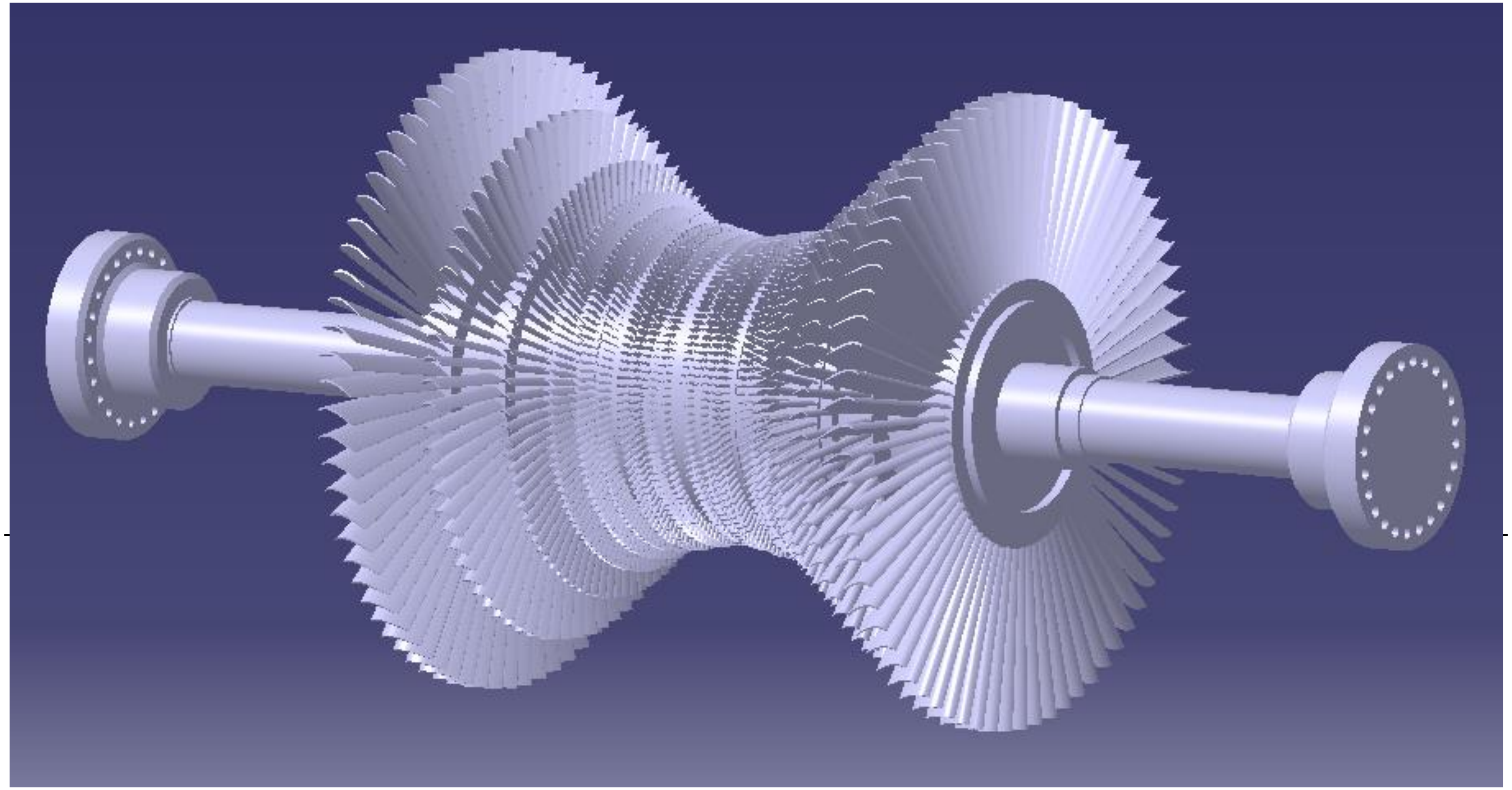
Rotordynamic Analysis of the AM600 Turbine-Generator Shaftline



Tshimangadzo Mudau 26 October 2018

사단법인 한국원자력학회
KOREAN NUCLEAR SOCIETY

KINGS KEPCO INTERNATIONAL NUCLEAR GRADUATE SCHOOL

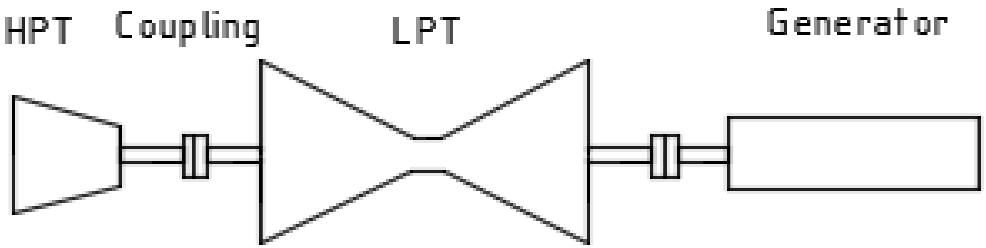
Contents

- Introduction
- Literature Review
- Methodology
- Discussions
- Conclusion

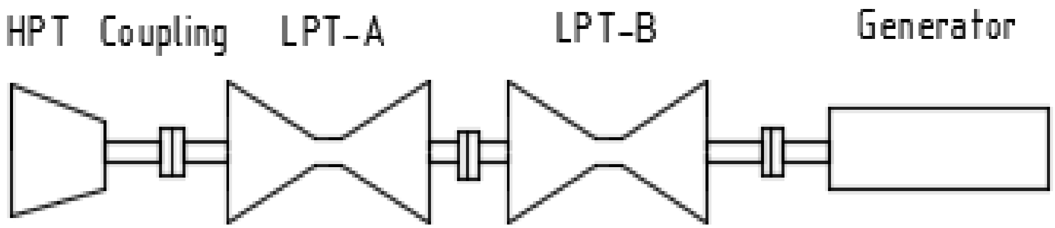
Introduction to the AM600

- Advanced Modern (AM) 600 MWe
- Address challenges of emerging markets interested in NPP - grid capacity and infrastructure
- Electrical grids are less stable, large variation in operating frequency drift, bringing shaftline into resonance
- Must be robust to torsional vibration

- 50 Hz market – 1500 rpm
- Single LPT cylinder, with 1.6m Last Stage Blades (LSB)
- Welded drum type LPT rotor



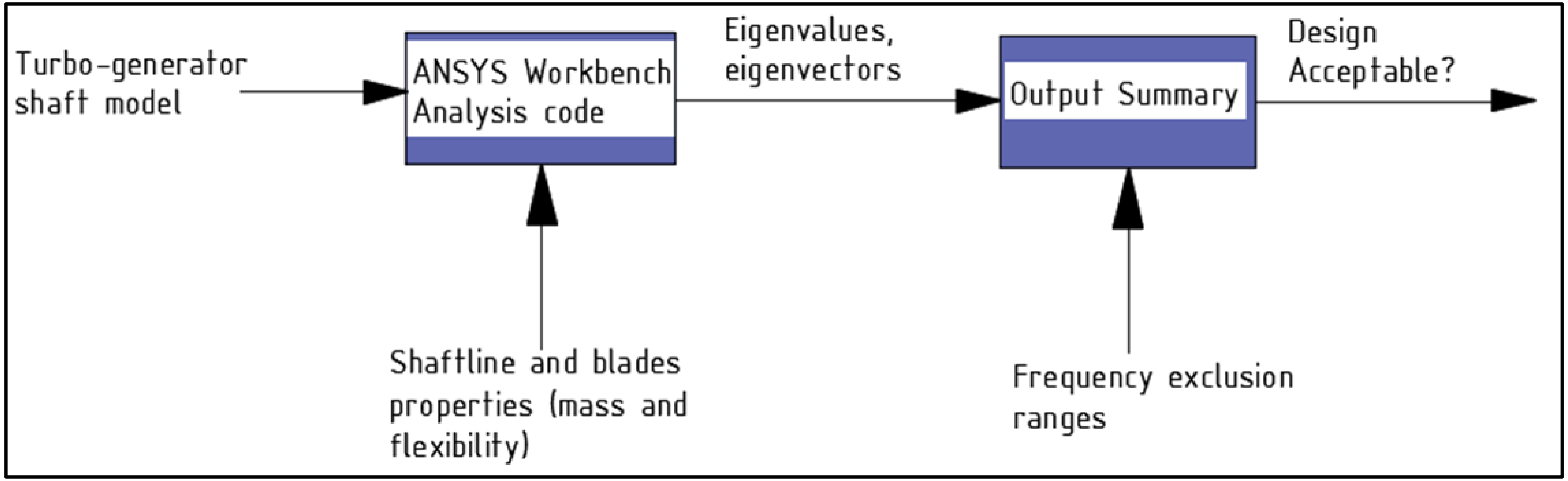
- Countries with low heat sink temperatures (<15 ˚C)
- Double LPT cylinders
- Welded drum type LPT rotor



Significance of Natural Frequencies and Mode Shapes

(1) Torsional Natural Frequencies

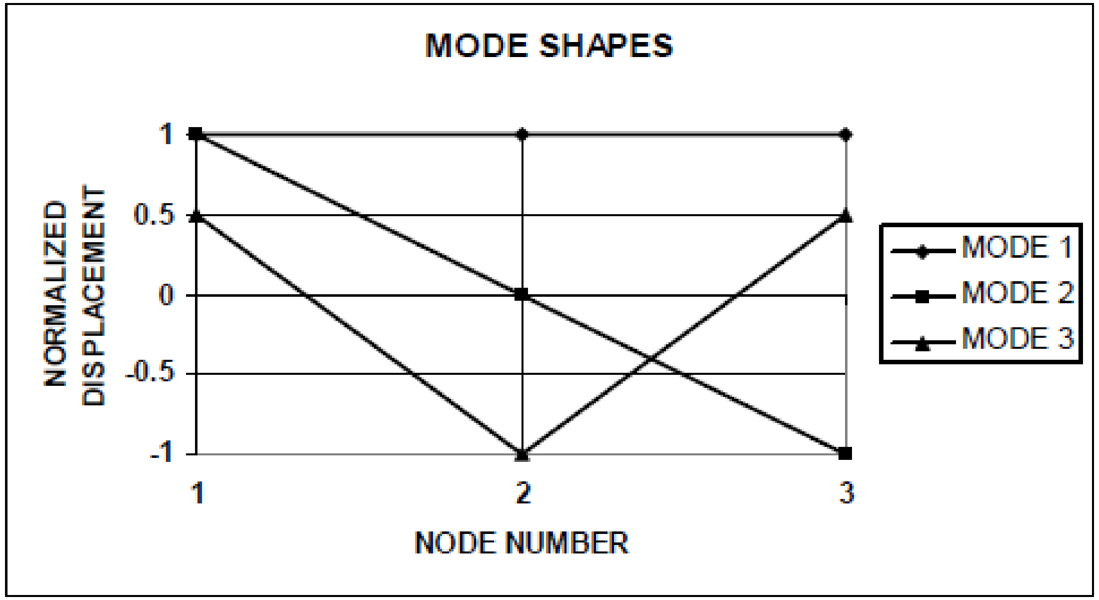
- Frequencies at which the system is most likely to respond to
- Used for evaluating against exclusion zones



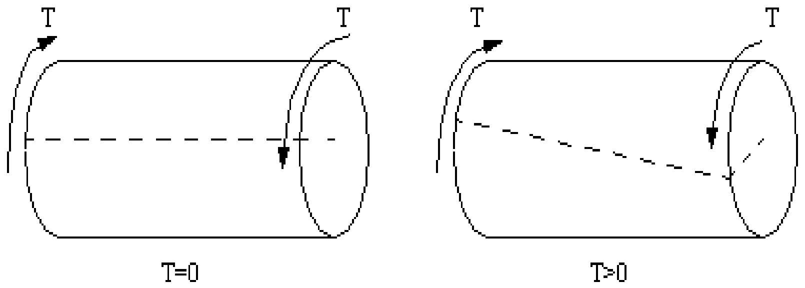
Significance of Natural Frequencies and Mode Shapes

(2) Torsional Mode Shapes - unique shape of deflection pattern

- Defines regions in the T - G that are most vulnerable to fatigue duty
- Estimating which modes which are most responsive to defined stimuli
- For guiding optimal locations of vibration sensors installations
- Identifying the most effective locations for modifying the inertia or stiffness (i.e., tuning)

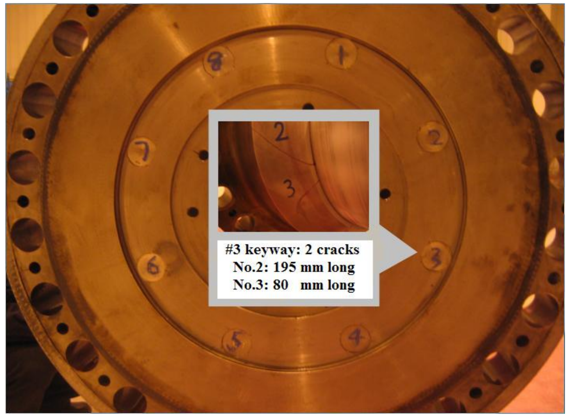


Torsional Vibration



Catastrophic Failures

- Retaining rings
- Shaft
- Couplings
- Last stage blades (LSB)



#3 keyway: 2 cracks
No.2: 195 mm long
No.3: 80 mm long

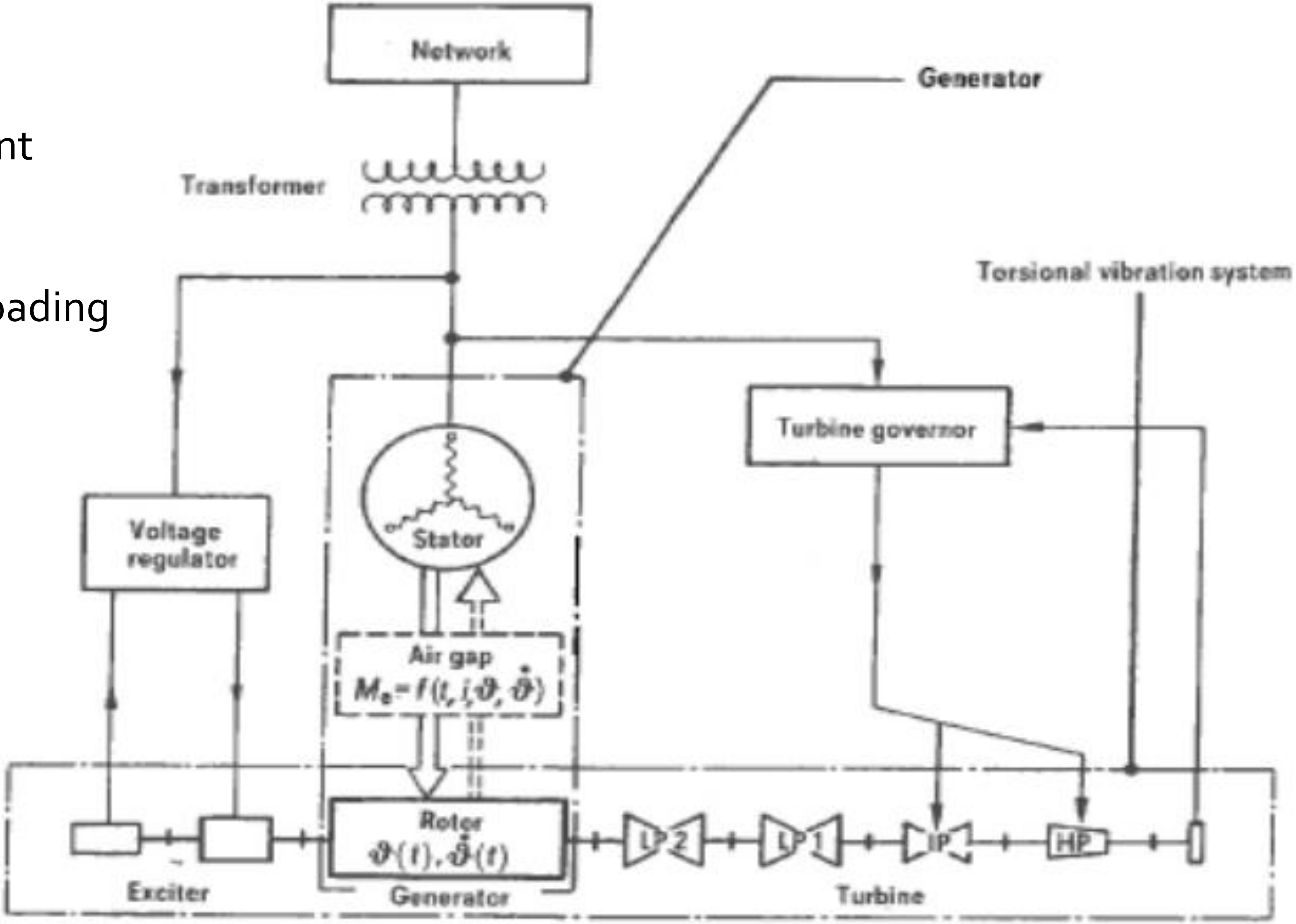
Torsional Excitations from the Generator

(1) Due to Electrical Systems

- Mal-sychronization
- Negative sequence current

(2) Due to Electrical Grid

- Non-symmetric electric loading (e.g. Steel industry)



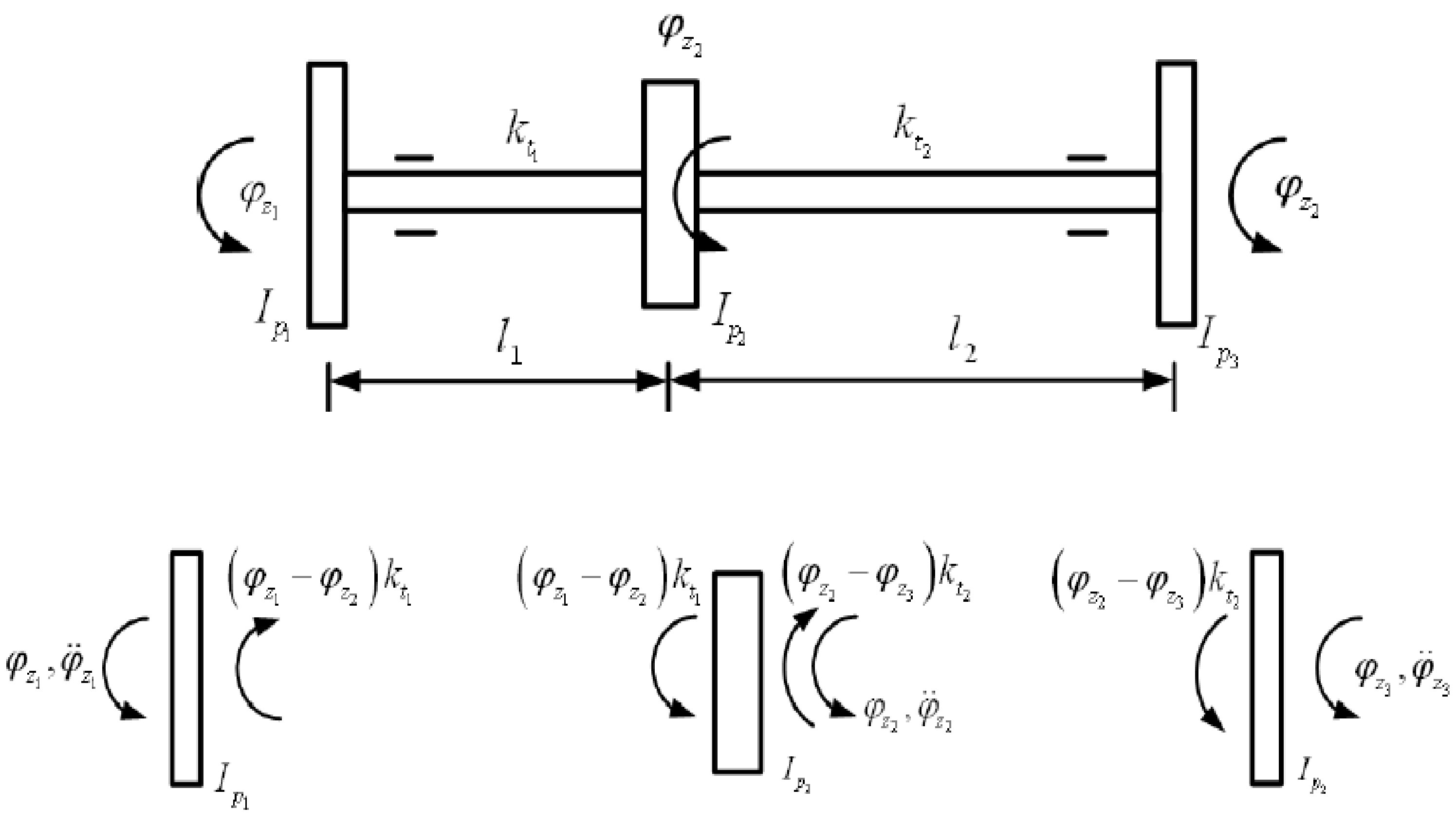
Conventional Approaches to torsional Vibration Modelling

(1) Theoretical Calculations
- Rankine, Jeffcott, Holzer (1800s, century later – World War II)
- Lumped mass (parameter) approach
- Distributed mass approach

(2) Direct Measurement Using Sensors
- Telemetry

(3) Finite Element Analysis Softwares
- (e.g ANSYS, MatLab, ExcelRotor, LabView, etc.)

Lumped Mass Approach



(a) Disc 1 (b) Disc 2 (b) Disc 3

Newton 2nd Law of Motion:

$$[M]\{\ddot{\varphi}\} + [C]\{\dot{\varphi}\} + [K]\{\varphi\} = \{F(t)\}$$

Free – free and undamped vibration

$$[M]\{\ddot{\varphi}\} + [K]\{\varphi\} = \{0\}$$

Assuming harmonic motion

$$\varphi_i(t) = \varphi_i \sin(\omega_{nf} t)$$

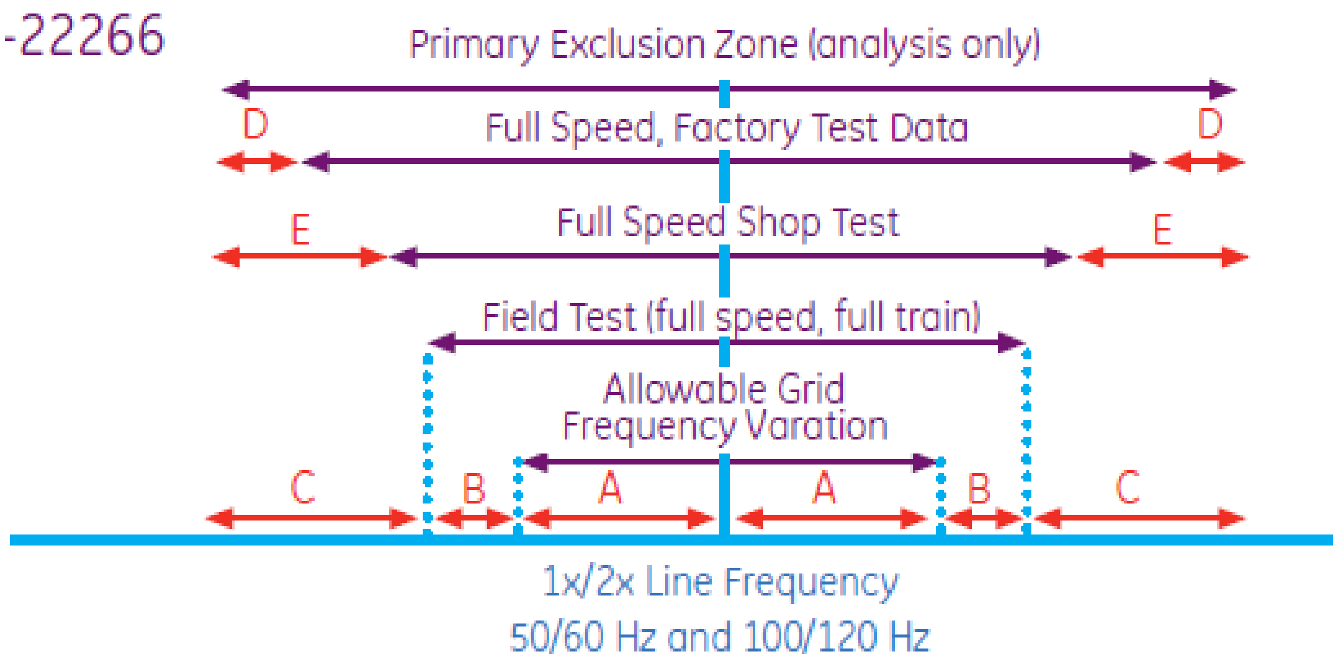
Therefore,

$$(-\omega_{nf}^2[I] + [K])\{\varphi\} = \{0\}$$

Which yields,

$$(-\omega_{nf}^2 + [D])\{\varphi\} = \{0\}$$

Torsional Frequency Margin (ISO – 22266)



If tests are carried out at room temperature, tempurature correction factor, F, should be added to upper and lower bounds

Informative Limits:

A. Allowable Grid Frequency Deviation ±2.5%
B. Margin from resonance ±1%
C. Calculation Uncertainty ±2.5%
D. Full-speed generator, static LP test ±1%
E. Full-speed generator and LP test ±2%
F. Temperature effects ±1%

Shifting Torsional Modes

Two (2) methods available:

(1) Temporary Solutions

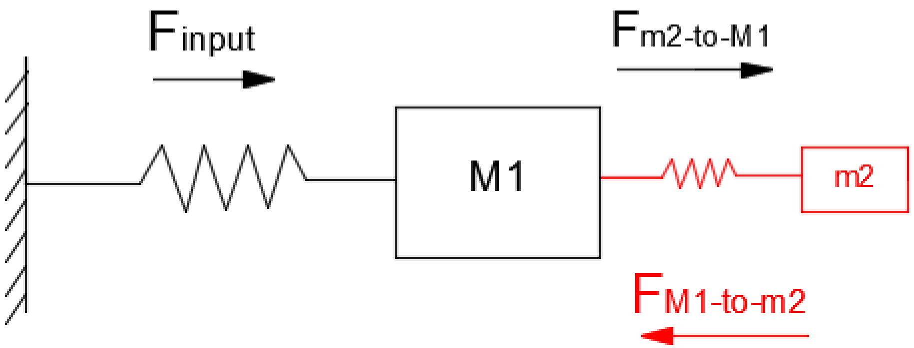
- Do not operate the unit
- Reduce the load, steam pressure
- Until permanent solution can be implemented
- (i.e., tuning)

(2a) Inertia Tuning

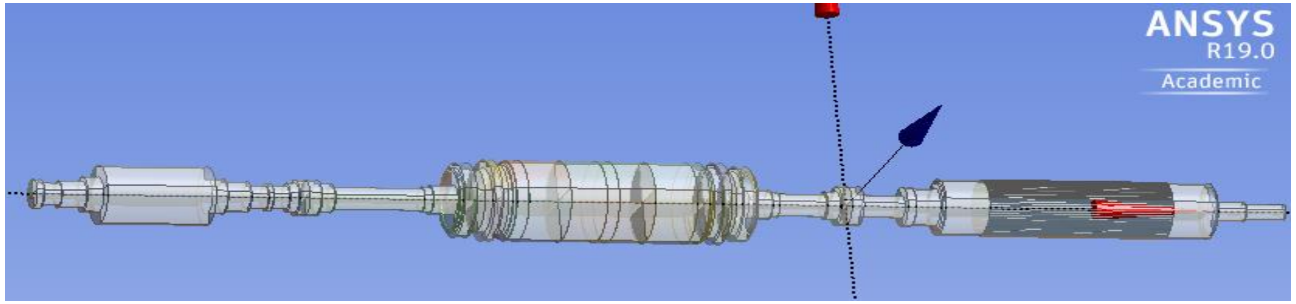
- Large enclosure steel rings on the couplings
- Can be added or removed

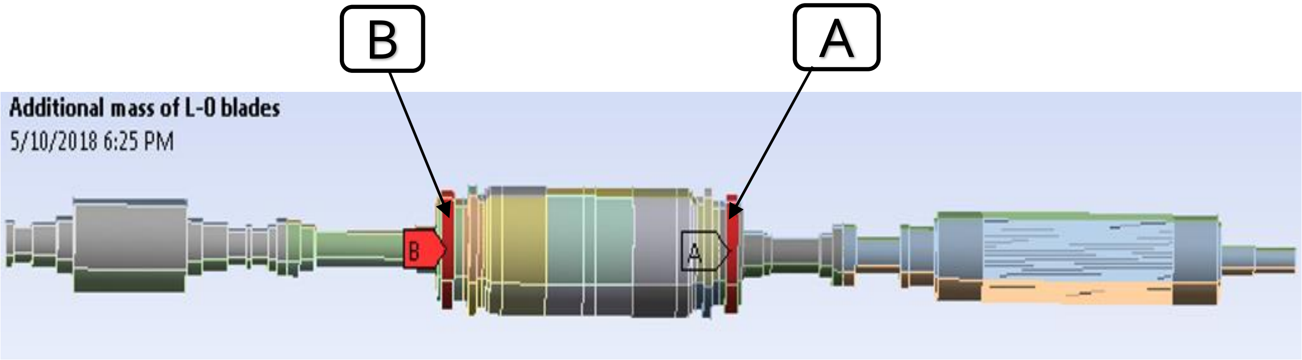
(2b) Dynamic Tuning

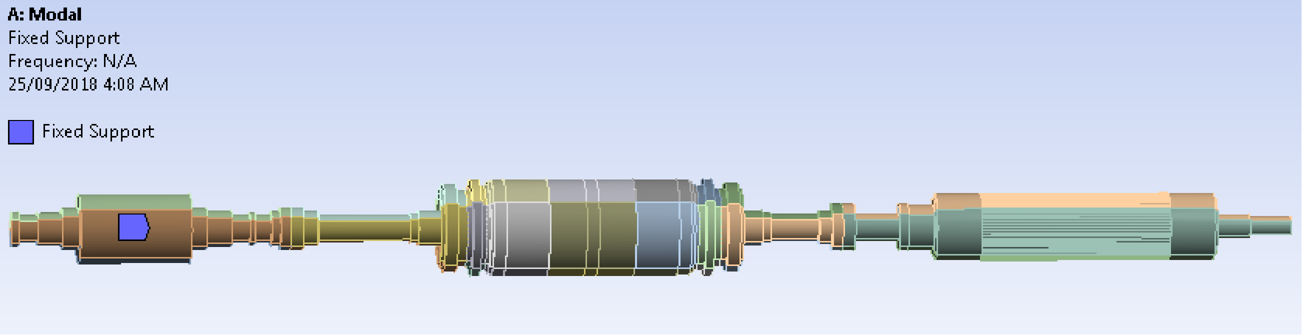
- Dynamic absorber concept



Modal Analysis Using ANSYS Workbench




Additional mass of L-0 blades
5/10/2018 6:25 PM

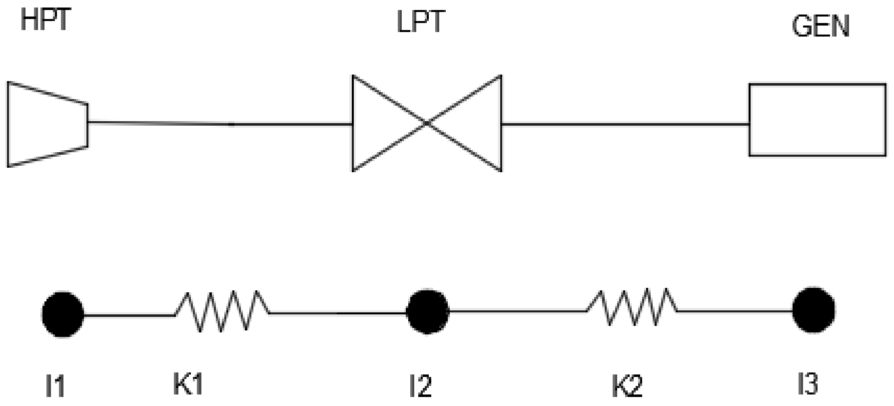

A: Modal
Fixed Support
Frequency: N/A
25/09/2018 4:08 AM

🟦 Fixed Support

Property	Value	Units
Density	7750	kg/m^3
Modulus of Elasticity	185	GPa
Poison's Ratio	0.3	-
Maximum Allowable Stress	130	MPa
Yield Strength	178	MPa

	Welded Drum Type LPT Frequency (Hz)		Monoblock Type LPT Frequency (Hz)	
Mode	1 LPT Cylinder	2 LPT Cylinders	1 LPT Cylinder	2 LPT Cylinders
1	0	0	0	0
2	18.4	13.0	18.1	12.8
3	22.9	22.6	21.3	22.7
4	108.9	25.3	62.4	25.6
5	130.7	158.7	129.3	63.0
6	178.8	160.4	163.7	65.2
7	179.4	170.9	189.5	175.4

Confirmation Using Simplified Model

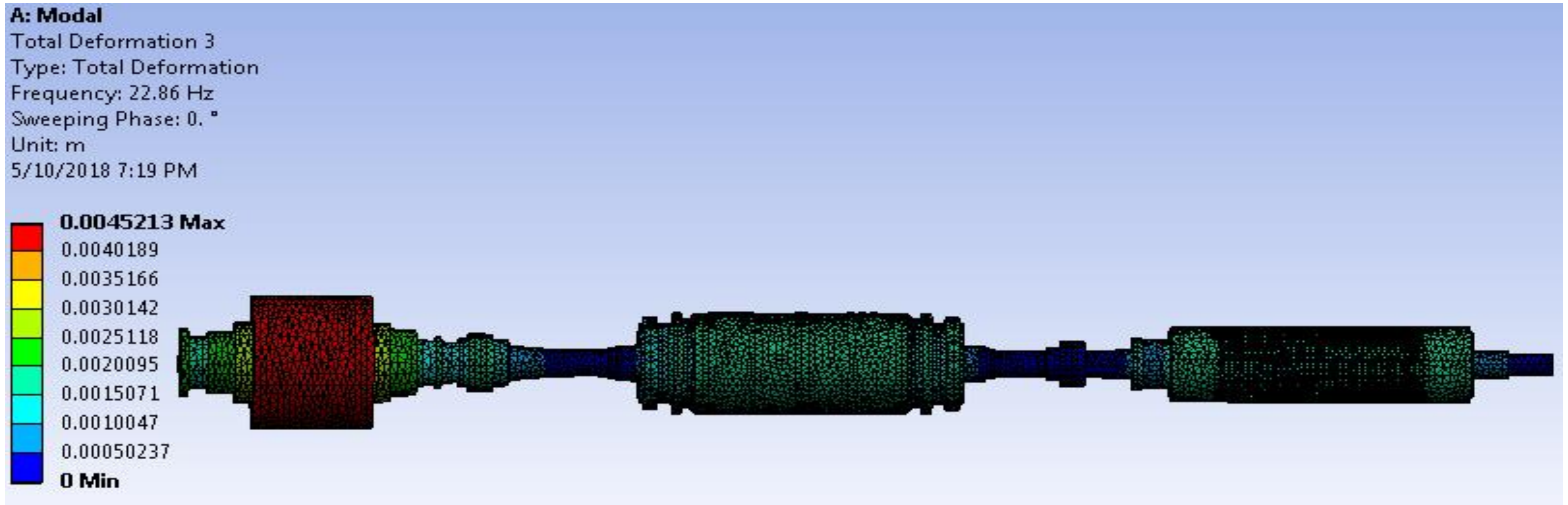


Geometry	Polar Moment of Inertia, I	Torsional Stiffness, k
Solid Shaft	$\frac{\pi\rho L D^4}{32}$	$\frac{\pi G D^4}{32L}$
Annulus Shaft	$\frac{\pi\rho L(D^4 - d^4)}{32}$	$\frac{\pi G(D^4 - d^4)}{32L}$

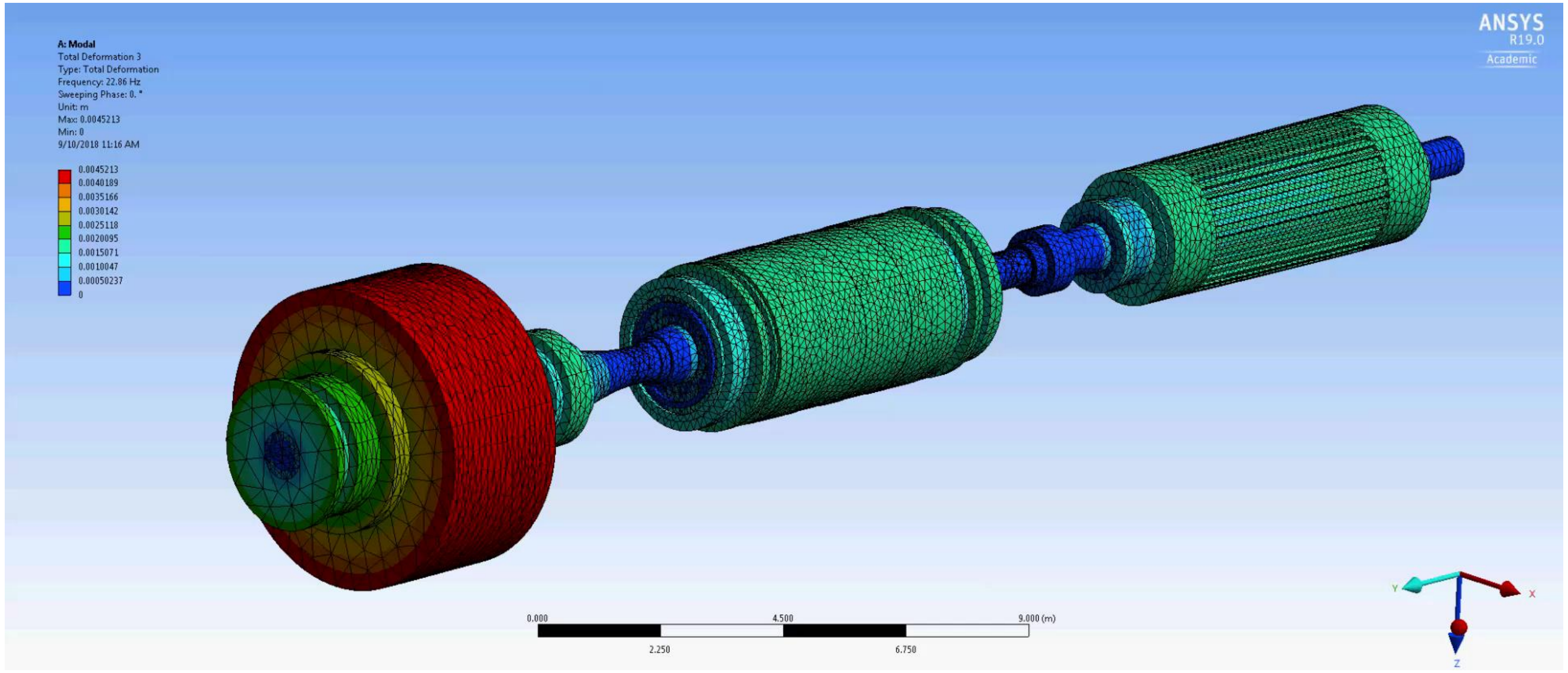
Mass	Inertia moment, I (kg.m²)	Span (-)	Torsional Stiffness, K (Nm/rad)
1	59,042	1-2	7.29E+8
2	140,625	2-3	1.43E+9
3	74,864		

Mode	Shaftline with Single LTP Cylinder Monoblock Rotor		
	ANSYS Results (Hz)	Calculated Results (Hz)	Δ (%)
1	0	0	0
2	18.1	18.6	2.7
3	21.3	21.8	2.3

Torsional Natural Frequencies and Mode Shapes--

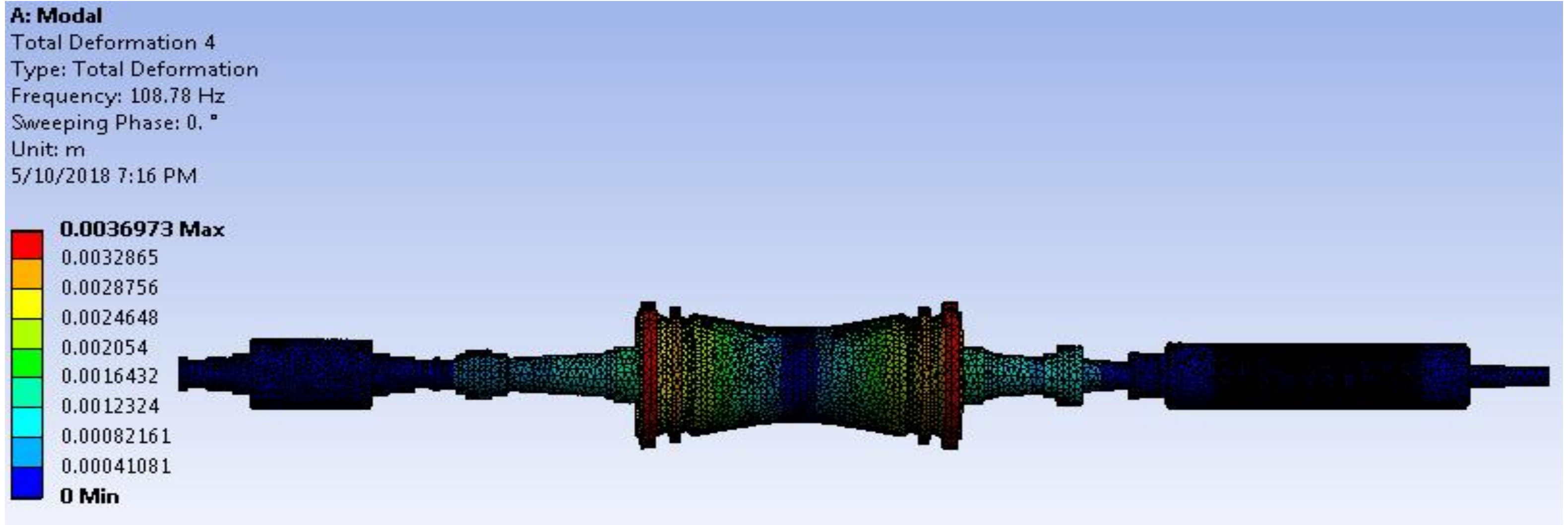


A: Modal
Total Deformation 3
Type: Total Deformation
Frequency: 22.86 Hz
Sweeping Phase: 0. °
Unit: m
5/10/2018 7:19 PM



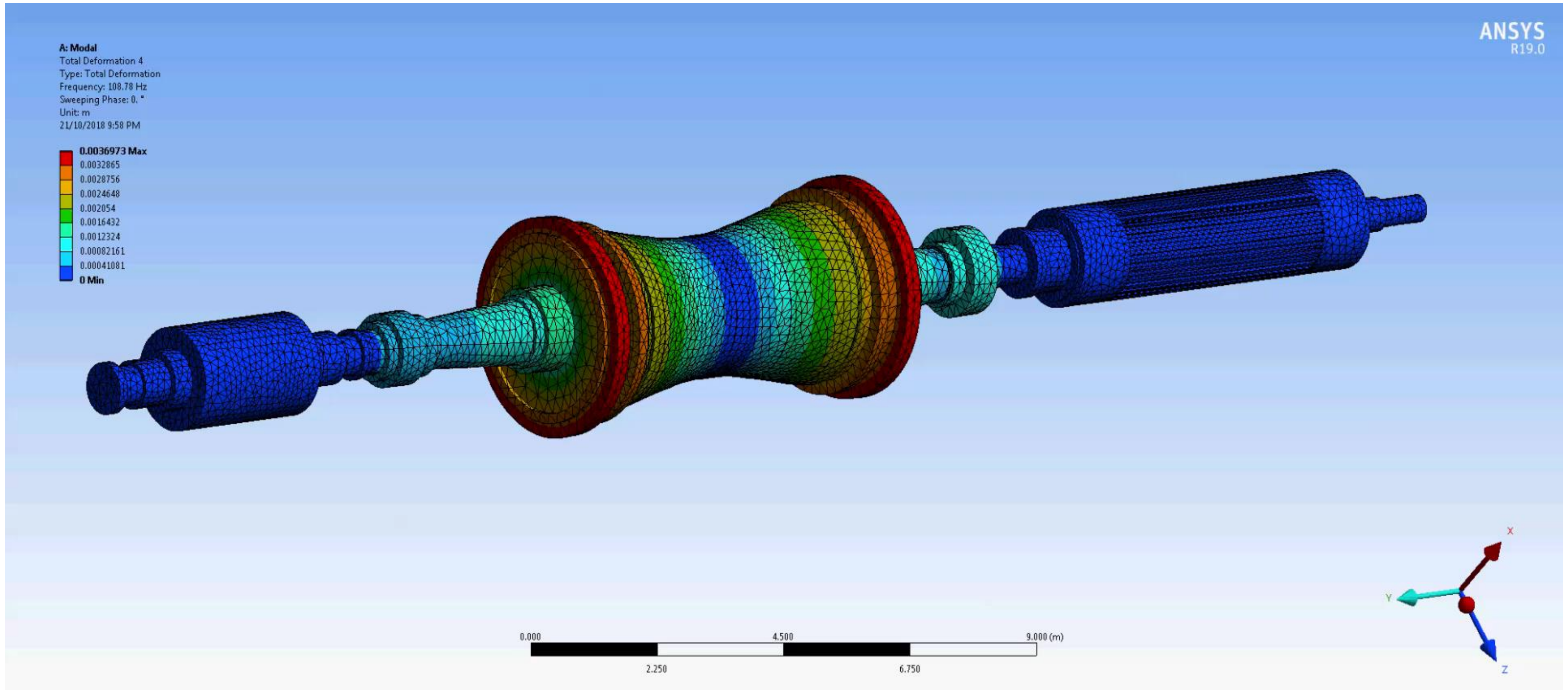
A: Modal
Total Deformation 3
Type: Total Deformation
Frequency: 22.86 Hz
Sweeping Phase: 0. °
Unit: m
Max: 0.0045213
Min: 0
9/10/2018 11:16 AM

Torsional Natural Frequencies and Mode Shapes- -



A: Modal
Total Deformation 4
Type: Total Deformation
Frequency: 108.78 Hz
Sweeping Phase: 0. °
Unit: m
5/10/2018 7:16 PM

0.0036973 Max
0.0032865
0.0028756
0.0024648
0.002054
0.0016432
0.0012324
0.00082161
0.00041081
0 Min



A: Modal
Total Deformation 4
Type: Total Deformation
Frequency: 108.78 Hz
Sweeping Phase: 0. °
Unit: m
21/10/2018 9:58 PM

0.0036973 Max
0.0032865
0.0028756
0.0024648
0.002054
0.0016432
0.0012324
0.00082161
0.00041081
0 Min

Summary

- Torsional natural frequencies and modes shaped generated
- Evaluated against frequency exclusion zones (1x and 2x grid frequency)
- Excellent separation of modes near exclusion zones
- Analytical and ANSYS results are comparable

THANK YOU

감사합니다