

Development of a Magnetic Bearing Rotor Dynamics Analysis Software Package

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Abstract: During the design and research stage of magnetic bearings, often need to solve numerous of the rotor dynamics problems. Sometimes, to process these issues quickly and get preliminary conclusions is very help for its design. Just for this reason, a finite element software package running in the ANSYS environment is designed. It could highly improve efficiency through some simplifications of analysis, and could still achieve acceptable accuracy.

Keywords: Magnetic Bearing, Rotor Dynamics Analysis, ANSYS, Software Package

1 Introduction

Rotor dynamics analysis is an important part we have to do during magnetic bearing design^[1]. With the current level of technology of high speed computer and software, most of the calculations and analyses of rotor dynamics are no longer any things particularly difficult. Even so, this paper demonstrates the development of an easy-used software package design in ANSYS finite element software environment, through simplified of some boundary conditions and modeling method, which can easily set up the rotor and bearing model and quickly complete a series of rotor dynamics analysis for the rotor, such as critical speed, modal analysis, unbalance harmonic analysis, stimulus-response analysis and so on. And this package has been well tested in some cases, and now became a fast and efficient tool used for magnetic bearing rotors' dynamics calculations.

2 Environment of software package design and run

There are no special hardware requirements to the computer, as long as it has been installed ANSYS. Since the software package is programmed by APDL language and run in ANSYS environment. ANSYS is general finite element analysis software. It can take into account the rotor inertia effects, so which can be used for rotor dynamics analysis. APDL (ANSYS Parametric Design Language) is a kind of scripting language provided by ANSYS. Through the APDL language, program can call all of the functions in ANSYS and use to automate common tasks or build model in terms of parameters.

Software package is edited in a text editor, such as Notepad, and it is designed as a set of macros and run in ANSYS software, which version used here is V10.0. When you need to start the package, enter "Modal" command to call the package macros in the ANSYS command line.

When the software package is running in ANSYS, the effect of the interface is shown in Figure 1.

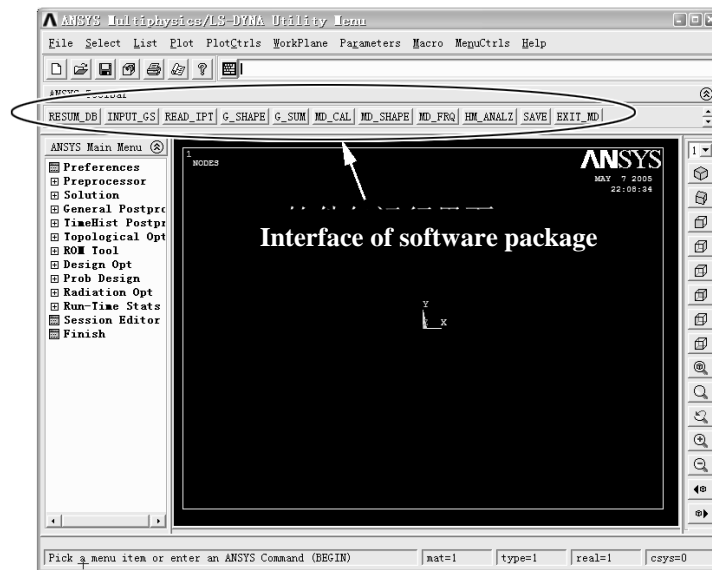


Figure 1. Interface of software package

Through a series of buttons, as well as a background of parameters input file, it can quickly finish general rotor dynamics analysis. To achieve efficient modeling and analysis, mainly due to the simplification of model and boundary conditions.

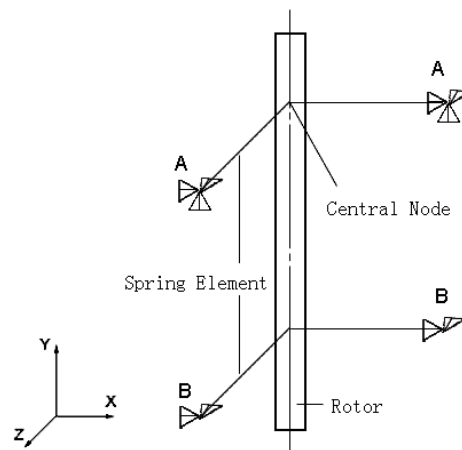
3 Modeling simplified

3.1 Simplification of magnetic bearing suspension

Active magnetic bearings are usually carried out in accordance with the mechanical properties of spring through control system design. So it is generally being considered as a spring during the analysis of rotor dynamics. Sometimes we have to consider the stiffness and damping change and even some nonlinear effects while the rotor speed rises up. But mostly, a spring assumption with constant stiffness and constant damping is enough for ordinary rotor dynamics calculations for magnetic bearing rotors.

Here in the software package, radial magnetic bearing is simulated by two orthogonal arrangement of spring-damper element. The stiffness and the damping of it are given in the input parameters file as fixed numbers. As the axial bearing effects can be ignored in the contributions of rotor dynamics, there are no special treatment to it when modeling.

As shown in figure 2. One end of the spring element is connecting to the mid-node of the bearing part on the rotor, and the other end of the element is connecting to a restrain key node. At the radial bearing side, set two-dimension bondage to the key node, and at the axial and radial bearing side, set full bondage^[2].



A) . XYZ full bondage B) . XZ two-dimension bondage
Figure 2. Boundary conditions

3.2 Simplification of rotor shape

Use the beam4 element supplied in ANSYS to set up the rotor model is very rough, but for most general computation, the accuracy is sufficient. Beam4 is a uniaxial element with tension, compression, torsion, and bending capabilities. It can be used to compute an unsymmetric gyroscopic damping matrix as well. By the real constant setting, the rotor diameter, moment of inertia is given to different element. A special point must be noted here is that disk on rotor is modeled by use of the beam4 element as well as the other part of the shaft, rather than a concentrated mass as common calculations. By the example behind, it can be seen that doing so is feasible to some extent.

4 Program function and structure design

This software package is going to design for convenient use. Therefore, the following features are considered during programming.

Parametric modeling: Through a parameter text document, the software package read the parameters of the rotor shape, materials, and bearings' character and so on.

Automatic Calculation: Except for writing parameter files, the rest of the calculation and analysis could be done automatically by the software. Calculations and analyses include: basic geometric calculation, critical speed, modal analysis, unbalance harmonic analysis, stimulus-response analysis and so on.

Program is designed with modular structure. Through parameters transfer, each module can call other modules and handle an independent part of the function.

The program structure is shown in figure 3.

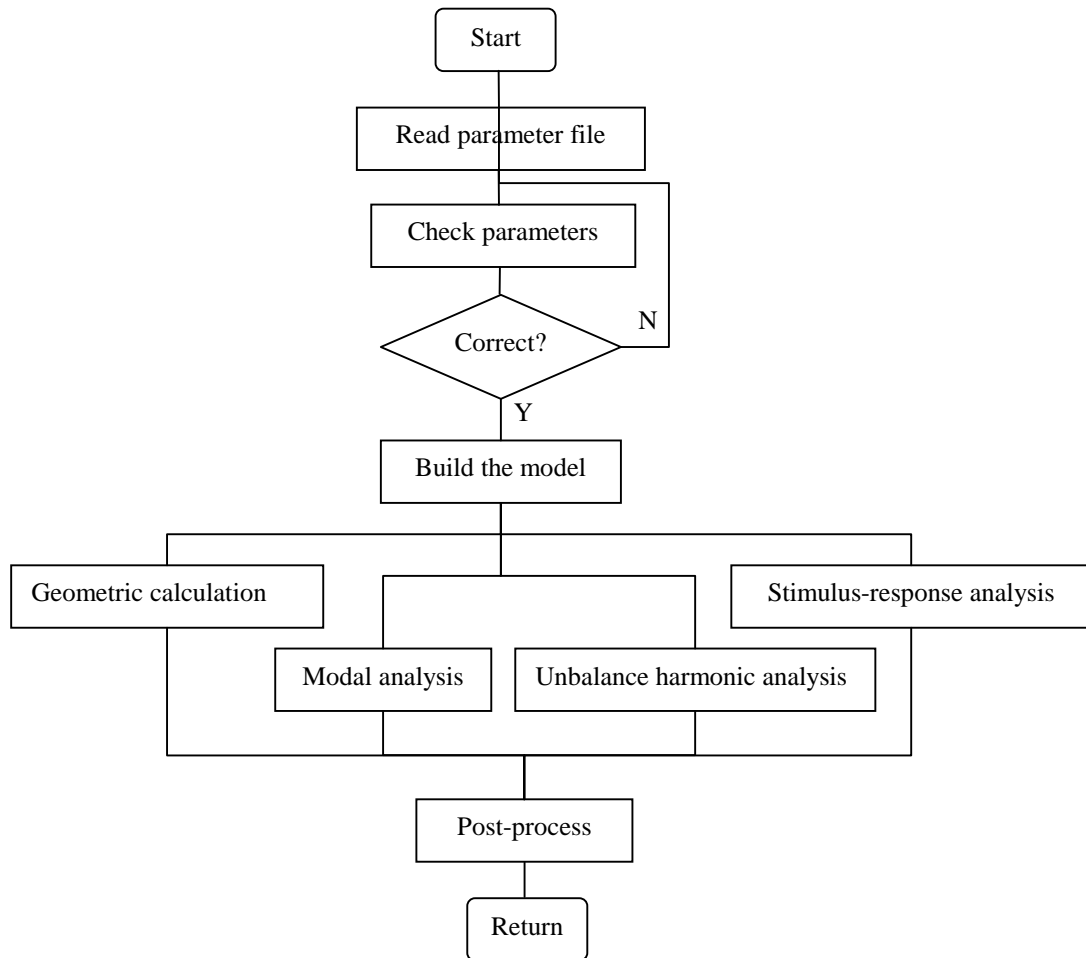


Figure 3. Program structure

In figure, it could be seen that this package builds a number of shortcut buttons on the interface. Parameters are read through a background file, and then most analysis functions could be achieved through just clicking the buttons. Detail function of each button is described below:

RESUM_DB: Load the data saved at the last time;

INPUT_GS: Impute parameters manual follow the prompt messages;

READ_IPT: Get the parameters through reading the input file;

G_SHAPE: Show the shape of the rotor;

G_SUM: Calculate the geometry character of the rotor, such as rotor mass, moment of inertial, center of gravity and so on;

MD_CAL: Calculate the critical speed;

MD_SHAPE: Show the first four mode shapes of calculation;

MD_FRQ: List the first 20 critical frequencies;

HM_ANALZ: Harmonic analysis. Stimulation type, position and power should be input follow the prompt;

SAVE: Save all data;

EXIT_MD: Exit the software package.

5 Test of the software package

Basically, there are three steps when use the package to process rotor dynamics analysis: modeling, solving and results display, which would be demonstrated through a test case of single-disk rotor analysis. Here we process only critical speed analysis.

5.1 Case description

A single-disk rotor model is shown in figure 4. Total length of the rotor is 750mm, diameter of the shaft is 30mm, disk diameter 240mm and weight 20kg. Elastic modulus of material is $2.058 \times 10^{11} \text{N/m}^2$, and density is 7800kg/m^3 .

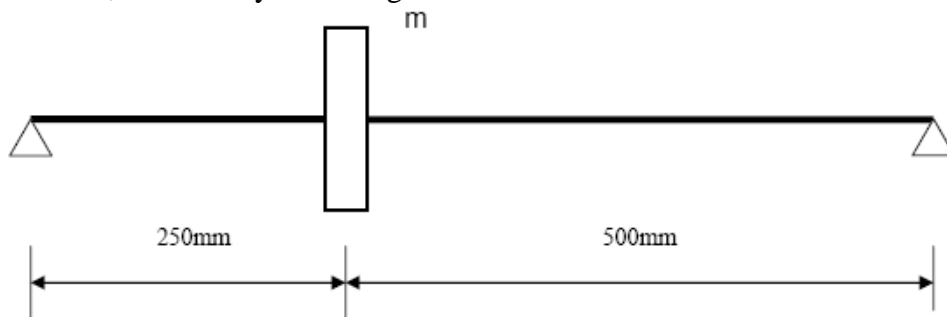


Figure 4. Single-disk rotor

1) Modeling

In the parameter input file, specify the material parameters, bearing stiffness, bearing location and the rotor shape along the data format. For example, the rotor shape should be input as every section length and its radius. Total length and total section number are both checked after parameters reading, to avoid mistake of typing.

After reading the parameters, we could click the button of G_SHAPE, and the finite element model is built up and shown as figure 5.

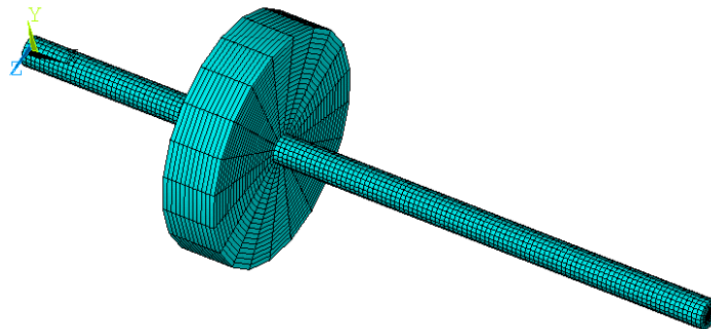


Figure 5. Finite element model of rotor

Click the G_SUM button, the structural characteristics of rotor will be listed like figure 6.

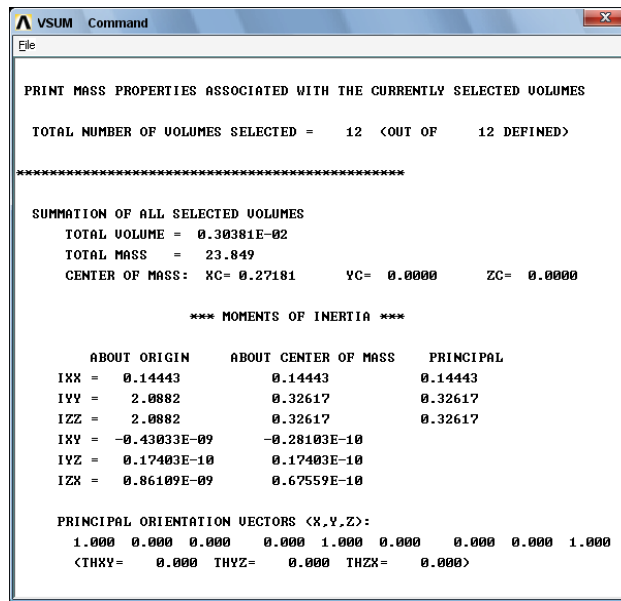


Figure 6. Characteristics of rotor

2) Solving

Before solving the problem, package would give a reminder to confirm some necessary boundary conditions parameters when processing the analysis, such as center of bearing location, stiffness and damping of bearings, frequency range of analysis, and so on.

In this case, demonstrate the analysis under two different support conditions. For simple support, the bearing stiffness can be set like magnitude of 10^{10} N/m or higher, and for magnetic bearing, it is set to 10^6 N/m in this case. Bearings located at the ends of the rotor.

When the screen appears “Solution is done!” message, it means that solving has completed.

3) Results display

The package will automatically show a most general result when the calculation is complete. In addition, through ANSYS utility menu of post-processing, other solution results could be directly shown as we want, such as eigenfrequencies, modal shapes or harmonic response curves and so on.

This case is a basic example of rotor dynamics and it can be calculated by use of general theoretical calculation^[3]. Table1 lists the theoretical results and package results of simple bearing, and the finite element analysis package results of magnetic bearing as well.

Table 1. Critical speed results

		1 st backward whirl critical speed /Hz	1 st forward whirl critical speed /Hz	2 nd backward whirl critical speed /Hz
Simple bearing	Package results	39.7	41.1	149.3
	Theoretical results	37.8	38.9	134.5
Magnetic bearing	Package results	29.9	30.1	91.7

To the case of simple bearing, compare package results with the theoretical calculation, the error is about 10%, still acceptable. One of the error reasons comes from the mass neglect of the shaft during the theoretical calculation. Campbell diagram result of this case is shown in Figure 7.

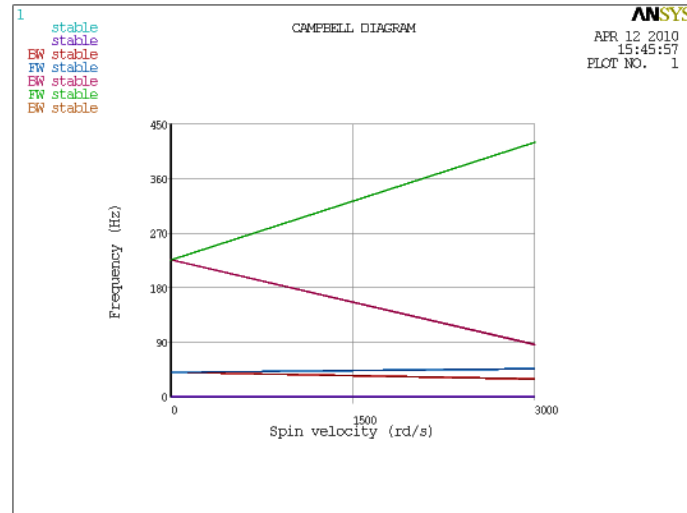


Figure 7. Campbell diagram of analysis

6 Conclusion

This paper demonstrates an easy-used magnetic bearing rotor dynamics analysis software package, which is program by APDL language in ANSYS environment. It can apply to quickly analyze general rotor dynamics with magnetic bearing suspension. Parametric modeling and some calculation simplified makes the efficiency greatly improved. Through two classic examples of single-disk rotor, indicates that this software package can run well. Because it's characteristics of convenience and high efficiency, this package has been applied to the preliminary design stage of a numbers of magnetic bearing projects, although not very high accuracy but still acceptable.

References

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