USING LITTLE-SHEAR-MODULUS MODEL TO SOLVE THE EIGENFREQUENCY OF AMB ROTOR WITH LAMINATION STACK

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ABSTRACT

In AMB design, the lamination stack is a general part of the rotor. It consists of pieces of stalloy, which is designed as very thin steel plate coating with special isolative paint. These sheets of assembly stacking stalloy will definitely influence the eigenfrequency and other dynamic effects of the rotor. But, considering the lamination's mechanical character, this influence is difficult to be well counted in the AMB design. Some simplified ways are used in solving this kind of problem, such as modeling the lamination as a part of the rotor and neglecting its rigidity influence. In this paper, two of these useful simple model solutions are studied and compared. Finally, the Little Shear Modulus (LSM) Model, a new model will be introduced, which exactly simulates the mechanical characters of the lamination stack and is easy to understand as well. An assumed simple rotor example is used to demonstrate this model. The eigenfrequency of this assumed rotor is solved by several models at the same time, and the comparison proves that the LSM model can give more reasonable result. Finally, an example is shown on how this LSM model is used to solve the eigenfrequency of an actual grinder rotor.

KETWORDS

Lamination, Rotor Dynamics, Eigenfrequency, FEA

INTRODUCTION OF LAMINATION STACK

The active magnetic bearing rotor laminations are constructed of low loss, electrical grade steel, which can well reduce the eddy current losses under high frequency electric-magnetic control signal.

The alternating magnetic flux creates electro motive forces inside the material it flows through. These electro motive forces fluctuate at the same speed as the flux and similarly create eddy currents normal to the flux path, i.e. the eddy currents circle around the flux. The eddy current power loss can be presented as the following equation:

$$P_{ec} = \frac{V_{lam}\left(\pi f \hat{B} \tau\right)^2}{6\rho_{lam}} \qquad (1)$$

It can be seen from Eq.(1) that there are several factors affecting the eddy current losses, but usually the outer dimensions of the AMB rotor, flux density B and the frequency f are constants and so there are only two variable factors: the thickness of the lamination τ and the resistivity ρ_{lam} of the iron. So, the structure with assembly stack of a very thin, low loss, electrical grade steel plate is used, and at least one side of the laminated plate has a non-magnetic insulation layer (such as silicon) which prevents eddy currents from traveling between the plates.

The structure of lamination stack solves the problem of eddy current losses, but it also brings difficulty in dynamic analysis. Now, the dynamic analysis, including modal analysis and eigenfrequency analysis are mostly dealed by Finite Element Analysis (FEA) through computer, and the most important work of FEA is to set up an appropriate model.

SEVERAL MODELS TO SIMULATE THE LAMINATION STACK

Of cause, the lamination stack changes the rotor dynamic effect. Consider the structure of lamination stack, it supplies a notable mass but only small rigidity to the rotor. That is just why it is difficult to set up an FEA modal for it. In this paper, three solution models for this case will be introduced. Two of them are commonly used and the other is a new one.

a) Middle-Result (MR) Model

There are two excessive situations to simplify the lamination structure. One is to consider the lamination as a part of the rotor, which will provide both mass and rigidity to the rotor, and the FEA eigenfrequency calculated result will be higher than the true eigenfrequency. The other is to consider the lamination as additional mass of the rotor, without stiffness. And then, the eigenfrequency calculated result will be lower than the truth value. When the lamination stack is placed near by the stationary point of a bending axis, or when the lamination stack is just a very small part of a rotor, its influence to the bending eigenfrequency is not very strong, and the middle result of these two excessive situations can be well close to the true value. So it is called Middle-Result (MR) Model. But if the lamination stack is placed over the peak of a bending axis, these two excessive situations will bring to two distinct results, and the middle result of them will lose its meaning.

b) Small-Rigidity (SR) Model

Another reasonable model to simulate the lamination stack is Small-Rigidity Model. It is known that the lamination will be very rigid when it is pressed by outer force, but when it is dragged, it will present to be very flexible, even very easy to be separated. Also consider the bending modal shape of the rotor, when the rotor is ideally purely bended, half of the cross section is under pressed and the other half is under dragged. So, assume that the lamination has only half rigidity of common steel, it comes out the half-rigidity model. In fact, each piece of the lamination stack is coating with the insulation layer. So mostly, when the lamination is under pressed, it can not even provide half rigidity of the steel material, just because the insulation layer is much softer than the steel. Base on the actual analysis object, some other models like one third or one fourth rigidity model under experiences are used. They are here looked like as the similar method, it is call Small-Rigidity model, which is often used in special situation when the object rotor has been well studied.

c) Little-Shear-Modulus (LSM) Model—A new ideal model

Consider the actual lamination stack, to each piece itself, it has the same basic mechanical character as the ordinary steel material, but there is little relationship between each isolated piece of stalloy when the bending deformation is not very large. When the lamination stack is modeled as a big block of solid mass, it ought to be such a kind of material which is hard to be pressed and very easy to be sheared off between the layers. So, in finite element analysis, it can be assumed to be an ideal anisotropic material which has little shear modulus on the plane direction parallel to the steel plate, this is called Little-Shear-Modulus material model. In addition, the idea of half-rigidity model is borrowed here, in the direction parallel to the axis, only half elastic ratio will be used. The other modulus in the other directions of this model is kept as usual. This LSM anisotropic material model can nearly simulate the full mechanical character of the lamination stack on the rotor.

If this LSM model is used to solve the rotor dynamics problem, several important factors should be carefully considered, such as balance of Poisson's coefficients and the change of Young's modulus. These will be shown in the following example.

A SIMPLE BEAM EXAMPLE

As a test of the LSM model, modal analysis of a simple rotor shown in figure 1 is performed by the above three solutions. The different bending eigenfrequency results are compared.

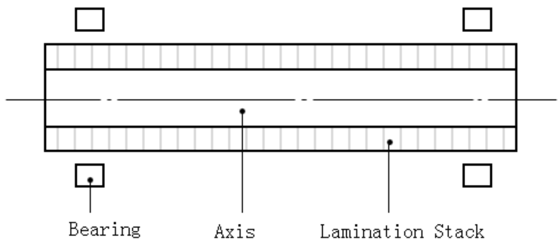


FIGURE 1: Beam model for lamination analysis

To this rotor, its eigenfrequency is largely changed when the outside lamination stack is added up. Assume the length of this rotor is 180mm, the rotor diameter is 14.6mm, the lamination diameter is 40mm, and the bearing stiffness is 1×10^5N/m, the distance from the AMB to the axis top is 30mm.

a) Material Property

The material of the rotor is assumed to be ordinary steel, which has the following steel material properties: density ρ_S is 7800kg/m^3, Young's modulus E_S is 200GPa, and Poisson's coefficient μ_S is 0.3.

The lamination steel property is differed from ordinary steel: density ρ_L is 7550kg/m^3, Young's modulus E_L is 200GPa, and Poisson's coefficient μ_L is 0.3. But this property will be assumed to be different with different model.

MR model will use two different Young's modulus: E_{MR1} = 200GPa, E_{MR2} = 0, other material properties are the same.

SR model will use 1/8 of the ordinary Young's modulus: E_{SR} = 25GPa, other material properties are the same.

LSM model will use the following assumed anisotropic material properties:

Young's modulus:

$E_X = E_Z = 200e9, \quad E_Y = 100e9$

Shear Modulus:

$G_{XY} = G_{YZ} = 80e7, \quad G_{XZ} = 80e9$

Poisson's coefficient:

$\mu_{XY} = \mu_{XZ} = \mu_{ZY} = \mu_{ZX} = 0.3,$

$\mu_{YX} = \mu_{YZ} = 0.15$

Density:

$\rho = 7850\ kg/m^3$

Here, the Y direction is parallel to the axis direction. And the six Poisson's coefficients are not fully isolated, they have to fit the function show as Eq.2.

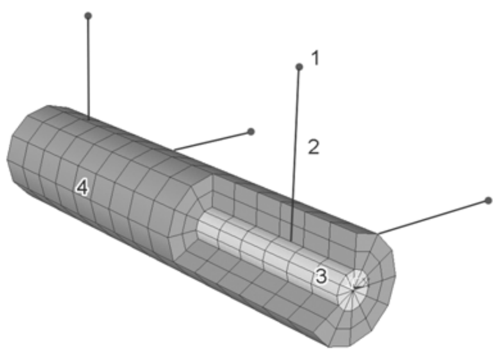
$$\begin{cases} E_X \cdot \mu_{YX} = E_Y \cdot \mu_{XY} \\ E_Y \cdot \mu_{ZY} = E_Z \cdot \mu_{YZ} \\ E_Z \cdot \mu_{XZ} = E_X \cdot \mu_{ZX} \end{cases} \qquad (2)$$

And the shear modulus can not be set to zero because of two reason. One is to avoid the instable of stiffness matrix, and the other is to represent the friction.

b) FEA model

Except for the material property, these three solutions will use the same boundary conditions, the same finite element mesh, and the same FEA software.

Firstly, the FEA calculation is based on 3D model, and a higher order 20-node 3D solid brick element is used in meshing. This kind of element has quadratic displacement behavior, and supports large deflection. The bearing suspension will be modeled as two directions springs connection from the middle node of the axis to the fix boundary, which have the same stiffness as the AMB. This FEA model is shown in figure 2.



1). Fix Boundary 2). Spring Element
3). Axis 4). Lamination

FIGURE 2: The FEA model of the beam example

This FEA 3D model includes totally 544 elements and 2832 nodes.

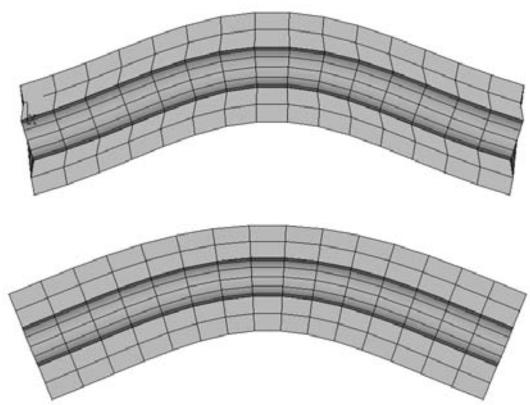
c) Modal Analysis Results

The eigenfrequency of modal analysis results from different models are listed below:

Eigenfrequency Solution	MR	SS (1/8 rigidity)	LSM
1st Rigid	53	54	53
2nd Rigid	61	62	61
1st Bending	2816	1918	2114
2nd Bending	6587	4663	3693

The two rigid eigenfrequency is all the same in different model calculation results, because it only depends on the rotor mass and the bearing stiffness. But the bending eigenfrequency results are quite different.

Judging by the frequency, it is hard to tell which model can give the best result. Thus, the simulated modal shapes of different models are also compared. It is obvious that the LSM model gives a quite different bending modal shape to the others. The following figure 3 shows the 1st bending modal shape of LSM model result and the ordinary bending modal shape.



1) Bending of LSM Model
2) Ordinary Bending
(displacement scale is largely amplified)

FIGURE 3: The 1st bending modal shape

Because each steel plate of the lamination stack is isolated, when the rotor is bending, these lamination plates are much easier to be sheared off than to be pressed, which is correctly showed in the LSM model bending shape. In other words, the bending of lamination stack is not a theoretical pure bending, and through an ideal anisotropic material, it can be well simulated by FEA calculation.

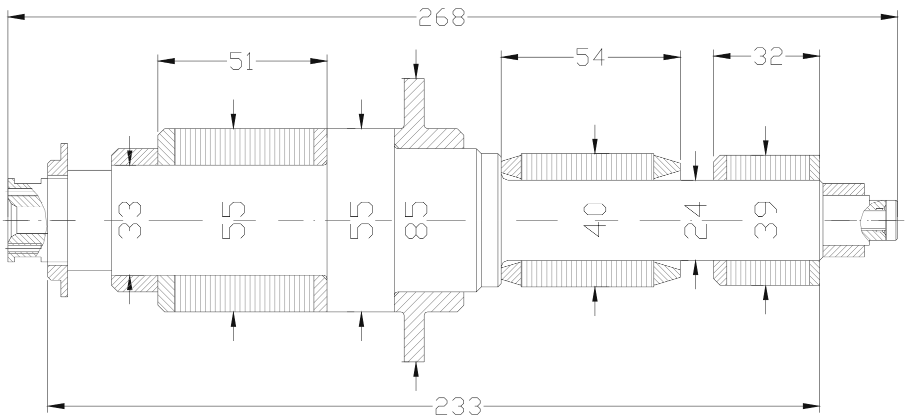


FIGURE 4: The grinder rotor

USE LSM MODEL TO SOLVE THE EIGENFREQUENCY OF AN ACTUAL GRINDER ROTOR

Finally, the LSM model is used to solve the eigenfrequency of an actual grinder rotor. This grinder rotor is shown in figure 4.

There are three sections on this rotor using lamination structural: two radial AMB and the electric motor. The FEA method with LSM model is used to solve the first bending eigenfrequency of this rotor. The detail of how to process the calculation will not be redescribed again.

The FEA calculation result of the first bending eigenfrequency of this grinder rotor is about 1879Hz, and the experiment test result is about 1800Hz. The relative deviation of the first bending eigenfrequency which solve by using LSM model is about 4.4%. And the other eigenfrequencies are not tested in the experiment.

CONCLUSIONS

The LSM model can well represent the property of lamination stack. Using the LSM model in FEA modal analysis can not only get the actual eigenfrequency, but also can show the actual bending shape of the rotor. This LSM model will be very useful in solving the dynamics problem of the rotor with lamination structure.

REFERENCES

[1] Schweitzer G, Bleuler H, Traxler A. Active Magnetic Bearings, Zurich, vdf Hochschulverlag AG., 1994

[2] Allaire PE, Kasarda MEF, Fujita LK: Rotor power losses in planar radial magnetic bearings – effects of number of stator poles, air gap thickness, and magnetic flux density. Proc. 6th Internat. Symp. on Magnetic Bearings, MIT Cambridge, 1998, August 5-7, 383-391.

[3] Rotating Machinery and Controls Laboratory. 2003 Romac Newsletter. http://www.virginia.edu/romac/