# SDLL129 - Pin addition to with 3 discs and 2 of the stages with variable characteristics according to the number of revolutions

**Summary:**

This test makes it possible to validate the calculation of the modes in rotation of a system of rotating shafts with order CALC_MODE_ROTATION if the characteristics in stiffness and damping depend on the number of revolutions.

In this test, there is a model of rotor with three discs, supported by two hydrodynamic bearings, whose matrices of stiffness and damping are nonsymmetrical and depend on the number of revolutions. 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 inflection.

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 stages (nodes $B1$ and $B2$ on the figure below), whose matrices of stiffness and damping are nonsymmetrical. It is composed of 3 discs, and 4 sections of tree.

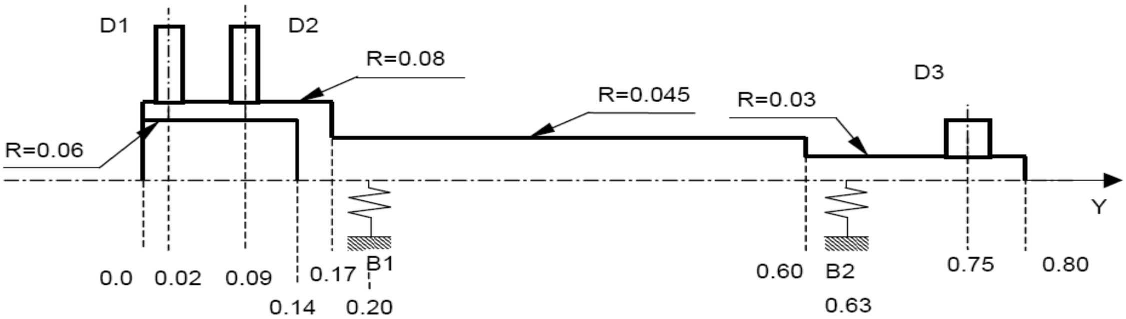


**Figure 1.1-a- has: Model of rotor with 3 asymmetrical discs and 2 stages**

## 1.2 Properties of 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 | $D1$ | $M=20 kg$ | $I_D=200.10^{-3} kg\,m^2$ | $I_P=400.10^{-3} kg\,m^2$ |
| | $D2$ | $M=17 kg$ | $I_D=170.10^{-3} kg\,m^2$ | $I_P=340.10^{-3} kg\,m^2$ |
| | $D3$ | $M=10 kg$ | $I_D=15.10^{-3} kg\,m^2$ | $I_P=30.10^{-3} kg\,m^2$ |

The characteristics of the stages are indicated in the tables which follow.

$\Omega=0\,tr/min$

Stage $P1$

$K_{yy}=90.10^6 N/m$ $K_{xx}=50.10^7 N/m$
$K_{yx}=-8.10^4 N/m$ $K_{xy}=9.10^4 N/m$
$c_{yy}=15.10^4 Ns/m$ $c_{xx}=45.10^4 Ns/m$
$c_{yx}=1.10^2 Ns/m$ $c_{xy}=-1.10^2 Ns/m$

Stage $P2$

$K_{yy}=60.10^6 N/m$ $K_{xx}=15.10^7 N/m$
$K_{yx}=-8.10^4 N/m$ $K_{xy}=8.10^4 N/m$
$c_{yy}=12.10^4 Ns/m$ $c_{xx}=19.10^4 Ns/m$
$c_{yx}=1.10^2 Ns/m$ $c_{xy}=-1.10^2 Ns/m$

$\Omega=5000\,tr/min$

Stage $P1$

| | | |
|---|---|---|
| | $K_{yy}=90.10^6\,N/m$ | $K_{xx}=50.10^7\,N/m$ |
| | $K_{yx}=-9.10^4\,N/m$ | $K_{xy}=9.10^4\,N/m$ |
| | $c_{yy}=15.10^4\,Ns/m$ | $c_{xx}=45.10^4\,Ns/m$ |
| | $c_{yx}=1.10^2\,Ns/m$ | $c_{xy}=-1.10^2\,Ns/m$ |

Stage $P2$

| | | |
|---|---|---|
| | $K_{yy}=60.10^6\,N/m$ | $K_{xx}=15.10^7\,N/m$ |
| | $K_{yx}=-8.10^4\,N/m$ | $K_{xy}=8.10^4\,N/m$ |
| | $c_{yy}=12.10^4\,Ns/m$ | $c_{xx}=19.10^4\,Ns/m$ |
| | $c_{yx}=1.10^2\,Ns/m$ | $c_{xy}=-1.10^2\,Ns/m$ |

$\Omega=6500\,tr/min$

Stage $P1$

| | | |
|---|---|---|
| | $K_{yy}=100.10^6\,N/m$ | $K_{xx}=40.10^7\,N/m$ |
| | $K_{yx}=-15.10^4\,N/m$ | $K_{xy}=15.10^4\,N/m$ |
| | $c_{yy}=13.10^4\,Ns/m$ | $c_{xx}=33.10^4\,Ns/m$ |
| | $c_{yx}=1.10^2\,Ns/m$ | $c_{xy}=-1.10^2\,Ns/m$ |

Stage $P2$

| | | |
|---|---|---|
| | $K_{yy}=70.10^6\,N/m$ | $K_{xx}=14.10^7\,N/m$ |
| | $K_{yx}=-13.10^4\,N/m$ | $K_{xy}=13.10^4\,N/m$ |
| | $c_{yy}=10.10^4\,Ns/m$ | $c_{xx}=15.10^4\,Ns/m$ |
| | $c_{yx}=1.10^2\,Ns/m$ | $c_{xy}=-1.10^2\,Ns/m$ |

$\Omega=8000\,tr/min$

Stage $P1$

| | | |
|---|---|---|
| | $K_{yy}=110.10^6\,N/m$ | $K_{xx}=35.10^7\,N/m$ |
| | $K_{yx}=-20.10^4\,N/m$ | $K_{xy}=20.10^4\,N/m$ |
| | $c_{yy}=11.10^4\,Ns/m$ | $c_{xx}=26.10^4\,Ns/m$ |
| | $c_{yx}=2.10^2\,Ns/m$ | $c_{xy}=-2.10^2\,Ns/m$ |

Stage $P2$

| | | |
|---|---|---|
| | $K_{yy}=80.10^6\,N/m$ | $K_{xx}=14.10^7\,N/m$ |
| | $K_{yx}=-20.10^4\,N/m$ | $K_{xy}=20.10^4\,N/m$ |
| | $c_{yy}=9.10^4\,Ns/m$ | $c_{xx}=13.10^4\,Ns/m$ |
| | $c_{yx}=2.10^2\,Ns/m$ | $c_{xy}=-2.10^2\,Ns/m$ |

$\Omega=10000\,tr/min$

Stage $P1$

| | | |
|---|---|---|
| | $K_{yy}=115.10^6\,N/m$ | $K_{xx}=33.10^7\,N/m$ |
| | $K_{yx}=-35.10^4\,N/m$ | $K_{xy}=35.10^4\,N/m$ |
| | $c_{yy}=10.10^4\,Ns/m$ | $c_{xx}=20.10^4\,Ns/m$ |
| | $c_{yx}=2.10^2\,Ns/m$ | $c_{xy}=-3.10^2\,Ns/m$ |

Stage $P2$

| | | |
|---|---|---|
| | $K_{yy}=90.10^6\,N/m$ | $K_{xx}=14.10^7\,N/m$ |
| | $K_{yx}=-30.10^4\,N/m$ | $K_{xy}=30.10^4\,N/m$ |
| | $c_{yy}=8.10^4\,Ns/m$ | $c_{xx}=10.10^4\,Ns/m$ |
| | $c_{yx}=2.10^2\,Ns/m$ | $c_{xy}=-2.10^2\,Ns/m$ |

$\Omega=14000\,tr/min$

Stage $P1$

| | | |
|---|---|---|
| | $K_{yy}=120.10^6\,N/m$ | $K_{xx}=30.10^7\,N/m$ |
| | $K_{yx}=-70.10^4\,N/m$ | $K_{xy}=70.10^4\,N/m$ |

$c_{yy}=7.10^4\ Ns/m$ $c_{xx}=15.10^4\ Ns/m$
$c_{yx}=3.10^2\ Ns/m$ $c_{xy}=-4.10^2\ Ns/m$

Stage $P2$ $K_{yy}=100.10^6\ N/m$ $K_{xx}=14.10^7\ N/m$
$K_{yx}=-60.10^4\ N/m$ $K_{xy}=60.10^4\ N/m$
$c_{yy}=6.10^4\ Ns/m$ $c_{xx}=8.10^4\ Ns/m$
$c_{yx}=3.10^2\ Ns/m$ $c_{xy}=-3.10^2\ Ns/m$

## 1.3 Boundary conditions

To block the movements of type rigid body in the direction $z$, the degrees of freedom are blocked $DZ$ and $DRZ$ with the node stage $B1$.

# 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 inflection. The following parameters were used for the results of reference:

- Calculation relates to a number of modes in rotation $NVES=8+4$ , in ROTORINSA.
- The beach number of revolutions is defined of $0$ with $20000\,tr/mn$ with a step $500\,tr/mn$ .

## 2.2 Sizes and results of reference

The results of ROTORINSA give the frequencies of the modes in inflection.

The calculation of the modes in rotation is carried out with Code_Aster by using same modeling as ROTORINSA. The results of Code_Aster give at the same time the frequencies of the modes of inflection, torsion and traction/compression. The number of calculated modes is 12.

## 2.3 References

[1] ROTORINSA, software finite elements intended to envisage the dynamic behavior of rotors in inflection, LaMCoS UMR5259, INSA-Lyon.

# 3 Modeling A

## 3.1 Characteristics of modeling

It is about a system of rotating shafts with positive number of revolutions.

## 3.2 Characteristics of the grid

The rotor is with a grid in 21 finite elements of tree of the type POU_D_T and comprises 5 discrete elements of type DIS_TR for the modeling of the discs and stages.

Many nodes: 22
Number and type of elements: 21 SEG2
5 POI1

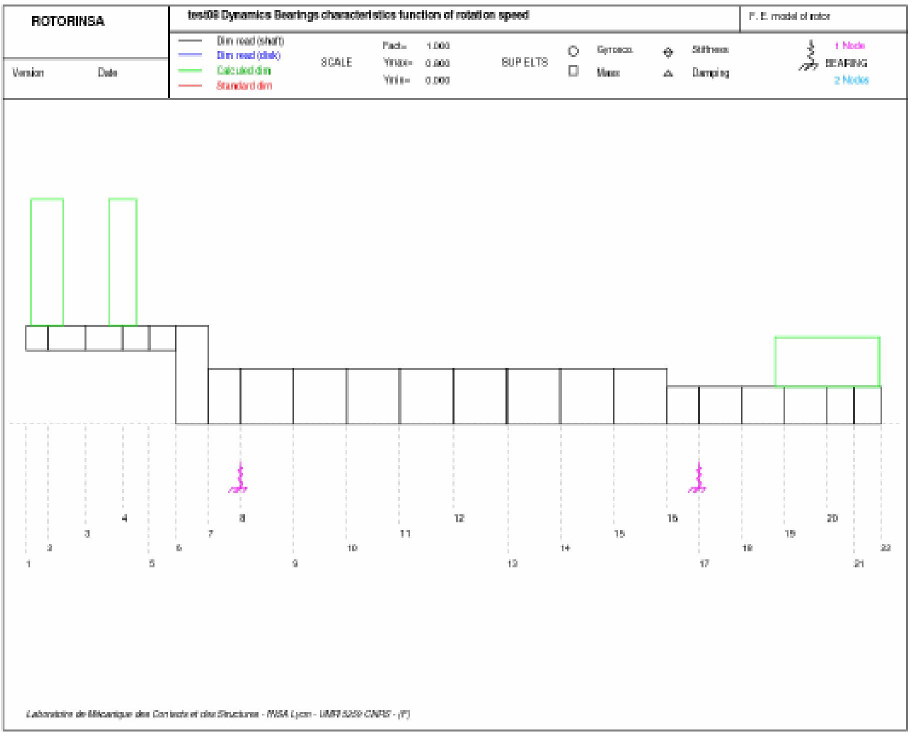


**Figure 1-b: Characteristic of the model finite elements under ROTORINSA**

## 3.3 Sizes tested and results

**Eigen frequencies according to the number of revolutions (direct calculation):**

Values of the first 8 frequencies of inflection for speeds $0\,tr/mn$ and $20000\,tr/mn$, for the two software, are presented in the table below.

| N° Fréq in inflection | Number of revolutions ( $tr/min$ ) | ROTORINSA | | Code_Aster | |
|---|---|---|---|---|---|
| | | $F(Hz)$ | Damping ratio | $F(Hz)$ | Damping reduced |
| 1 | 0 | 130,695 | 6.37866E-01 | 131,547 | 6.37613E-01 |
| | 20000 | 123,683 | 1.24817E-01 | 123,706 | 1.24678E-01 |
| 2 | 0 | 227,925 | 9.58757E-02 | 227,716 | 9.49991E-02 |
| | 20000 | 200,581 | 2.17961E-01 | 200,728 | 2.17632E-01 |
| 3 | 0 | 313,311 | 2.27364E-01 | 313,935 | 2.27701E-01 |
| | 20000 | 286,743 | 1.81652E-01 | 286,912 | 1.81388E-01 |
| 4 | 0 | 381,529 | 6.52812E-01 | 375,305 | 6.61825E-01 |
| | 20000 | 308,624 | 4.32727E-01 | 309,825 | 4.31714E-01 |
| 5 | 0 | 390,802 | 1.77361E-01 | 390,241 | 1.74485E-01 |
| | 20000 | 370,338 | 2.54912E-01 | 369,917 | 2.54178E-01 |
| 6 | 0 | 1448.01 | 1.42312E-01 | 1439.66 | 1.54371E-01 |
| | 20000 | 409,861 | 5.58764E-01 | 412,422 | 5.63110E-01 |
| 7 | 0 | 1554.84 | 1.07354E-01 | 1554.35 | 1.11688E-01 |
| | 20000 | 813,124 | 4.73230E-01 | 824,952 | 4.70031E-01 |
| 8 | 0 | 2050.12 | 3.08294E-01 | 1928.78 | 3.04586E-01 |
| | 20000 | 997,312 | 4.93828E-01 | 1006.17 | 5.08301E-01 |

**Table 2-a: Eigen frequencies of standard inflection for ROTORINSA and Code_Aster (direct calculation)**

The criteria of tolerance into relative are of 10% on the results with the stop and of 5% on the results with 20000 tr/min. Except for the tolerance, the frequencies obtained are in adequacy with those of ROTORINSA.

**Eigen frequencies according to the number of revolutions (calculation in 2 stages):**

Values of the first 8 frequencies of inflection for speeds $0\,tr/mn$ and $20000\,tr/mn$, for the two software, are presented in the table below.

| N° Fréq in inflection | Number of revolutions ( $tr/min$ ) | ROTORINSA | | Code_Aster | |
|---|---|---|---|---|---|
| | | $F(Hz)$ | Damping ratio | $F(Hz)$ | Damping reduced |
| 1 | 0 | 130,695 | 6.37866E-01 | 130,909 | 6.37982E-01 |
| | 20000 | 123,683 | 1.24817E-01 | 123,701 | 1.24816E-01 |
| 2 | 0 | 227,925 | 9.58757E-02 | 227,890 | 9.56146E-02 |
| | 20000 | 200,581 | 2.17961E-01 | 200,634 | 2.17876E-01 |
| 3 | 0 | 313,311 | 2.27364E-01 | 313,433 | 2.27817E-01 |
| | 20000 | 286,743 | 1.81652E-01 | 286,805 | 1.81739E-01 |
| 4 | 0 | 381,529 | 6.52812E-01 | 380,699 | 6.55069E-01 |
| | 20000 | 308,624 | 4.32727E-01 | 308,825 | 4.32616E-01 |
| 5 | 0 | 390,802 | 1.77361E-01 | 390,883 | 1.76940E-01 |
| | 20000 | 370,338 | 2.54912E-01 | 370,399 | 2.54825E-01 |
| 6 | 0 | 1448.01 | 1.42312E-01 | 1448.54 | 1.45247E-01 |
| | 20000 | 409,861 | 5.58764E-01 | 410,199 | 5.60285E-01 |
| 7 | 0 | 1554.84 | 1.07354E-01 | 1556.64 | 1.07779E-01 |
| | 20000 | 813,124 | 4.73230E-01 | 814,475 | 4.72976E-01 |
| 8 | 0 | 2050.12 | 3.08294E-01 | 2009.06 | 3.09277E-01 |
| | 20000 | 997,312 | 4.93828E-01 | 998,343 | 4.95564E-01 |

**Table 2-b: Eigen frequencies of standard inflection for ROTORINSA and Code_Aster (calculation in 2 stages)**

The criteria of tolerance into relative are of 5% on the results with the stop and of 1% on the results with 20000 tr/min. Except for the tolerance, the frequencies obtained are in better adequacy with those of ROTORINSA (by comparison with the method of cacul modal direct). Indeed, it is this method of calculating modal in 2 stages which is used in ROTORINSA.

In *Code_Aster*, one observes also frequencies and modes of torsion and modes of traction/compression. These modes are not calculated by ROTORINSA, because it models only the behavior in inflection.

Values of the first frequency in torsion for speeds $0\,tr/mn$ and $20000\,tr/mn$, for Code_Aster, are presented in the table below

| N° Fréq in Torsion | Number of revolutions (tr/min) | $F(Hz)$ |
|---|---|---|
| 1 | 0 | 5.81803E+02 |
| | 20000 | 5.81803E+02 |

**Table 2-c: Frequencies of torsion given by Code_Aster**

The value of the first frequency in traction for speeds $0\,tr/mn$ and $20000\,tr/mn$ , for Code_Aster, are presented in the table below

| **N° Fréq in Torsion** | **Number of revolutions (tr/min)** | $F(Hz)$ |
|---|---|---|
| 1 | 0 | 1.67224E+03 |
| | 20000 | 1.67224E+03 |

**Table 2-c: Frequencies of traction given by Code_Aster**

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.

Many detected eigenvalues: 12
Many frequencies requested for the layout: 8

| | calculated | layouts |
|---|---|---|
| Many total frequencies | 12 | 8 |
| Many frequencies in inflection | 8 | 7 |
| Many frequencies torsion | 1 | 1 |
| Number of frequencies traction/compression | 1 | 0 |

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

# 4 Summary of the results

This CAS-test makes it possible to validate the functionality Digraph of Campbell for lines of trees whose characteristics in stiffness and damping depend on the number of revolutions since one finds the same results by Code_Aster and ROTORINSA.