

Graphical User Interface (GUI) for Torsional Vibration Analysis of Rotor Systems Using Holzer and MatLab Techniques

Dr. Ameen Ahmed Nassar

ameenedani@yahoo.com

Assistant Professor, Department of Mechanical Engineering,
College of Engineering, University of Basrah.

Abstract: In this study, a new approach for the torsional vibration analysis of rotor systems using Holzer and Matlab techniques, by developing a graphical user interface (GUI), has been introduced. The objective of the work is to show the usefulness and power of Matlab GUI in investigating and analyzing the effects of torsional vibration on rotor systems. Also to carry out an analysis using the developed GUI to simulate three different rotor configurations such as 2-Rotor, 3-Rotor, and 5-Rotor systems. Illustrated problems in the field of analysis of torsional vibration are carried out. The results show that the developed GUI is very useful for engineers, designers, and analysts of torsional vibration problems in rotor systems.

1-Introduction

Investigation and analysis of torsional vibration in rotating shafts are an essential part of design of these systems. In the design of rotating shaft, torsional vibration analysis is important for ensuring reliable machine operation due to machine passing through that range of vibration from rarely occurring high-level transients to continuous relatively low levels of excitation. If the shaft and rotating component failures occur on large machines as a result of shaft torsional oscillations, the consequences can be catastrophic. In turbo machinery the worst case, an entire machine can be wrecked as a result of the large unbalancing forces that can arise following shaft separation and turbine blade failures, and this has actually occurred [1]. For these reasons great attention is generally taken at the design stage to ensure that high-speed rotating machines have the required torsional capability. This can be done by the use of numerical techniques such as Holzer and matlab.

Different rotor system configurations require considerable analytical and computational effort. In order to prepare engineers to completely solve these problems numerically, the engineers must master a suitable programming package. A proper analysis and calculations of torsional vibration parameters can be handled by the use of software like Matlab. MATLAB is a commercially available software package originally developed in the seventies by Cleve Moler, [2], for easy numerical computations, especially matrix manipulations. Now a day, it has grown to a high-level technical computing language and interactive developing environment, for algorithm development, data visualization, data analysis, and numerical computation, widely used in the academic world and in industry [3]. The combination of analysis capabilities, flexibilities, reliability, and powerful graphics makes Matlab the one of the most suitable software package for engineers and scientists [4]. Matlab provides an interactive environment with a lot of reliable and accurate built-in mathematical functions. These functions provide solutions to a wide range of mathematical and engineering problems such as matrix algebra, linear and nonlinear systems, etc.

In this paper, the need for Matlab as a programming tool to design and build a graphical user interface (GUI) for the analysis of torsional vibration in rotor systems using Holzer technique [5], can be done using MATLAB/GUIDE environment [6].

2-Rotor System Modeling

Rotating turbo-machinery shafts usually consists of several rotors that are connected in tandem by coupling. Generally the main body regions of an individual rotor have

significantly larger diameter sections than the rotor extensions at each end. These shaft extensions often contain the seals and bearing journals and may terminate with integral or shrunk-on couplings.

To achieve good accuracy in the analysis results, the required number and distribution of elements along the axial length of the machine shaft are often gained through modeling of a particular class of machine. This includes the vibration response frequency range of interest, the number of locations that have distinctly different diameters and other geometric discontinuities, and the relative values of stiffness and inertia for discrete spans of the rotor. For a large turbine generator in which the shaft torsional response needs to be estimated following a transient disturbance, the model is strongly influenced by the fact that the shaft response is primarily in the lower order modes of vibration (i.e. less than 60 Hz) [1]. In this paper, the rotor system is modeled as shafts and masses in away appropriate for the torsional vibration analysis using Holzer procedure given by the following equation

$$\theta_n = \theta_{n-1} - \frac{\omega^2 L_{n-1}}{GJ_{n-1}} \sum_{i=1}^{n-1} I_i \theta_i$$

Where θ is the normalized angular displacement, ω is the critical speed of the shaft corresponding to mode of vibration, L is the length of the shaft, G the modulus of rigidity of the material of the shaft, J the second moment of area of the shaft cross section area, and I moment of inertia of each disk.

3- Analysis Procedure

In this work, the analysis procedure of torsional vibration analysis of rotor system using Holzer method developed by the author in Reference [7] can be used. A Matlab GUI is developed in this paper based upon this procedure to study the effects of torsional vibration on different rotor configurations. To validate the GUI, three case studies of rotor system with different configurations are chosen for this purpose and the results were shown in the next section.

4- Case Studies

In this work, three case studies where considers for the analysis using the developed GUI. These case studies are:

- 1- 2-Rotor system case.
- 2- 5-Rotor system case.

They represents the most practical situations in torsional vibration system.

5- Results and Discussion

In order to validate the developed GUI, three case studies with known solutions have been chosen for the analysis.

(a) 2-Rotor System Case

A shaft of stiffness 4 MN.m/rad carries two flywheels of 2 and 4 kg.m² respectively given in Reference [8] is selected for the analysis. The main menu of the developed GUI shown in Figure (1), will allow the user to choose the rotor configuration required for the analysis.

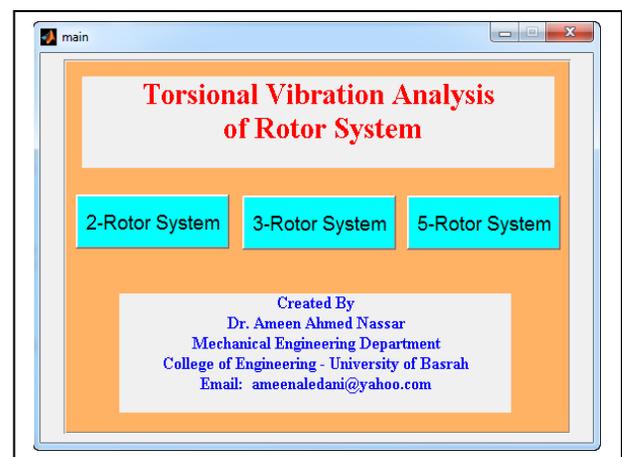


Fig.1 Main menu.

The analysis starts by clicking on the 2-Rotor System button, the window shown in Figure (2) will appear.

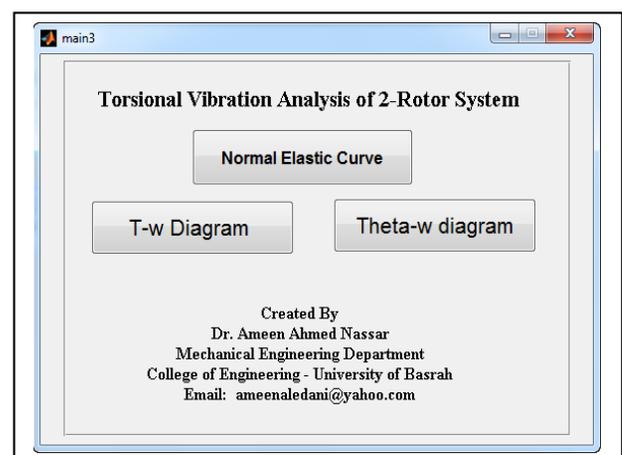


Fig. 2 Two-Rotor System window.

From this window, the user can choose the parameter of torsional vibration analysis required, such as, Normal Elastic

Curve (a Curve showing the mode shapes of torsional vibration and the location of the vibration nodes), T-w diagram (a

diagram shows the torque of each flywheel for a range of speeds, and the values of the critical speeds), and the Theta-w diagram (a diagram shows the values of the torsional amplitude for arrange of speeds, and the nodes of vibration corresponding to a critical speed). Clicking on the **Normal Elastic Curve** button will generate the window shown in Figure (3).

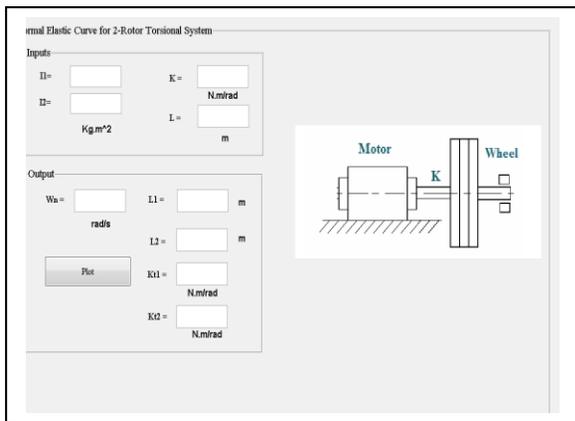


Fig.3 Normal Elastic Curve.

By inserting the required data and hitting the **Plot** button, the following results are obtained: Figure (6) shows the critical speed W_n , the location of the vibration nodes L_1 , L_2 , and the stiffness of each part of the shaft corresponding to the node of vibration, and also a plot of the linear elastic curve for the considered case study. It is obvious that the information gained from this figure is very essential for the designers and analyst of rotor systems. Comparing our results with the results of Reference [8], gained by hand calculation, and shown in figure [4].

It is clear that is a good agreement between them.

Returning to the menu shown in Figure (2) and hitting the **T-w diagram** button will generate the results shown in Figure (7) after inserting the required data.

Figure (7) illustrate the behavior of each flywheel torque at different speeds. This figure is very essential for vibration analyst since it can show the critical speed of the system, which is the point of intersection of T_2 with the zero line and also show

the critical speed in which the two flywheels has the same value of torque.

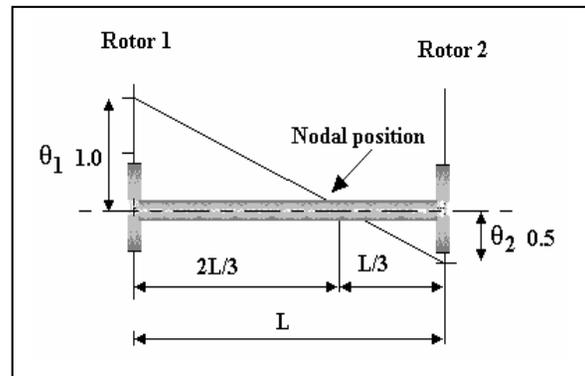


Fig.4 Results of Reference [8].

The **Theta-w Diagram** can be plotted by returning to the menu of Figure (2) and hitting the required button. This action will generate the plot shown in Figure (8). This Figure presented the calculated torsional amplitude at different speeds, in which the point of intersection with the zero line represent a critical speed that another node of vibration can be occur.

(b) 3-Rotor System Case

A rotor has three inertias 2, 4, and 2 kg.m^2 respectively viewed from left to right. The shaft connecting the first two inertias has stiffness of 3 MN.m/rad and the shaft connecting the last two inertias has a stiffness of 2 MN.m/rad . To start the analysis, the **3-Rotor System** button in the main menu shown in Figure (1) showed be pressed. This will generate a menu for this type of rotor configuration similar to the menu shown in Figure (2), in which the three type of analysis can be carried out in a similar procedure as explained for the 2-Rotor System. The results are shown in Figures (9), (10), and (11) respectively.

These figures show the behaviors of the calculated parameters for this type of rotor system. Comparing the results of Figure (10) with the results of Reference [8] obtained by tabulated Holzer procedure, for the T_3 values, as shown in Figure [5]. It is clear that there is a good agreement between them.

(c) 5-Rotor System Case

This case represent, a gas turbine layout shown in Figure (12). There are five moments of inertia corresponded to each mass and four shaft sections. The analysis can be carried out by

hitting the **5-Rotor system** button in the main menu Figure (1). The results for this case study are shown in Figures (13), (14), and (15) respectively.

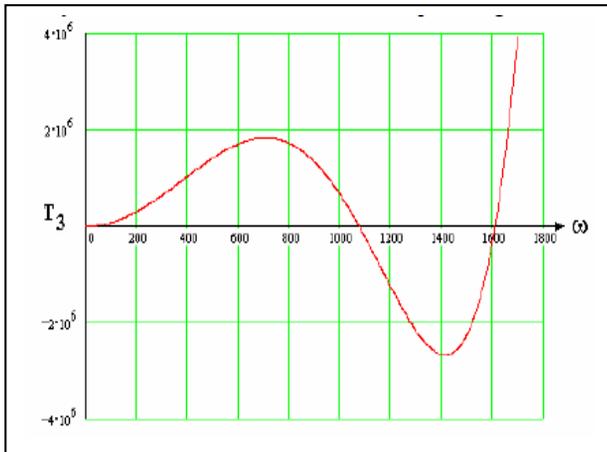


Fig.5 Normal Elastic Curve of Reference [8].

Figure (13), shows the normal elastic curve for the system, in which two nodes of vibration occurred at speed of 500 rad/s. The first between mass 1 and mass 2, and the second between mass 3 and 4. Figure (14), presented the T-w diagram, which is shows clearly that, there is two critical speeds occurred. The first at about 200 rad/s and the second at 360 rad/s for the T_5 curve. While for T_2 and T_3 there is another critical speed at 310 rad/s. Finally, Figure (15), shows the Theta-w diagram for the system which is illustrate the torsional amplitude of each mass due to unit amplitude at mass 1. It clear from this, that there is six nodes of vibrations occurred at different speeds corresponding to masses 2 - 5 of the system.

6-Conclusions

From the above analysis, the following conclusions can be drawn:

1- The developed GUI for torsional vibration analysis of rotor systems presented in this paper shown to be very convenient and essential for describing the behavior of different parameters of torsional vibration for different rotor configurations.

2- The developed GUI reduced the need for tabulated hand calculation and sophisticated numerical analyses such as finite elements, which require more time and effort, to calculate the same parameters tackled in this research.

3- Comparison of some results of this work with Reference [8], proves the accuracy of the developed GUI for torsional vibration analysis.

7- References

- [1] Walker Duncan N., "Torsional Vibration of Turbomachinery", McGraw-Hill, 2004.
- [2] Mathworks, Inc, "Matlab User's Guide", (1991).
- [3] Hingham, D. J., "Matlab Guide", Philadelphia Society for Industrial and Applied Mathematics, (2005).
- [4] Mathworks, Inc, "MATLAB, the Language of Technical Computing", (2002).
- [5] Thomson William T., "Theory of Vibration With Applications", Third Edition, Prentice Hall, 1988.
- [6] Mathworks, Inc., "Building GUI's with MATLAB", Version 5, (1996).
- [7] Nassar A. A., "Torsional Vibration Analysis of Large Rotor System Using Finite-Element and Matlab Procedures", Basrah Journal for Engineering Sciences, Vol. 1 , 2013.
- [8] Torsional Vibrations with Multiple Modes- Free study, website: www.freestudy.co.uk/dynamics/holzer.pdf

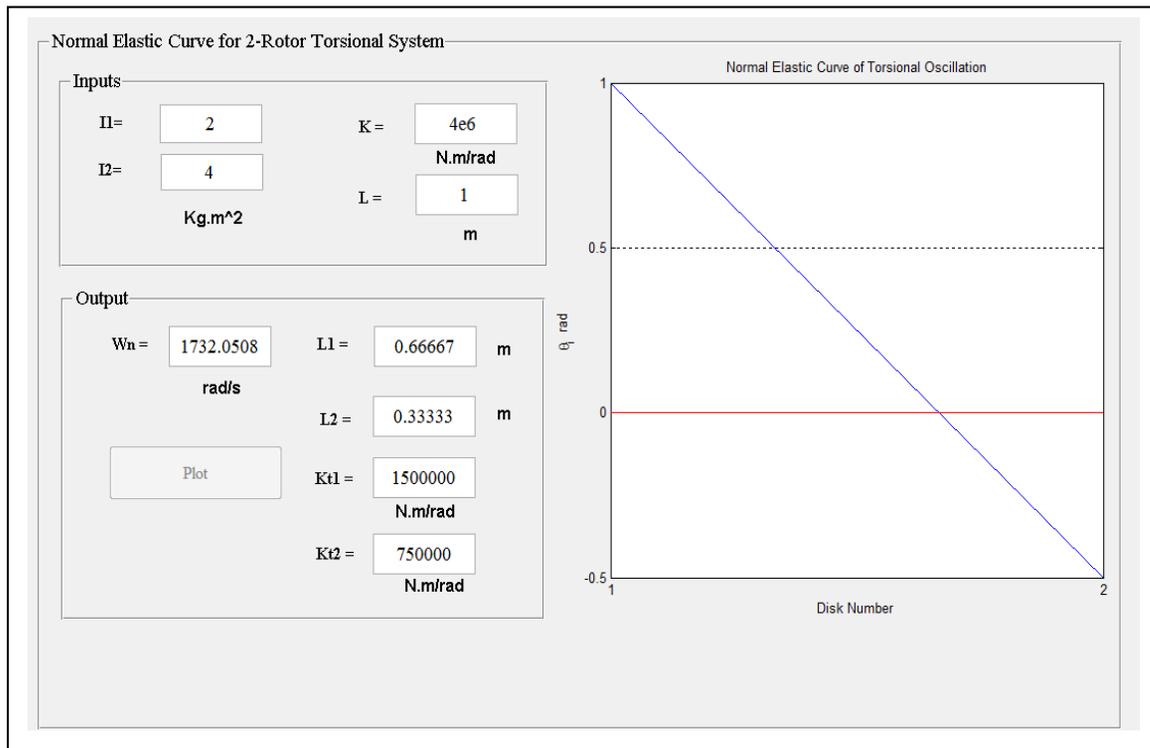


Fig. 6 the Normal Elastic Curve for 2-Rotor Torsional System.

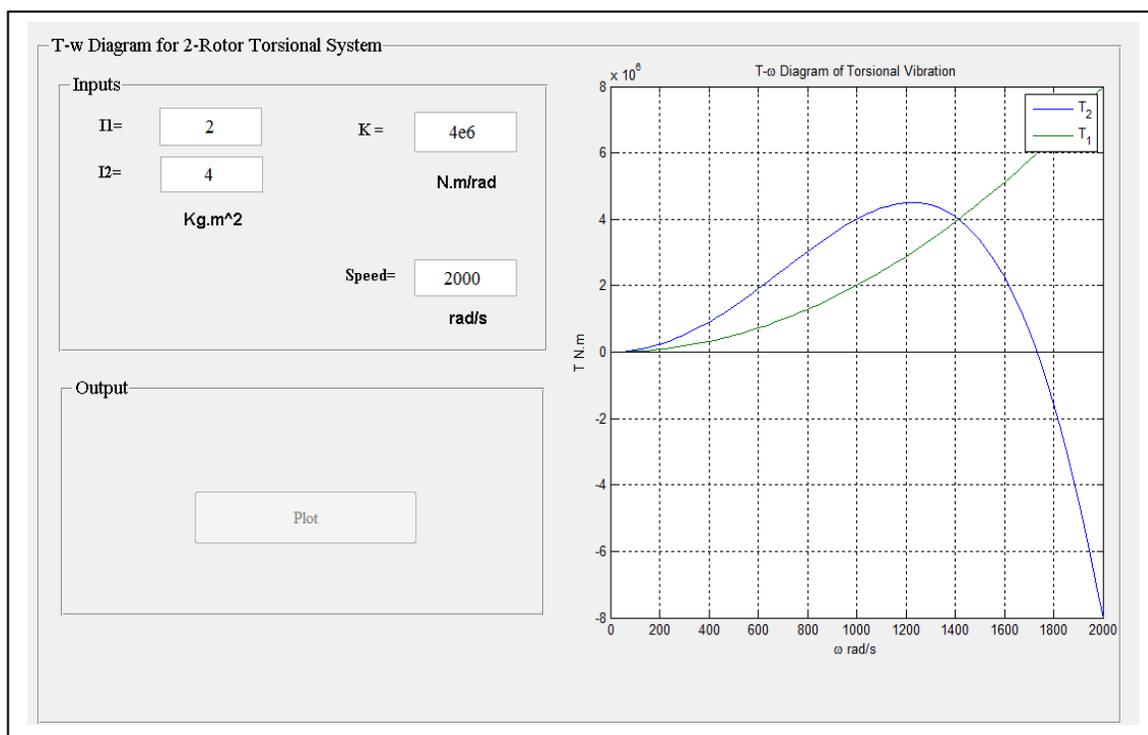


Fig. 7 the T-w Diagram for 2-Rotor Torsional System.

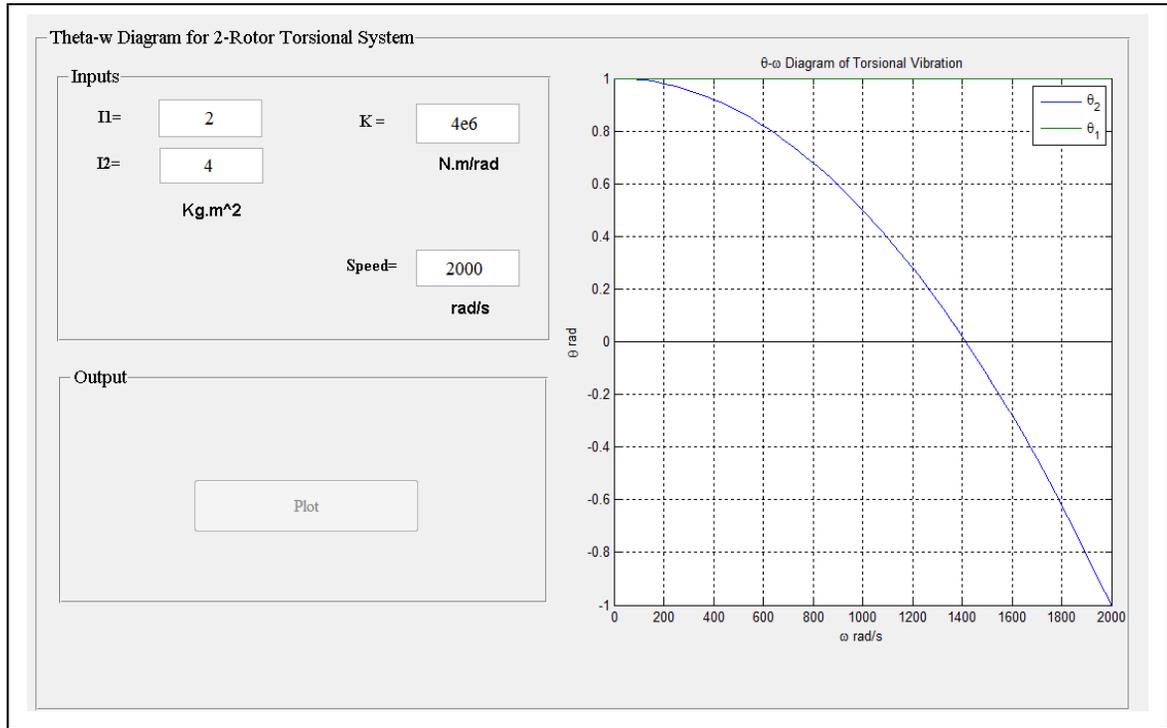


Fig. 8 Theta-w Diagram for 2-Rotor Torsional System.

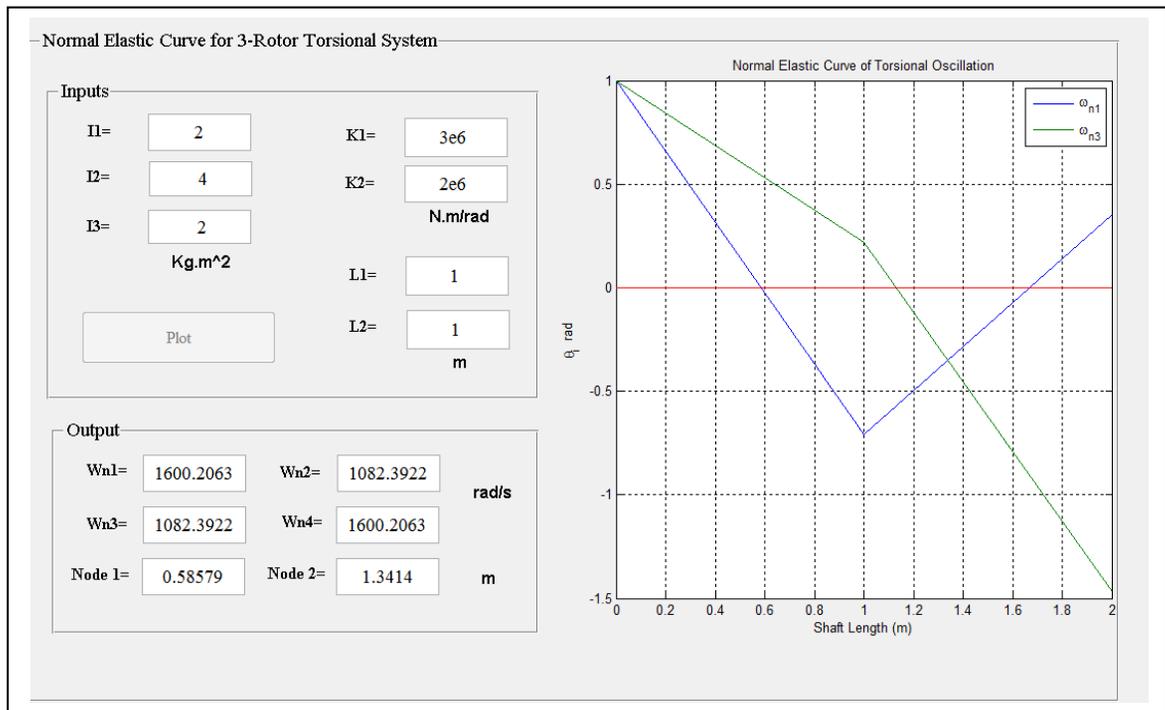


Fig. 9 The Normal Elastic Curve for 3-Rotor Torsional System.

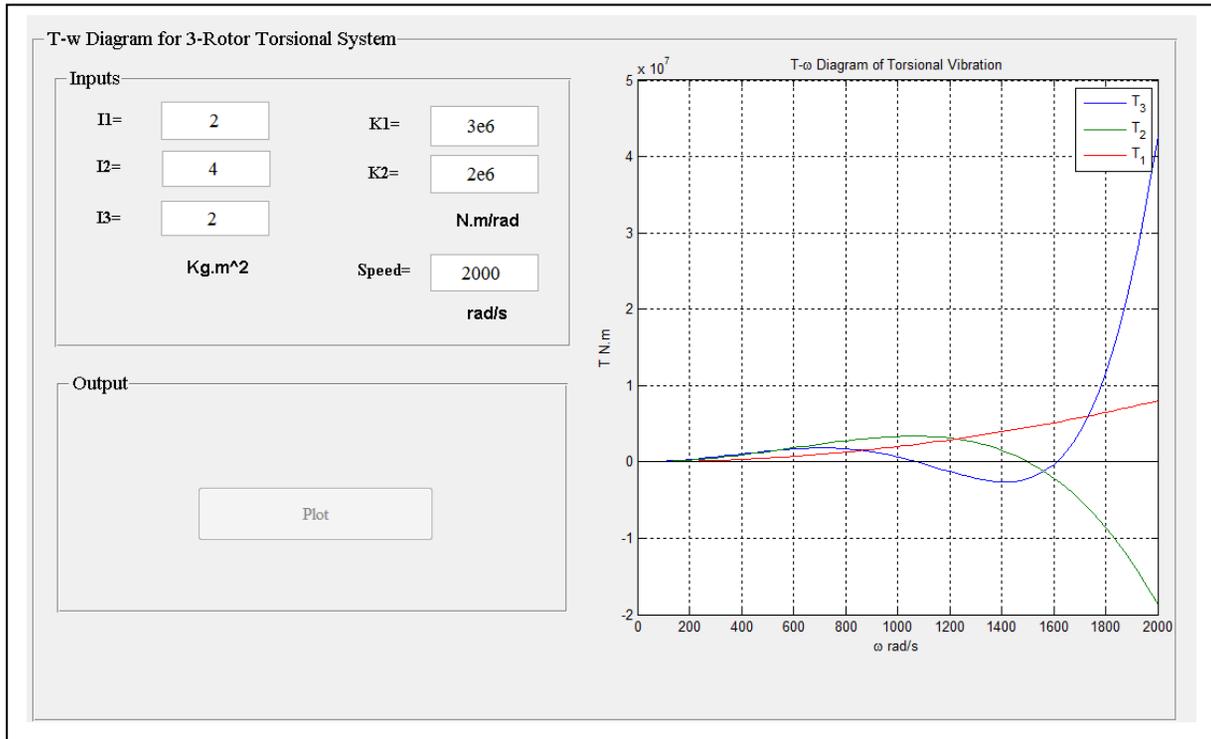


Fig.10 The T-w Diagram for 3-Rotor Torsional System.

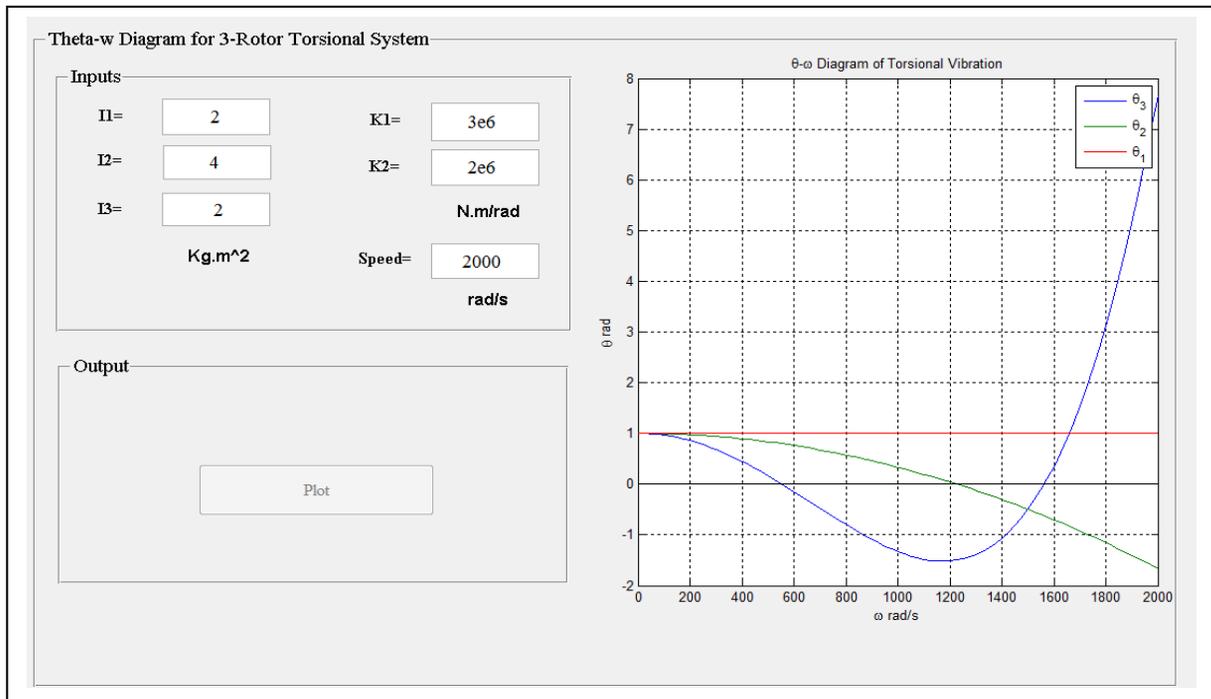


Fig. 11 Theta-w Diagram for 3-Rotor Torsional System.

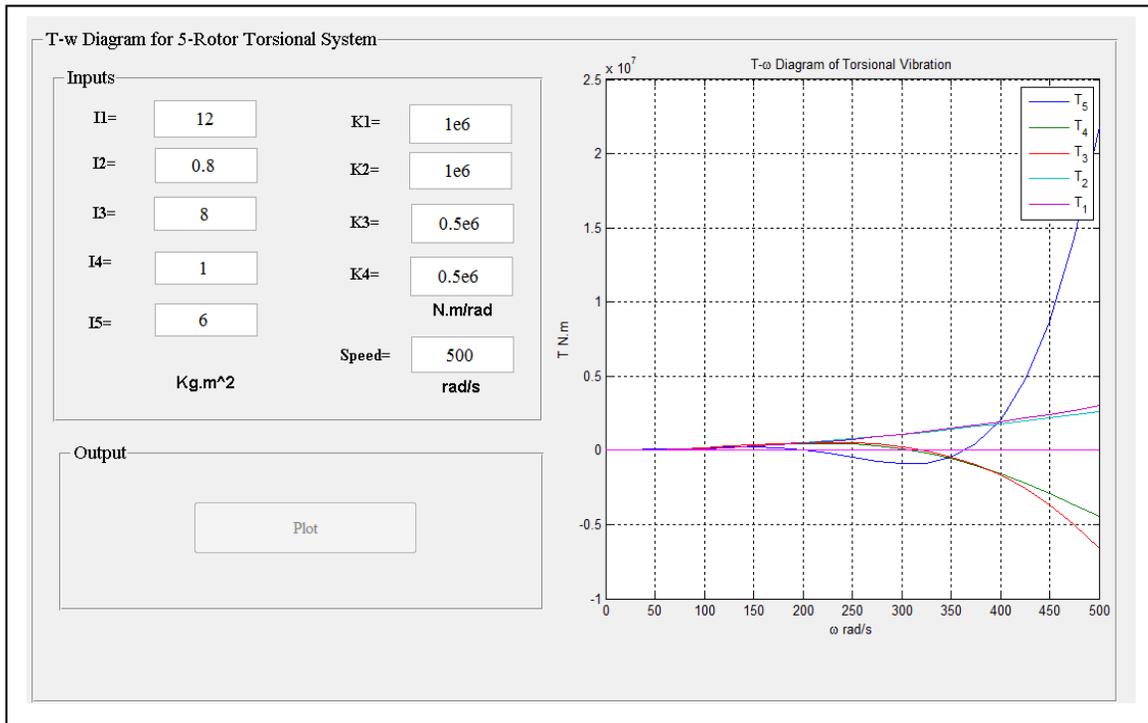


Fig. 14 T-w Diagram for 5-Rotor Torsional System.

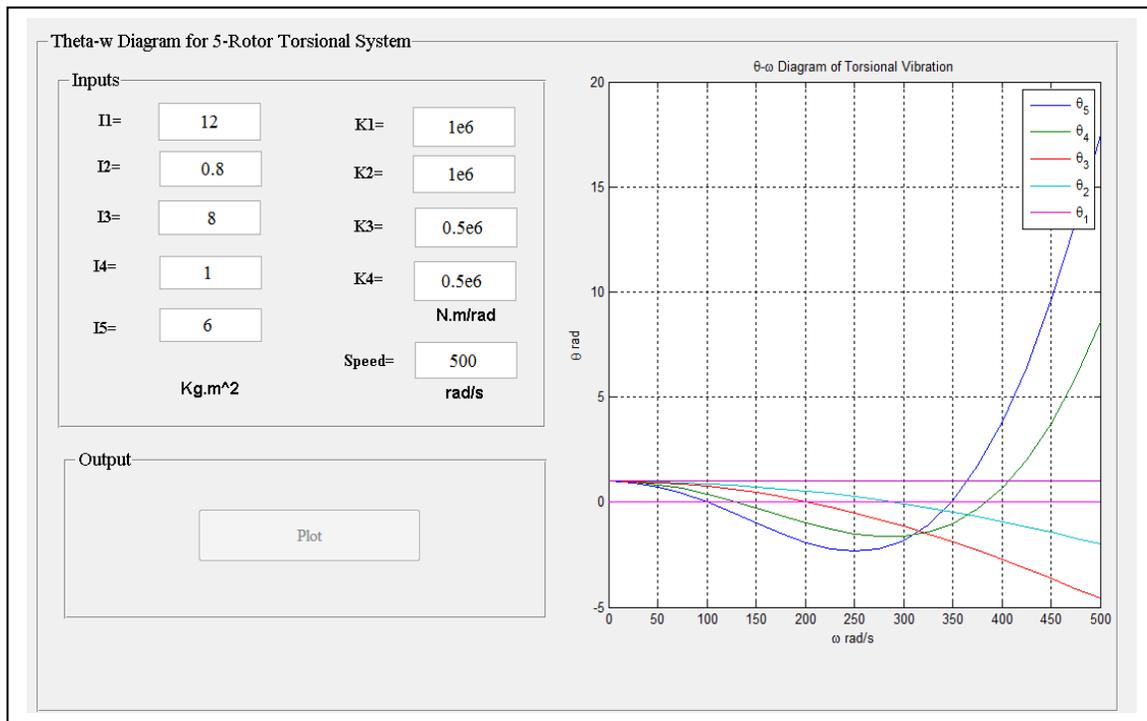


Fig. 15 Theta-w Diagram for 5-Rotor Torsional System.