Faculdade de Engenharia
Depto. de Engenharia Mecânica
Programa de Pós-Graduação em
Engenharia Mecânica

Second Seminar - PPG-EM UERJ / 2016

Validation of Experimental Rig with Emphasis on Dynamic Phenomenon of Rotors

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Experimental Rig

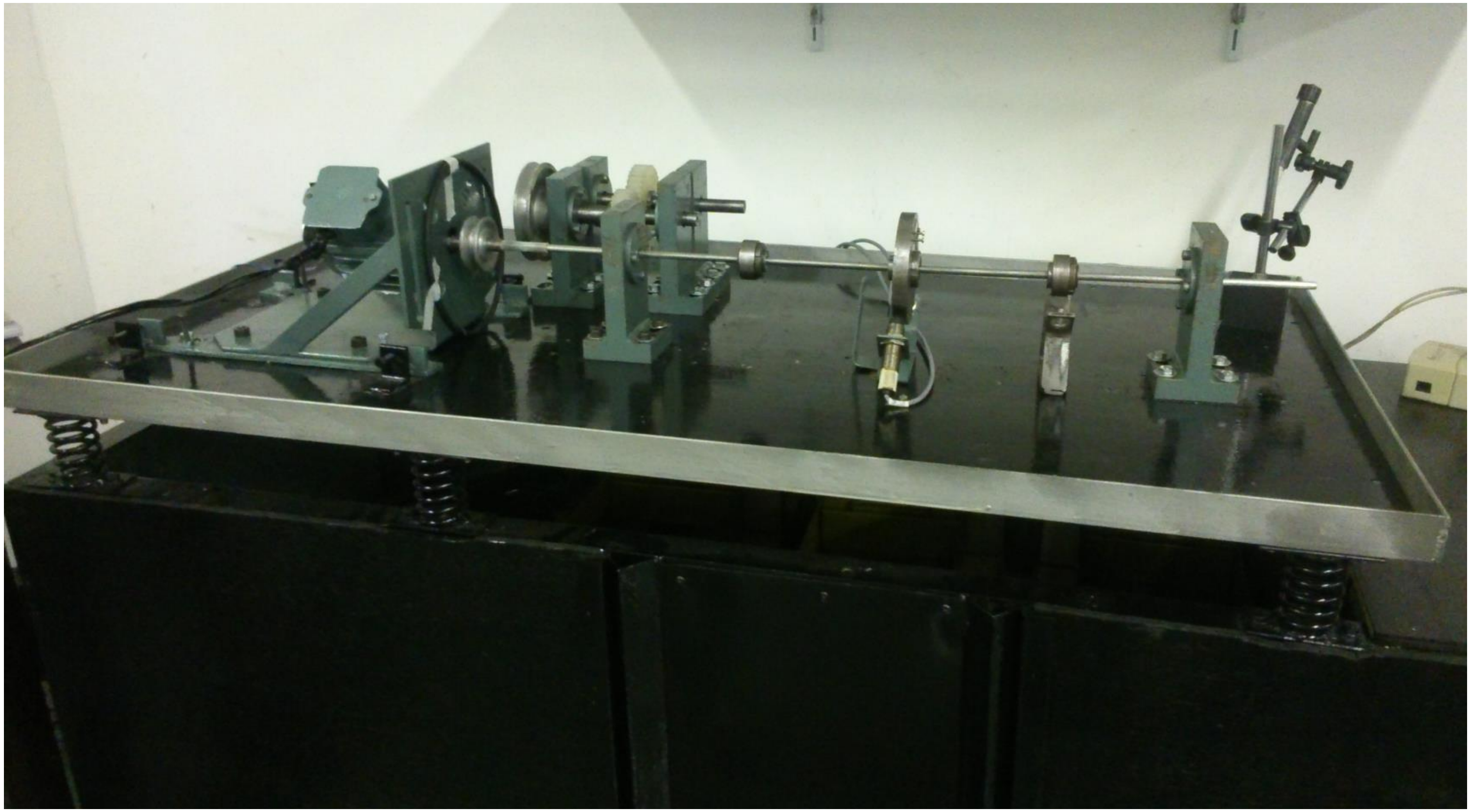


Figure 1 – Experimental Rig

Motivations

- ✓ Work Experimental
- ✓ The First Work About Fenomenon in This Experimental Rig
- ✓ Interface Instrumentation/Hardware/Software
- ✓ Signal Processing
- ✓ Finite Element Analyses

Objective

- ✓ Build computer models using analysis software for finite element.
- ✓ Identify the main characteristics presented by the rotor when subjected to different pre-set settings to rehearse it.
- ✓ Compare the simulations results with results of experimental tests.
- ✓ Present Results.

Methodology

- ✓ Simulations (Solidworks e Rotmef)
- ✓ Experimental Tests
- ✓ Signal Processing

Evaluation of the Dynamic Behavior of the Experimental Rig (Rigid Body Analysis)

- ✓ Frequency Sweep Test
- ✓ SolidWorks Simulation
- ✓ Experimental Instrumented Tests

Rigid Body Analysis - Fundamentals

✓ Single mass element illustrating all the possible degrees of freedom.

✓ The six degrees of freedom of the rigid body consist of three rotational and three translational motions.

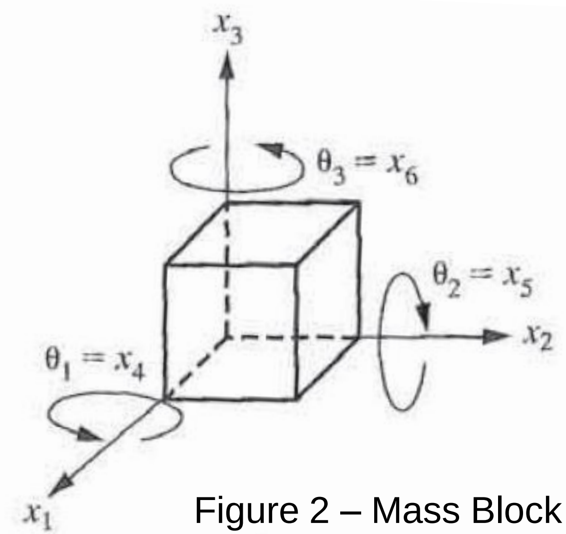
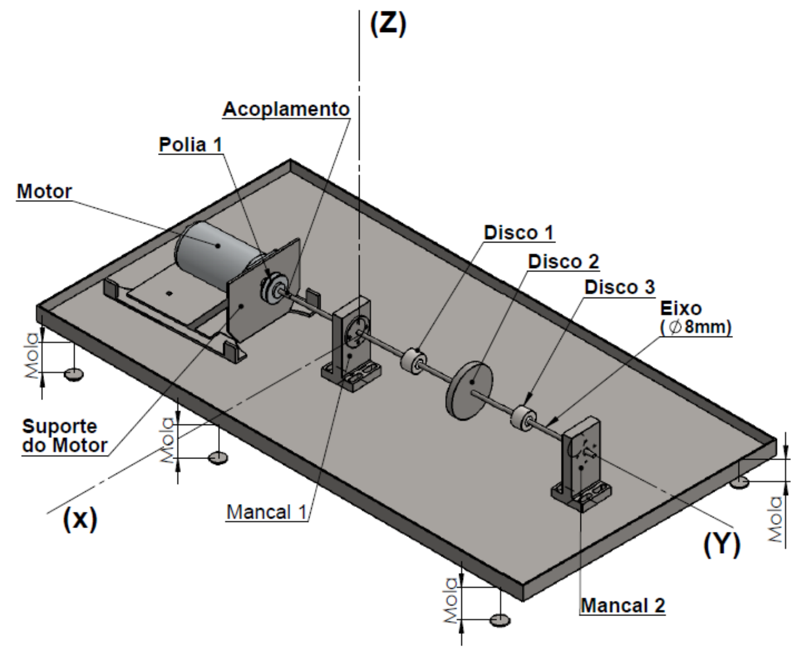


Figure 2 – Mass Block and Main Shafts



Rotor Behavior and Phenomena Analysis

- ✓ Definition of rotor

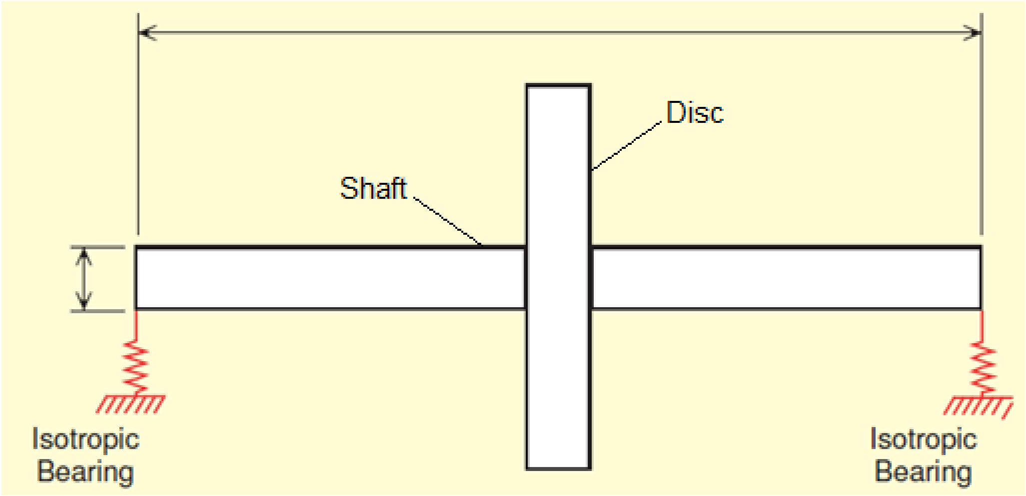


Figure 5 – First Three mode shapes of pinned-pinned beam

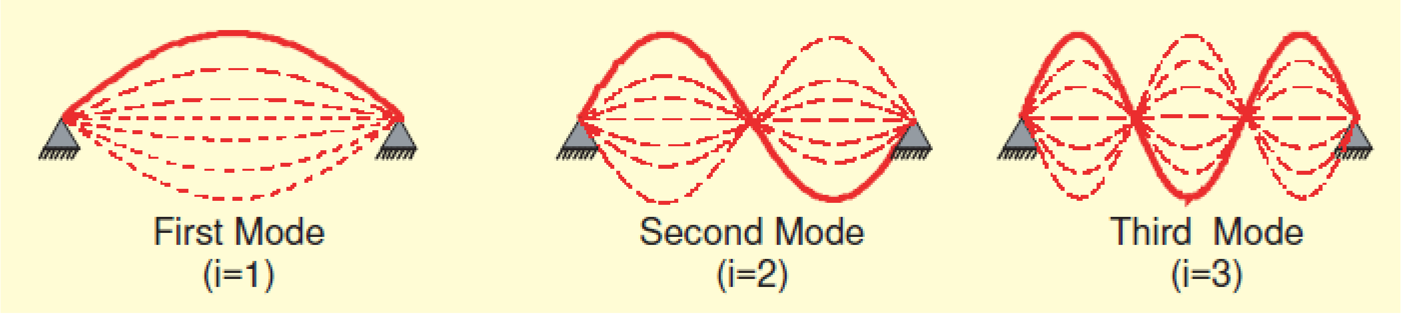


Figure 6 – Basic machine model cross section

Rotor Behavior and Phenomena Analysis

- ✓ Gyroscopic effect
- ✓ Reverse modes

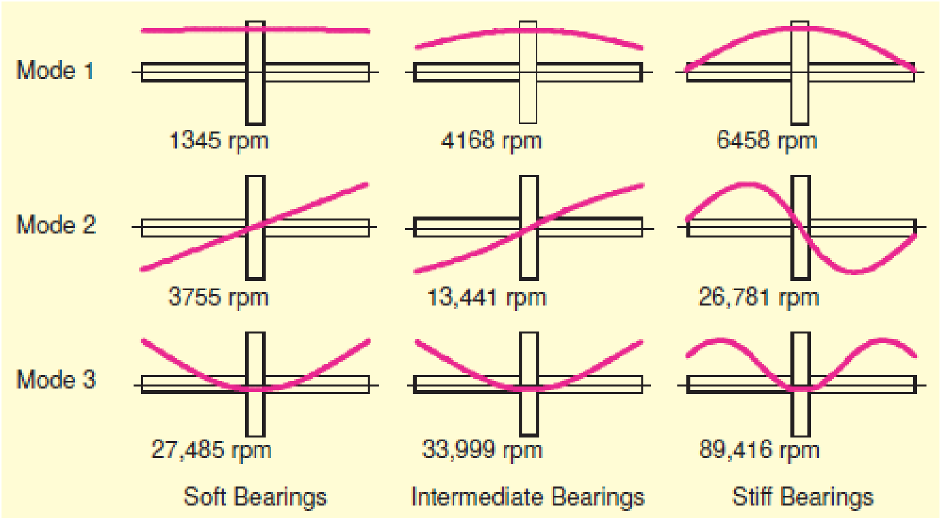


Figure 7 - Mode shapes versus bearing stiffness, shaft not rotating.

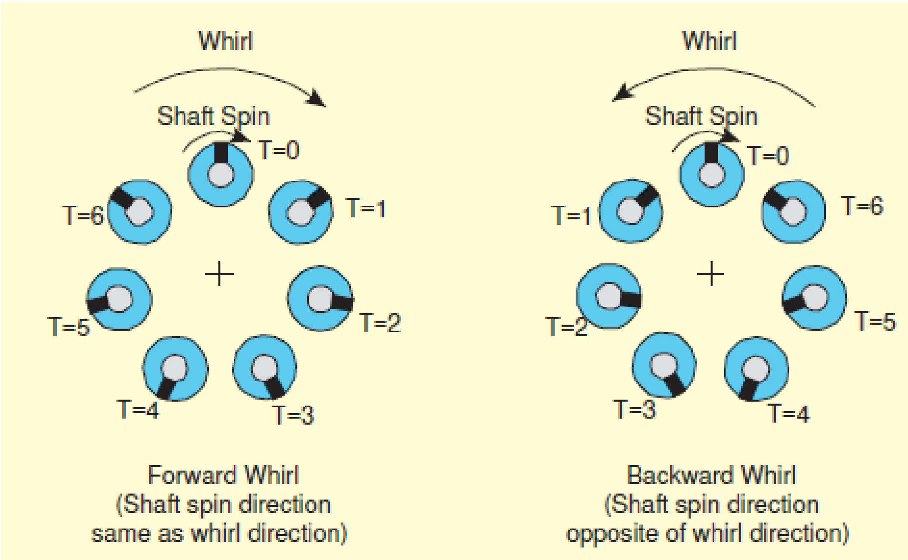


Figure 8 - Whirl sense.

Rotor Behavior and Phenomena Analysis

✓ Campbell Diagram

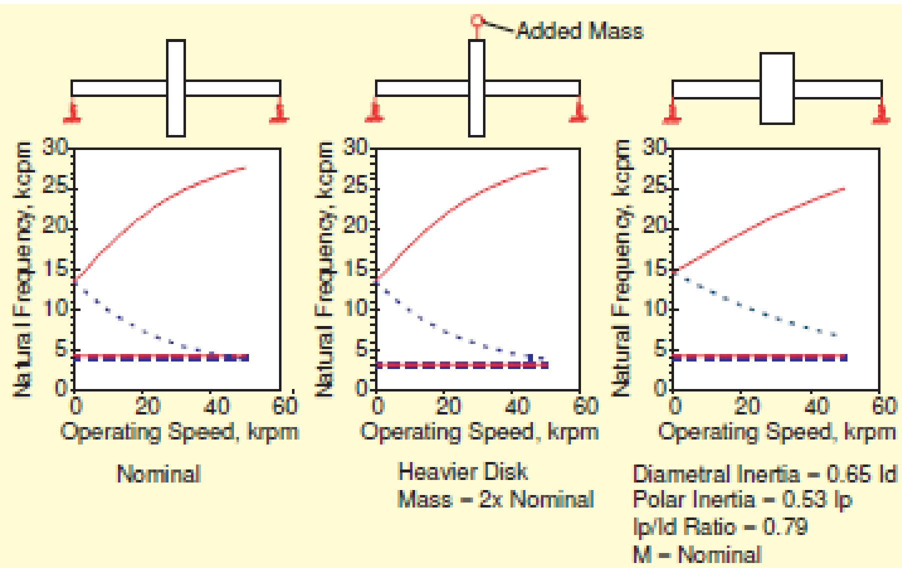


Figure 13. Comparison of different disk properties, center disk configuration.

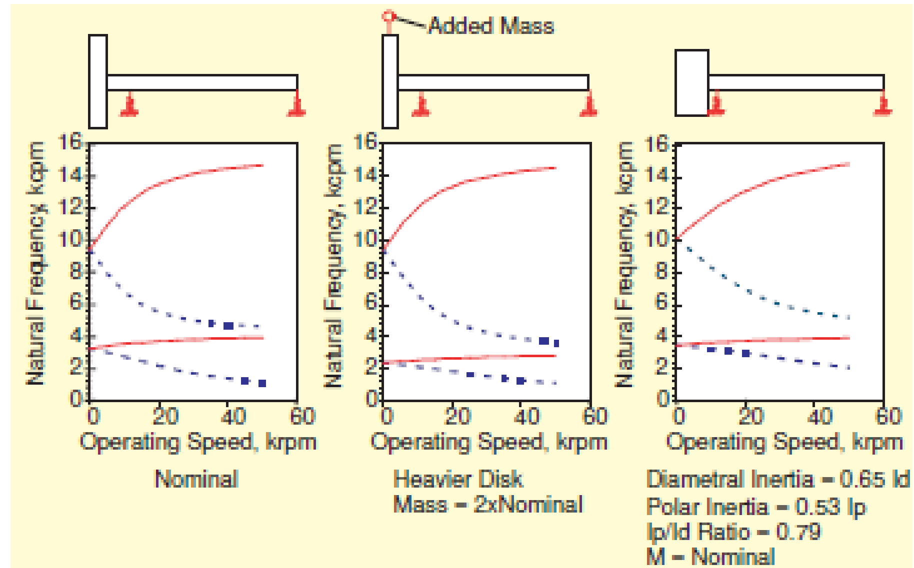


Figure 14. Comparison of different disk properties, overhung configuration

Rigid Body Analysis
Frequency Sweep Test

*Unbalanced disc 2

Unbalanced mass = 60g

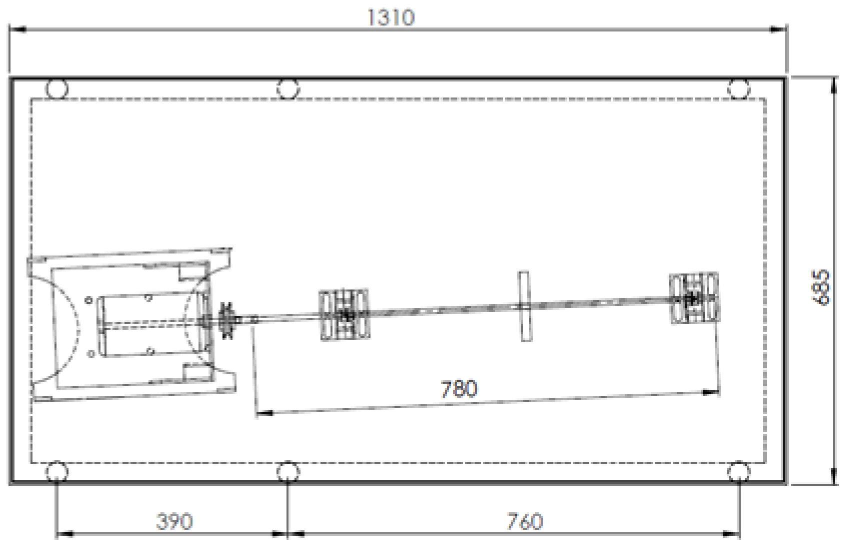
Table 1 – Frequency and Experimental Modes – Frequency Sweep

Frequency (rpm)	Modes
310,20	Translation em X
387,00	Translation em Z
452,00	Rotation em Z
505,00	Rotation em X
678,00	Rotation em Y

Solidworks Simulation

Tabela 2 - Materiais

Components	Material	Elastic Module (N/m²)	Yield strength (N/m²)	Poisson's Coefficient	Specific Mass (kg/m³)
Coupling	Borracha	6,10E+06	9,24E+11	0,49	1000
Pulley 1 e 2	Alumínium	6,90E+10	2,76E+12	0,33	2700
Gears	Nylon	1,0E+09	6,00E+07	0,30	1150
Other Components	Aço 1020	2,00E+11	3,52E+13	0,29	7900



Dimensions in mm

Figure 12 – Main dimensions of Experimental Rig

Total Mass of Model: 105,213 Kg

Axial and Radial Stiffness of Bearings: 10^7 N/m

Solidworks Simulation

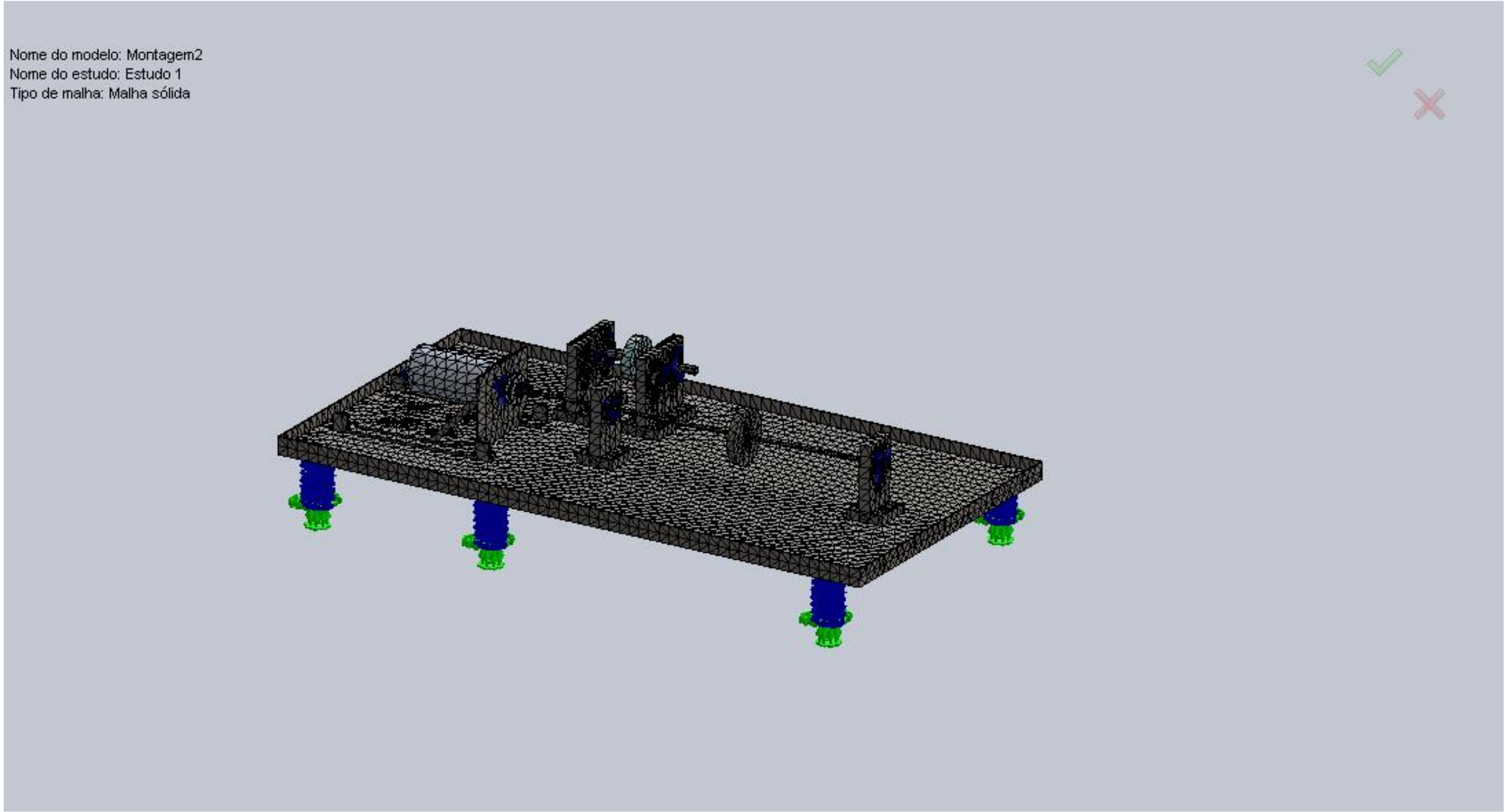


Figure 13 - Mesh

Solidworks Simulation

Table 4 – Mesh Configurations

Type of Mesh	Solid Mesh
Generator of Mesh:	Mesh based on curvature
Points Jacobianos	4 Points
Total of nodes	80359
Element Types	Tetraédrico 3D
Total of elements	42969
Maximum Proportion	62.584
% of elements with proportion < 3	61.8
% of elements with proportion < 10	4.16
Time for run the mesh (hh;mm;ss):	00:01:24

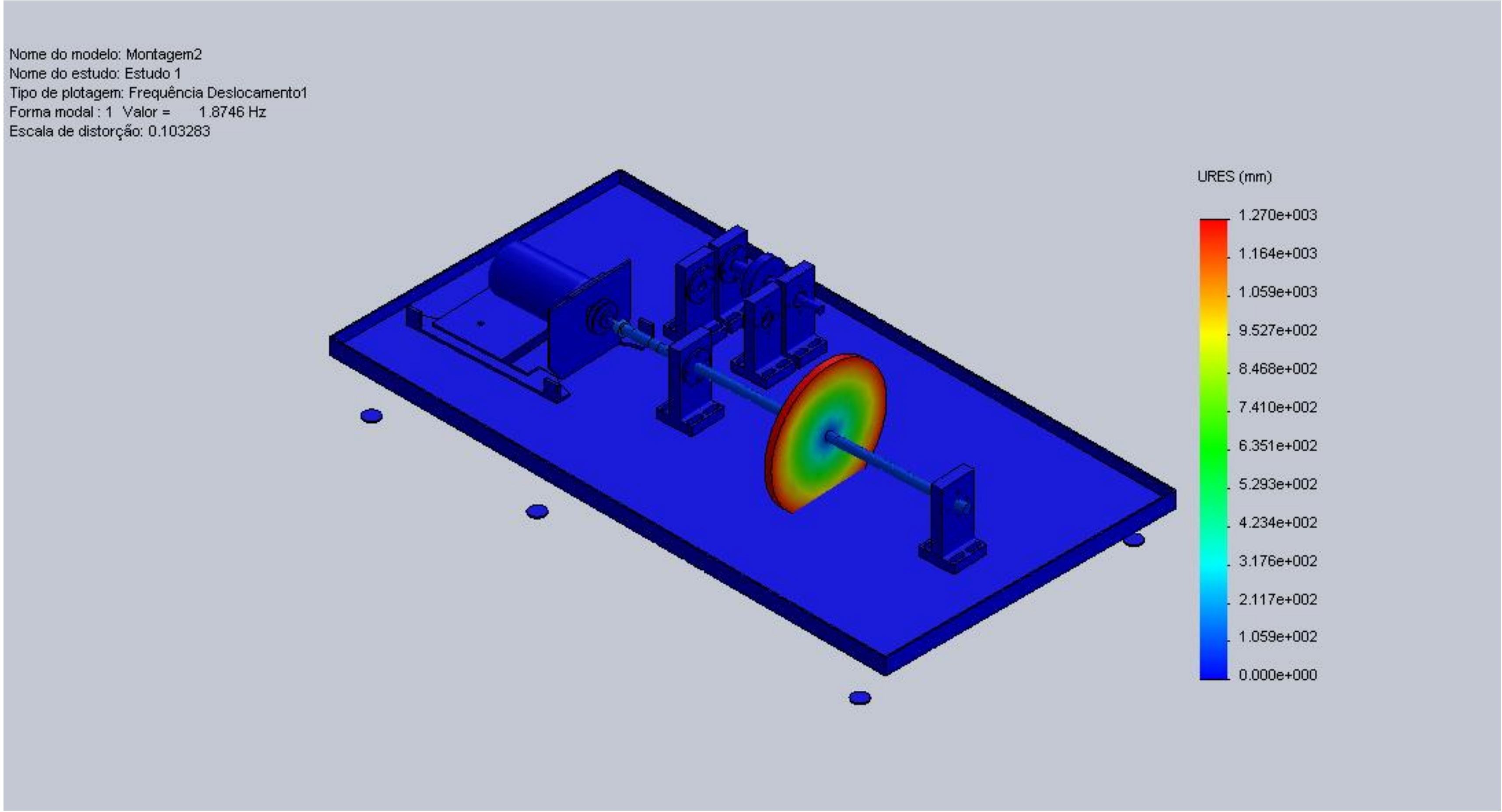


Figure 14 – Mode 1

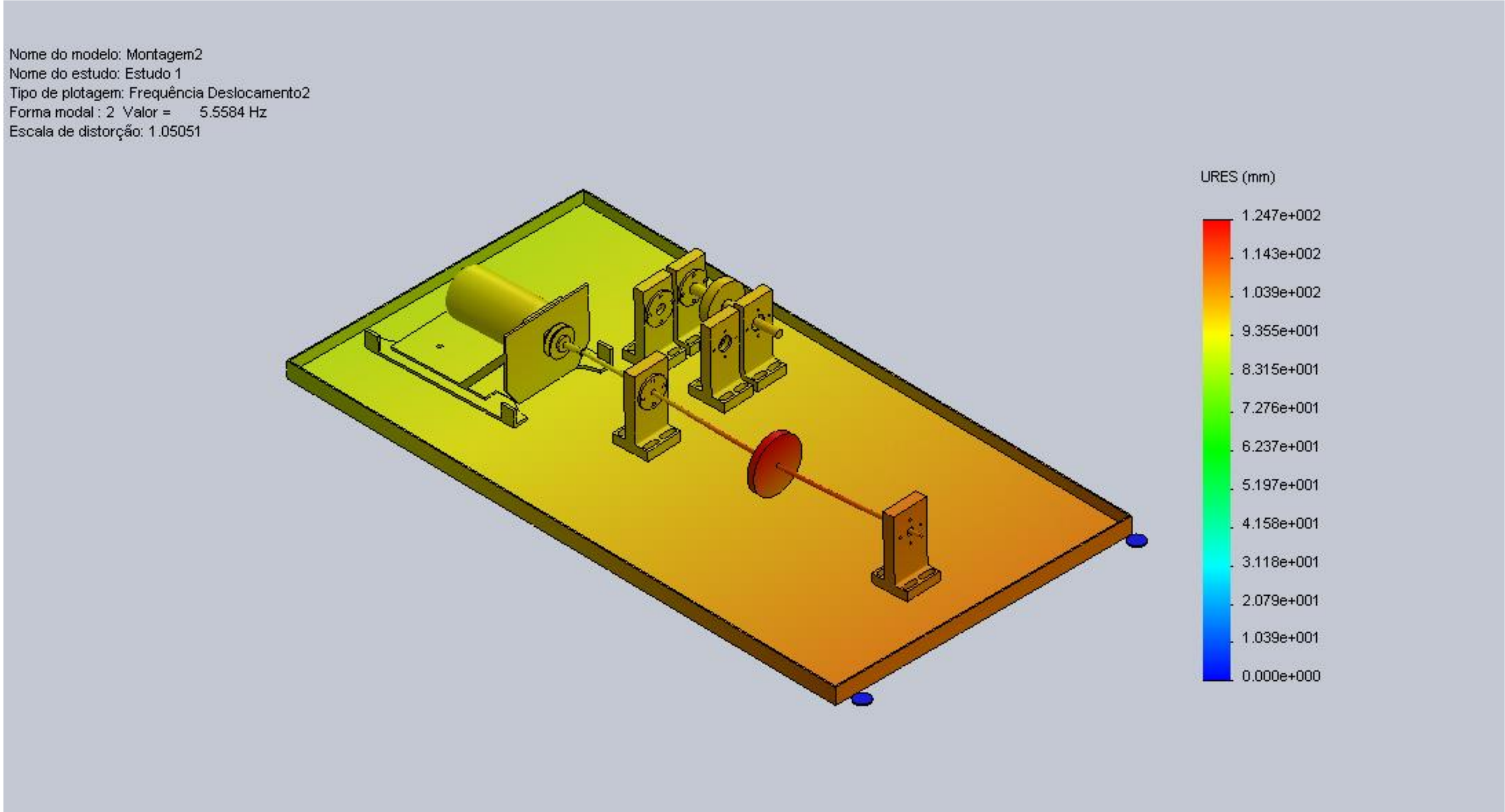


Figure 9 - Mode 2

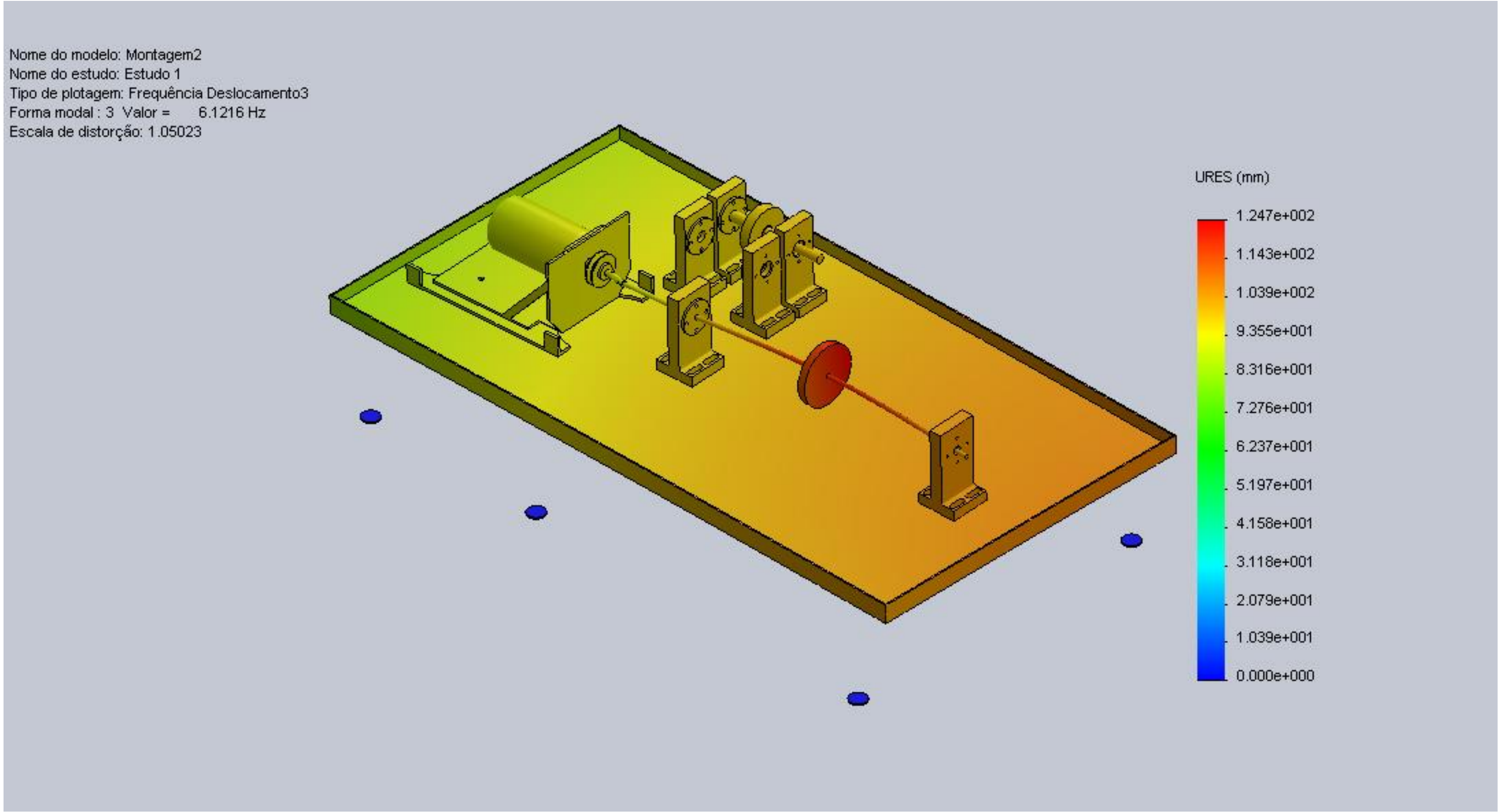


Figure 10 - Mode 3

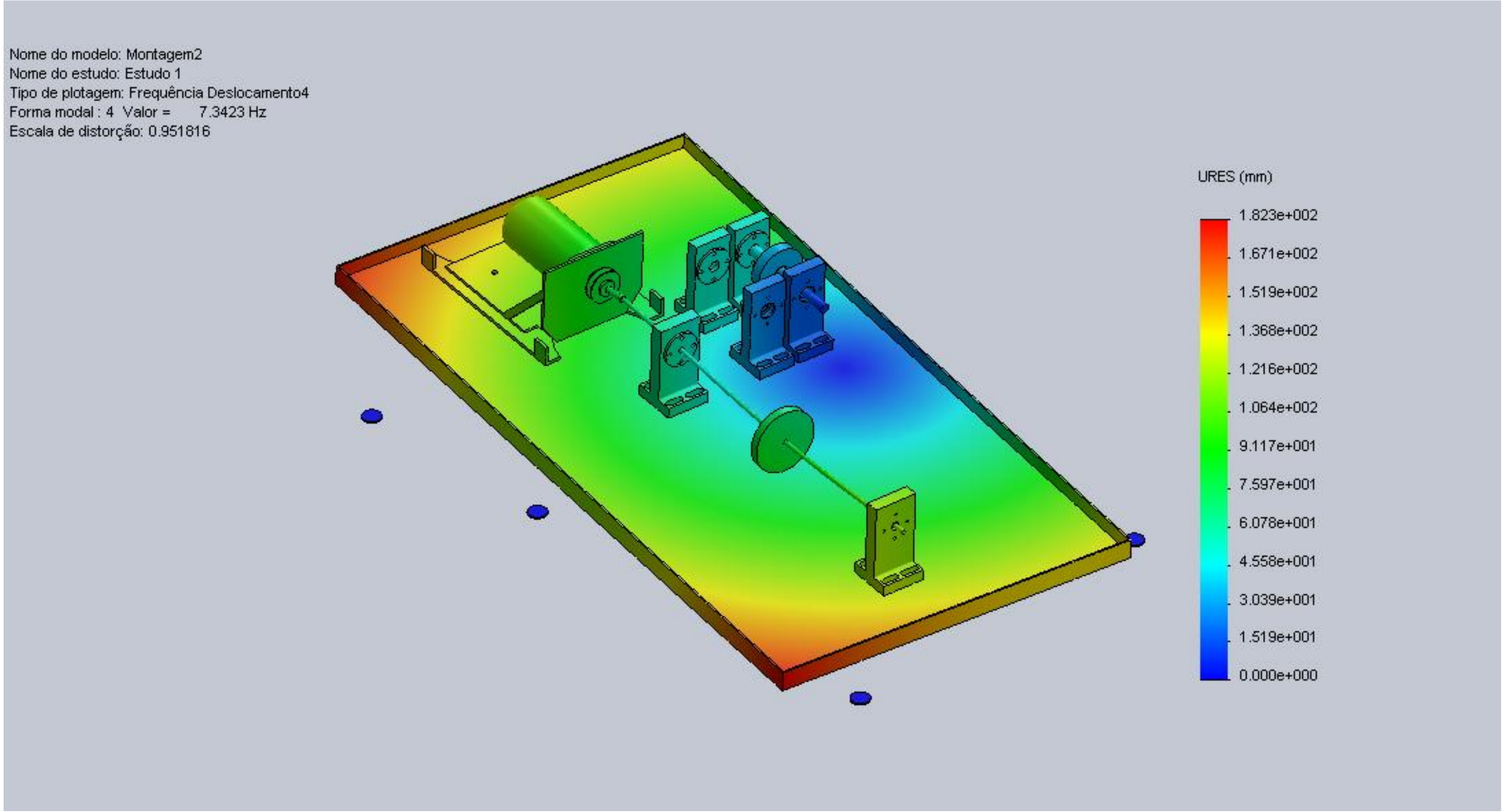


Figure 11 - Mode 4

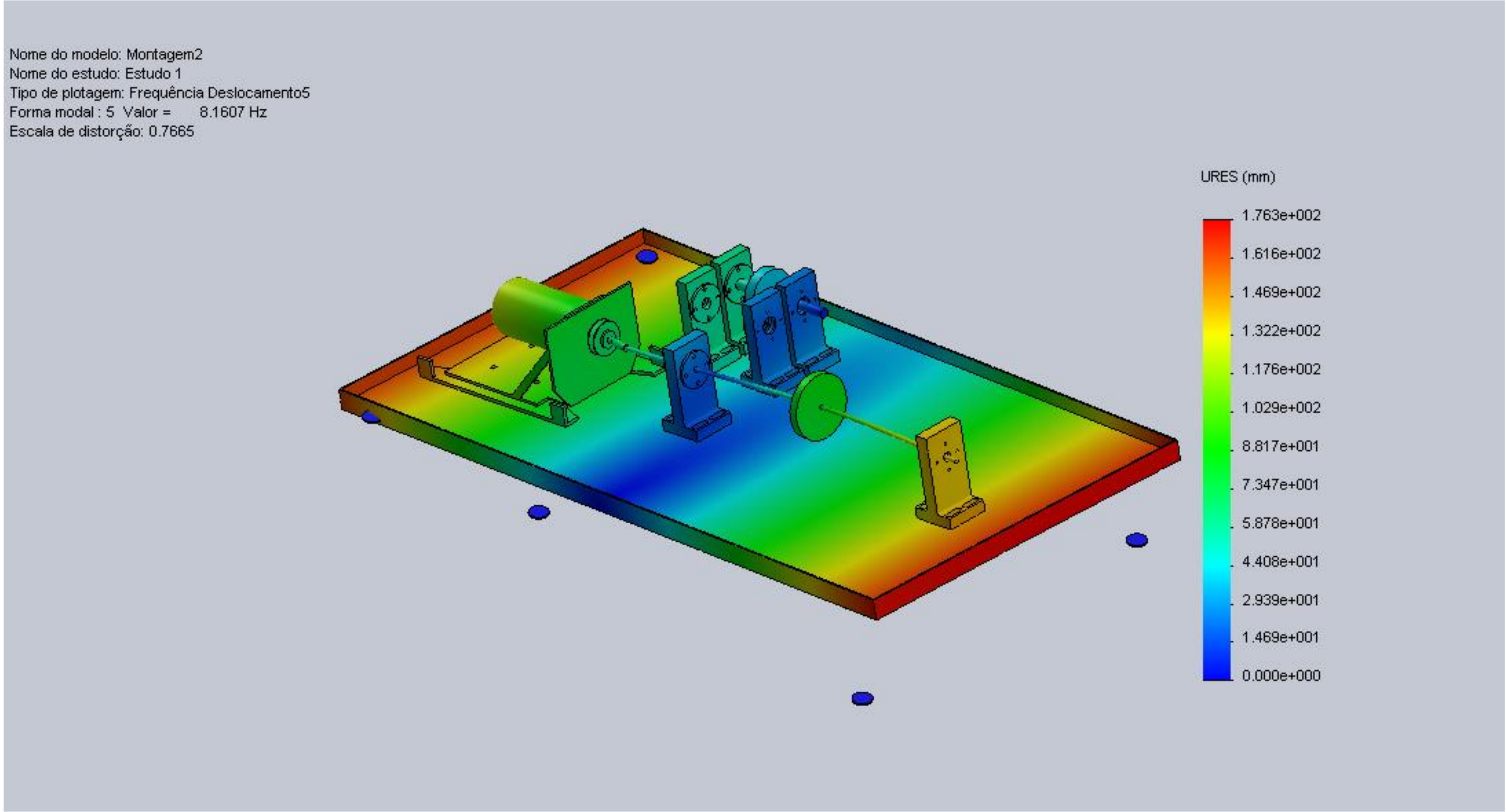


Figure 12 - Mode 5

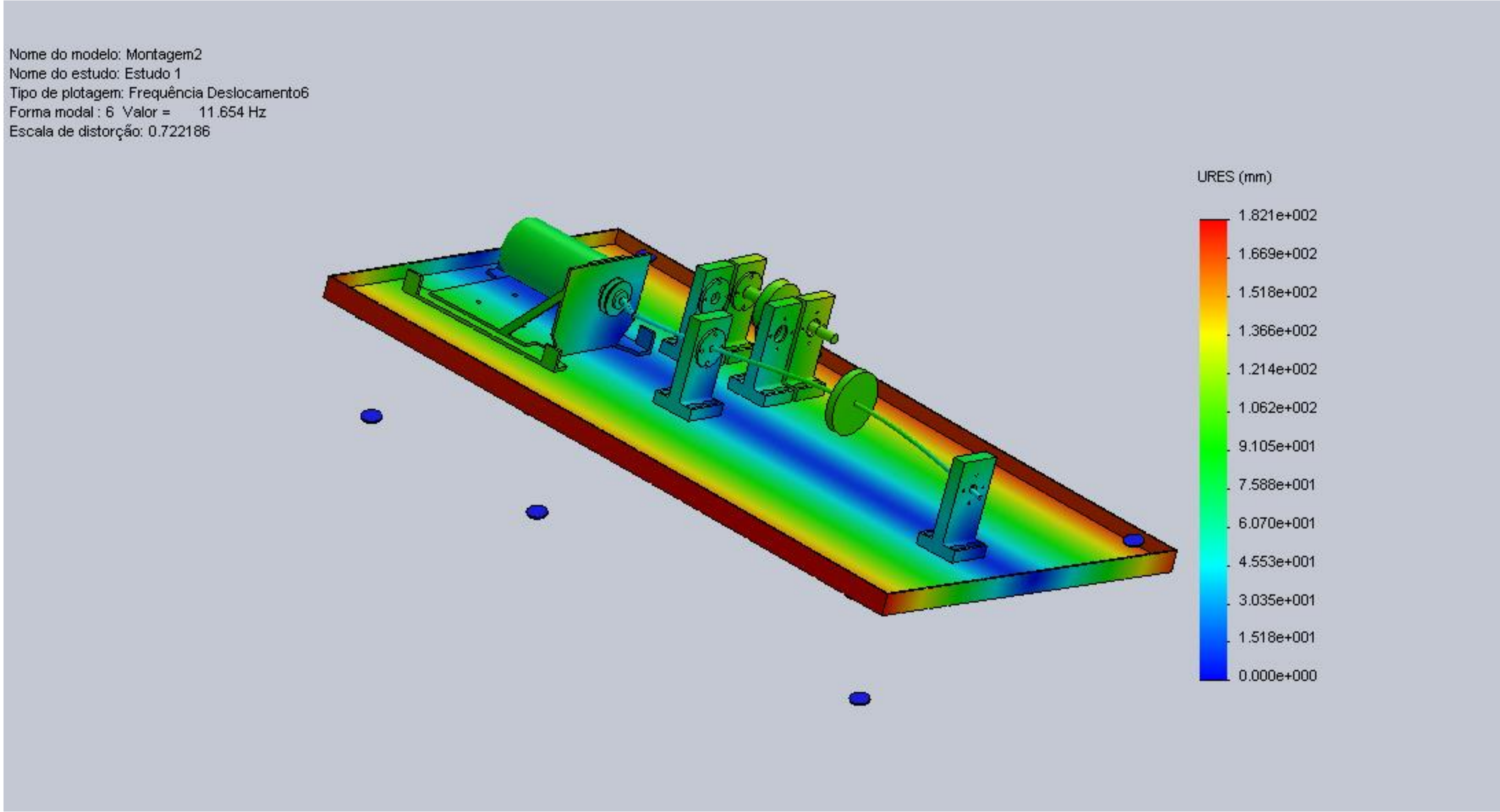


Figure 13 - Mode 6

Solidworks Simulation

Table 5 – Frequency and Modes (Model and Experimental)

Frequencies	Model (rpm)	Experimental-Sweep (Rpm)	Modes	Difference (%)
1	112,6	Not identified	Translation Y	
2	333,50	310,20	Translation X	6,99
3	367,30	387,00	Translation Z	-5,36
4	440,54	452,00	Rotation Z	-2,60
5	489,64	505,00	Rotation X	-3,14
6	699,24	678,00	Rotation Y	3,04

Experimental Test
(Accelerometer)

Figure 14 – Position of accelerometer

Experimental Test
(Accelerometer)

Translation Y

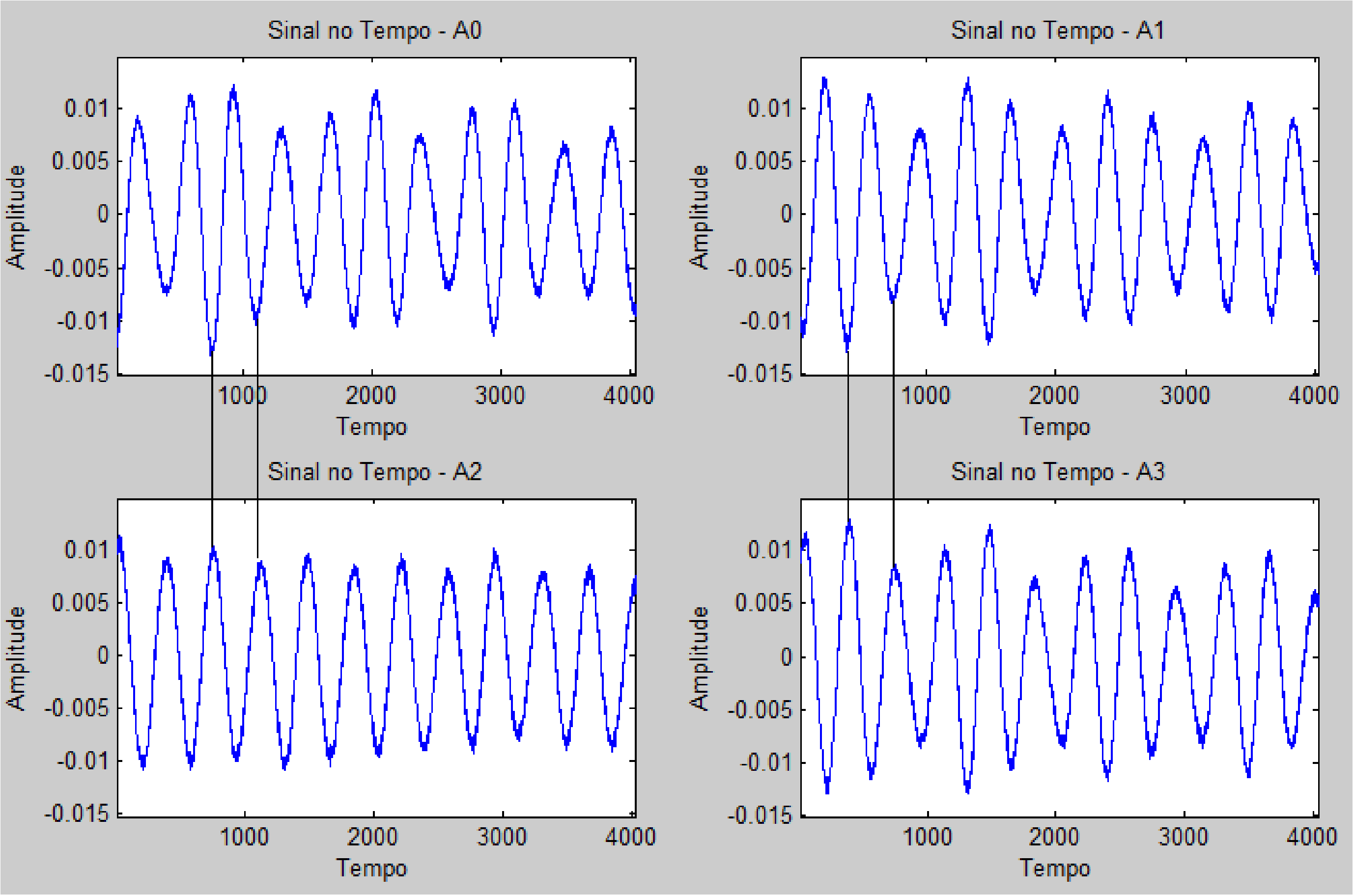


Figura 15 – Time Signal of the Four Accelerometer

Experimental Test
(Accelerometer)

Translation Y

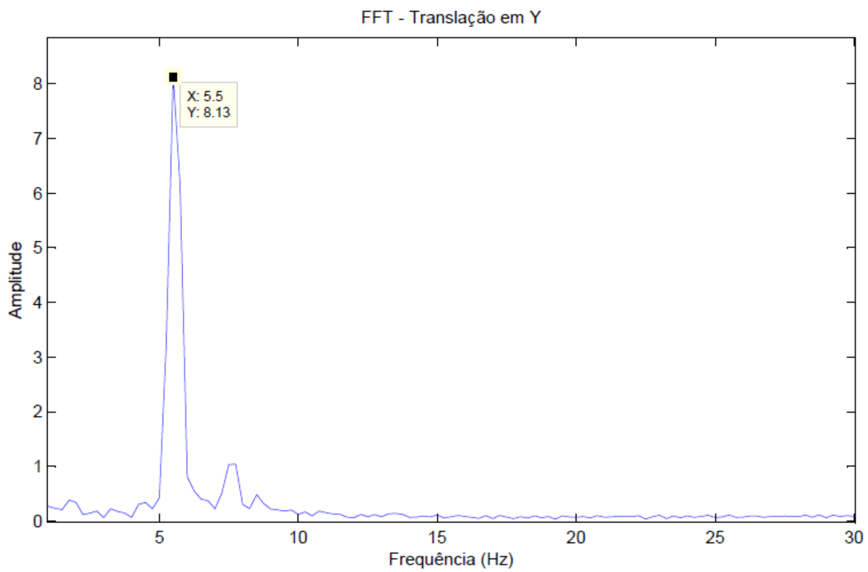


Figure 16 - FFT of Time Signal A0

Table 6 – Phases for Translation Y

Phase Analysis	A0	A1	A2	A3
A0	0º	0º	180º	180º
A1	0º	0º	180º	180º
A2	180º	180º	0º	0º
A3	180º	180º	0º	0º

Experimental Test
(Accelerometer)

Translation X

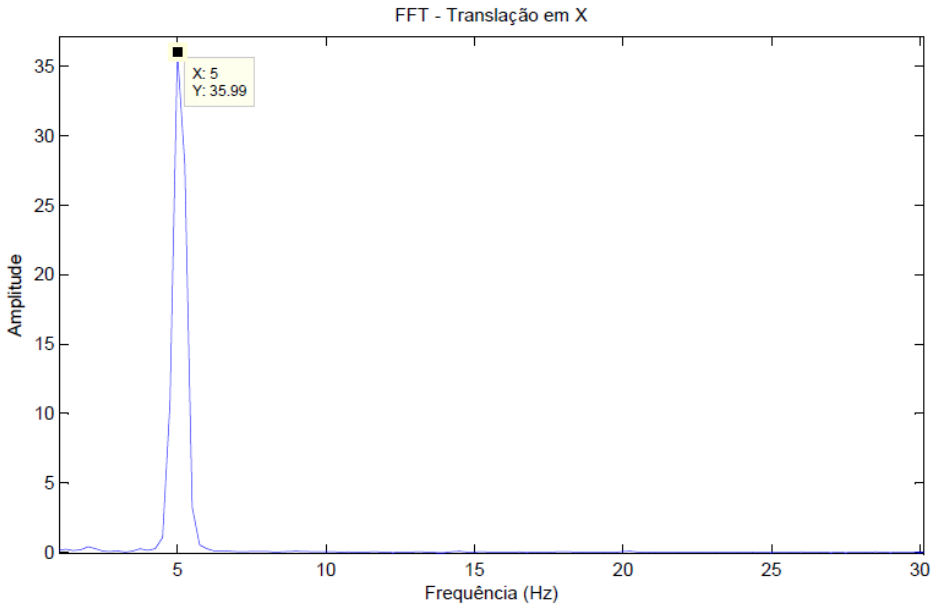


Figure 17 – FFT of Time Signal A0

Table 7 – Phases Translation X

Phase Analysis	A0	A1	A2	A3
A0	0º	180º	0º	180º
A1	180º	0º	180º	0º
A2	0º	180º	0º	180º
A3	180º	0º	180º	0º

Experimental Test
(Accelerometer)

Translação em Z

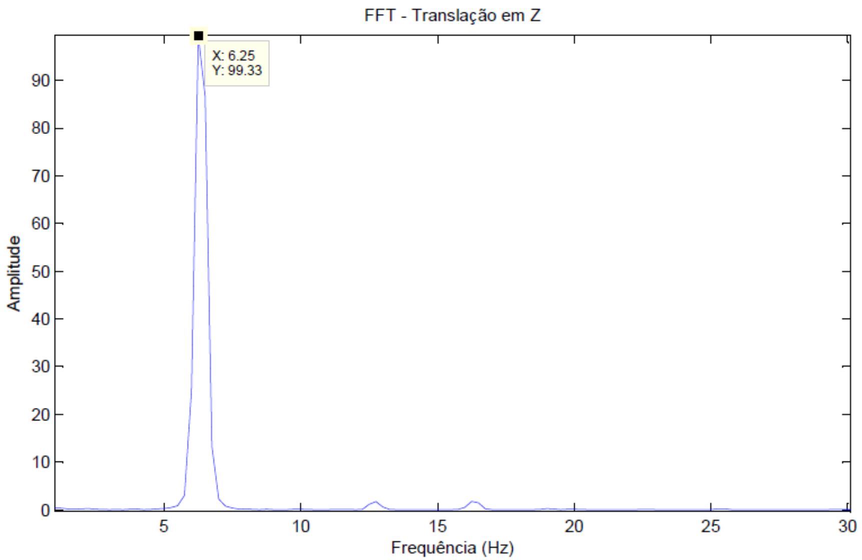


Figura 18 - FFT do sinal no tempo de A0

Tabela 8 – Fases para Translação em Z

Análise de fase	A0	A1	A2	A3
A0	0º	0º	0º	0º
A1	0º	0º	0º	0º
A2	0º	0º	0º	0º
A3	0º	0º	0º	0º

Experimental Test
(Accelerometer)

Rotation X

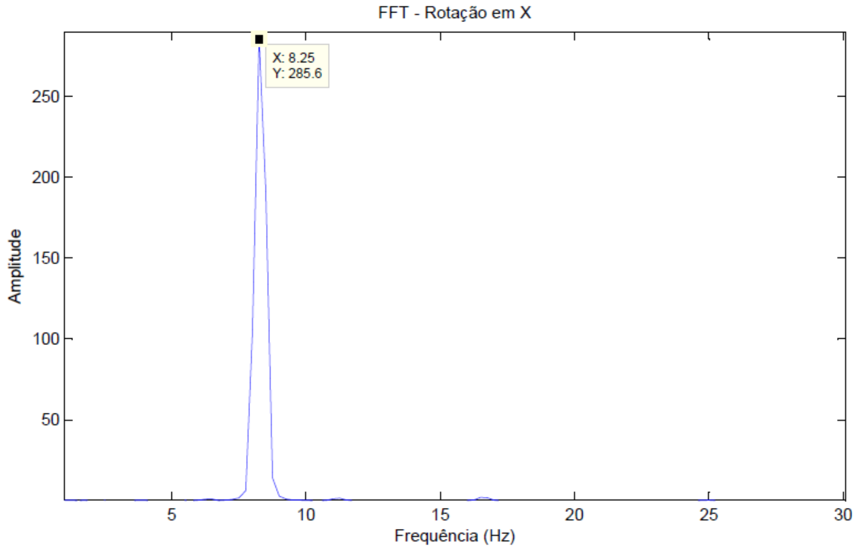


Figura 19 - FFT of Time Signal A0

Table 9 – Phases for Rotation X

Phase Analysis	A0	A1	A2	A3
A0	0º	0º	180º	180º
A1	0ª	0º	180º	180º
A2	180º	180º	0º	0º
A3	180º	180º	0º	0º

Experimental Test
(Accelerometer)

Rotation Y

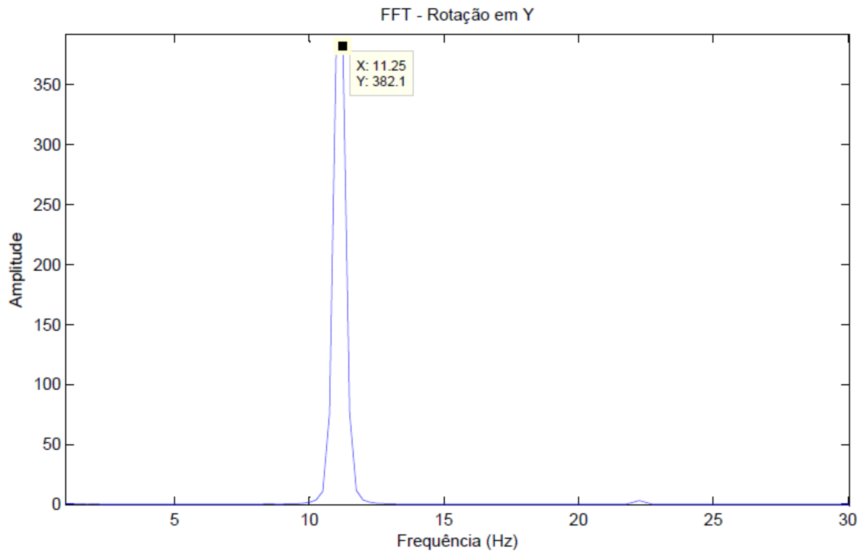


Figure 20 - FFT Time Signal A0

Table 10 – Phases for Rotation Y

Phase Analysis	A0	A1	A2	A3
A0	0º	180º	0º	180º
A1	180º	0º	180º	0º
A2	0ª	180º	0º	180º
A3	180º	0ª	180º	0º

Verificação Experimental
(Acelerômetros)

Rotação em Z

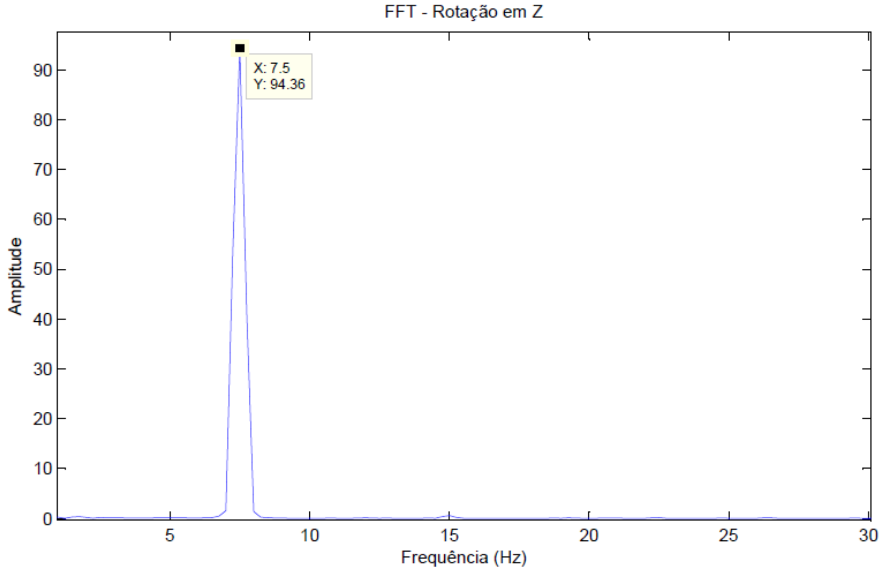


Figura 21 - FFT do sinal no tempo de A0

Tabela 11 – Fases para Rotação em Z

Phase Analysis	A0	A1	A2	A3
A0	0º	180º	0º	180º
A1	180º	0º	180º	0º
A2	0º	180º	0º	180º
A3	180º	0ª	180º	0º

Experimental Test
(Accelerometer)

Table 12 – Comparison of Results

Frequecies	Model (rpm)	Sweep (rpm)	Experimental Test(rpm)	Modes
1	112,6	Not identified	330	Translation Y
2	333,5	310,2	300	Translation X
3	367,3	387	375	Translation Z
4	440,54	452	450	Rotation Z
5	489,64	505	495	Rotation X
6	699,24	678	675	Rotation Y

Rotor Analysis
Rotmef Simulations

Table 14 – Tests configuration

Configuration	Disc position	Distance between bearings	Critical speed(rpm)
1	Centered between bearings	590 mm	950
2	136mm of bearing 1		1180
3	190mm of bearing 1		1025
4	Cantilever - 130mm of bearing 2	380 mm	832
5	Cantilever - 190mm of bearing 2		600

Tabela 15 – Speed test

Speeds (rpm)
550
1300
2000

Rotmef Simulation

Configuration 1

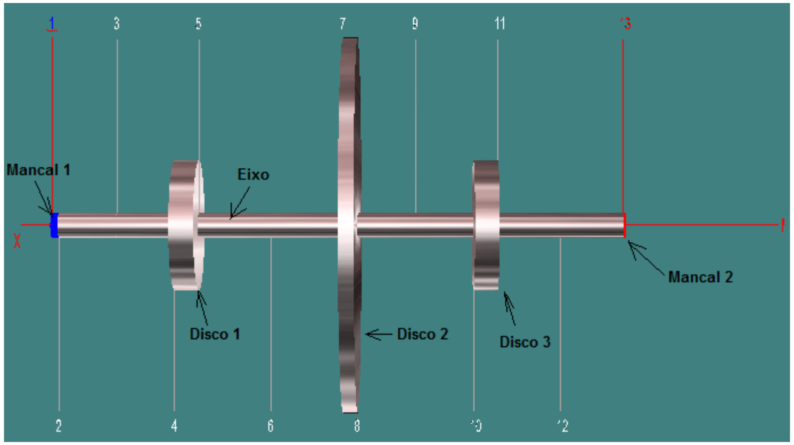


Figure 21 - Configuration 1 - Rotmef

Table 15 – Frequency of each mode acording to rotation of first configuration.

Rotation (rpm)	Frequency of modes (Hz)					
	1	2	3	4	5	6
550	15,4	15,41	84,78	88,72	161,77	162,1
1300	15,39	15,41	82,03	91,34	161,55	162,31
2000	15,38	15,42	79,45	93,7	161,33	162,5

Rotmef Simulation

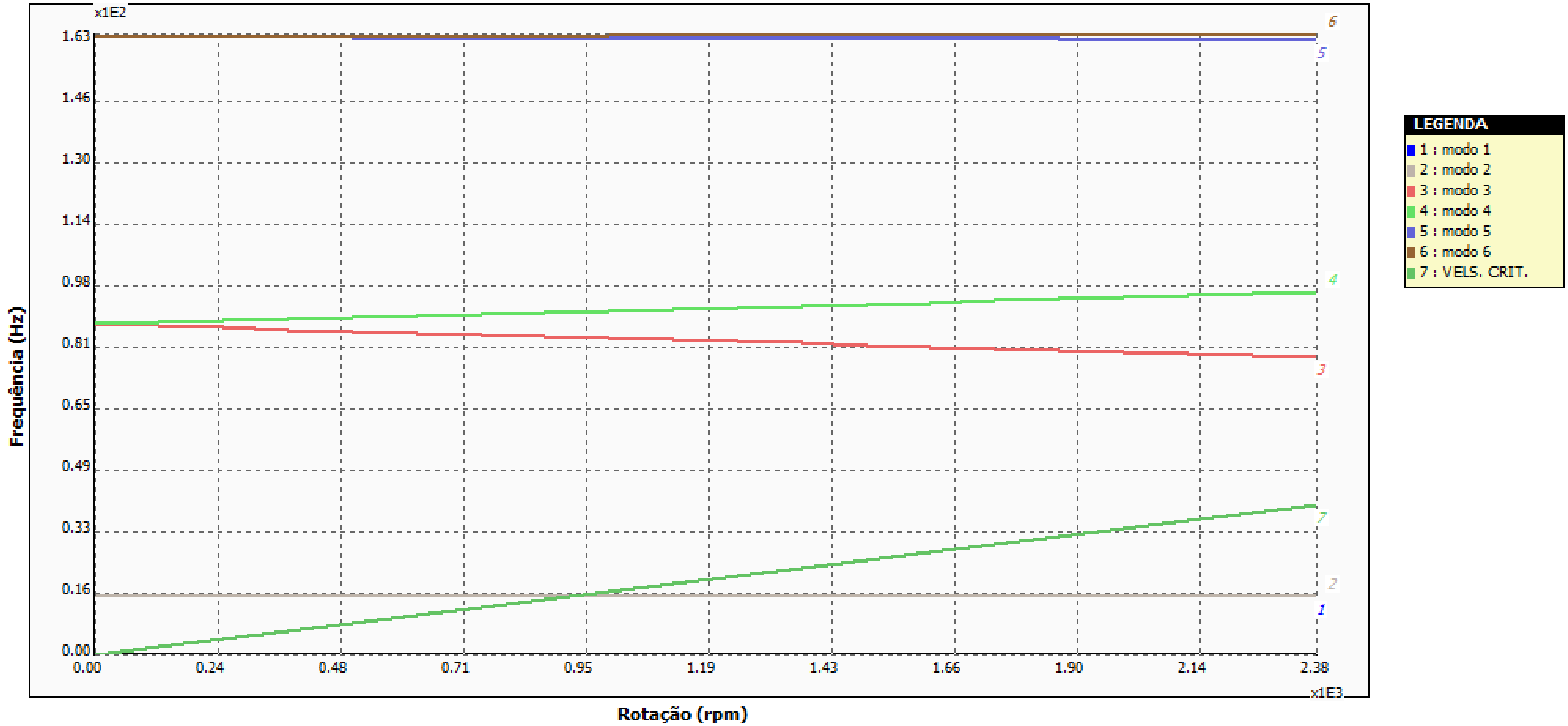
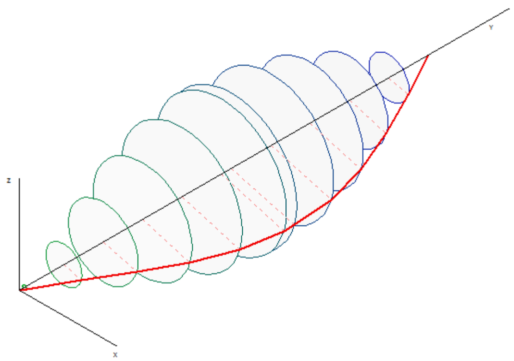


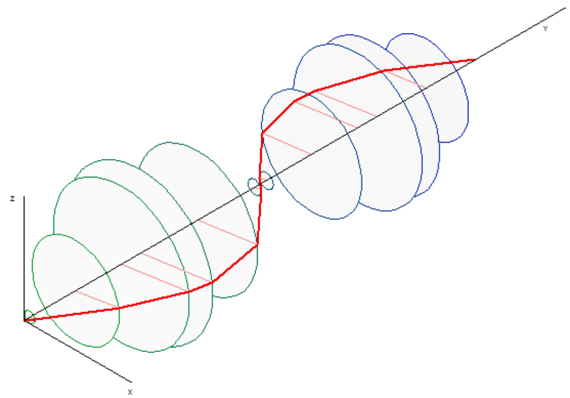
Figure 22 – Campbell diagram - configuration 1

<u>Critical speed = 950rpm</u>

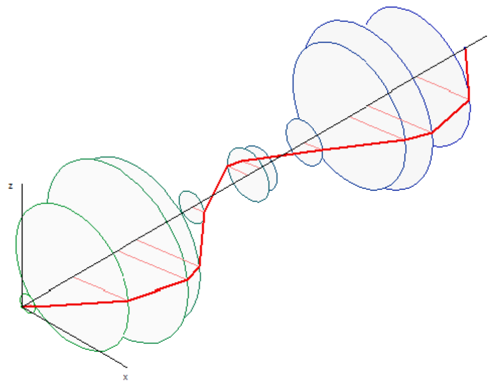
Rotmef Simulation



Mode 1 e 2



Mode 3 e 4



Mode 5 e 6

Rotmef Simulation

Configuration 2

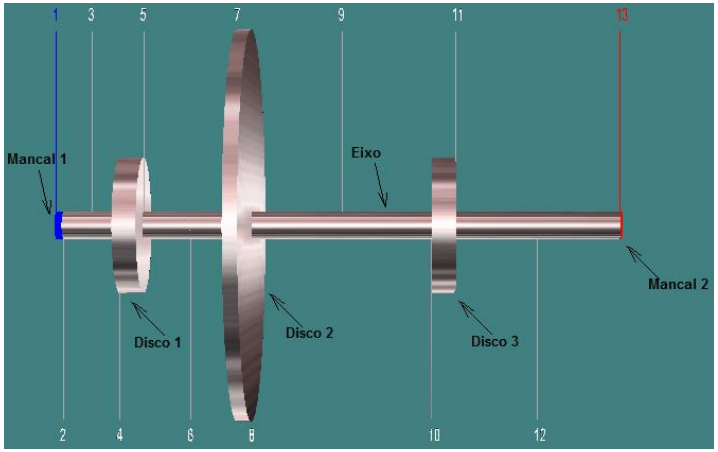
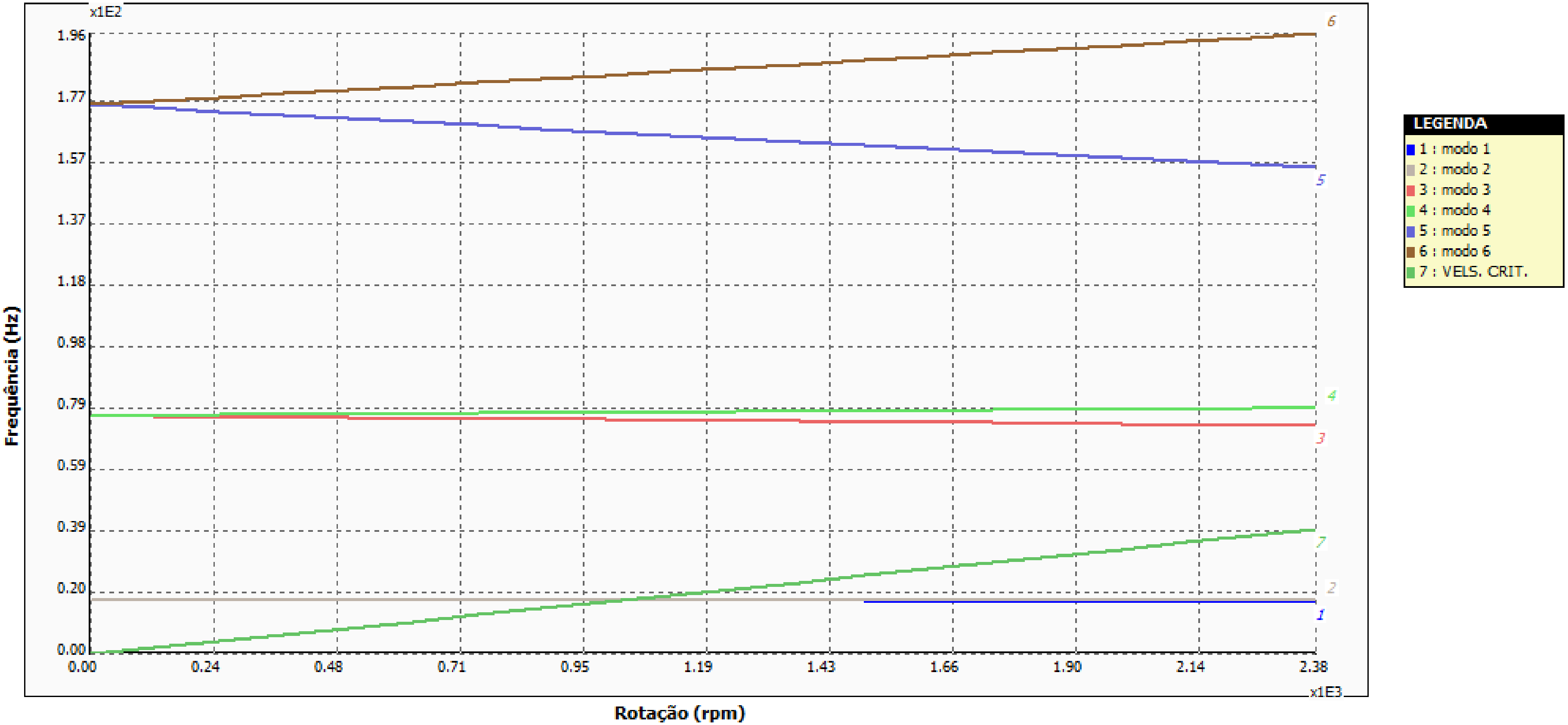


Figure 23 - Modelo da configuração 2 no Rotmef

Tabela 16 – Frequência de cada Modo de acordo com as rotações para a configuração 2

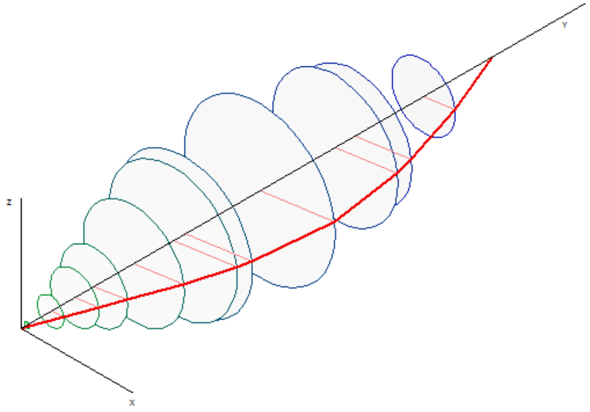
Rotações (rpm)	Frequência(Hz) dos Modos					
	1	2	3	4	5	6
550	19,79	20,14	72,66	72,85	196,07	208,97
1300	19,55	20,37	72,51	72,98	187,76	218,22
2000	19,33	20,59	72,37	73,09	180,37	227,15

Rotmef Simulation

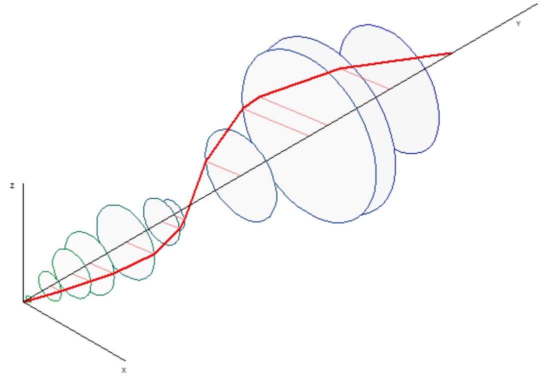


<u>Velocidade Crítica = 1180rpm</u>

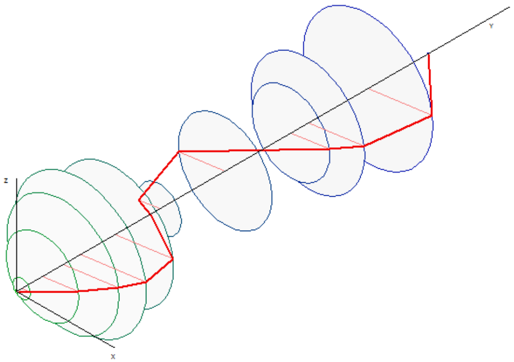
Simulações no Rotmef



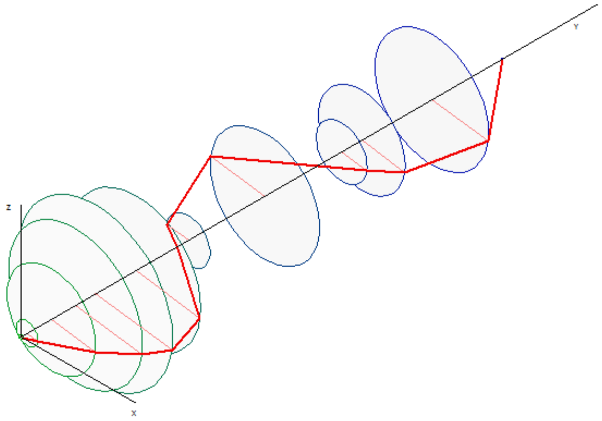
Forma dos modos 1 e 2



Forma dos modos 3 e 4



Forma do modo 5



Forma do modo 6

Simulações no Rotmef

Configuration 3

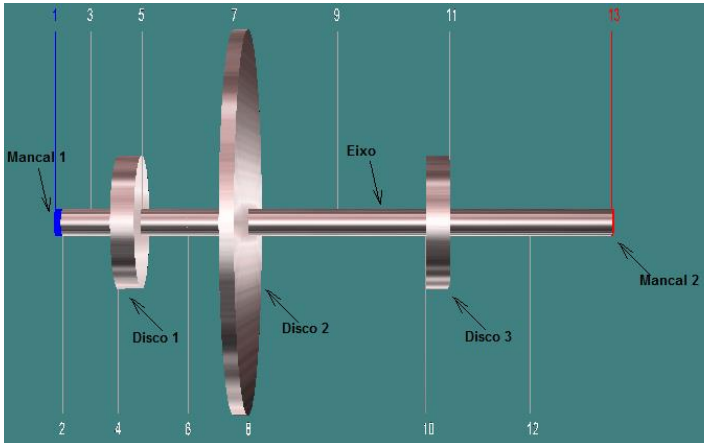
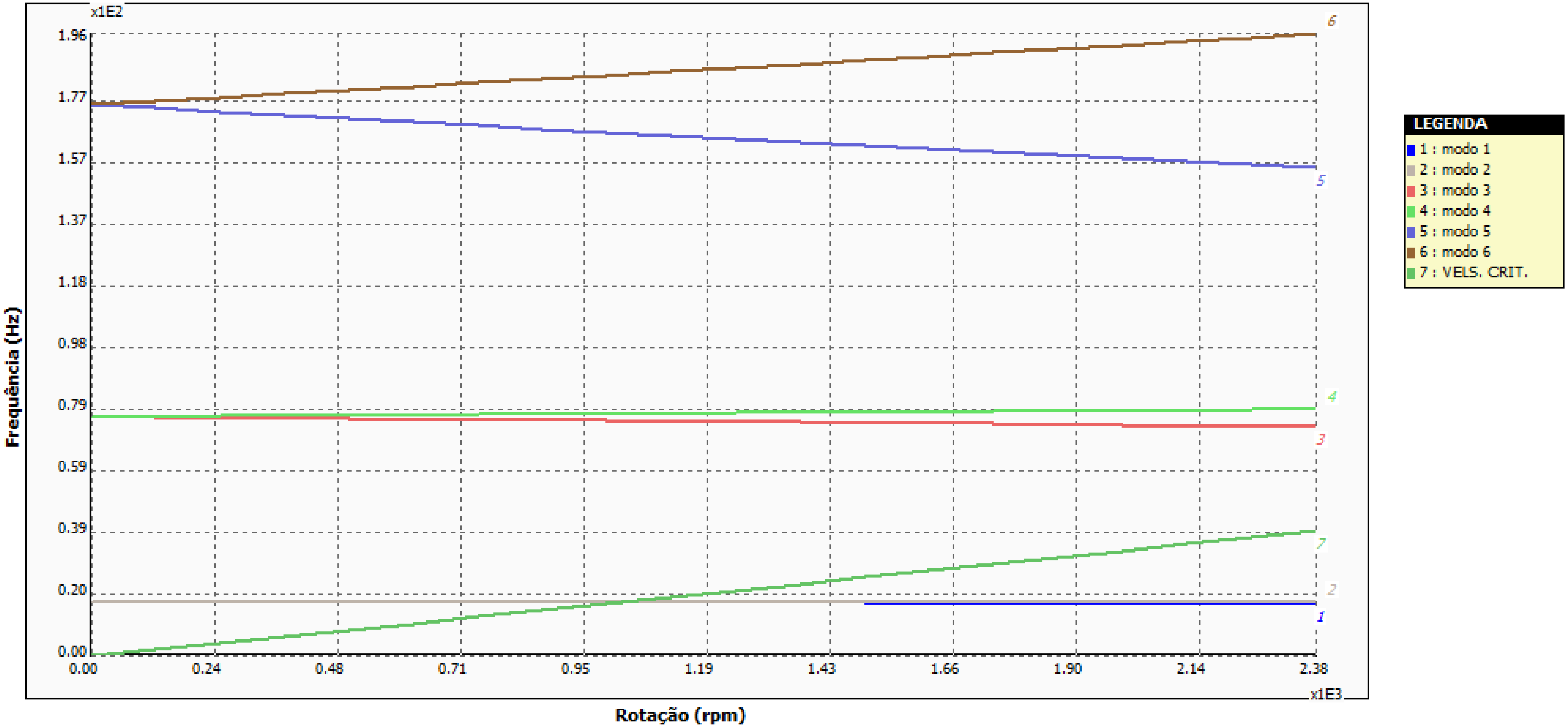


Figura 24 – Model of configuration 3 in Rotmef

Tabela 17 – Frequência de cada Modo de acordo com as rotações para a configuração 3

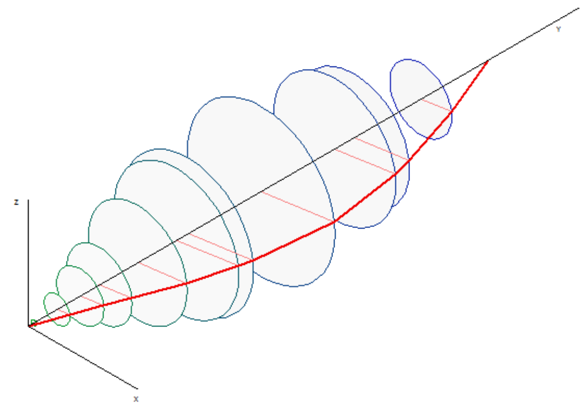
Rotações (rpm)	Frequência(Hz) dos Modos					
	1	2	3	4	5	6
550	17,07	17,2	74,81	76,08	169,22	179,1
1300	16,98	17,28	73,87	76,86	162,85	186,1
2000	16,9	17,36	72,92	77,55	157,21	192,75

Simulações no Rotmef

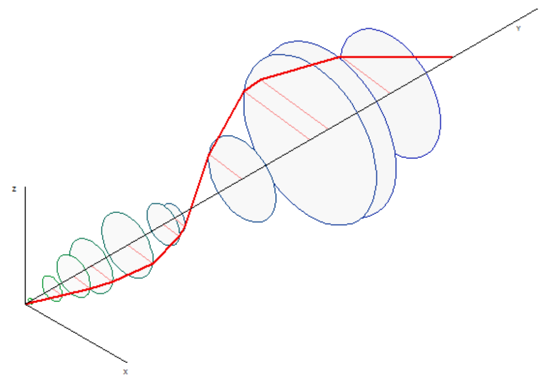


<u>**Velocidade Crítica = 1025rpm**</u>

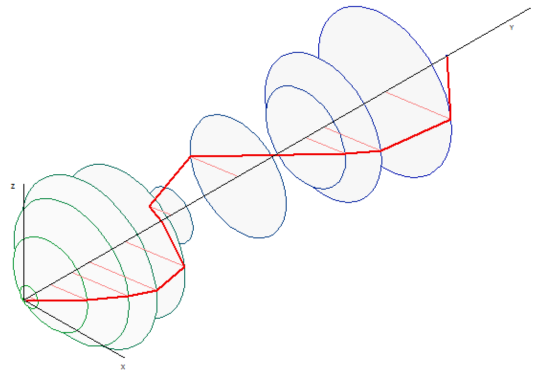
Simulações no Rotmef



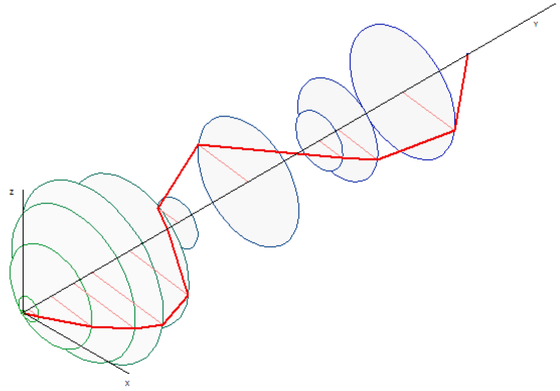
Forma dos modos 1 e 2



Forma dos modos 3 e 4



Forma do modo 5



Forma do modo 6

Simulações no Rotmef

Configuração 4

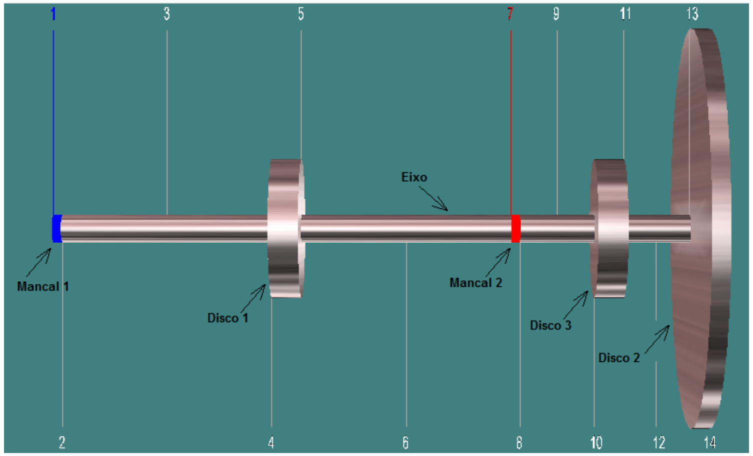
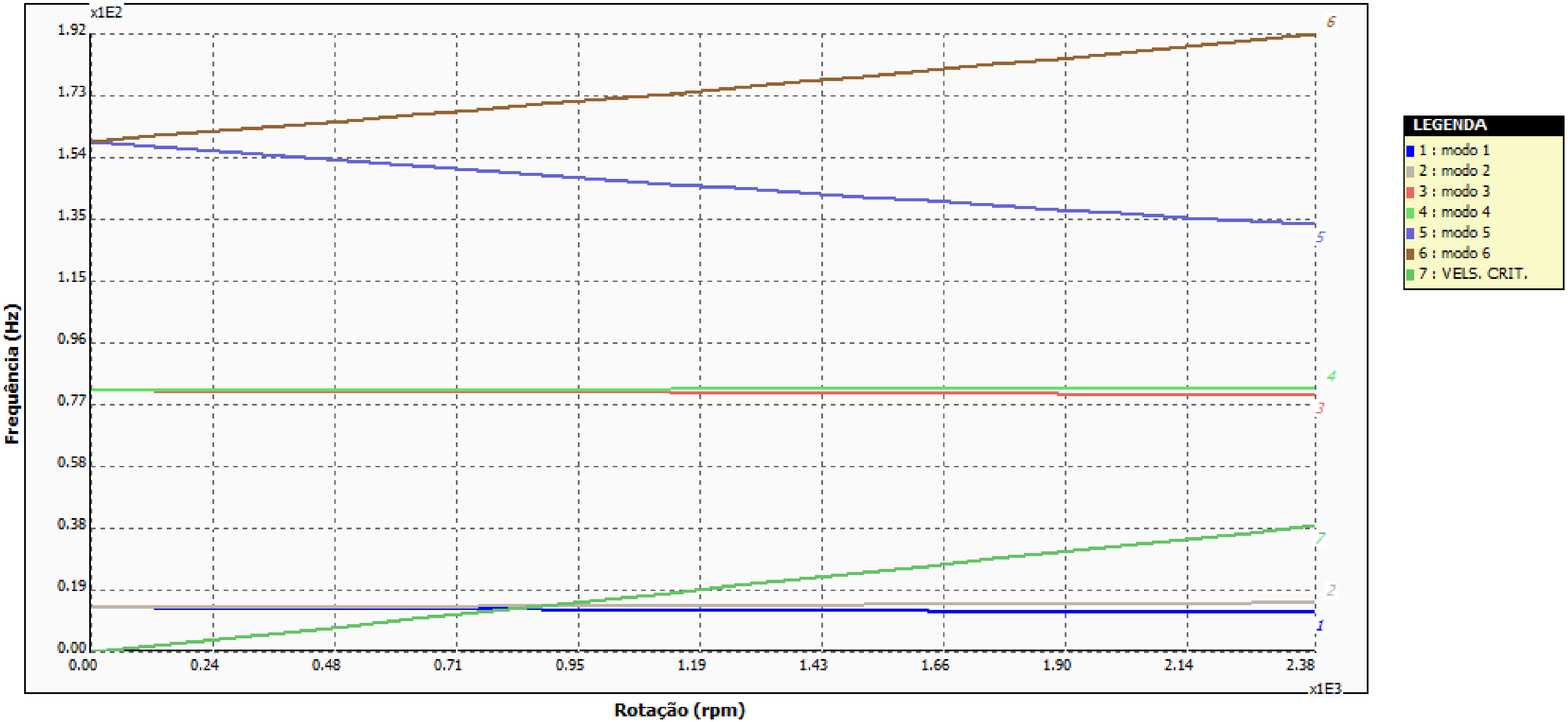


Figura 25 - Modelo da configuração 4 no Rotmef

Tabela 18 – Frequência de cada Modo de acordo com as rotações para a configuração 4

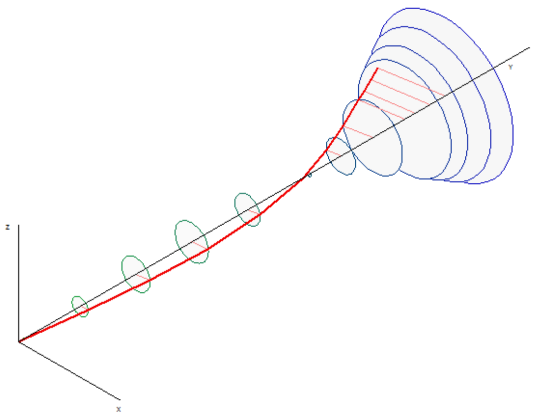
Rotações (rpm)	Frequência(Hz) dos Modos					
	1	2	3	4	5	6
550	13,56	14,26	81,24	81,73	152,65	166,41
1300	13,1	14,73	80,85	82,01	144,17	176,66
2000	12,67	15,18	80,43	82,24	136,93	186,82

Simulações no Rotmef

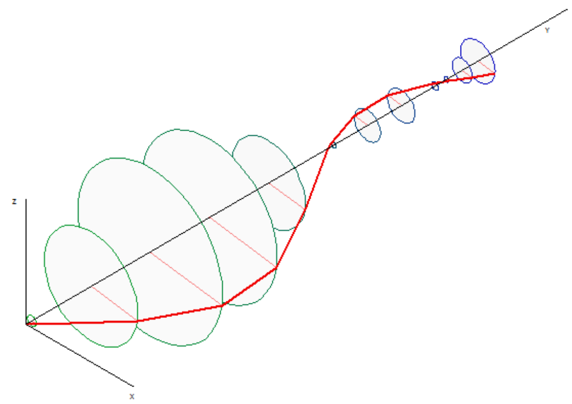


<u>Velocidade Crítica = 832rpm</u>

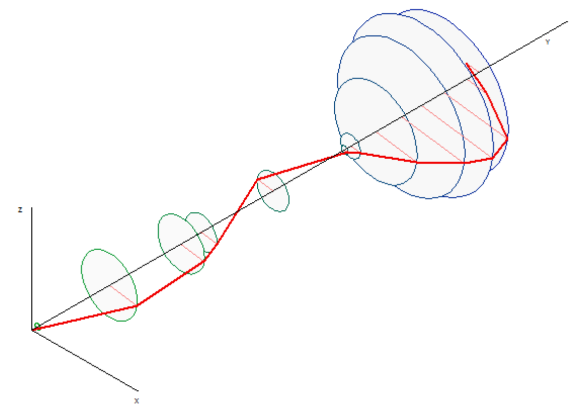
Simulações no Rotmef



Forma dos modos 1 e 2



Forma dos modos 3 e 4



Forma dos modos 5 e 6

Simulações no Rotmef

Configuração 5

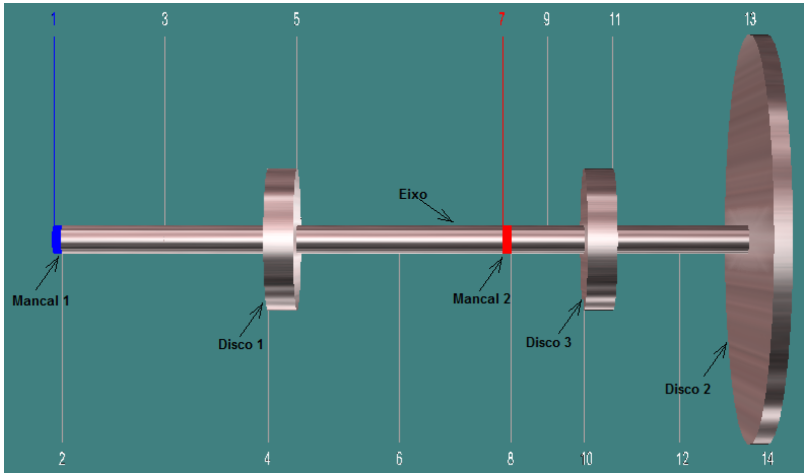
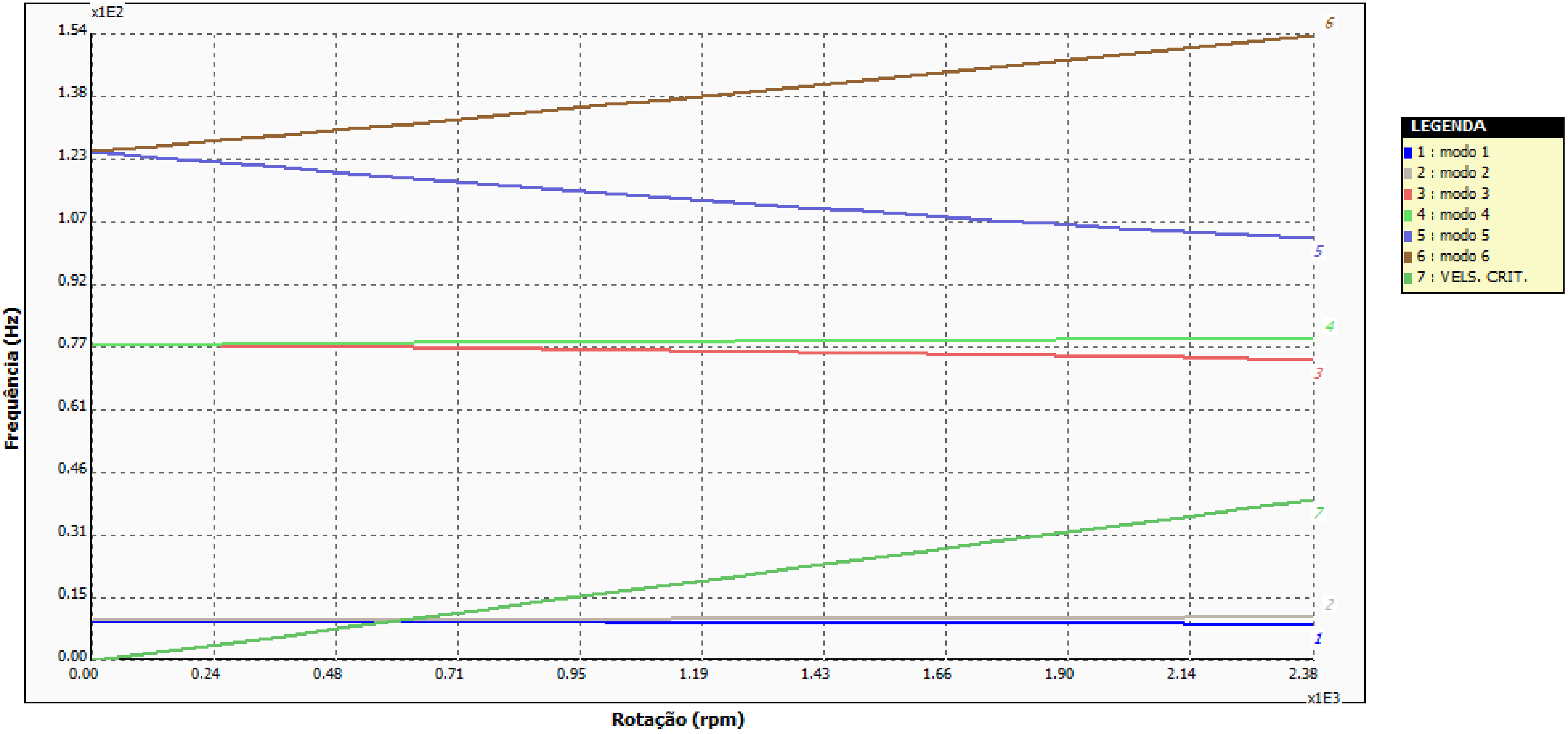


Figura 26 - Modelo da configuração 5 no Rotmef

Tabela 19 – Frequência de cada Modo de acordo com as rotações para a configuração 4

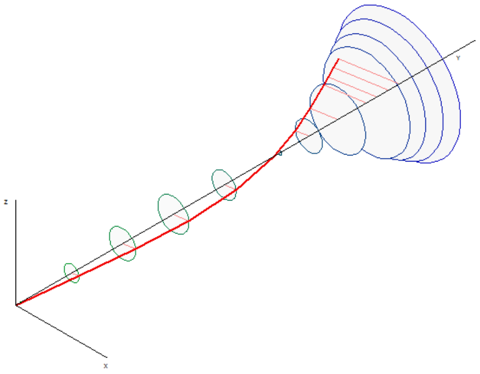
Rotações (rpm)	Frequência(Hz) dos Modos					
	1	2	3	4	5	6
550	9,64	10,05	76,84	77,89	119,06	130,92
1300	9,36	10,33	75,86	78,42	112	139,85
2000	9,1	10,6	74,7	78,83	106,25	148,65

Simulações no Rotmef

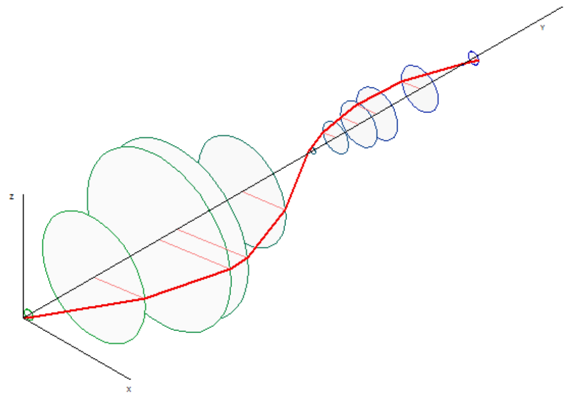


<u>Velocidade Crítica = 600rpm</u>

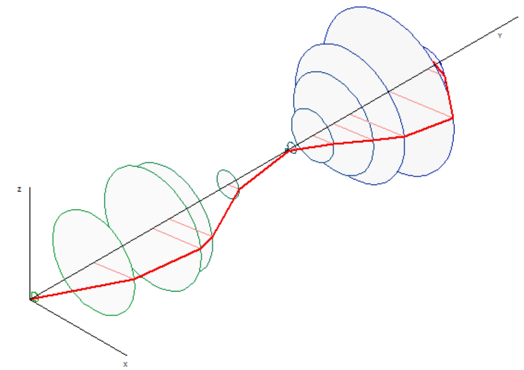
Simulações no Rotmef



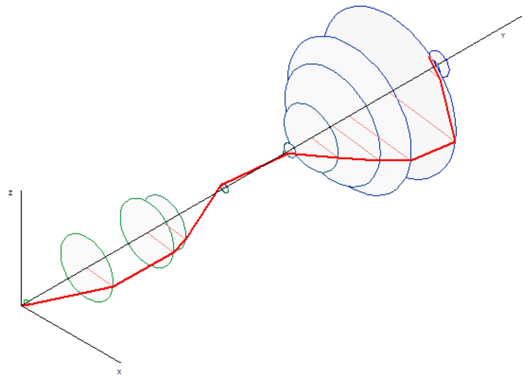
Modes 1 e 2



Modes 3 e 4

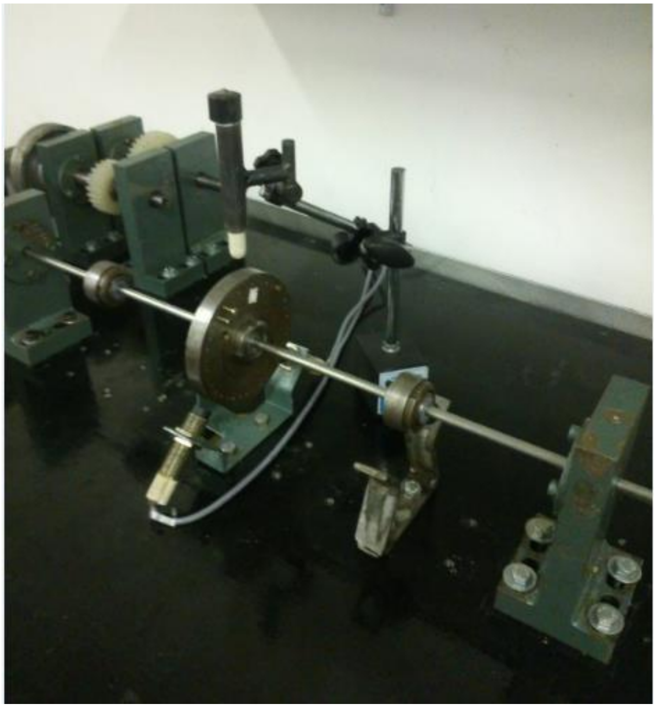


Mode 5



Mode 6

Rotor Tests



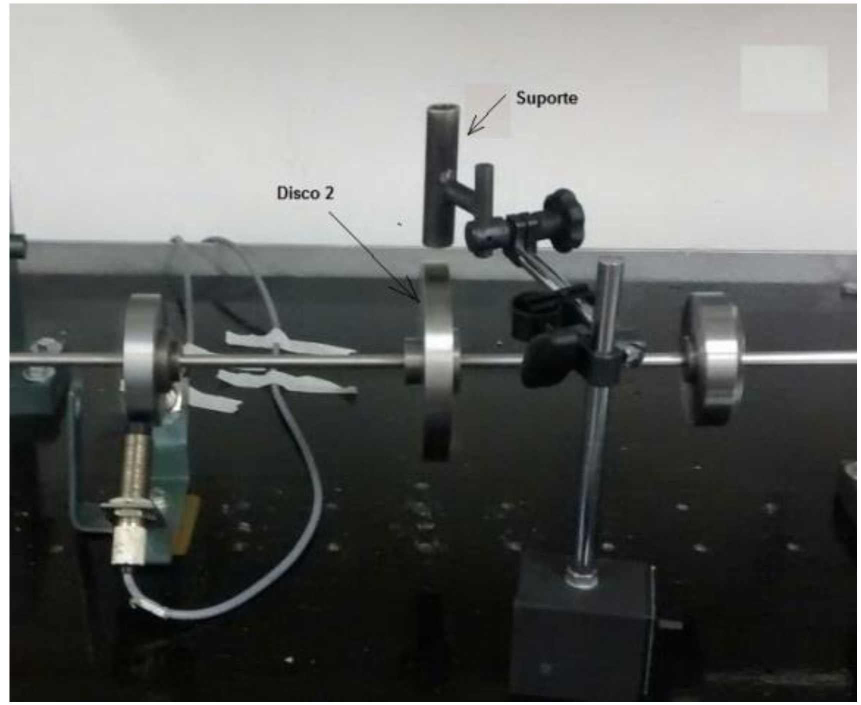


Figure 27 – Magnetic Base

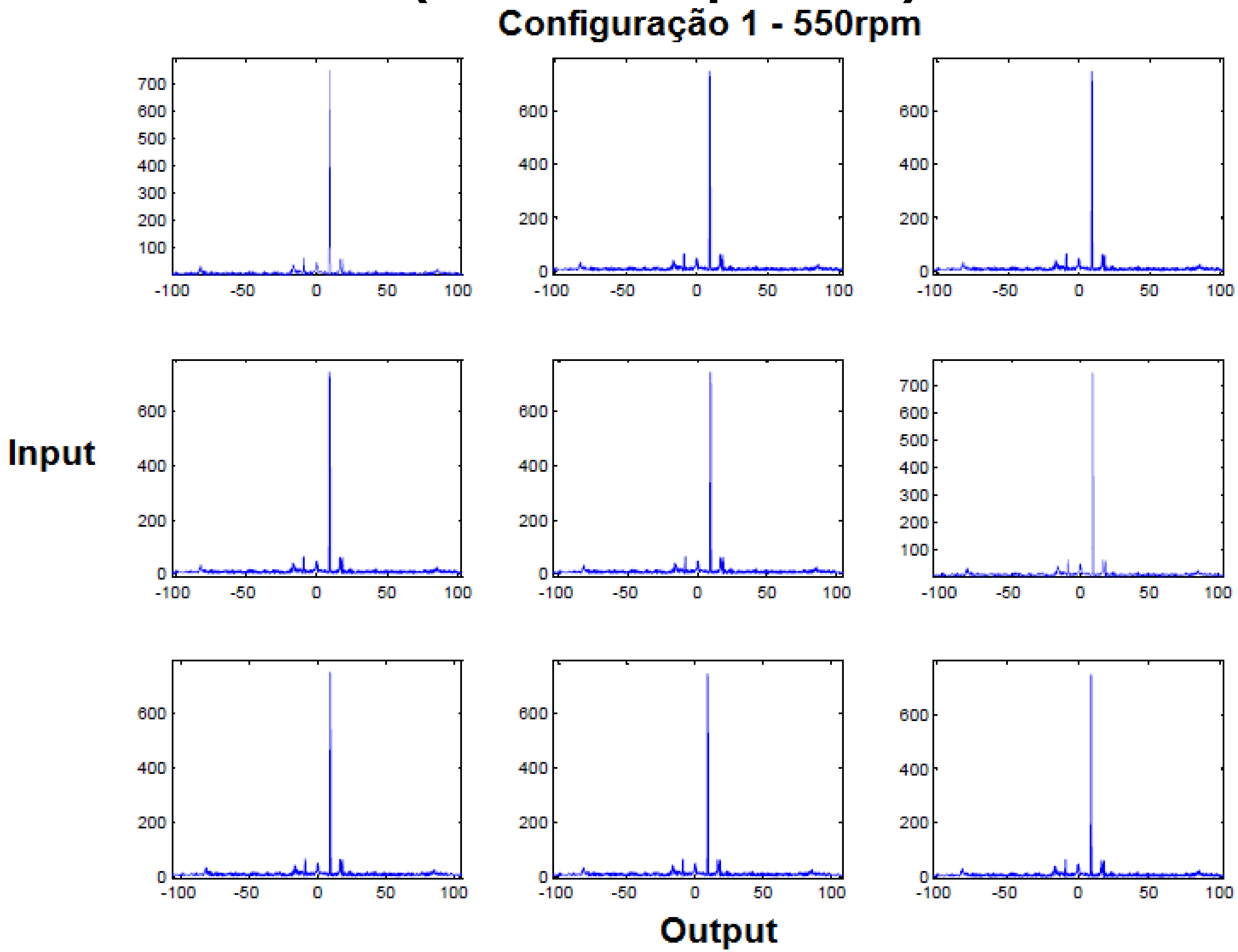
Rotor Tests

Matrix of tests

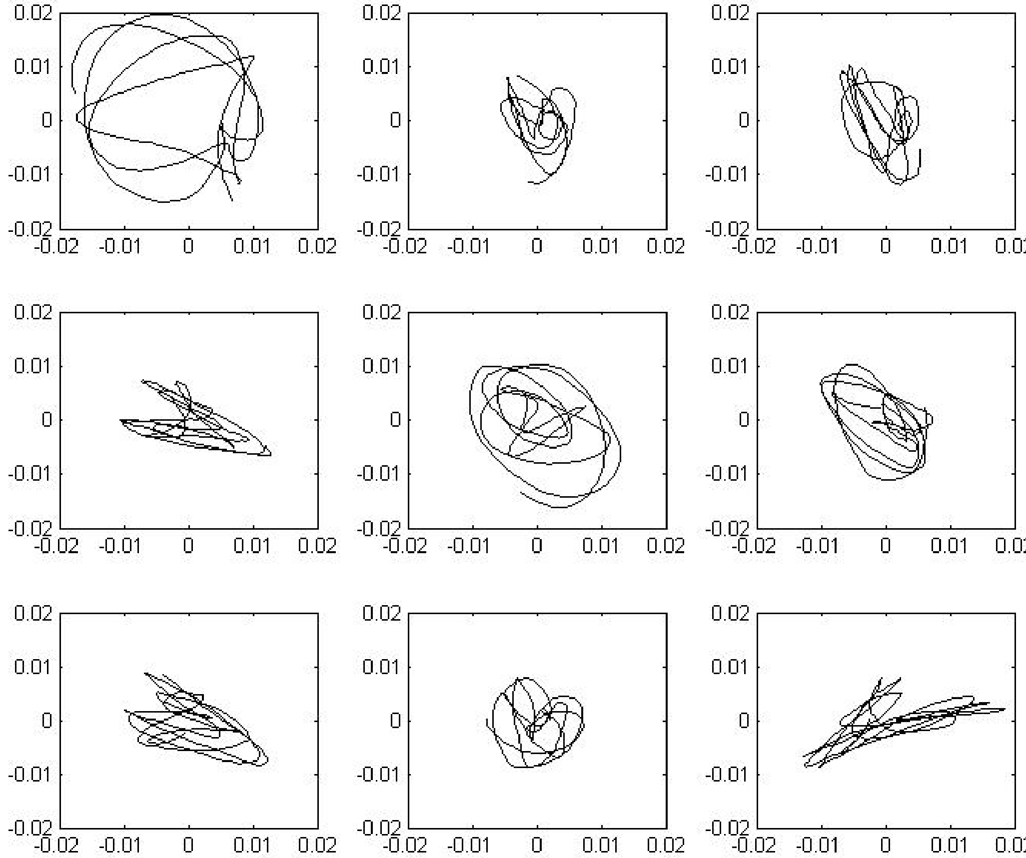
Configurações	5
Rotações	3
Input	3
Output	3
Total de Ensaios	135

Input: Impacto com pino
Output: Leitura do sinal (Instrumentos)

Rotor Tests
(Matrix of Spectros)



Rotor Tests
(Órbitas)



Orbits – Configuration 1 – 550 Rpm

Conclusions

- ✓ In the evaluation of non-rotating parts of the critical frequencies were identified as was also possible to correspondingly validating the first six vibration modes.

- ✓ With respect to the horizontal rotor and the phenomena that the same features can be seen that the values are quite close to the values generated by Rotmef, then it can be concluded that the tests have expected results and about frequency analysis the gyroscopic effect can be observed and the presence of reverse modes by analyzing the full spectra.

- ✓ It is considered that the horizontal rotor of the experimental rig has similar characteristcs of a real rotating machine and can be used for research and development in this field of mechanical engineering.

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