

A Modified Approach for Torsional Vibration Analysis of Some Rotor Systems Using Holzer and Matlab GUI Techniques

Ameen Ahmed Nassar
Amen.nassar@uobasrah.edu.iq
Professor,
College of Engineering
University of Basrah.

Duna Tariq Yaseen
duna.yaseen.@stu.edu.iq
Assist. Lecturer,
Basrah Technical Institute,
South Technical University

Abstract

A modified approach for the analysis of torsional vibrations in some rotor systems using modified Holzer and Matlab techniques, by building a graphical user interface (GUI), has been developed. The specific objective of this work is to illustrate the applicability and usefulness of the modified approach and the Matlab GUI in analyzing the effects of torsional vibration on some well known rotor systems such as two, three, and five rotor systems. Well Known problems in the field of torsional vibration were analyze. The results illustrate that the developed approach and the GUI are very useful tools for engineers, designers, and analysts of vibration problems in rotor systems.

1-Introduction

Analysis of torsional vibration in rotating components is an essential part of design of rotating systems. In design of rotating shaft, the vibration analysis is useful for ensuring reliable machine work due to machine passing

through that range of vibration frequencies from occurring high-level transient level to continuous relatively low levels of excitation. When the shaft and rotating component failure occur on large machines because of torsional oscillations, the consequences can be catastrophic. For machinery the bad condition that, when the entire machine breakdown as a result of large unbalanced forces that can cause shaft separation and turbine blade failures [1]. For these causes a great attention is needed at design stage to ensure that high-speed rotating machines have the required capability against vibrations. This can be carried out by the application of numerical technique such as Holzer method.

Some rotor configurations needs considerable theoretical and

computational effort. In order to completely analyze these problems numerically, the engineers must master a suitable programming package. A proper analysis of torsional vibration parameters can be handled by a software such as Matlab. MATLAB is a widely used software package originally generated in the seventies by Cleve Moler, [2], for numerical computations, mainly matrix calculations. These days, it has a high-level technical computing and interactive environment, for analysis development, data visualization, and numerical computations, used in the academic fields and in industry [3]. The mixing of analysis capabilities, reliability, and powerful graphics makes Matlab one of the most useable packages for engineers and scientists [4]. Matlab offers an interactive environment consists of many reliable and accurate mathematical functions. These functions give solutions to a range of scientific and engineering problems such as "matrix algebra, linear and nonlinear systems, etc".

In this study, Matlab is selected as a programming tool to design and build a Graphical User Interface (GUI) for torsional vibration analysis of rotor systems using a modified Holzer

technique with the use of MATLAB / GUIDE environment [6].

2-Rotor System Modeling

Machine shafts often consists of several rotors which connected in tandem by integral or shrunk-on coupling. Often, the main body regions of an individual rotor have significantly bigger diameter sections than the rotor extensions at each end. These extensions usually consist of seals and bearing journals and may end with couplings.

In order to achieve good accuracy in the analysis results, the required number of elements along the axial length of the shaft is often gained through modeling of a particular type of machine. This contains the vibration frequency range, the locations that have different diameters and geometric discontinuity, and the relative values of stiffness and mass for discrete elements of rotor. For large rotor setups where the shaft response requires to be calculated after some transient disturbance, the model is effected by the fact that "the shaft response is primarily in low order mode of vibration (less than 60 Hz)" [1].

In this work, the rotor system is modeled as shafts and inertias in a way

suitable for the analysis of torsional vibrations using a modified Holzer procedure depend on the following equation [7]:

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

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

3- Analysis Procedure

In this work, the procedure of torsional vibration analysis of rotor system using Holzer method developed by the author in Reference [8] has been used. A modified Matlab GUI is developed based upon the above mentioned procedure to study the effective parameters of torsional vibration of some rotor configurations. The modified GUI has been validated by three case studies of rotor system with different configurations.

4- Results and Discussion

In this paper, three case studies where considers for the analysis using the modified GUI. These case studies are 2-Rotor system case, 3-Rotor system, case, and 5-Rotor system case.

They represents the most practical cases in torsional vibration systems. In order to validate the modified GUI, three case studies with known solutions have been selected for the analysis.

(1) 2-Rotor System Case

A shaft of stiffness 4 MN.m/rad carries two flywheels of 2 and 4 kg.m² respectively shown in Reference [9] is chosen for the analysis. The main menu of the modified GUI shown in Figure (1), will guide the user to select the rotor configuration required for the analysis.

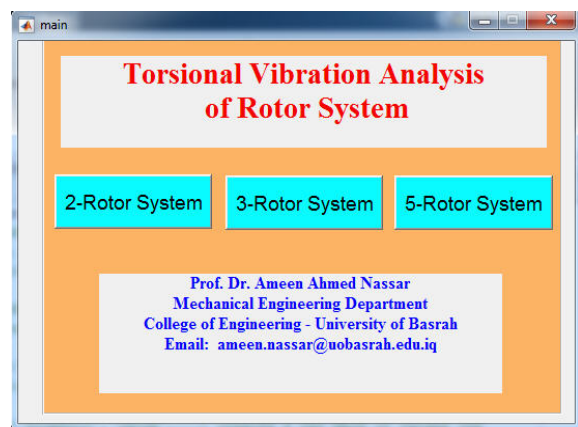


Figure (1) Main menu.

The analysis activated by hitting the 2-Rotor System button, the following window will appear.

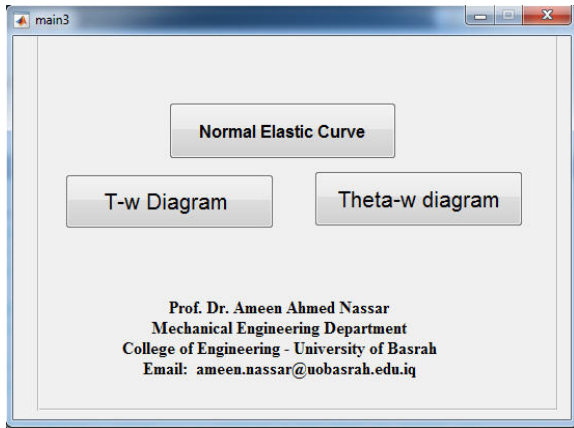


Figure (2) 2-Rotor System window.

From the above window, the user can select the appropriate parameter for analysis, such as, "Normal Elastic Curve (a curve shows the mode shapes of torsional vibration and the location of the vibration nodes)",

"T-w diagram (a diagram showing the torque of each mass 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 a range of speeds, and the nodes of vibration corresponding to each critical speed)".

Pressing on the **Normal Elastic Curve** button will open the window shown in Figure (3).

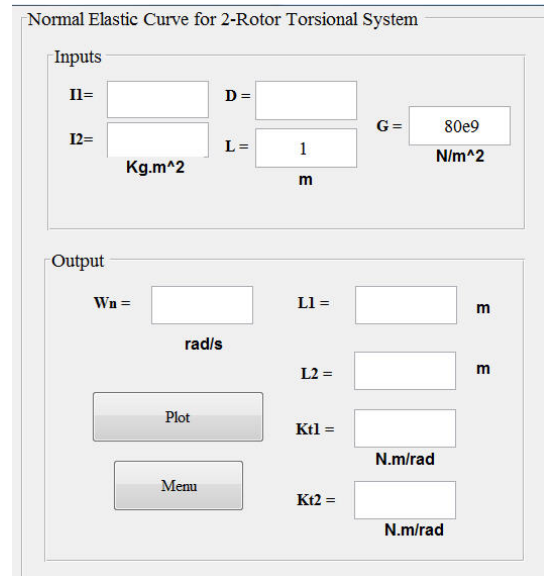


Figure (3) Normal Elastic Curve.

By inserting the required data and clicking the **Plot** button, the results shown in Figure (4) are obtained.

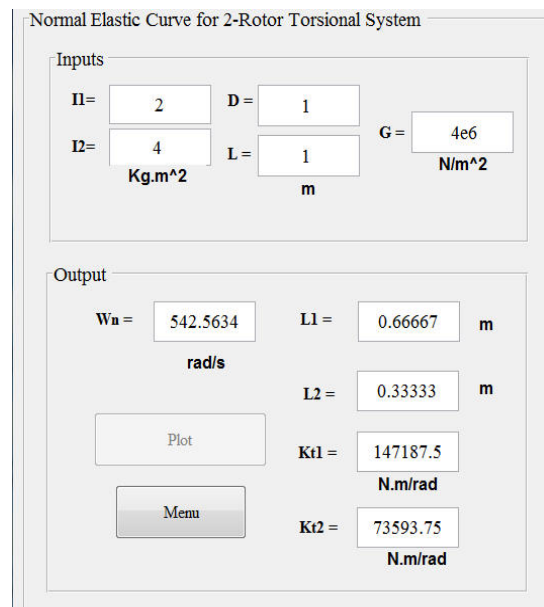


Figure (4) Results of Normal Elastic Curve.

The above figure shows the critical speed, the location of the vibration nodes, and the stiffness of each shaft corresponding to each side of the node of vibration. A plot of the linear elastic curve for the analyzed case is shown in Figure (5).

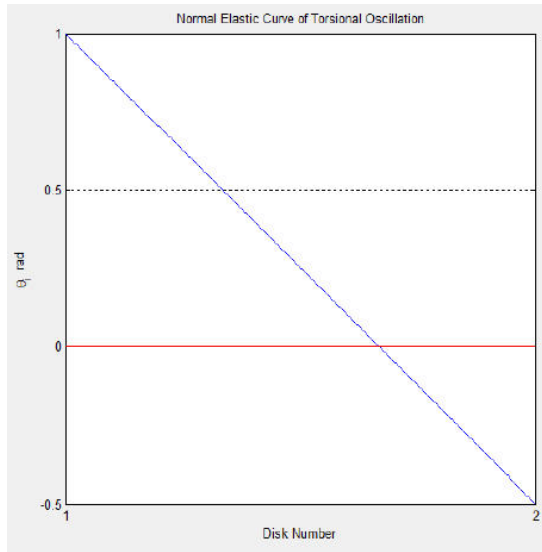


Figure (5) Normal Elastic Curve.

It is clear that, this curve is very useful for designers and analysts of rotor systems. Comparing our results with the results of Reference [9], calculated by hand as shown in figure [6].

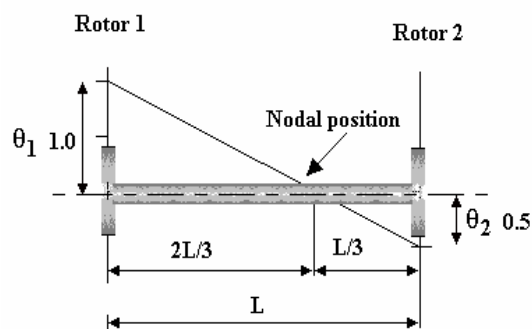


Figure (6) Results of Reference [9].

A good agreement between them its obvious. Returning back to the menu shown in Figure (2) and pressing the **T-w diagram** button will generate the output shown in Figure (7).

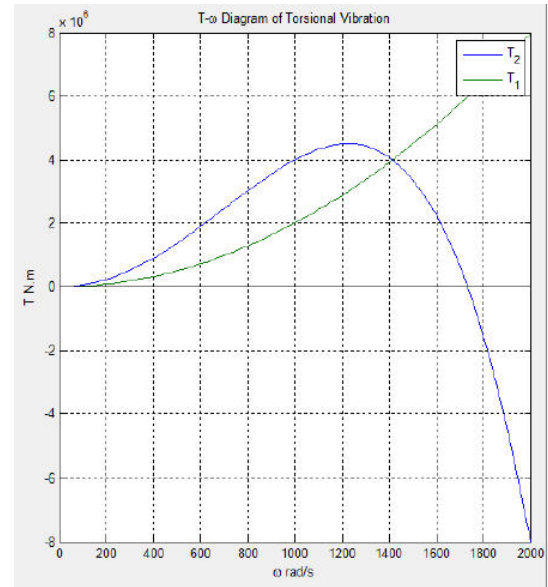


Figure (7) Plot of T-w diagram

The above figure shows the behavior of each mass torque at different speeds. It is very useful for vibration analyst, since it provide the critical speed of the system, which is the T_2 point of intersection with the zero torque line and also shows the critical speed when the two masses has the same value of torsional torque.

The **Theta-w Diagram** can be generated by using the menu of Figure (2) and clicking the desired button. This action will provide the plot shown in Figure (8).

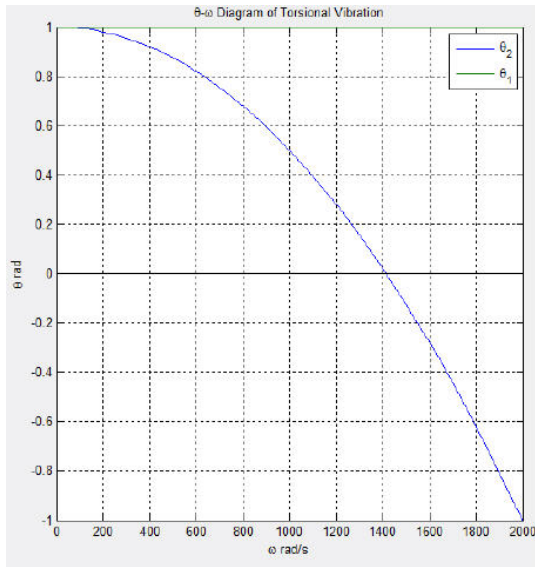


Figure (8) Plot of Theta-w Diagram

The above Figure present the computed the normalized torsional amplitude at different speed values, in which the point of intersection with the theta zero line represent a critical speed that another node of vibration will take place at such speed.

(2) 3-Rotor System Case

A system with three masses 2, 4, and 2 kg.m² respectively set from left to right is considered [8]. "The shaft between the first two masses has stiffness of 3 MN.m/rad and the shaft between the last two masses has a stiffness of 2 MN.m/rad". To start the analysis, the button **3-Rotor System** in the main menu shown in Figure (1) should be pressed. This will allows a menu for this type of rotor analysis, in which the

analysis can be carried out in a similar procedure, as for the 2-Rotor case. The results are presented in the following figures.

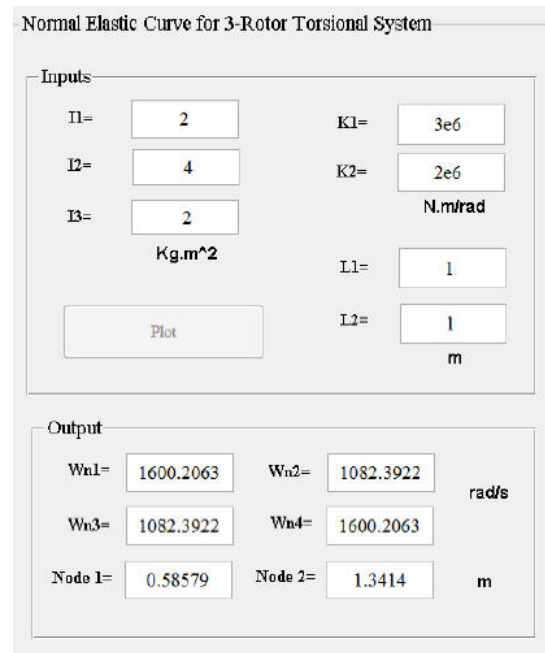


Figure (9) 3-Rotor system results.

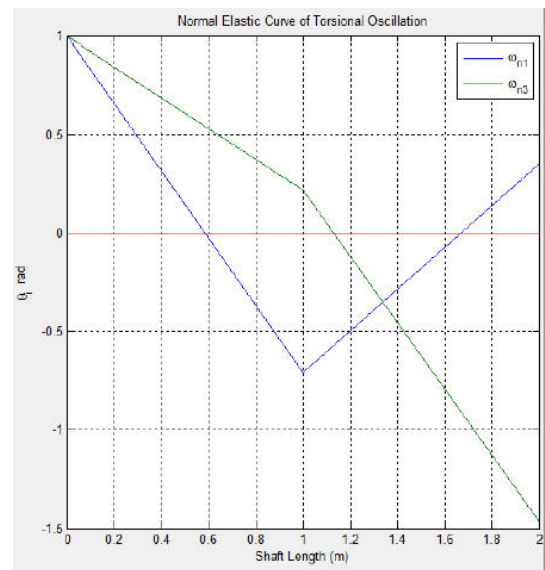


Figure (10) Normal Elastic Curve, 3-Rotor system case.

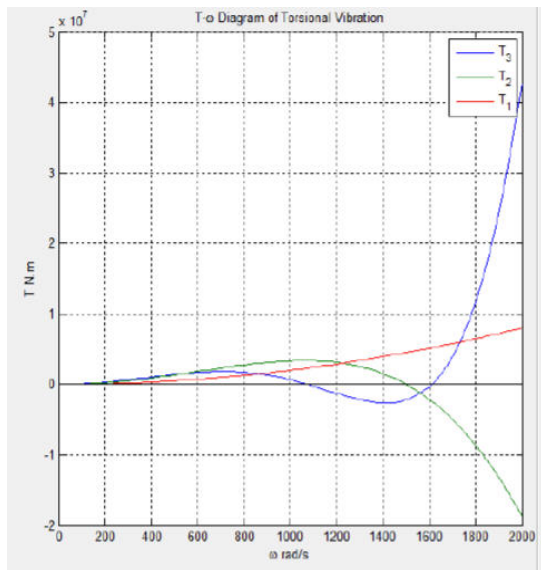


Figure (11) T-w diagram, 3-Rotor system case.

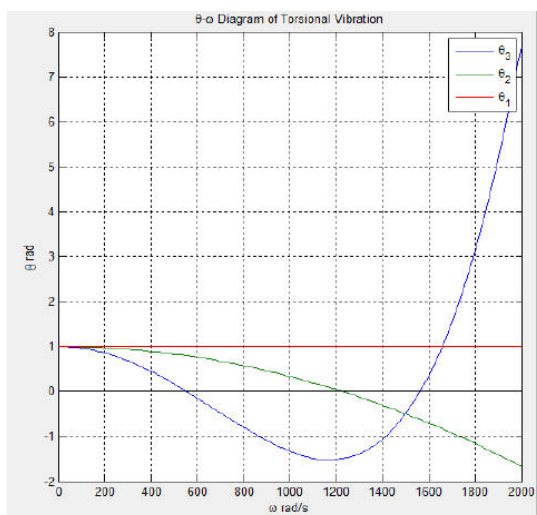


Figure (12) Theta-w diagram, 3-Rotor system case.

Figure (9) present the critical speeds of four modes of vibration that will appears in this kind of rotors as well as the location of the two nodes of vibration of the system. The Following figures (10, 11, 12) shows the other

results of the analysis: These figures show the behaviors of the vibration parameters for this type of rotor system. Comparing the results of Figure (11) with that of Reference [9] obtained by tabulated Holzer method, for T_3 values, shown in Figure [13]. It is obvious that, there is a good match between the results.

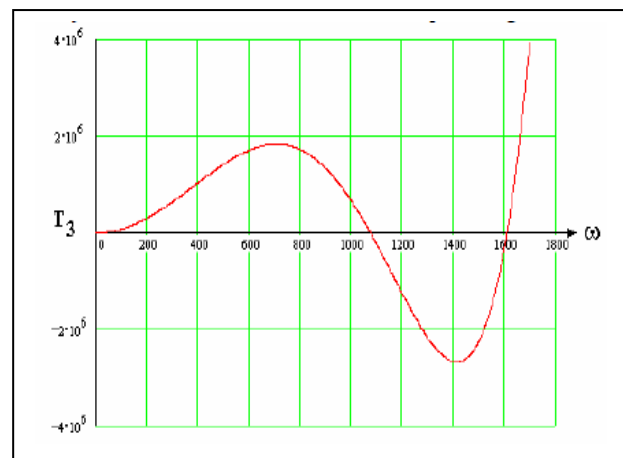


Figure (13) T-w diagram of Ref.[8].

Figure (12) presented a plot of the Theta-w curves for each mass and shows the intersection points which represent the critical speeds that the rotor passes through during its operation from 0-2000 rad/s.

(3) 5-Rotor System Case

The case shows, a gas turbine layout shown in Reference 8. "There are five masses and four shaft sections". The analysis can be started by clicking the **5-Rotor system** button in the main

menu Figure (1). The outcomes for this case are shown in the following figures.

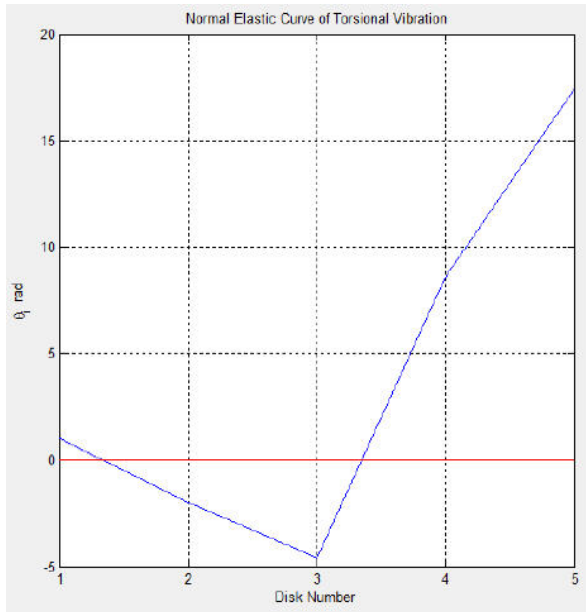


Figure (14) Normal Elastic Curve of case (3).

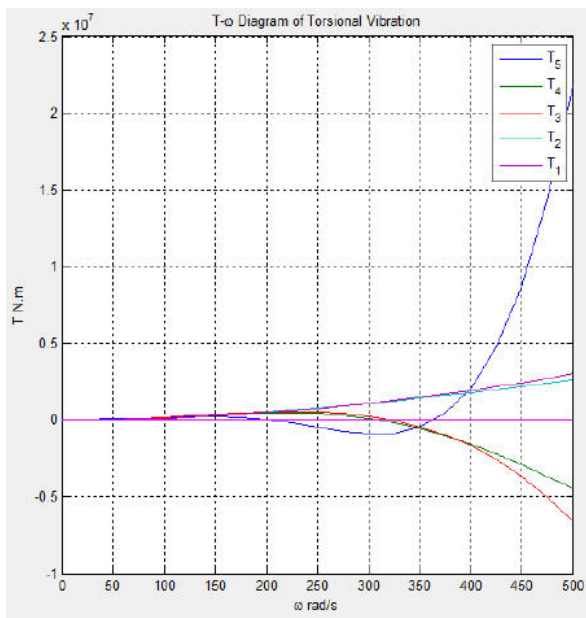


Figure (15) T-w diagram for case (3).

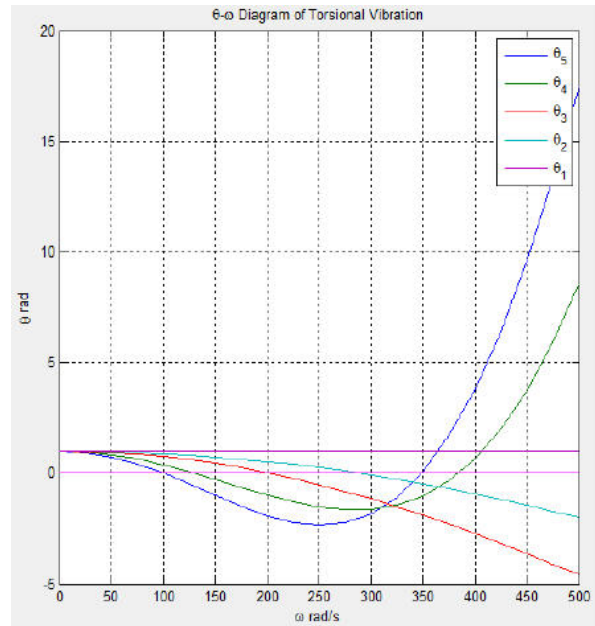


Figure (16) Theta-w Diagram case(3)

Figure (14), shows the normal elastic curve for case (3), in which two nodes of vibration appeared at speed of 500 rad/s. "The first between mass 1 and 2, and the second between mass 3 and 4". Figure (15), present the T-w diagram, which is illustrate clearly the two critical speeds occurred during operation. "The first at 200 rad/s and the second at 360 rad/s for T_5 curve". Meanwhile, there is another critical speed at 310 rad/s appears for T_2 and T_3 . Finally, Figure (16), shows the Theta-w diagram for the case which plots the amplitude of each mass due to unit amplitude at mass 1. It is clear, from this curve, that there is six nodes of vibrations appeared at different

operating speeds corresponding to the masses of the system.

5-Conclusions

The study of torsional vibration is very important as it can cause component failures or excessive deflections which can lead to premature fatigue failures if the machine is vibrating at speed near the natural frequencies of the vibrating system. Different methods have been discussed in the literature to analysis torsional vibration. Only holzer's method has specifically been used with matlab programming to produce the normal elastic curve, $t-\omega$, and $\theta-\omega$ diagrams, in which, these curves are very important for engineers and vibration analyst. The above analysis, may leads to the following conclusions:

First, the modified GUI developed for in this work, provide very convenient and useful tool for the behavior of parameters of torsional vibration for different rotor configurations.

Second, it eliminate the need for tabulated hand calculation and sophisticated numerical analyses such as finite elements, which require more time and effort, to obtain the same results. Finally, comparison of some results of this work with References [8], proves that, the accuracy of the

modified GUI for torsional vibration analysis is obvious.

6- References

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