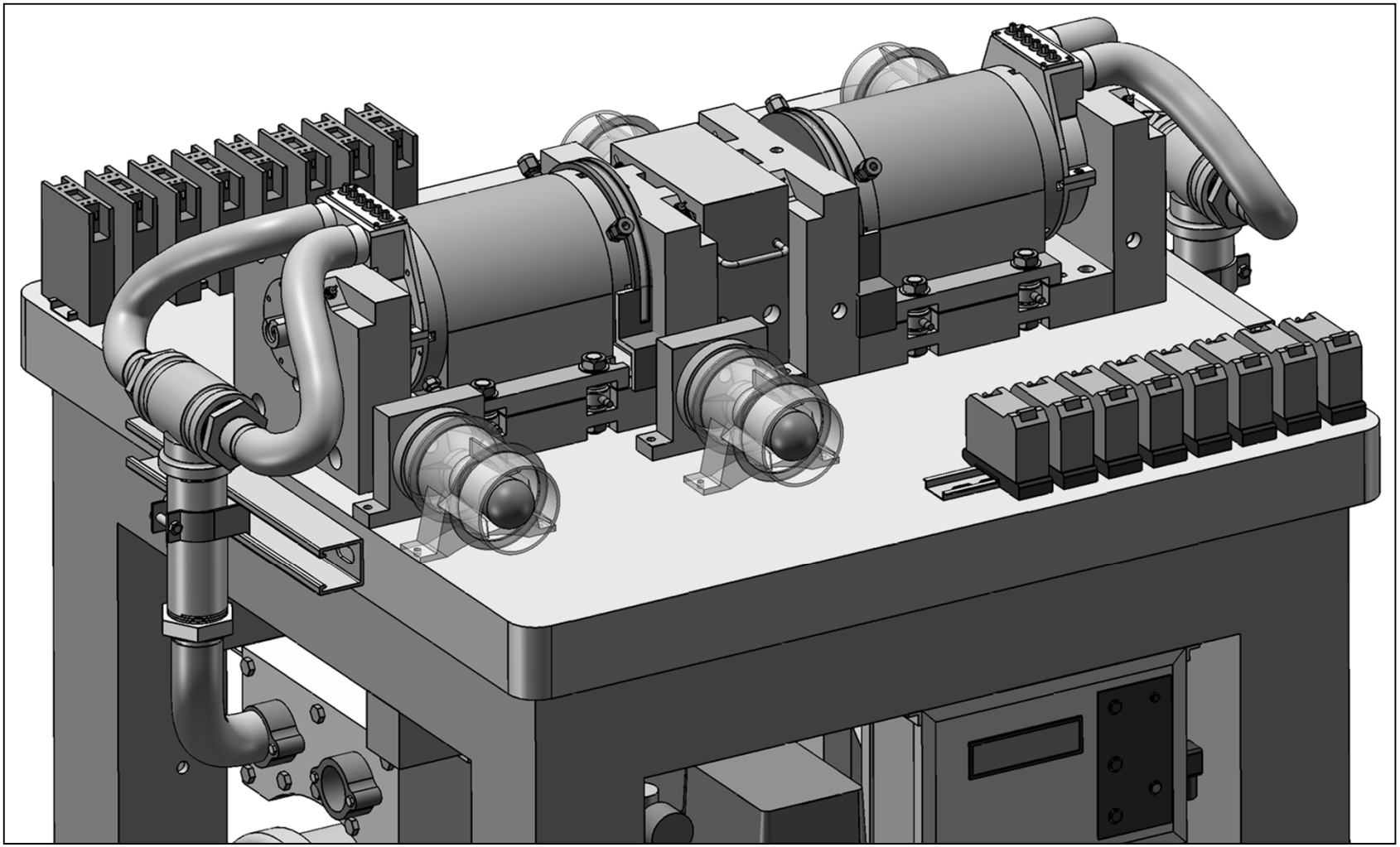
Free-Free Impact Hammer Testing



Bugra Ertas

4/07/2010

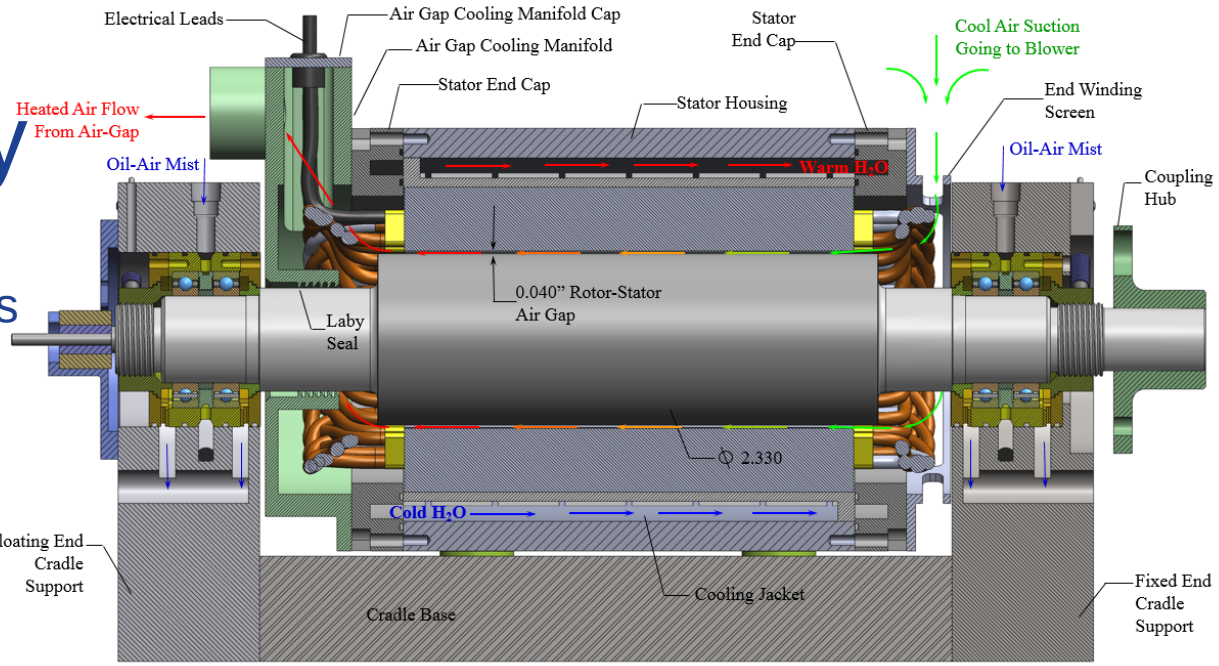
imagination at work

Objective

- To predict rotor bearing system natural frequencies/Critical Speeds
- Understand the limits of residual mass unbalance
- Select the correct bearing preload levels

Design Strategy

- Operate at sub-critical speeds
- Tight air gaps
- Low vibration required

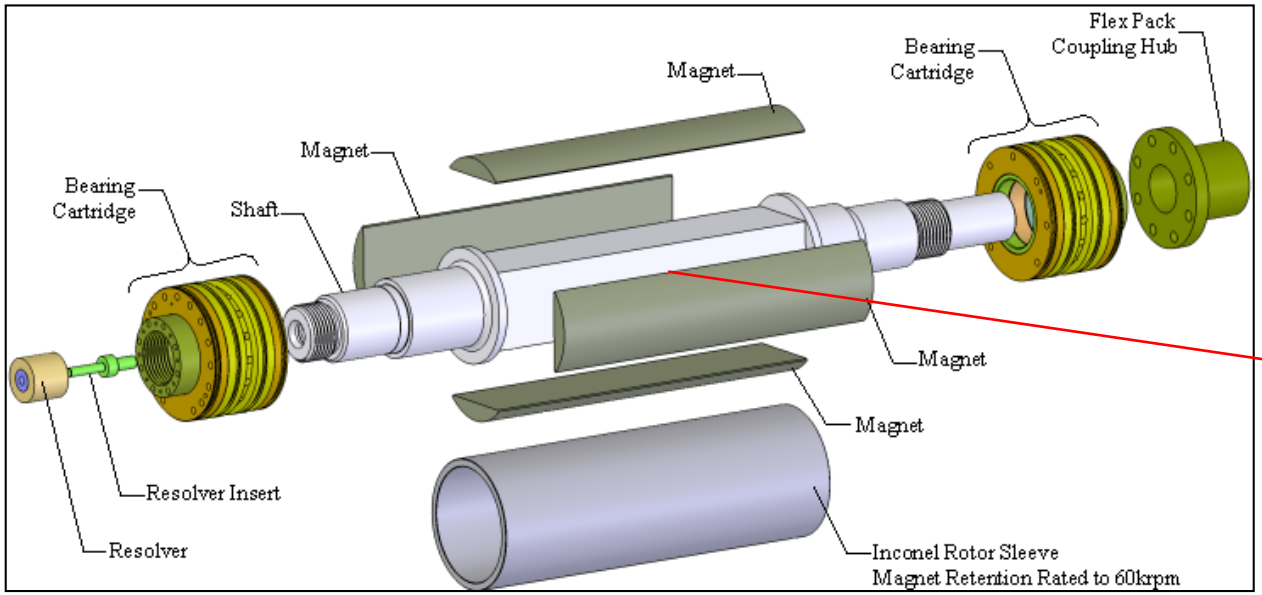


Unknowns

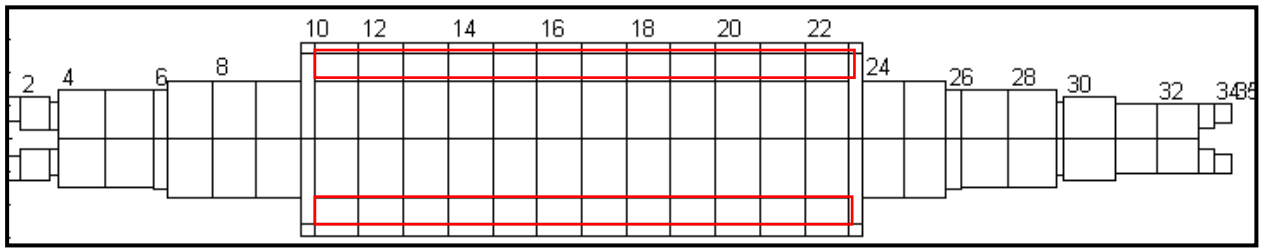
- Contribution of magnets to the rotor bending stiffness
  -was understood through free-free modal testing
- Bearing stiffness values and influence on critical speeds
  -determined through rotordynamics

IMPORTANT for PERMANENT MAGNET MOTORS

Motor/Generator Rotor Architecture



Rotor is a COMPOSITE of metal (solid and thin sleeves) and non-metal parts



- Rotor design with 3 main components
  -shaft, magnets, and rotor retaining sleeve

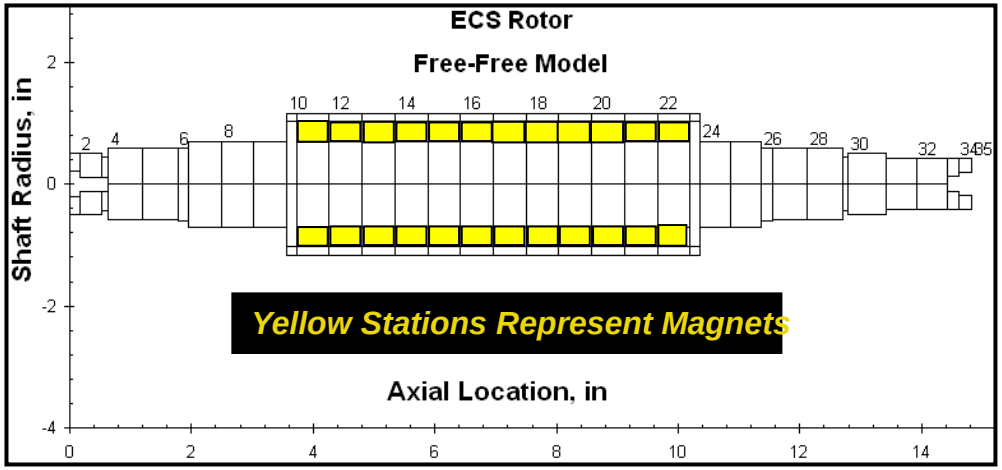
- Need to understand the stiffness contribution of the magnets

Free-Free Rotordynamic Model

- Free-Free model built for calibrating elastic (E_m) and shear (G_m) modulus of magnets….wrt E_s and G_s (s=steel)

- This will determine bending stiffness of the rotor assembly and therefore will have an impact on critical speed locations

First Stn	Last Stn	Level Length	Total Level	Level CG	Total Level It	Total Level Ip
		in	lb	in	lb-in2	lb-in2
1	35	14.815	10.900	6.977946	100.998878	6.249
All stations			10.900	6.977946	100.998878	6.249
All rotating stations			10.900	6.977946	100.998878	6.249
All non-rotating stations			0.000	0	0	



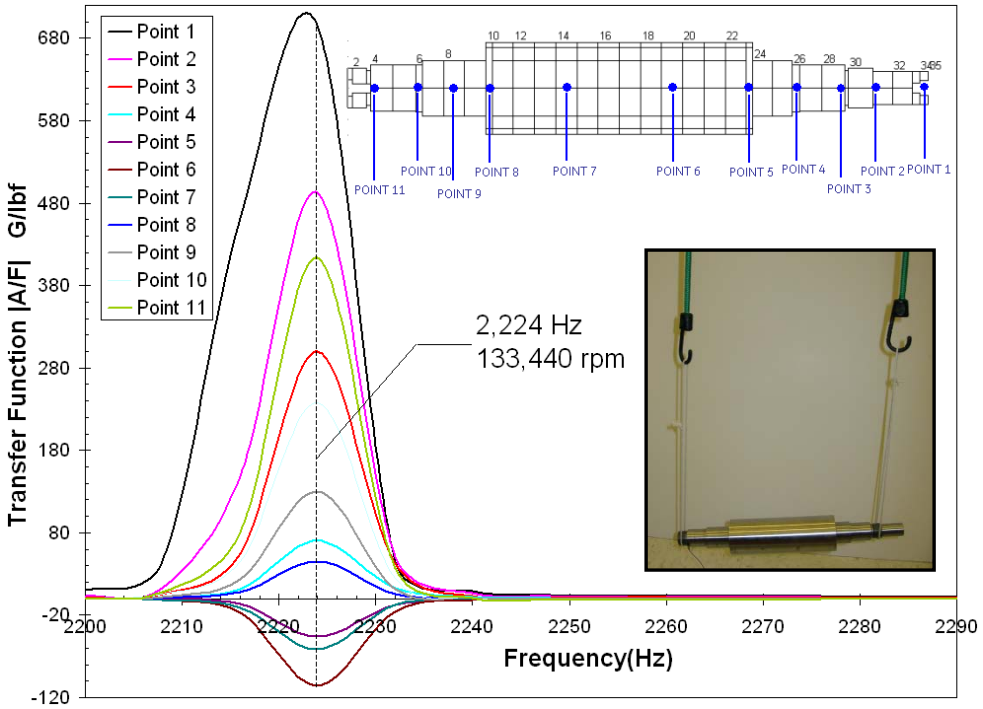
INPUT TABLE OF BEAM AND STATION DEFINITIONS, MORE THAN ONE BEAM PER STATION IS OK										
Station	Length	OD	ID	Weight Density	Elastic Modulus	Shear Modulus	Added Weight	Added Ip	Added It	Speed Factor
#	in	in	in	lb/in^3	psi	psi	lb	lb-in^2	lb-in^2	
1	0.165	1	0.42	0.283	30.0E+6	12.0E+6				1.0
2	0.36	1	0.228	0.283	30.0E+6	12.0E+6				1.0
3	0.1	0.88	0.228	0.283	30.0E+6	12.0E+6				1.0
4	0.575	1.1808	0	0.283	30.0E+6	12.0E+6				1.0
5	0.575	1.1808	0	0.283	30.0E+6	12.0E+6				1.0
6	0.185	1.2	0	0.283	30.0E+6	12.0E+6				1.0
7	0.53333	1.4	0	0.283	30.0E+6	12.0E+6				1.0
8	0.53333	1.4	0	0.283	30.0E+6	12.0E+6				1.0
9	0.53333	1.4	0	0.283	30.0E+6	12.0E+6				1.0
10	0.162	2.051	0	0.283	30.0E+6	12.0E+6				1.0
10	0.162	2.33	2.051	0.283	30.0E+6	12.0E+6				1.0
11	0.53967	1.4	0	0.283	30.0E+6	12.0E+6				1.0
11	0.53967	2.051	1.4	0.3	18.0E+6	7.2E+6				1.0
11	0.53967	2.33	2.051	0.29	30.0E+6	12.0E+6				1.0
12	0.53967	1.4	0	0.283	30.0E+6	12.0E+6				1.0
12	0.53967	2.051	1.4	0.3	18.0E+6	7.2E+6				1.0
12	0.53967	2.33	2.051	0.29	30.0E+6	12.0E+6				1.0
13	0.53967	1.4	0	0.283	30.0E+6	12.0E+6				1.0
13	0.53967	2.051	1.4	0.3	18.0E+6	7.2E+6				1.0
13	0.53967	2.33	2.051	0.29	30.0E+6	12.0E+6				1.0
14	0.53967	1.4	0	0.283	30.0E+6	12.0E+6				1.0
14	0.53967	2.051	1.4	0.3	18.0E+6	7.2E+6				1.0
14	0.53967	2.33	2.051	0.29	30.0E+6	12.0E+6				1.0
15	0.53967	1.4	0	0.283	30.0E+6	12.0E+6				1.0
15	0.53967	2.051	1.4	0.3	18.0E+6	7.2E+6				1.0
15	0.53967	2.33	2.051	0.29	30.0E+6	12.0E+6				1.0
16	0.53967	1.4	0	0.283	30.0E+6	12.0E+6				1.0
16	0.53967	2.051	1.4	0.3	18.0E+6	7.2E+6				1.0
16	0.53967	2.33	2.051	0.29	30.0E+6	12.0E+6				1.0
17	0.53967	1.4	0	0.283	30.0E+6	12.0E+6				1.0
17	0.53967	2.051	1.4	0.3	18.0E+6	7.2E+6				1.0
17	0.53967	2.33	2.051	0.29	30.0E+6	12.0E+6				1.0
18	0.53967	1.4	0	0.283	30.0E+6	12.0E+6				1.0
18	0.53967	2.051	1.4	0.3	18.0E+6	7.2E+6				1.0
18	0.53967	2.33	2.051	0.29	30.0E+6	12.0E+6				1.0
19	0.53967	1.4	0	0.283	30.0E+6	12.0E+6				1.0
19	0.53967	2.051	1.4	0.3	18.0E+6	7.2E+6				1.0
19	0.53967	2.33	2.051	0.29	30.0E+6	12.0E+6				1.0
20	0.53967	1.4	0	0.283	30.0E+6	12.0E+6				1.0
20	0.53967	2.051	1.4	0.3	18.0E+6	7.2E+6				1.0
20	0.53967	2.33	2.051	0.29	30.0E+6	12.0E+6				1.0
21	0.53967	1.4	0	0.283	30.0E+6	12.0E+6				1.0
21	0.53967	2.051	1.4	0.3	18.0E+6	7.2E+6				1.0
21	0.53967	2.33	2.051	0.29	30.0E+6	12.0E+6				1.0
22	0.53967	1.4	0	0.283	30.0E+6	12.0E+6				1.0
22	0.53967	2.051	1.4	0.3	18.0E+6	7.2E+6				1.0
22	0.53967	2.33	2.051	0.29	30.0E+6	12.0E+6				1.0
23	0.162	2.051	0	0.283	30.0E+6	12.0E+6				1.0
23	0.162	2.33	2.051	0.283	30.0E+6	12.0E+6				1.0
24	0.5	1.4	0	0.283	30.0E+6	12.0E+6				1.0
25	0.5	1.4	0	0.283	30.0E+6	12.0E+6				1.0
26	0.185	1.2	0	0.283	30.0E+6	12.0E+6				1.0
27	0.575	1.1808	0	0.283	30.0E+6	12.0E+6				1.0
28	0.575	1.1808	0	0.283	30.0E+6	12.0E+6				1.0
29	0.1	0.88	0	0.283	30.0E+6	12.0E+6				1.0
30	0.62	1	0	0.283	30.0E+6	12.0E+6				1.0
31	0.5	0.85	0	0.283	30.0E+6	12.0E+6				1.0
32	0.5	0.85	0	0.283	30.0E+6	12.0E+6				1.0
33	0.2	0.85	0.25	0.283	30.0E+6	12.0E+6				1.0
34	0.2	0.85	0.375	0.283	30.0E+6	12.0E+6				1.0
35	0									1.0

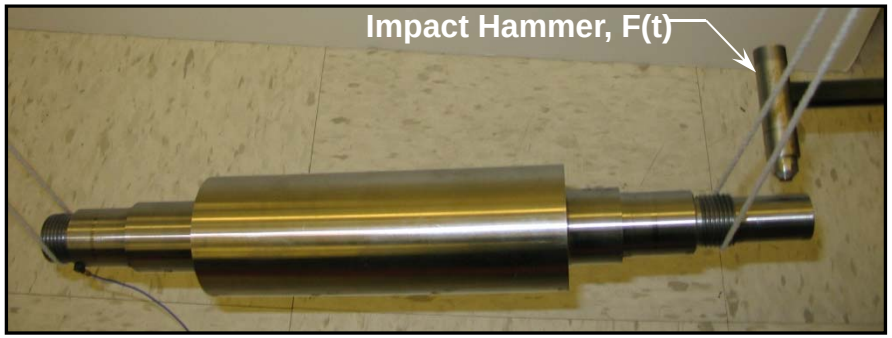
Free-Free Modal Vibration Testing

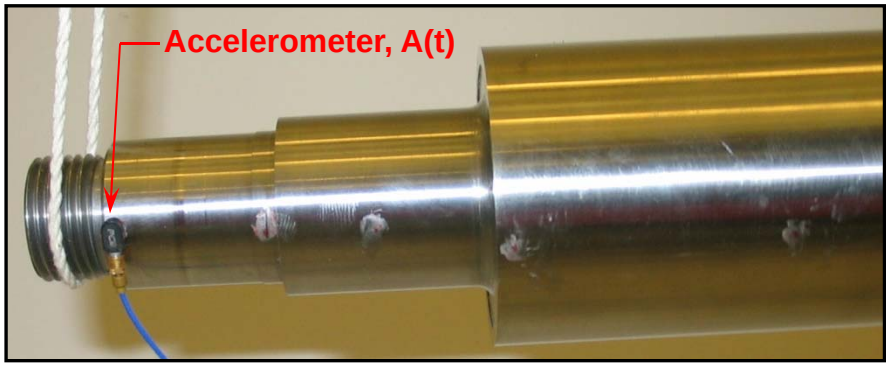
- Hang rotor through elastic cords

- Impact rotor with hammer at one location while “roaming” the accelerometer ….roaming accelerometer method

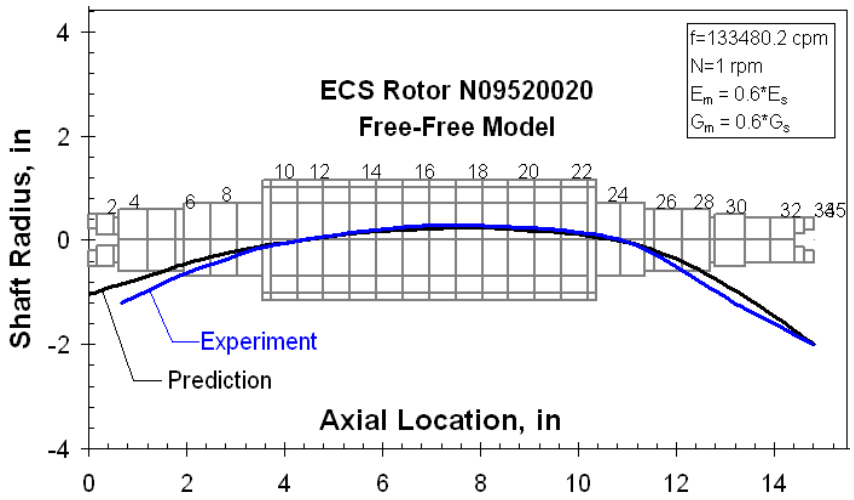
- Measured transfer function (mechanical/inertial impedance)

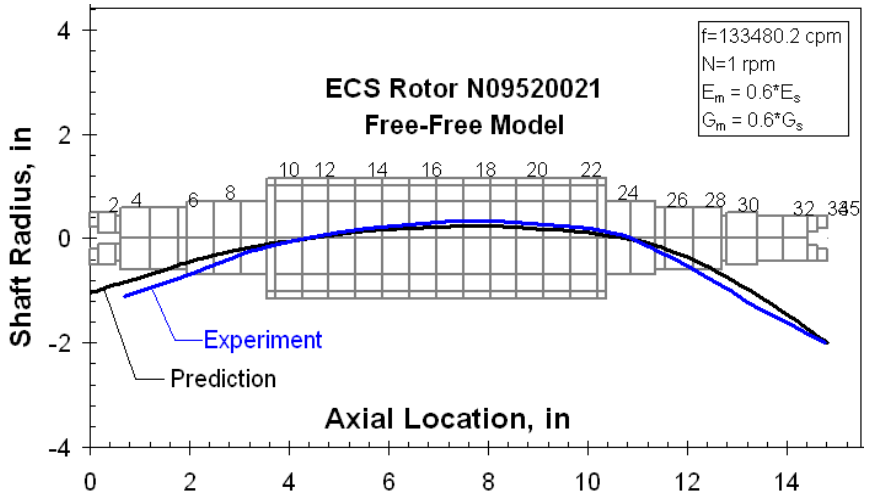


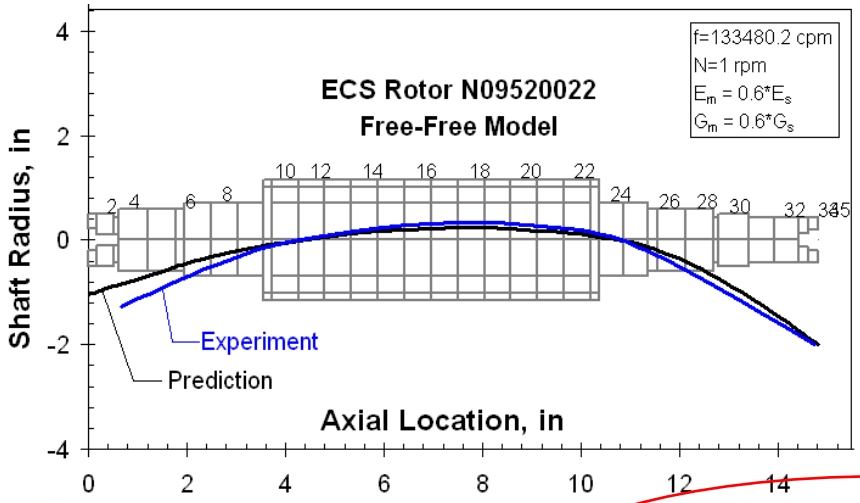


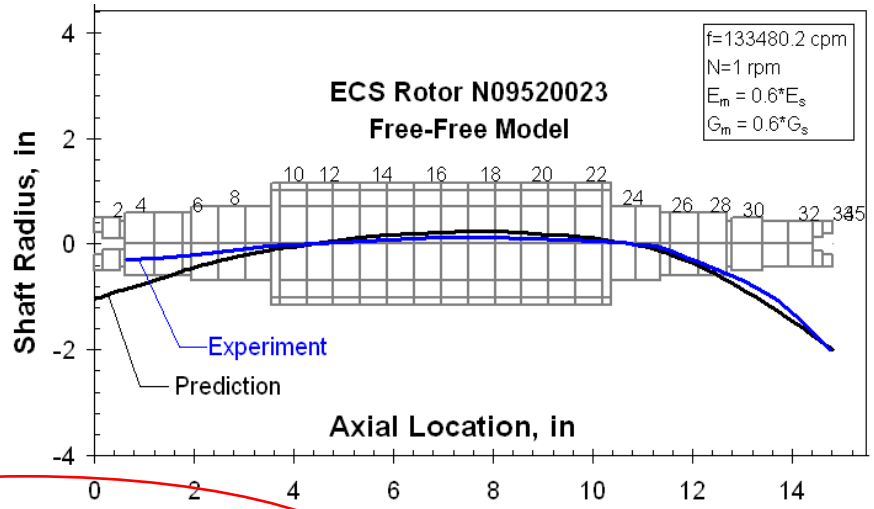


Free-Free Modes: Experiments vs. Predictions









E_m and G_m Calibrated to 60% of E_s and G_s to Match Frequencies