VIBRATION ANALYSIS OF COMPOSITE DISKS

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ABSTRACT. Often, disks rotating at high speeds are fabricated from high-strength, filament-wound composites. The carbon and glass fiber bundles, or tows that make up a filament, are often similar in different disk designs, and steady-state stress analyses are usually reported. Typically, little information is reported about the dynamic deformation and vibrations of the disk, which are important for understanding instabilities at high rotational speeds.

First, experimental and FEM modal analyses are performed for a non-rotating disk to verify the FEM model. The disk is made from composite rings which are press-fit or urethane bonded onto a hub. Then, the FEM model is used to analyze the effect of prestressing and stress stiffening due to rotation at various speeds.

1. INTRODUCTION

Rotors are quite often made of multiple layers which are press fit to induce compressive hoop stress to somewhat offset the tensile hoop stress due to spinning. The analysis involving isotropic materials for different layers are simple and available in classical text books on strength of materials [1]. However, application of isotropic materials are limited due to the fact that hoop stress is much greater than the radial stress resulting in inefficient or bulky design.

A solution to such problems of stresses of different magnitude in different directions is the use of composite materials. Use of composite materials due to their anisotropic (in this case orthotropic) properties have been prevalent for years. Analysis of such composite materials have also been integrated into finite element codes such as ANSYS [2]. However, comparison of theory and experiment lacks in general.

2. FINITE ELEMENT ANALYSIS

In general it is not recommended to perform modal analysis (which is linear analysis) of a structure which has contact elements. Contact elements were needed to simulate the appropriate prestress due to interferences/gaps. By nonlinear static analysis using contact elements, prestress was generated. Since the modal analysis is linear, whereas contact elements are nonlinear, after computing prestress contact elements were "frozen": nodes were coupled instead of connected by contact elements. Also, in order to observe the effect of prestress, modal analysis was performed ignoring the gaps/interence. Subspace method was used (along with eigenvalue shift) to compute first few nonrigid body natural frequency and mode shapes.

3. RESULTS

The press-fit rotor was tested with an impact hammer under free-free boundary condition (supported on sponge), using a PCB accelerometer, Bruel & Kjaer dual channel FFT analyzer, and STAR MODAL software.

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Natural frequencies and mode shapes were obtained. The experimental results and finite element results are presented in Table 1.

Next the rotor with urethane layer connections was analyzed both experimentally and by finite element analysis. Since urethane stiffness is much lower than the rest of the components, the stiffness of urethane primarily governs the natural frequency. The urethane modulus increases with frequency and tensile modulus data up to 400 Hz only is available. Table 2 presents the experimental frequencies as well as finite element results with various modulii of urethane.

Finally, natural frequencies of the press-fit rotor were obtained by finite element analysis at various speeds, including stress stiffening and spin softening. Results are presented in Table 3.

4. CONCLUSIONS:

Finite element results are in close agreement with experimental results for the press-fit rotor, if prestress is included. However, the presence of the visco elastic connection material, whose modulus changes with frequency, makes correlation with experiment difficult. Finite element results for spinning case shows that stress stiffening has significant effect at higher speeds but spin softening did not have much effect. For future work it is recommended to perform experimental analysis under rotation to correlate with finite element analysis.

5. REFERENCES

[1] Cook, R.D. and Young, W.C.
Advanced Mechanics of Materials, MacMillan, New York, 1985.

[2] ANSYS version 5.3, ANSYS Inc., PA, 1996.

Mode #	Mode Shape	Experiment (Hz)	FEM w/o Pre-stress	FEM with Pre-stress
1	2 nodal dia	850	761	834
2	0 nodal dia	1400	1389	1451
3	1 nodal dia	1800	1732	1767
4	3 nodal dia	2030	1807	1868

Table 1. Rotor with Press-fit

Mode #	Mode Shape	Experiment Hz	FEM (Hz)		
			Urethane =15.1 MPa	E urethane = 45.3 MPa	E urethane = 90.6 MPa
1	2 nodal dia	310	241	258	271
2	0 nodal dia	630	400	542	607
3	1 nodal dia	861	489	683	783

Table 2. Rotor with Urethane

Mode #	Mode Shape	Frequency with prestress at zero speed	Frequency with prestress and stress stiffening at 1000 rad/sec	Frequency with prestress and stress stiffening at 2000 rad/sec	Frequency with prestress and stress stiffening at 4000 rad/sec
1	2 nodal dia	834	886	1028	1468
2	0 nodal dia	1451	1453	1465	1502
3	1 nodal dia	1767	1770	1802	1925
4	3 nodal dia	1868	1927	2069	2564

Table 3. *Press-fit Rotor at Various Speeds*