ABSTRAK

Tujuan projek ini adalah untuk mengkaji bandul kilasan Trifilar untuk menentukan eksperimen momen inersia bagi sebuah objek yang pejal. Kaedah ini dilihat sebagai satu kaedah yang boleh diperbaiki dengan menambah keupayaan komunikasi antara computer dan alat eksperimen ini. Hanya dengan satu objek yang pejal, kaedah ini membolehkan pengukuran momen inersia dengan hanya satu ujian yang mudah. Perisian turut dilaksanakan dalam eksperiman ini untuk merekod data dan mengira semua parameter yang diperlukan oleh pecutan dan dipindahkan ke komputer melalui Arduino. Kemudian data yang dipindahkan akan dipaparkan dan dikira oleh perisian LabView. Dalam projek ini, hanya satu jenis objek yang akan digunakan iaitu bar pepejal silinder. Setiap parameter bar pepejal silinder direkodkan seperti berat dan juga saiz objek tersebut. Untuk langkah terakhir bagi eksperimen ini adalah perbandingan keputusan akhir eksperimen dengan keputusan teori untuk menunjukkan kebekersanan kaedah eksperimen ini.

TABLE OF CONTENTS

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Inertia properties are an important thing that used for designing the dynamic performance of a mechanical system. Mostly, this properties is been used in automotive field for vehicle comfort. Inertia properties of a body consist of the mass, the center of gravity, moment of inertia and product of inertia. Where, the moment of inertia and the product of inertia are the components of inertia tensor.

Moment of inertia is a property of a body that defines its resistance to a change in angular velocity about an axis of rotation. It is how rotation of body is affected by Newton's law of inertia. In this context, inertia refers to resistance to change. Moment of inertia applies to an extended body which the mass is constrained to rotate around an axis. It arises as a combination of mass and geometry in the study of the movement of continuous body, or assembly of particles, or known as rigid body dynamic.

Moment of inertia is the rotational equivalent of mass. Mass describes an object's resistance to change in velocity. The easiest way to think it is pushing the object in a straight line. The smaller the object's mass, the faster it will rotates. Moment of inertia is the equivalent concept, only for rotation. Imagine an object at rest. Then, a twisting force (a torque) is applied to it. The smaller the object's moment of inertia, the faster it will rotates. It is a measure of mass is distributed in a body with respect to a center of rotation. Higher inertia means mass is distributed further away from its center of rotation. Units are Mass x Distance^2. Higher inertia means more difficult to start, or stop rotating, similar to linear acceleration.

1.2 PROJECT BACKGROUND

Method identification of inertia properties of a regular-shaped body especially divided into three categories: calculation method based on three-dimensional solid model, model parameter identification method and conventional experiment method such as Torsional pendulum and Multi-cable pendulum method.

In this project, we will focus more on three-dimensional and conventional experiment method in order to decide which is have the highest accuracy method in determining the moment of inertia of a rigid body. For three-dimensional method we will used Solidwork as our medium for simulation method and combination of Trifilar Torsional Pendulum (TTP) method for conventional experiment method. Element that will be defined is moment of inertia of a rigid body.

Moment of inertia is related in many ways for example in driving. Inertia is the resistance to change the direction or velocity of a body, either at rest or in motion. In this case, it is related in changing the heading, or direction of a vehicle; that is, changing from straight ahead driving to a turn. The importance of inertia and weight distribution as they related to driving is they affect the amount of time required to make a transition from straight to turning or vice versa.

1.3 PROBLEM STATEMENT

Finding an accurate moment of inertia is an important task for many engineers. For example, just knowing the moment of inertia of a car is enough to predict or estimate whether the can tipped over by maneuvers on ground. Moment of inertia is controlling the stability of a rigid body in turning motion. The higher the moment of inertia, the higher the difficulty of a body to move or stop in rotation.

It is a huge task to accomplish the three-dimensional solid modeling of an irregular-shaped body with all details; therefore the calculation method based on the CAD model is seldom used. The methodology based on experiment modal analysis is simple in positioning postures of the body when identifying the center of gravity. But with this method too many parameters need to be identified, the principle is too complicate, the error analysis is difficult to define and the hardware requirement to undergo this experiment is quite expensive.

Therefore, this project will prove a method which is Trifilar Torsional Pendulum to determine moment of inertia interface with computer. The experiment only consists of simple procedure. The result of the experiment will be compared in order to prove the efficiency of this method.

1.4 PROJECT OBJECTIVE

Research objective set the purpose and focus the research on what we are going to achieve by this project. It is similarly to the purpose or aim for the project.

These are the objectives that must be achieved from this research, there are:

I. To study on Trifilar Torsional Pendulum method to determine the moment of inertia of a rigid body.
II. To design a test rig for doing the experiment.
III. To design and analyze the moment of inertia of a rigid body through the LabView.
IV. To compare the results data of each method in order to determine the highest accuracy of finding moment of inertia of complex system.

1.5 PROJECT SCOPE

This project is about to design a test rig for a method on finding the moment of inertia of a complex system. There is also simulation method in order to compare with this experiment method. Thus, the focuses of this project are stated below:

I. Modeling and building a test rig for doing the experiment Trifilar Torsional Pendulum in order to define the moment of inertia.

II. Modeling and simulating a rigid body in Solidwork in order to define the moment of inertia.

III. Collect the results data from these two different methods.

IV. Comparing and displaying the data of two different methods in order to determine the highest accuracy among these methods.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Moment of inertia is one of the elements of inertia properties. Inertia properties are set of ten inertia parameters of a rigid body which are the mass, the three coordinates of center of mass and the six components of the central inertia tensor which is required in different applications. In many applications the analysis of the motion especially for a complex system is required. An accurate analysis can be performed only if the inertia properties of each rigid body of the system are known. These parameters are very important for example in ground vehicles such as car; it has been proved that small errors in the inertia properties can produce non-negligible errors in the computed dynamic responses.

In addition, the extra diagonal component of the inertia tensor is affect the comfort and stability of cars. Same as the air vehicles such as planes, the knowledge of the inertia tensor and the orientation of the principal axes of inertia is importance for flight controls and performance. Due to difficulties to obtain such an accurate data, very often people just roughly estimate and depend on the accuracy of the simulation.

In this project, we focus on the finding moment of inertia. Moment of inertia is one of the inertial properties elements. Moment of inertia is defines the resistance to change in angular velocity about at axis or rotation. All rotating objects have an axis to rotate. Some objects require more force to change the speed of this rotation than others. Those that will change their rotational speed easily have a low moment of inertia, while those that are difficult to change have a high moment of inertia.

There are a few methods that have been used in industry applications. Focusing on the classification of inertia parameters and the moment of inertia identification method, there are two main categories of identification method. There are:

- Static methods
- Dynamic methods.

Static methods only allow for the identification of a subset of rigid body parameters that cover only overall mass and the center of gravity location. In the last two decades the researches have devoted particular attention to the *dynamic methods* which this method can be classified according to the type of domain of the input measure data for example *time domain* and *frequency domain.*

The earliest *time domain methods* to mention are the classical pendulum method which can effectively determine some of rigid body parameters and there are still used. However, this methods for a complex structure estimation may no easy as the pendulum required a special skills and can lead to large experimental errors. Therefore, some researches nowadays have developed variation of time domain methods upon the vibration test data. One of these evolutions is a systematic method which calculates the rigid body inertia properties through time domain test data of six-axes shaking table system. The advantage of this method is direct evaluation of the data without the necessity of a transformation into frequency domain. But if the system does not behave like a rigid body in the exited frequency range, low past filtering of the test data must be performed.

Meanwhile, *Frequency domain methods* (FDM) is possible to separate the rigid body from the elastic system behavior, even the first elastic natural is very low. The FDM can be divided into three groups which are: *Inertia Restraint Methods* (IRM), *Methods of Direct Physical Parameter Identification* (MDPI) and *Modal Methods* (MM).

2.2 INERTIA PARAMETERS IDENTIFICATION METHODS

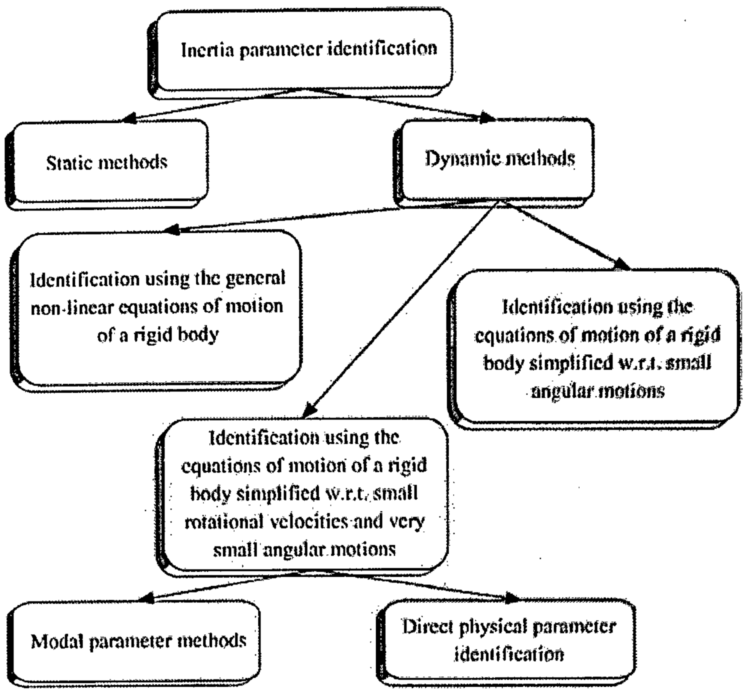


Figure 2.1: Classification of inertia parameter identification methods

2.2.1 Static Method

Weighing method

The determination of weigh using standard weigh scale. For this test, the weight of the specimen is determined and subsequently converted to mass. The weighing method is a very safe method and approved in industry applications. No limitation with respect to size and shape of the mechanical system and also only a basic skill needed to do this method.

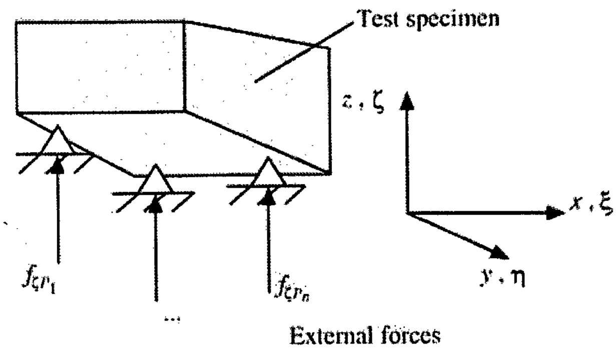


Figure 2.2: Principle of weighing method

Interface force measurement method

The mass and center of gravity may be identified if static forces are measured. The use of multiple scale weight scales represents a special case of this method. It is a generalization of weighing method. This method can be used generally for determine mass and center of gravity of mechanical system. In order to determine all coordinates center of gravity two test are necessary. The interface force measurement method is a safe method that is already approved in industrial application. Practically, no limitations exist with respect to size and shape of the mechanical system under investigation. The skill requirements for the testing personal are basic knowledge of the procedure and software is needed.

Suspension method

This method is start by determining center of gravity. Then the value of center of gravity is placed in an equation in order to determine all 10 inertia parameters including moment of inertia. The suspension method yields the center of gravity location of the test specimen as geometric information. The test specimen is suspended at several points by a wire. The intersection point of all wire lines depicts the center of gravity location. In order to identify the center of gravity location at least two suspensions is needed.

The suspension method is safe and approved by in industry. Skills requirement for handling this method is basic. Only hardware needed is a suspension wire and no software needed.

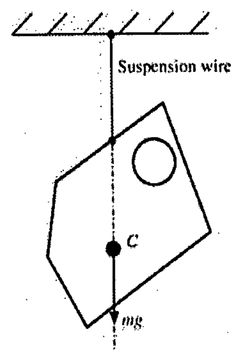


Figure 2.3: Principle of suspension

Balancing method

Balancing method also yields the center of gravity of rigid body. Balancing machines are in principle horizontal beam supported by knife edges. The mass of rigid body should be known through weights or load cell. The center of gravity can be determined if the mas of the rigid body is known. Since the lever arms of the counter forces are known, the coordinates of the center of gravity can be calculated if the mass of the test specimen is known. In order to identify all coordinates including moment of inertia, all the coordinates of center of gravity should undergo three tests.

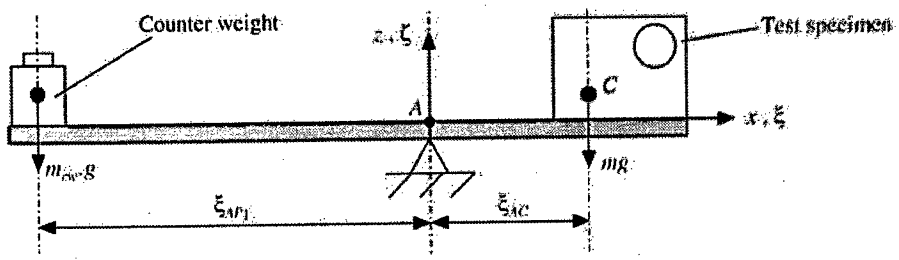


Figure 2.4: Principle of balancing method

2.2.2 Dynamic Method

Multi-filar pendulum method

Multi-filar pendulum method consist two types that are bifilar pendulum method and trifilar pendulum method. The difference between these two methods is the number of wire of pendulum that used. The test specimen is suspended by those wires. It then acts as a rotational pendulum while then restoring torque is generated by gravitation.

By having a rigid and its mass, this method allows measuring the center of gravity location and the inertia tensor during a single test. The motion of the pendulum and the forces acting on the system are recorded and the inertia properties are identified by a proper mathematical procedure based on a least square estimation. After the body is positioned on the test rig, the full identification procedure takes less than 10 minutes. This method is very application because the natural frequencies and the accelerations that involved are low. This method can be used to test a huge scale of mass for example used for analysis cars body.

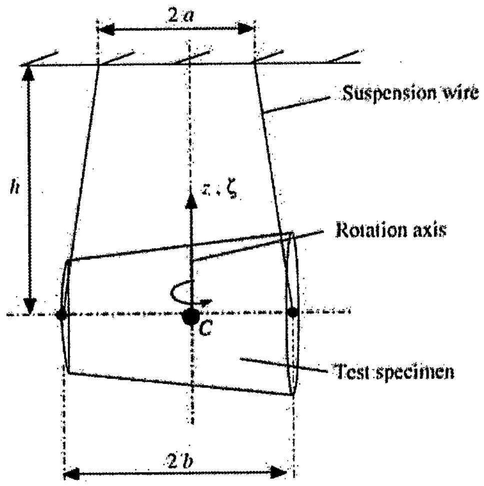


Figure 2.5: Principle of bifilar pendulum method

Suspension wires or a special test rig including measurement, signal processing and computer units are needed for this method. This method also has been approved in industry application. The accuracy of the result is quiet high using this method.

Torsional pendulum method

The moment of inertia about a specific rotation axis can be identified using torsional pendulum method. The test specimen oscillates about the rotation axis while the restoring torque is generated by springs. The moment of inertia with respect to the rotation axis can be calculated from the measured oscillation frequency if the rotational spring stiffness is known (absolute method).

If a known mass is added to the test specimen the moment of inertia of the test specimen can be calculated using the measured oscillation frequencies of two tests performed with the unmodified and modified test specimen (relative method). This method also been approved in industry application.

An oscillating table and no or simple software for a moment of inertia identification is needed. The skill requirement personal is basic while the time requirement to undergo this method is high since only one moment of inertia can be identified simultaneously.

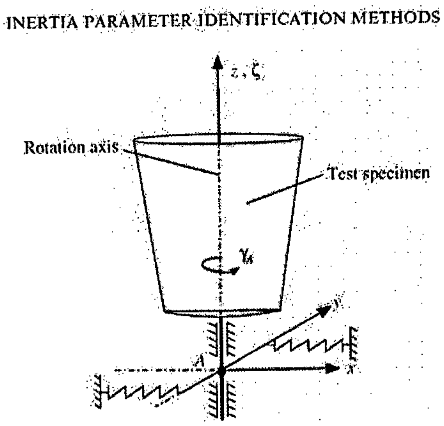


Figure 2.6: Principle of torsional pendulum method

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

The methodologies for the determining the moment of inertia with the concept of Trifilar Torsional Pendulum which will be improvised with computer communication with the test rig. This is will be a better method compare to conventional method which we need a stopwatch to measure the period oscillation. Every object has a moment of inertia which, in general, will be different about every axis which is possible to rotate the object. If the axis of the rotation is chosen so that it passes through the center of gravity of the object, then the moment of inertia will be found as a point on an ellipsoid. If three, orthogonal axes of rotation will be representing a point on the ellipsoid. The resulting inertia tensor is the familiar, fully-coupled inertia matrix containing moment of inertia and product of inertia.

3.1.1 Theory Moment Of Inertia

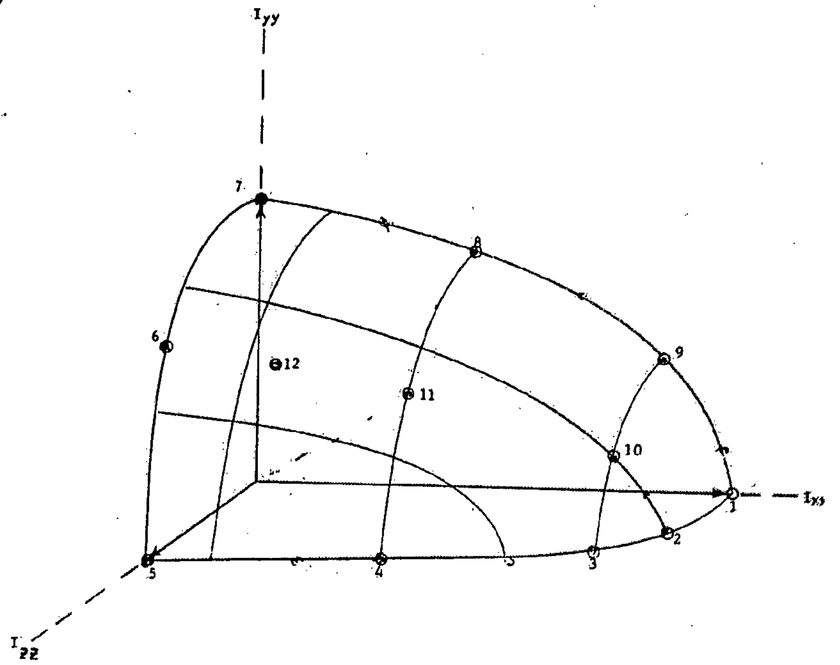
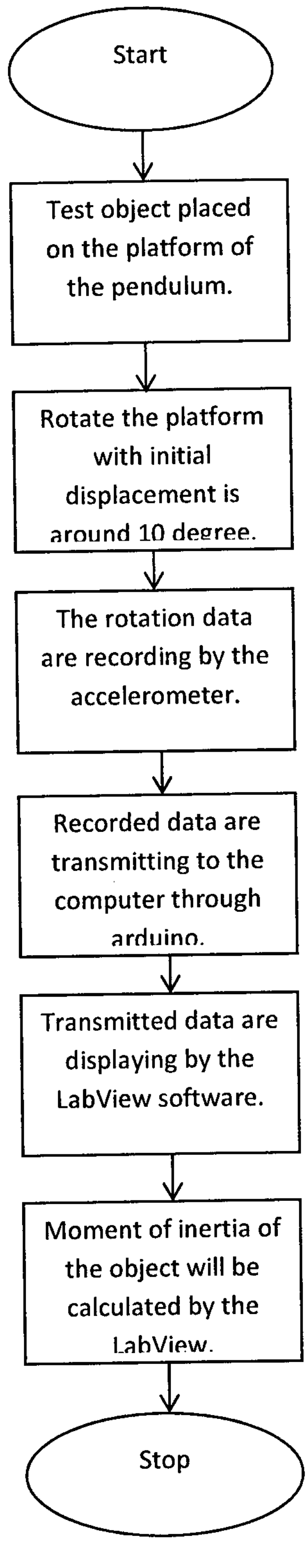


Figure 3.1: Surface of the inertia ellipsoid

Figure 3.1 is a representation of the surface of the inertia ellipsoid. If the inertia properties of a three dimensional object, such as an automotive powertrain needs to be estimated, a significant number of points can be determined on the surface of the ellipsoid by rotating the object about different axes. Once the significant number of points is determined, the data can be used in a parameter estimation procedure where the characteristics of the ellipsoid are determined. Once the characteristics of the inertia ellipsoid are known, the principal axis and the moment of inertia about these axes can be estimated accurately.

3.2 FLOW CHART OF PROJECT



3.3 HARDWARE

AccelerometerSN-IMU5D-LC

An accelerometer will be used in this experiment. This sensor is a low cost 5 degree of freedom Inertial Measurement Unit (IMU) which incorporates 2-Axis Gyro and a 3-Axis accelerometer. This sensor is designed to keep the cost as low as possible without sacrificing the performance. Gyro and accelerometer with the analog output are sued to make interfacing more easily. It is also incorporates a low-noise amplifier to increase the sensitivity of the gyro sensor.

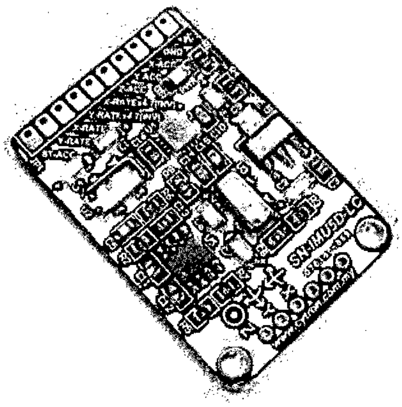


Figure 3.2: 5DOF IMU

Arduino

This experiment also will used arduino as a communication device between the test rig and computer. Arduino is an open-sourced electronics prototyping platform based on flexible, easy-to-use hardware and software. It is intended for artist, designers, hobbyists and anyone interested in creating interactive objective or environment. Arduino can sense the environment by receiving the input from variety of sensors and can affects its surroundings by controlling lights, motors, and other actuators. This microcontroller on the board is programmed using Arduino programming language (based on Wiring) and the Arduino development environment (based on Processing). Arduino projects can be stand-alone or they can communicate with the software running on computer.

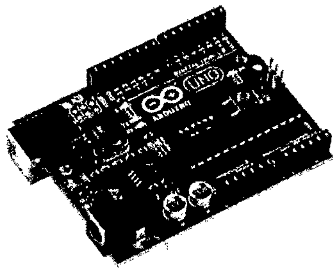


Figure 3.3: Arduino Uno

3.4 SOFTWARE

LabView (short for Laboratory Virtual Instrument Engineering Workbench) is a system-design platform and development for a visual programming language and National Instrument. This software is commonly used for data acquisition, instrument control, and industrial automation on a variety of platform including Windows. This software used the graphical language which is named "G". Besides that, LabView is support for thousand hardware devices including microcontroller named arduino. This software will be used as data acquisition and arduino as the communication device between hardware and computer.

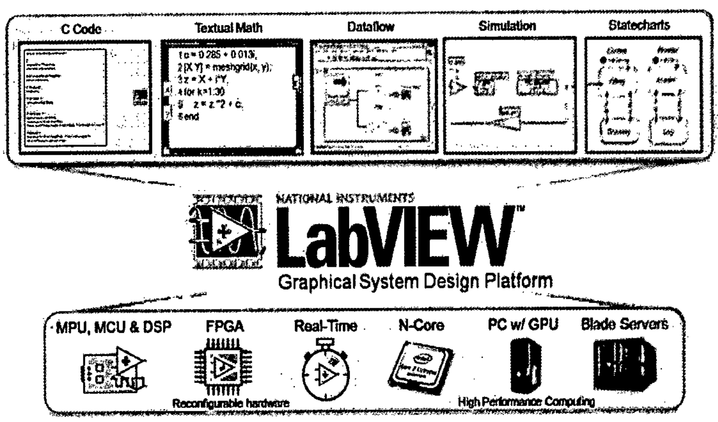


Figure 3.4:

3.5 EXPERIMENT SETUP

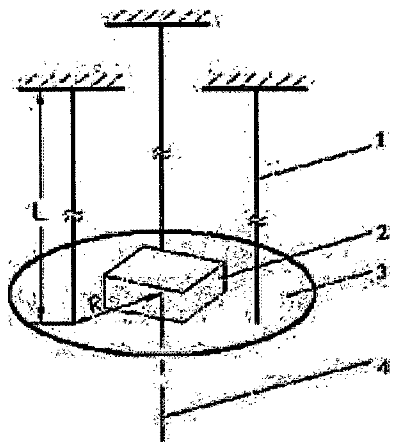


Figure 3.5: Trifilar Pendulum test rig

Figure above will be the model for this experiment test rig. This pendulum consists of a hanging plate that attached with three strings with constant radius from the center of the plate. A solid object that have selected will be placed on the plate with the center of the object is coincident with the center of the rotational of trifilar pendulum. The trifilar pendulum acts like a single degree of freedom torsional pendulum. The single degree of freedom characteristics of the trifilar pendulum can be used to determine the moment of inertia.

Procedure

The procedure involves the following steps:

- The natural frequency of the trifilar pendulum can be determined experimentally by measuring the period of oscillation of the pendulum. The period of the trifilar pendulum can be measured accurately by using accelerometer that mounted tangentially on the platform of the pendulum.
- Choose a part that is regular in dimension and material so that a reasonable analytical prediction of the moment of inertia is possible. The part or the object will be placed on the platform. The initial displacement of the pendulum should be small.

- The object is loaded onto the torsional pendulum, taking care to locate the center of gravity of the object coincident with the center of rotation of the trifilar pendulum.
- The natural frequency of the trifilar pendulum can again be estimated experimentally by measuring the period of oscillation of the pendulum. The period of oscillation of the pendulum will be directly recorded by LabView based on the input that recorded by accelerometer.
- Using theoretical equations for the trifilar pendulum, the moment of inertia will be measured from the measured data (natural frequency of the trifilar pendulum)
- Repeat the test for the case where the point/axis does not pass through the center of gravity.

3.6 CONCLUSION

In this project, comparison between three-dimensional calculation methods with Trifilar Torsional Pendulum method is made in order to define the most accurate method. Expectation have been made for the TTP method which are center of gravity can be easily obtained from this method, thereby it will improving the measurement efficiency. Besides that, by using tri-coordinate measuring instrument, the measurement accuracy is significantly enhanced. In addition, the data processing technique can be distinguish the experimental error and help the user to select better data for calculation center of gravity.