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Balancing of Rotating Masses using MATLAB Simulation

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Abstract: ***Any link or member that is in pure rotation can theoretically be perfectly balanced to eliminate all shaking forces and shaking moments. It is accepted to design practice to balance all rotating members in a machine unless shaking forces are desired. A rotating member can be balanced either statistically or dynamically. A static balance is a subset of dynamic balance. To achieve complete balance requires that dynamic balancing to be done. In some cases, static balancing can be an acceptable substitute for dynamic balancing and is generally easier to do. However the vagaries of production tolerances guarantee that there will be some small unbalance in each part. Thus a balancing procedure will have to be applied to each part after manufacture. The amount and location of any imbalance can be measured quite accurately and compensated by adding or removing material in correct locations. In this project, an investigation is carried out in the mathematics of determining and designing a state of static and dynamic balances in rotating elements by using MATLAB programme.***
Keywords: ***Static Balancing, Dynamic Balancing, Rotating Elements, MATLAB Programme***

I. INTRODUCTION

All rotating components experience significant quality and performance improvements if balanced. Balancing is the pre-requisite of minimization of vibration, noise and bearing wear of rotating bodies. It is accomplished by reducing the centrifugal forces (i.e., aligning the principal inertia axis with the geometric axis of rotation) through the addition or removal of material at a suitable radius.

The present paper aims at developing a system to study static & dynamic balancing and to execute tests under different parameters to find the solutions for balancing a system. Balance or imbalance in a system is dependent on the states of working forces and moments on the body. Any unresolved force or moment, results in imbalance in the system. Balance in a rotating body is related to concepts like mass center, center of gravity, axis of rotation, principal axis of inertia, centrifugal forces. The mass center is the point about which the total mass of a rigid body is equally distributed. A force vector that acts through this point will move the body in a straight line according to Newton’s second law of motion, with no rotation shown in Fig. 1.

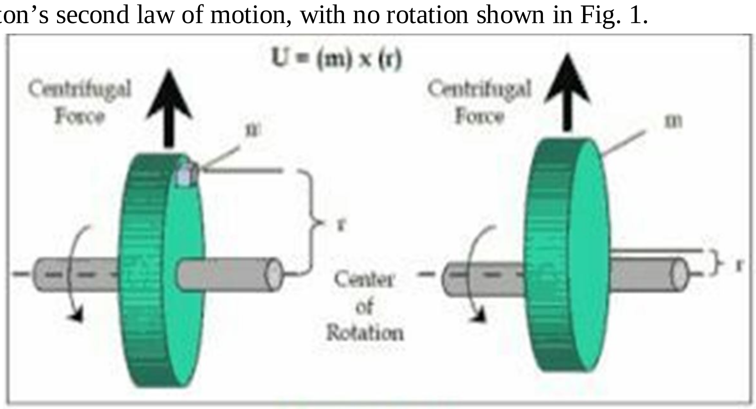
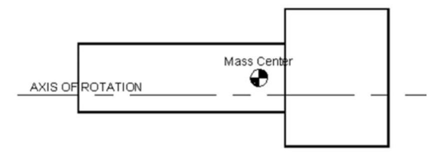


Fig. 1 Centrifugal Forces

The location of the mass center and the principal inertia axes are determined by the distribution of mass within the part. Imbalance exists when the axis of rotation is not coincident with a principal inertia axis. The rotating imbalance observed can be classified as:

1) Static Imbalance
2) Couple Imbalance
3) Dynamic Imbalance
4) Quasi – Static Imbalance

Table 1 Classification of rotating imbalances

<table>
<tr><td>Static Imbalance: A condition of static imbalance exists when the mass center does not lie on the axis of rotation. Static imbalance is also known as Force Imbalance. As defined, static imbalance is an ideal condition, with an additional condition that the axis of rotation be parallel to the central principal axis – no couple imbalance. When static balance exists, the part can spin on the axis with no inertial forces (i.e., no centrifugal force).</td><td>
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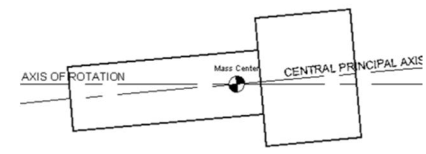
<tr><td>Couple Imbalance: It is a specific condition that exists when the central principal axis of inertia is not parallel with the axis of rotation. Couple imbalance appears as the off-diagonal terms in the inertia matrix for a rigid body. This is an indication that the inertial axes are not aligned with the principal axes. It can be expressed as a vector with direction perpendicular to the plane of the radius vector and the couple arm vector. This is the axis about which the couple acts and is 90^0 or normal to the plane in which balance correction should be made</td><td>
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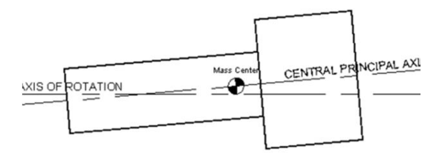
<tr><td>Dynamic Imbalance: It is also referred to as two plane imbalance, indicating that correction is required in two planes to fully eliminate dynamic imbalance. A two plane balance specification is normally expressed in terms of w*r per plane and must include the axial location of the correction planes to be complete. Dynamic imbalance captures the entire imbalance which exists in a rotor. This type of imbalance can only be measured on a rotating balancer since it includes couple imbalance. The condition for dynamic imbalance - $\sum F \neq 0$ and $\sum M \neq 0$</td><td>
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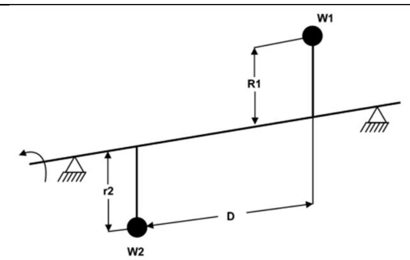
<tr><td>Quasi – Static Imbalance: A special form of dynamic imbalance in which the static and couple imbalance vectors lie in the same plane. The central principal axis intersects the axis of rotation, but the mass center does not lie on the axis of rotation. This is the case where an otherwise balanced rotor is altered (weight added or removed) in a plane some distance from the mass center. The alteration creates a static imbalance as well as a couple imbalances. Conversely, a rotor with quasi-static imbalance can be balanced with a single correction of the right magnitude in the appropriate plane</td><td>
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A. Balancing of Rotating Masses

We have already discussed, that whenever a certain mass is attached to a rotating shaft, it exerts some centrifugal force, whose effect is to bend the shaft and to produce vibrations in it. In order to prevent the effect of centrifugal force, another mass is attached to the opposite side of the shaft, at such a position so as to balance the effect of the centrifugal force of the first mass. This is done in such a way that the centrifugal force of both the masses is made to be equal and opposite. The process of providing the second mass in order to counteract the effect of the centrifugal force of the first mass, is called balancing of rotating masses

The following cases are important from the subject point of view:

1) Balancing of a single rotating mass by a single mass rotating in the same plane.
2) Balancing of a single rotating mass by two masses rotating in different planes.
3) Balancing of different masses rotating in the same plane.
4) Balancing of different masses rotating in different planes.

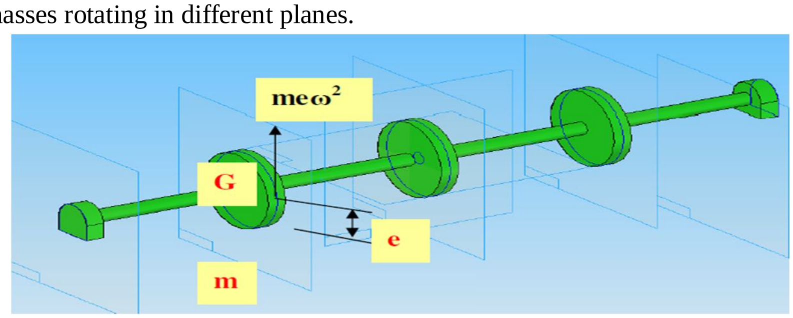

Fig. 2 Balancing of a Single Rotating Mass By a Single Mass Rotating in the Same Plane

Applications use rotating balancing to maintain their characters properly Engine crank shaft, Automobile wheel, Grinding wheels, Steam turbines and etc.

II. LITERATURE REVIEW

Imbalance related vibrations account for approximately eighty percent of all vibration problems in rotating equipment. It can cause excessive vibration, short bearing life and noise.

Föppl (1895) formulated and solved the equations governing the response of a single mass undamped rotor system [1]. His analysis showed that at speeds significantly higher than that the critical speed, the rotor would turn about its mass center; his undamped analysis predicted infinite response at the critical speed and a transient response at the critical speed frequency.

Jeffcott analyzed the fundamental nature of the response of a single mass flexible rotor to imbalance in 1919 [2]. Proper instrumentation to experimentally verify these results would not exist for years.

Rieger references electronic and stroboscopic measurements first developed in the 1930's [3]. Even before Jeffcott explained the fundamental response of rotor systems, balancing machines were in use.

Everett (in 1987), experimentally verified a two plane balancing technique for rigid and flexible rotors operating at constant speed based upon influence co-efficient extends the single-plane four run balancing procedure to two planes [5].

DeSmidt explain (in 2009), the valuable insights for balancing of flexible rotor systems operating at supercritical speeds [7]. This research explores the use of Automatic Balancing (AB) devices or "auto balancers" for imbalance vibration suppression of flexible shafts operating at supercritical speeds, currently utilized for imbalance correction in some single plane rotor applications such as computer hard disk drives, CD-ROM drives, machine tools and energy storage flywheels.

Researchers around the world have concentrated on trying to develop balancing practices for the following purposes:

A. Increase the overall quality of a device
B. Minimize vibration
C. Minimize audible and signal noises
D. Minimize structural stresses
E. Minimize fatigue

III. EXPERIMENTAL SETUP

Balancing of any rotating parts is a very delicate matter. As the system become more sophisticated, balancing becomes increasingly difficult. A system can be balanced by proper designing of the system and by precision manufacturing with the best of materials. But in practice, it is not feasible (i.e., costly and time expensive) to manufacture a perfectly balanced system. In the fabrication of the experimental setup, it is necessary to evaluate-compare-choose among the available options of materials and design process. This chapter aims at describing some of the design considerations of the parts. The experimental setup is shown in Fig. 3.

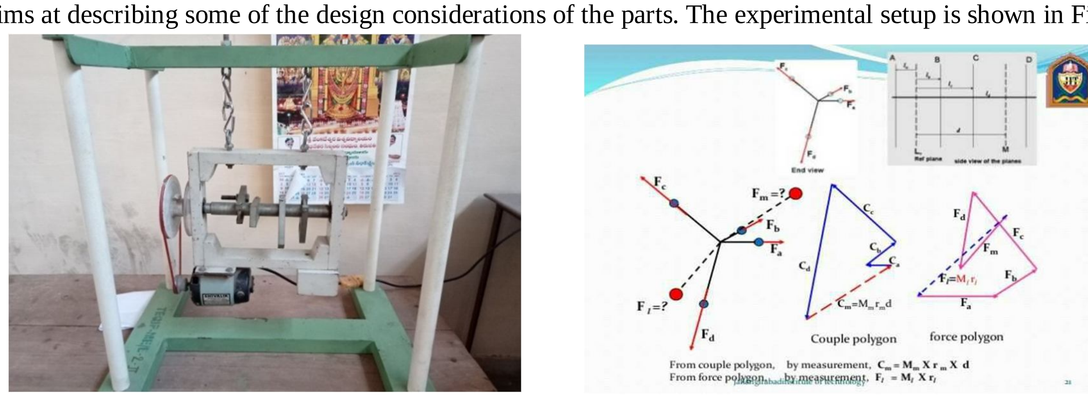

Fig. 3 Experimental Setup

A. Working Principle

First, imbalance is created by moving and rotating the loosened masses randomly. After they are fixed in position, their angular and linear position on shaft is determined from the scales embedded on setup. For static balance, motor remains off and only angular position of the masses matter. A force polygon is drawn from the data acquired. Upon solving the data, required angle of balance masses are found.

In order to have a complete balance of the several revolving masses in different planes,

1) The forces in the reference plane must balance, i.e., the resultant force must be zero and
2) The couples about the reference plane must balance i.e., the resultant couple must be zero.

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The setup currently in use at BUET is shown in Fig. 3. Here, the whole system is suspended from a rigid support by four tension springs. Four fixed masses are bolted around a solid shaft, which is attached to a motor by means of belt and pulley arrangement. The non-removable loosened mass can be slid along the shaft or rotated about it. This provides a way to change the linear and angular position of the mass with respect to the shaft. The masses are arranged in such a manner that when they are rotating due to force and couple polygons, the balanced mass is found out. The setup consists of several rotating and few static mechanical parts, beside the electrical components. When assembled, the setup can measure force at its support and electrical parts feed the data to a mathematical model to find imbalance position and angle.

The most important mechanical parts are:

a) Shaft
b) Rotating Disc
c) Support

Electrical parts are covered in more detail in the following chapter. However, a high-level overview is provided in this chapter for the context of design process. The shaft is supported by two bearings located near the ends of it. The holes are used for inserting small masses for the purpose of creating imbalance to be detected by the system. The shaft is directly coupled to a 12V DC motor that rotates the whole system. The coupling method is screw adjusted with motor shaft.

IV. MATLAB PROGRAMMING

MATLAB (Matrix Laboratory) is a multi-paradigm numerical computing environment and 4th generation programming language. Developed by Mathworks, MATLAB allows matrix manipulations, plotting of functions and data, implementation of algorithms, creation of user interfaces, and interfacing with programs written in other languages, including C, C++ and Java. MATLAB is a high – performance language for technical computing. It integrates computation, visualization, and programming environment. Furthermore, MATLAB is a modern programming language environment: it has sophisticated data structures, contains built-in editing and debugging tools, and supports object-oriented programming. These factors make MATLAB an excellent tool for research, engineering application development and teaching.

Rotating of balancing masses can be used in MATLAB for:

1) The MATLAB coding for finding critical speed, mode shapes and unbalances response was done and tested for different rotor and operating conditions. On success of the code a Graphical User Interface was developed using MATLAB GUIDE, which can incorporate different rotor models and boundary conditions. The simulation/analysis obtained from the software was verified with standard problems and those are coming with reasonable accuracy.
2) The back – end programs were written with great care and attention to include all kind of possible cases.
3) The software was deployed as executable file, so that any user can install it in his / her local machine.

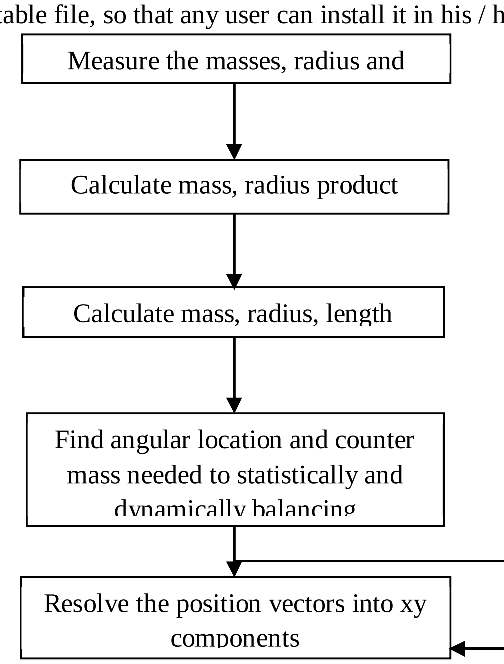

Fig. 4 Balancing of rotating masses by MATLAB programme (theoretically)

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From the above flow chart, the balancing of rotating masses by MATLAB programme is shown in below Fig. 5 & 6.

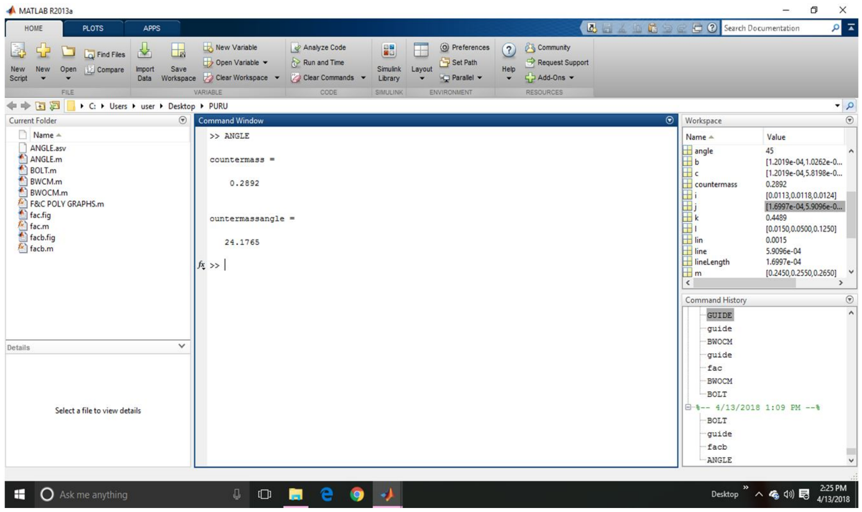

Fig. 5 Balancing of rotating masses for angular location

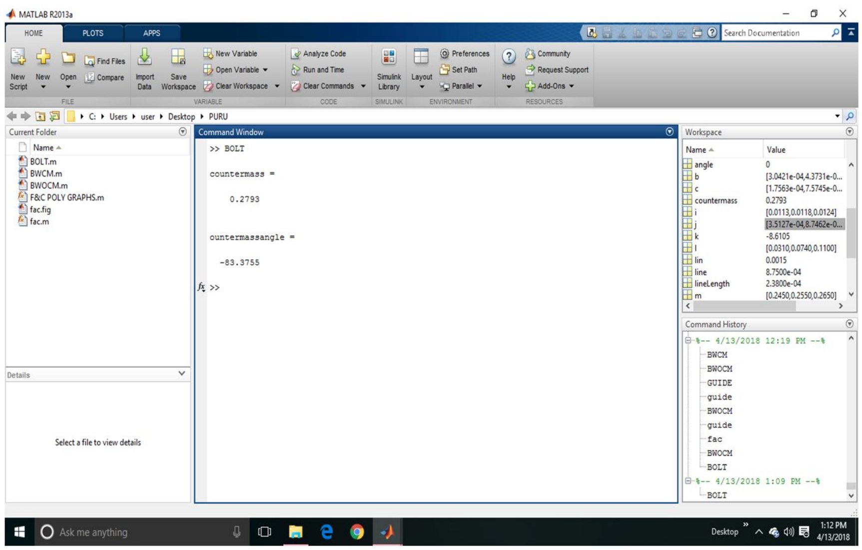

Fig. 6 Balancing of rotating masses for bolt

A. Advantages

1) In iterative waterfall model one can only create a high level design of the applicationbefore developers actually begins to build the product and define the design solution for the entire product. Later on developers can design and built a skeleton version of that, and then evolved the design based on what had been built.
2) In iterative model developers are building and improving the product step by step. Hence they can track the defects at early stages. This avoids the downward flow of the defects.
3) In iterative model developers can get the reliable user feedback. When presenting sketches and blueprints of the product to users for their feedback, they are effectively asking them to imagine how the product will work.
4) In iterative model less time is spent on documenting and more time is given for designing.

B. Disadvantages

1) Each phase of iteration is rigid with no overlaps.
2) Complex system architecture or design issues may arise because not all requirements are gathered up front for the entire lifecycle.

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V. RESULTS AND DISCUSSION

This is essentially an electro-mechanical project. Mathematical model that is developed requires three parameters to provide the location and angle of imbalance. First is rpm, which is essentially constant due to speed control of buck converter and also, it's measured easily. Second is the, amplitudes of loads on supports. This is measured by the masses. Load is affected by various things including spring, motor coupling, and gain value of resistance, voltage level of power supply and most importantly by load cell.

The flexible rotor balancing technique of influence coefficient method will be used to balance an experimental rotor test rig. Balancing a rotating machine properly and efficiently is a fundamental step to manufacturing a reliable system. The current design for all Computed Tomography (CT) scanners requires a well balanced rotor to generate a fine image quality, but with this setup the development of a balancing procedure which will effectively balance a CT scanner rotor.

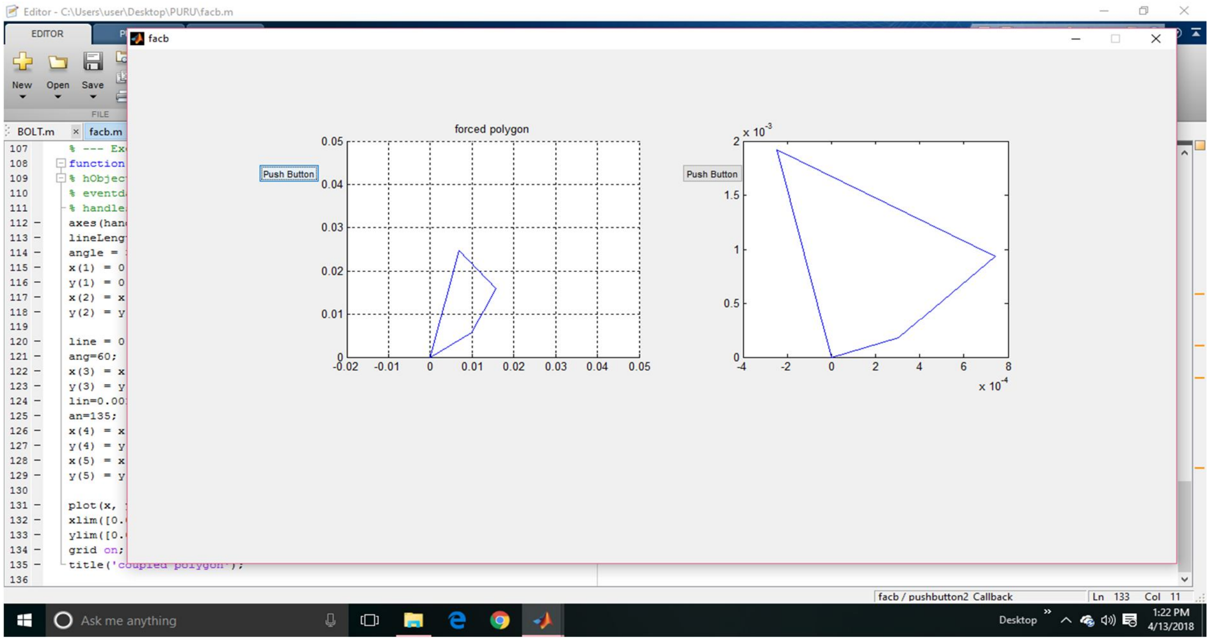

Fig. 7 Unbalanced system

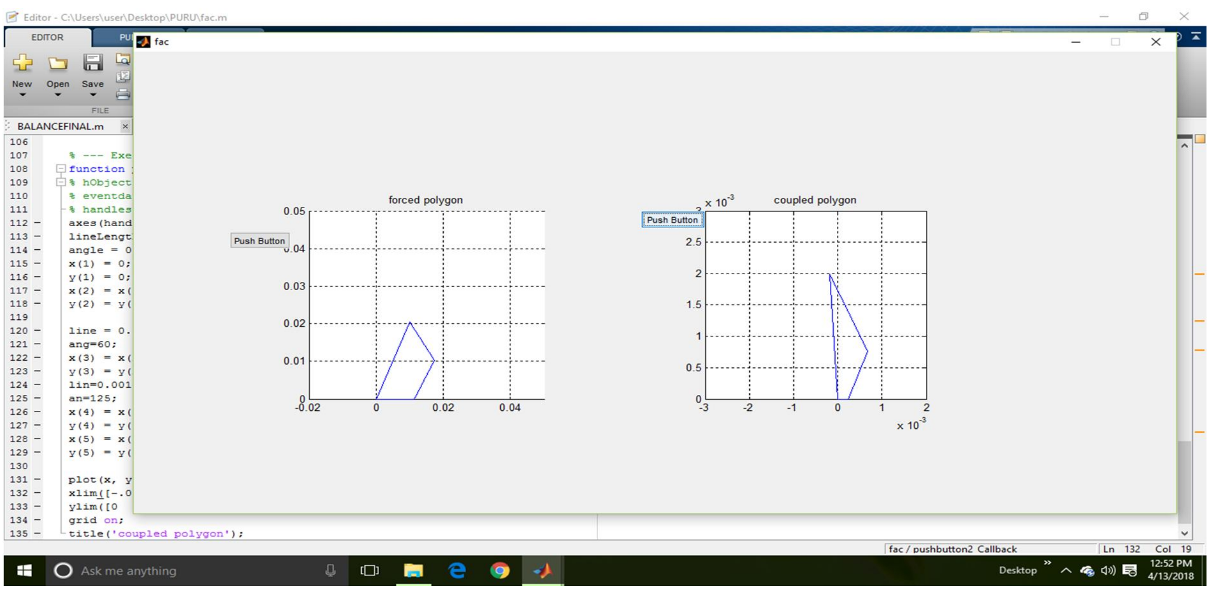

Fig. 8 Balanced system

From Fig. 7 & 8, it can be observed that, in forced polygon the maximum masses will be decreased from 0.015 to 0.010 and in coupled polygon the maximum masses will be decreased from 0.1 to 0.7.

VI. CONCLUSIONS

Current needs to solve any engineering issue or new design need knowledge on multi-disciplinary subjects. Knowledge on all subjects is difficult to harness, so an attempt was done to reduce time for design engineers to do rotodynamic analysis.

Based on this research work the following conclusions are drawn:

A. Design and fabricated a versatile experimental setup to study balancing of multiple rotating mass in several planes.
B. Setup a modeling instrument to simulate real life unbalanced systems.
C. Study and analyzed characteristics of an unbalanced system.
D. Developed an informed trial-and-error method to find ways to balance an unbalanced system
E. It is observed that, simplifying the roto dynamic analysis of rotor to help the engineering society for faster decision making and design of modern machinery.

VII. ACKNOWLEDGEMENTS

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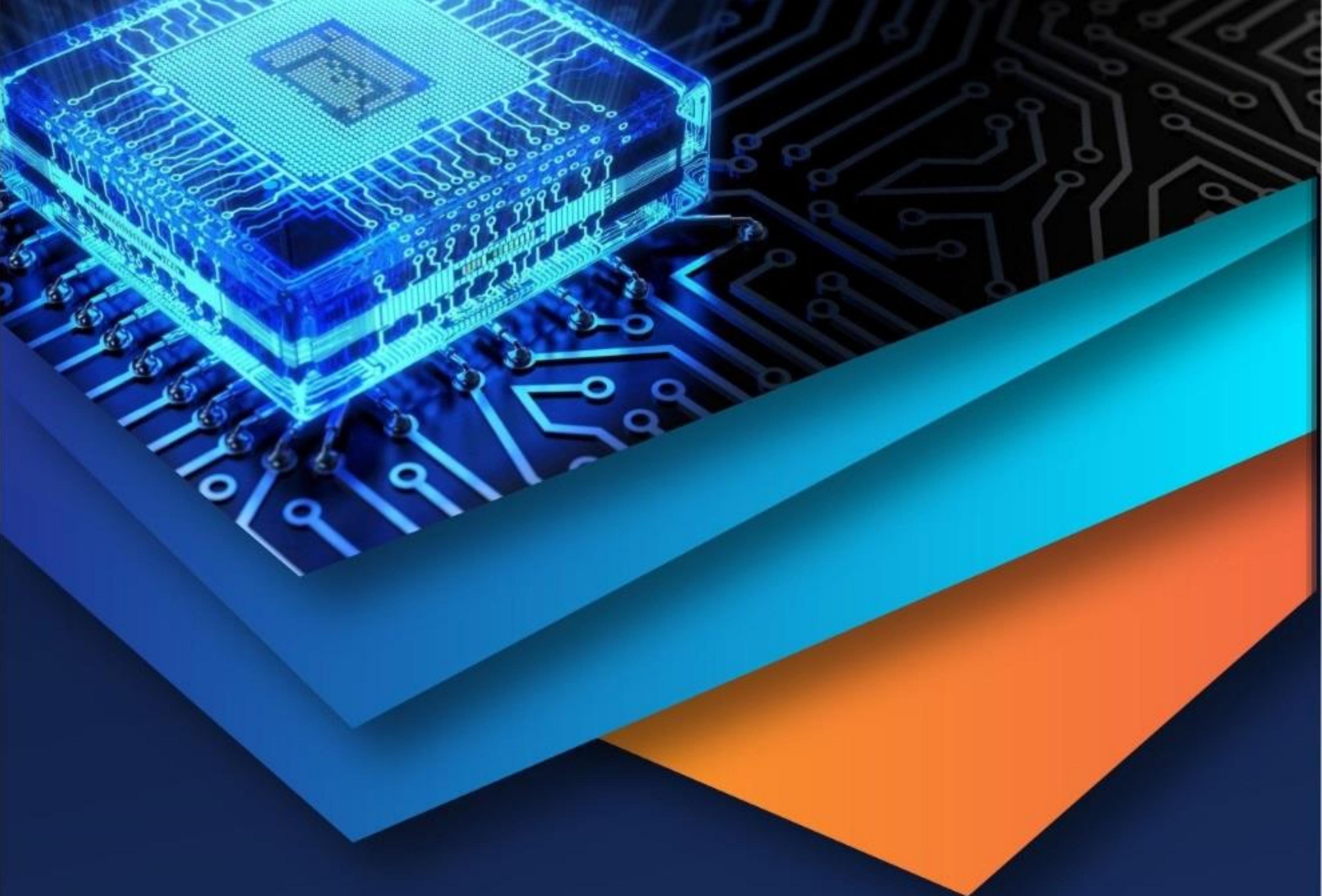

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