SDLL125 – Diagram of Campbell of a beam in rotation with 2 asymmetric discs and 2 bearings subjected to the gyroscopy

Summarized:

This test makes it possible to validate the computation of the modes in rotation of a system of rotating shafts according to the rotational axis X with the macro `CALC_MODE_ROTATION` and of the diagram of Campbell with the macro `IMPR_DIAG_CAMPBELL`, to highlight instability. This validation relates to positive rotational speeds as well (modelization A) that negative rotational speeds (modelization B). The modelization C, as for it, the taking into account of a system of rotating shafts according to the rotational axis validates Y.

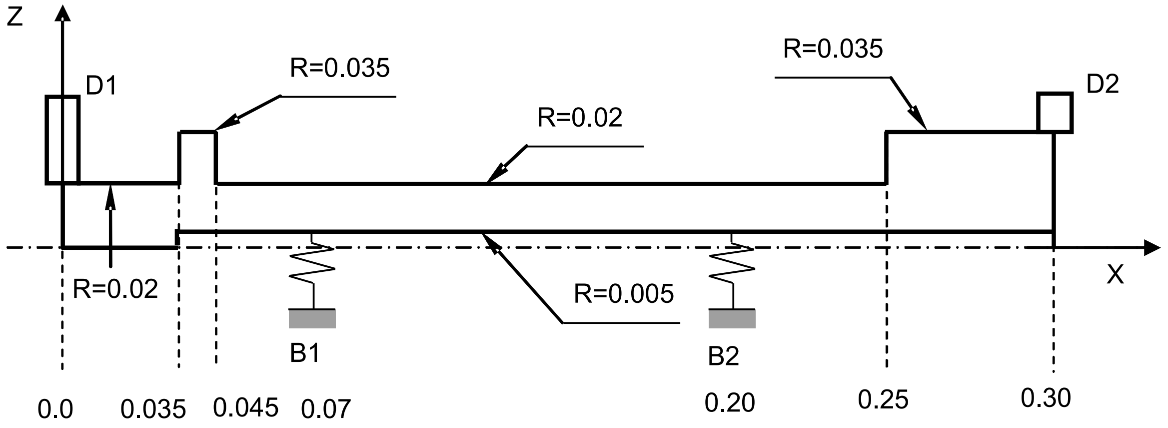
In this test, there is a model of rotor with two discs, supported by two hydrodynamic bearings, whose stiffness matrixes and of damping are asymmetric. This example as well as the corresponding results of reference are drawn from the handbook of qualification of ROTORINSA, [bib2], software finite elements intended to envisage the dynamic behavior of rotors in bending.

A good agreement is observed between the results of Code_Aster and the reference solution.

1 Problem of reference

1.1 Geometry

a model of rotor supported by 2 bearings (nodes $B1$ and $B2$ on the figure below), whose stiffness matrixes and of damping are asymmetric. It is composed of 3 discs, and 3 sections of shaft.



Appear 1.1-a: Model rotor with 2 discs and 2 asymmetrical bearings

1.2 Properties of the material

the geometrical characteristics and material are listed in the following table.

Material		$E=2.10^{11} N/m^2$	$\rho=7800 kg/m^3$	$\nu=0.3$
Disc	$D1$	$M=3.5 kg$	$I_D=3.5\,10^{-3} kg\,m^2$	$I_P=7.10^{-3} kg\,m^2$
	$D2$	$M=3.0 kg$	$I_D=3.0\,10^{-3} kg\,m^2$	$I_P=6.10^{-3} kg\,m^2$

the characteristics of the bearings are indicated in the table which follows.

Bearing	$P1$	$K_{yy}=8.10^7 N/m$	$K_{zz}=1.10^8 N/m$
		$K_{yz}=1.10^7 N/m$	$K_{zy}=6.10^7 N/m$
		$C_{yy}=8.10^3 Ns/m$	$C_{zz}=1.2\,10^4 Ns/m$
		$C_{yz}=3.10^3 Ns/m$	$C_{zy}=3.10^3 Ns/m$
Bearing	$P2$	$K_{yy}=5.10^7 N/m$	$K_{zz}=7.10^7 N/m$
		$K_{yz}=2.10^6 N/m$	$K_{zy}=4.10^7 N/m$
		$C_{yy}=6.10^3 Ns/m$	$C_{zz}=8.10^3 Ns/m$
		$c_{yz}=1.5\,10^3 Ns/m$	$C_{zy}=1.5\,10^3 Ns/m$

1.3 Boundary conditions

to block motions of type rigid body in the direction x , one blocks the degree of freedom DX with the node bearing $B1$.

2 Reference solution

2.1 Method of calculating

the results of reference are given by ROTORINSA, code with the finite elements intended to envisage the dynamic behavior of rotors in bending. The following parameters were used for the results of reference:

- The computation relates to a number of modes in rotation $NVES=8+4$, in ROTORINSA.
- The beach rotational speeds is defined of 0 with $60000\,tr/mn$ a step $5000\,tr/mn$.

2.2 Quantities and results of reference

the Results of ROTORINSA give the frequencies of the modes in bending.

The computation modes in rotation is carried out with Code_Aster by means of the same modelization as ROTORINSA. The results of Code_Aster give at the same time the frequencies of the modes of bending, torsion and tension/compression. The number of calculated modes is 20.

2.3 Bibliographical references

1.Mr. LALANNE, G. FERRARIS, “ Rotordynamics Prediction in Engineering ”, Second Edition, Wiley, 2001.

2.ROTORINSA, software finite elements intended to envisage the dynamic behavior of rotors in bending, LaMCoS UMR5259, INSA-Lyon.

3 Modelization A

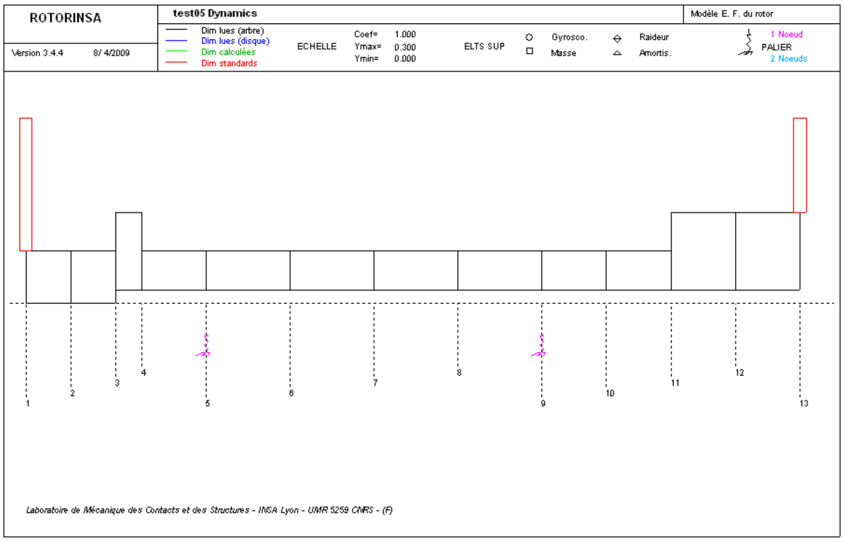
3.1 Characteristic of the modelization

It acts of a system of rotating shafts according to the axis X with positive rotational speeds.

3.2 Characteristics of the mesh

the rotor is with a grid in 12 finite elements of shaft of the type `POU_D_T` and comprises 4 discrete elements of the type `DIS_TR` for the modelization of the discs and the bearings.

Many nodes: 13
Number and type of elements: 12 SEG2
4 POI1



Appear 1-b: Characteristic of the model finite elements under ROTORINSA

3.3 Quantities tested and Eigenfrequencies

3.3.1 results according to rotational speed

the values of the first 8 frequencies of bending for the velocities $0\,tr/mn$ and $60000\,tr/mn$, for the two software, are presented in table below

N° Fréq in flexionV itess	**of rotation (tr/min)**	**ROTORINSA**		**Code_AsterFacteur**	
		$F(Hz)$	**of amortissementTolérances**	**of $F(Hz)$**	**Tolerances of amortissementréduit102.16212E+024.76544E-021.E-31.E-3600001.85365E+02-5.17463E-021.E-31.1E-3202.63539E+027.87281E-021.E-36.E-3600002.96078E+021.55245E-011.E-35.E-3303.83210E+02**
			5.01438E-021.E-314.E-3600003.24718E+02		
			1.57489 E-03	1.E-37.E-3404.39642E+02	
			6.02275E-021.E-3		12.E-3600004.72541E+02
			1.59683E-011.2E-33.E-3		

Table 2-a: Eigenfrequencies of type bending for Code_Aster and ROTORINSA

the frequencies obtained are in perfect adequacy with those of ROTORINSA.
One notes an instability of the first mode, which appears with $16\,760\,tr/mn$.

In Code_Aster, one observes also frequencies and modes of torsion and modes of tension/compression. These modes are not calculated by ROTORINSA, because it models only the behavior in bending. The values of these frequencies are tested in `NON_REGRESSION` and this only with the stop. Indeed, the modes of torsion and tension are, by definition, invariants compared to the rotational speed.

In short in the table below, are presented, the numbers the frequencies calculated and used in the layout of the diagram of Campbell in Code_Aster.

Number of values clean detected: 20
Many frequencies requested for the layout: 10

	calculated	traced
Many total frequencies	20	10
Many frequencies in bending	14	8
Many frequencies torsion	3	1
Number of frequencies tension/compression	3	1

Table 2-d: Calculated and traced frequencies (Code_Aster)

3.3.2 Diagram of Campbell

the diagram of Campbell obtained in Code-Aster while following the modes of bending per comparison of form (MAC matrixes) corresponds perfectly to that obtained by ROTORINSA.

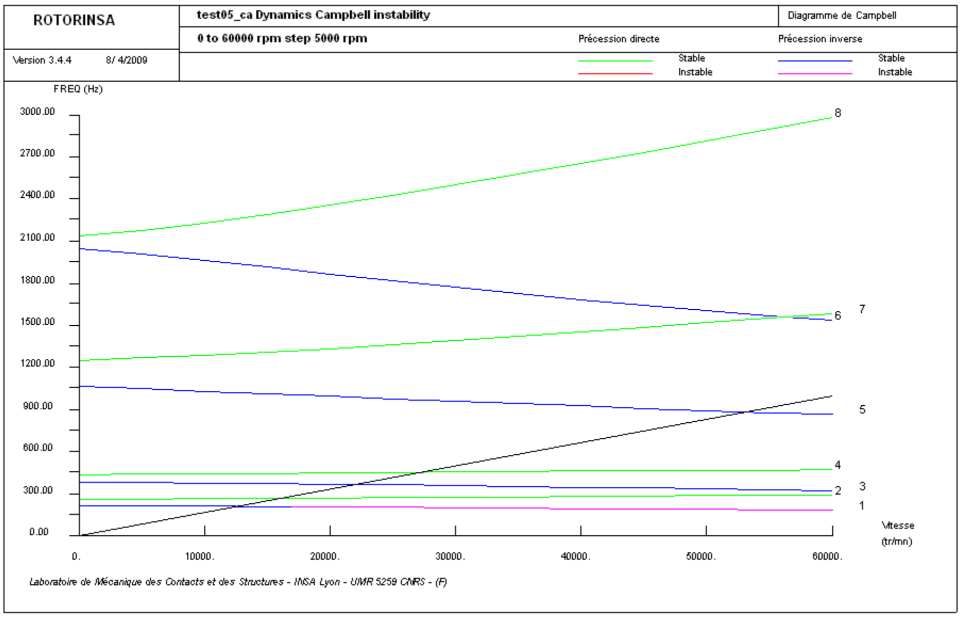
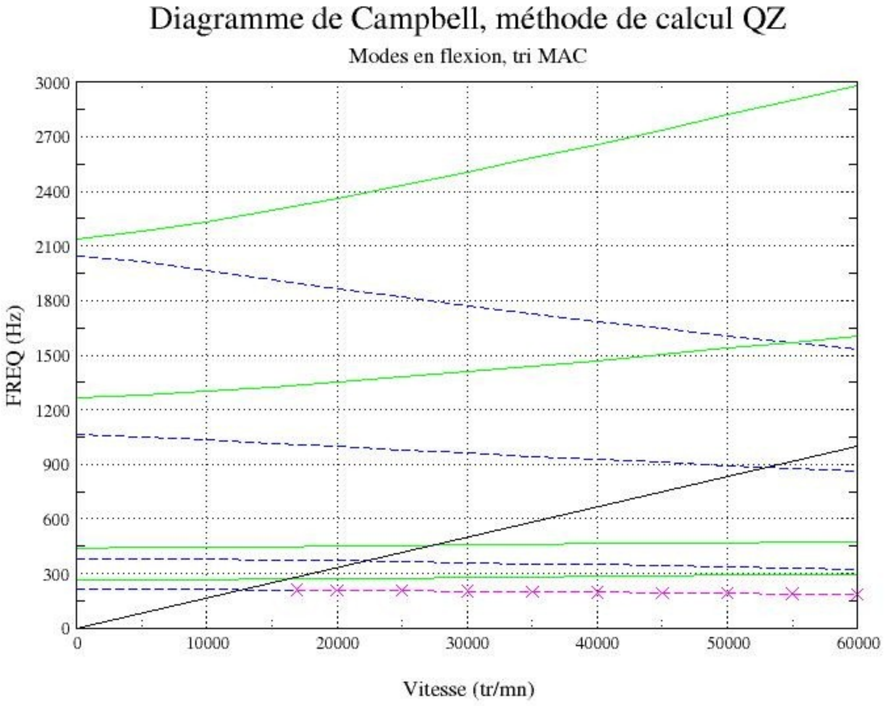


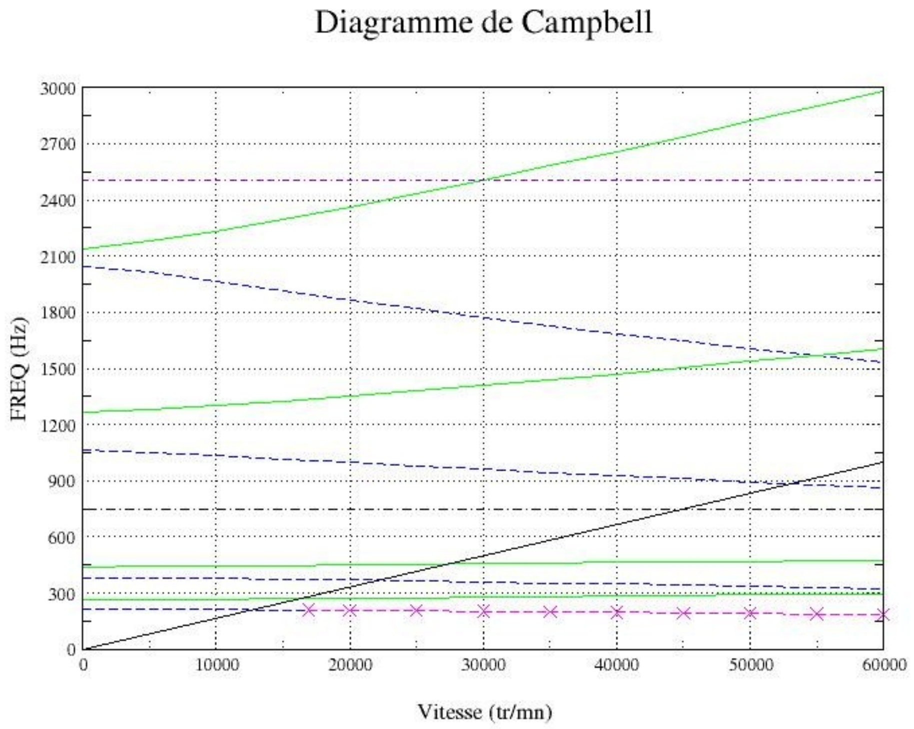
Figure 3-a : Diagram of Campbell in bending given by ROTORINSA



Appears 3-b: Diagram of Campbell in bending given by Code_Aster

There is an instability of the first mode, it appears in magenta color, style long indents, marker X , on the diagram of Campbell de Code_Aster.

One observes in more the follow-up of the modes of torsion and tension/compression. For this application, these modes are invariants compared to the vistess of rotation and thus the curves of evolution are horizontal lines.



Appear 3-c: Diagram of Campbell in bending, torsion and traction and compression

For the modes of torsion: line color black, style an indent, a dotted line.
For the modes of tension/compression: line color purple, style two indents, a dotted line.

3.3.3 Critical velocities (Points of intersection with the lines $Y=SX$)

the possible critical velocities due to the unbalances or synchronous revolving forces at the speed of the rotor, are obtained by the intersections of the right of slope $S=1$ with the curves of evolution of the frequencies. They are indicated in the output file of unit 25 of the command `IMPR_DIAG_CAMPBELL`.

Table below watch that the points of intersection for the modes in bending obtained are in perfect adequacy with those of ROTORINSA.

ROTORINSA $S=1$		**Code-Aster** $S=1$	
Velocity (tr/mn)	**Frequency** (Hz)	**Velocity** (tr/mn)	**Frequency** (Hz)
12688.88	211.48	12686.01	211.43
16220.54	270.34	16219.49	270.32
22086.98	368.12	22084.57	368.08
27373.72	456.23	27377.79	456.30
53122.26	885.37	53112.41	885.21

Table 4-a: Critical engine failure speeds by Code_Aster and ROTORINSA

Mode in Torsion
Points D intersection with the line $Y=SX$, with $S=1.00$
Velocity = $44944.08\,tr/mn$, Frequency = $749.07\,Hz$

4 Modelization B

4.1 Characteristic of the modelization

It acts of a system of rotating shafts according to the axis X with negative rotational speeds. To get the same results as the modelization A (with the minus sign less nearer), it is necessary to put a minus sign on the cross terms of the stiffness matrixes and damping. The characteristics of the bearings are indicated in the table which follows.

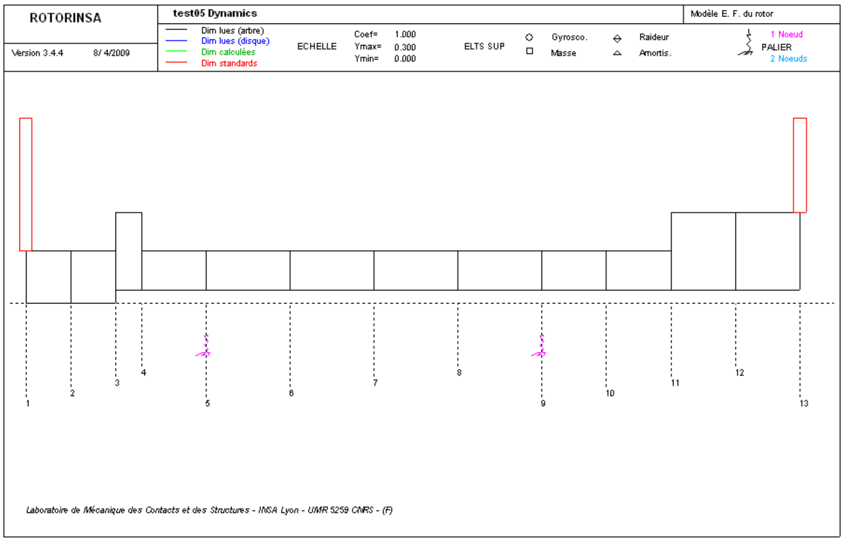
Bearing $P1$
$K_{yy}=8.10^7\,N/m$ $K_{zz}=1.10^8\,N/m$
$K_{yz}=-1.10^7\,N/m$ $K_{zy}=-6.10^7\,N/m$
$C_{yy}=8.10^3\,Ns/m$ $C_{zz}=1.2\,10^4\,Ns/m$
$C_{yz}=-3.10^3\,Ns/m$ $C_{zy}=-3.10^3\,Ns/m$

Bearing $P2$
$K_{yy}=5.10^7\,N/m$ $K_{zz}=7.10^7\,N/m$
$K_{yz}=-2.10^6\,N/m$ $K_{zy}=-4.10^7\,N/m$
$C_{yy}=6.10^3\,Ns/m$ $C_{zz}=8.10^3\,Ns/m$
$C_{yz}=-1.5\,10^3\,Ns/m$ $C_{zy}=-1.5\,10^3\,Ns/m$

Consequently, the precessions of the modes are also reversed, i.e. that the direct modes become retrograde and vice versa.

4.2 Characteristics of the mesh

the rotor is with a grid in 12 finite elements of shaft of the type `POU_D_T` and comprises 4 discrete elements of the type `DIS_TR` for the modelization of the discs and the bearings.
Many nodes: 13
Number and type of elements: 12 SEG2
4 POI1



Appear 1-b: Characteristic of the model finite elements under ROTORINSA

4.3 Quantities tested and Eigenfrequencies

4.3.1 results according to rotational speed

the values of the first 8 frequencies of bending for the velocities $0\,tr/mn$ and $-60000\,tr/mn$, for the two software, are presented in the table below.

N° Fréq in flexionV itess	**of rotation (tr/min)**	**ROTORINSA**		**Code_AsterFacteur**	
		$\lvert F\rvert(Hz)$	**of amortissementTolérances**	**of** $\lvert F\rvert(Hz)$	**Tolerances of amortissementréduita102.16212E+024.76544E-021.E-31.E-3-600001.85365E+02-5.17463E-021.E-31.1E-3202.63539E+027.87281E-021.E-36.E-3-600002.96078E+021.55245E-011.E-35.E-3303.83210E+02**
	-60000				
	-60000				
			5.01438E-021.E-314.E-3-600003.24718E+02		
	-60000		1.57489 E-03	1.E-370.E-3404.39642E+02	
			6.02275E-021.E-3		12.E-3-600004.72541E+02
	-60000		1.59683E-011.2E-33.E-3		

Table 2-a: Eigenfrequencies of type bending for Code_Aster and ROTORINSA

the frequencies obtained are in perfect adequacy with those of ROTORINSA.
One notes an instability of the first mode, which appears with $-16\,760\,tr/mn$.

In Code_Aster, one observes also frequencies and modes of torsion and modes of tension/compression. These modes are not calculated by ROTORINSA, because it models only the behavior in bending. The values of these frequencies are tested in `NON_REGRESSION` and this only with the stop. Indeed, the modes of torsion and tension are, by definition, invariants compared to the rotational speed.

In short in the table below, are presented, the numbers the frequencies calculated and used in the layout of the diagram of Campbell in Code_Aster.

Number of values clean detected: 20
Many frequencies requested for the layout: 10

	calculated	traced
Many total frequencies	20	10
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Many frequencies torsion	3	1
Number of frequencies tension/compression	3	1

Table 2-d: Calculated and traced frequencies (Code_Aster)

4.3.2 Diagram of Campbell

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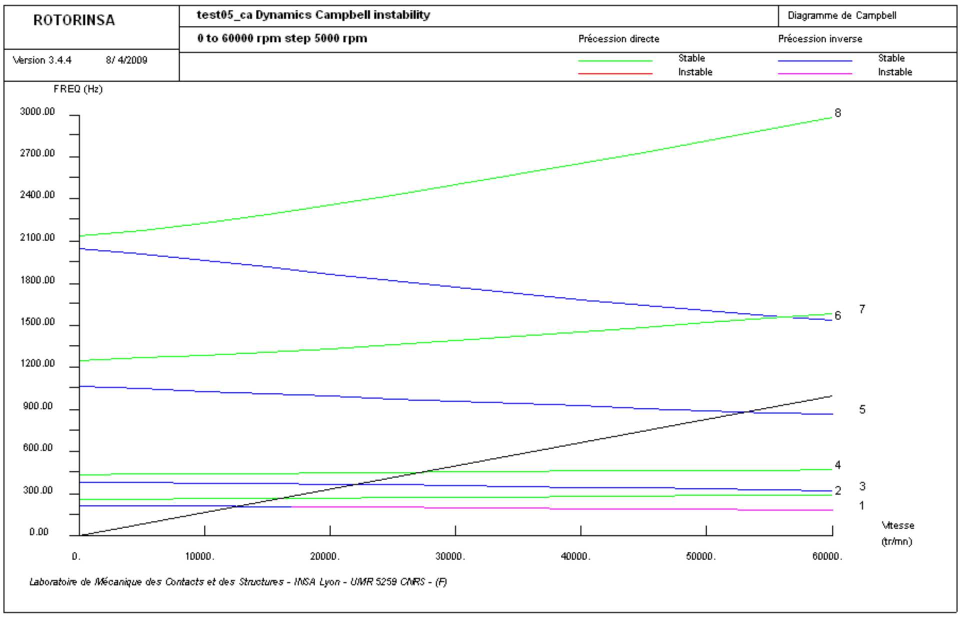

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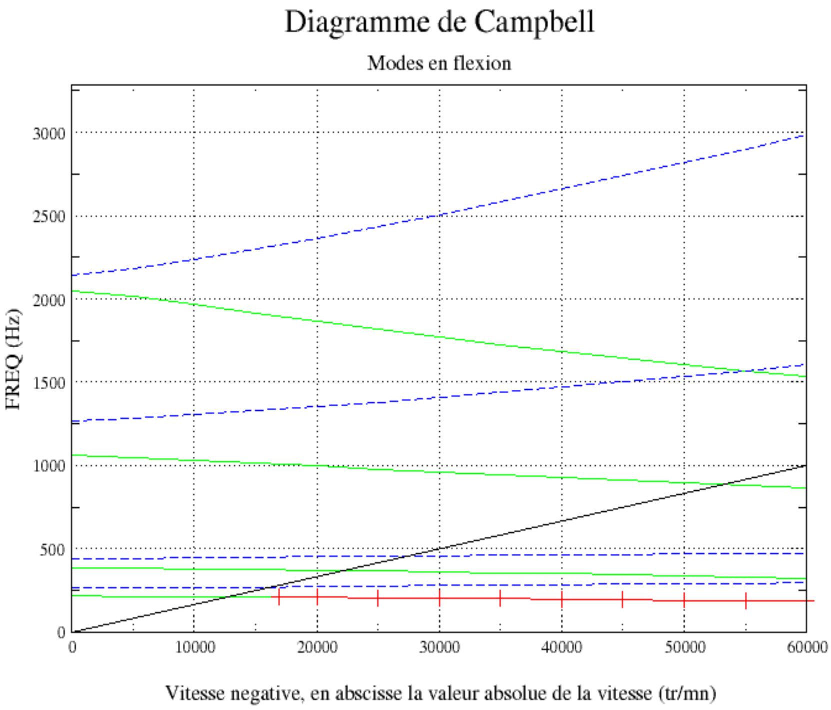
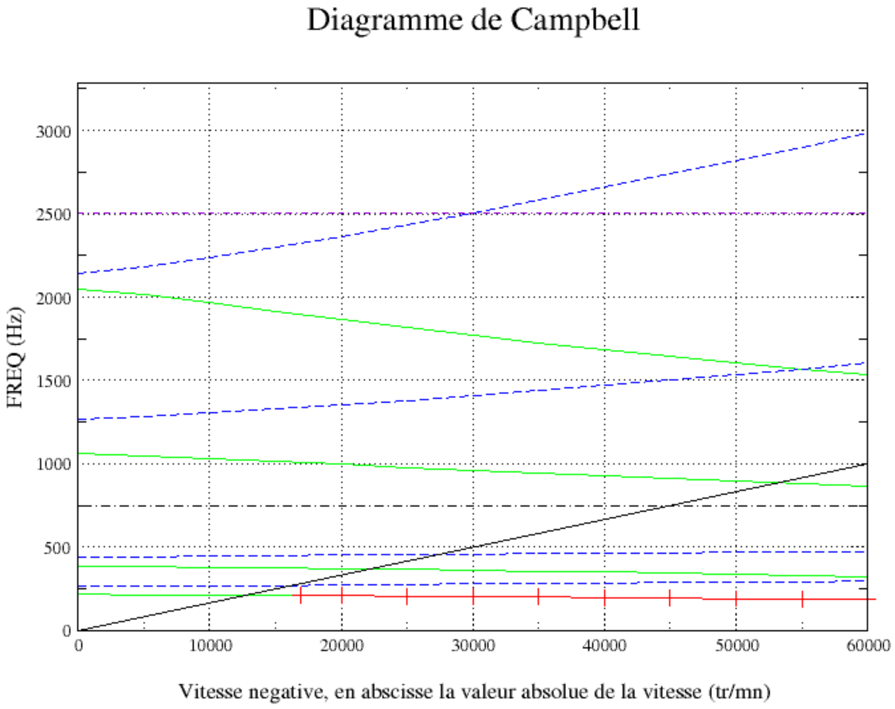


Appears 4-b: Diagram of Campbell in bending given by Code_Aster

There is an instability of the first mode, it appears in red, style long indents, marker +, on the diagram of Campbell de Code_Aster.

One observes in more the follow-up of the modes of torsion and tension/compression. For this application, these modes are invariants compared to the vistess of rotation and thus the curves of evolution are horizontal lines.



Appear 4-c: Diagram of Campbell in bending, torsion and traction and compression

For the modes of torsion: line color black, style an indent, a dotted line.
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4.3.3 Critical velocities (Points of intersection with the lines $Y=SX$)

the possible critical velocities due to the unbalances or synchronous revolving forces at the speed of the rotor, are obtained by the intersections of the right of slope $S=1$ with the curves of evolution of the frequencies.

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Velocity (tr/mn)	**|Frequency|** (Hz)	**Velocity** (tr/mn)	**|Frequency|** (Hz)
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Table 4-a: Critical engine failure speeds by Code_Aster and ROTORINSA

Mode in Torsion
Points of intersection with the line $Y=SX$, with $S=1.00$
$Vitesse=-44944.08\,tr/mn$, $|Fréquence|=749.07\,Hz$

5 Modelization C

5.1 Characteristic of the modelization

It is about a system of rotating shafts according to the axis Y with positive rotational speeds. The change of reference requires a new setting in data of the characteristics of the bearings, which are indicated in the table which follows.

Bearing	$P1$	$K_{xx}=8.10^7\ N/m$	$K_{zz}=1.10^8\ N/m$
		$K_{xz}=-1.10^7\ N/m$	$K_{zx}=-6.10^7\ N/m$
		$C_{xx}=8.\,10^3\ Ns/m$	$C_{zz}=1.2\,10^4\ Ns/m$
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Bearing	$P2$	$K_{xx}=5.10^7\ N/m$	$K_{zz}=7.10^7\ N/m$
		$K_{xz}=-2.\,10^6\ N/m$	$K_{zx}=-4.\,10^7\ N/m$
		$C_{xx}=6.\,10^3\ Ns/m$	$C_{zz}=8.\,10^3\ Ns/m$
		$C_{xz}=-1.5\,10^3\ Ns/m$	$C_{zx}=-1.5\,10^3\ Ns/m$

5.2 Characteristics of the mesh

the rotor is with a grid in 12 finite elements of shaft of the type `POU_D_T` and comprises 4 discrete elements of the type `DIS_TR` for the modelization of the discs and the bearings.

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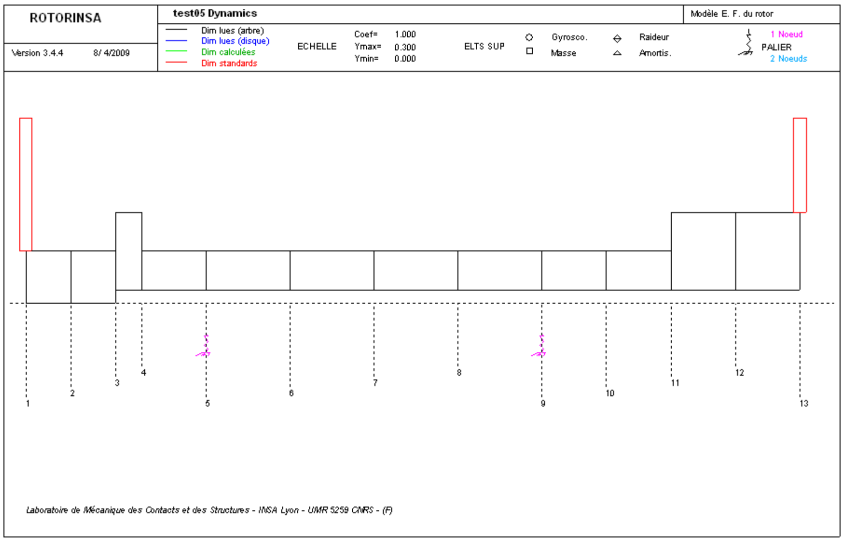

Appear 1-b: Characteristic of the model finite elements under ROTORINSA

5.3 Quantities tested and Eigenfrequencies

5.3.1 results according to rotational speed

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			5.01438E-021.E-314.E-3600003.24718E+02		
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Number of frequencies tension/compression	3	1

Table 2-d: Calculated and traced frequencies (Code_Aster)

6 Summary of the results

This benchmark makes it possible to validate the functionality Diagram of Campbell at the same time for negative and positive rotational speeds since one finds the same results by Code_Aster and ROTORINSA.