

## Postprocessing of calculations of lines of trees: diagram of Campbell

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### Summary :

This document presents the orders `CALC_MODE_ROTATION` and `IMPR_DIAG_CAMPBELL` allowing the follow-up of the modes of the revolving machines according to the number of revolutions as well as the zones of instability of these modes. The definition of this tool is first of all pointed out, then his flow chart is detailed. Finally the principal stages of the algorithm are exposed corresponding such as it are conceived and established in *Code\_Aster*.

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## 1 Goal

The object of this document is to describe the macro-orders necessary to plot the diagram of Campbell in *Code\_Aster*. The approach is based on that already developed in software ROTORINSA [bib1]. The diagram of Campbell is a chart of the natural frequencies of a system in rotation according to its number of revolutions. The natural frequencies and the modes of a system turning are obtained by the resolution of the dynamic equilibrium equation of a system of rotating shafts, without second member and including the effects due to damping.

$$\mathbf{M} \ddot{\delta} + \mathbf{C}(\Omega) \dot{\delta} + \mathbf{K} \delta = 0 \quad \text{éq 1 - 1-1}$$

Where  $\mathbf{M}$  is the matrix of mass of the system,  $\mathbf{C}(\Omega)$  is a nonsymmetrical matrix, function number of revolutions, including the gyroscopic effect (antisymmetric) and the characteristics of damping of the stages, and  $\mathbf{K}$  is the matrix of stiffness of the system.

The data necessary for the layout of the Diagram of Campbell are thus the natural frequencies, as well as the corresponding modes, according to the number of revolutions in the form of table. The stage allowing the calculation as of these modes is already developed in *Code\_Aster* (cf. [R5.01.01]).

Two macro-orders are developed. The first macro-order `CALC_MODE_ROTATION` calculate the frequencies and the modes on the complete system according to the number of revolutions. The second macro-order `IMPR_DIAG_CAMPBELL` class the modes in inflection, torsion and traction/compression, normalizes these modes, determines the direction of precession of the modes in inflection, carries out the sorting of the frequencies according to various methods of follow-up of modes, then trace the diagram of Campbell.

## 2 Flow chart

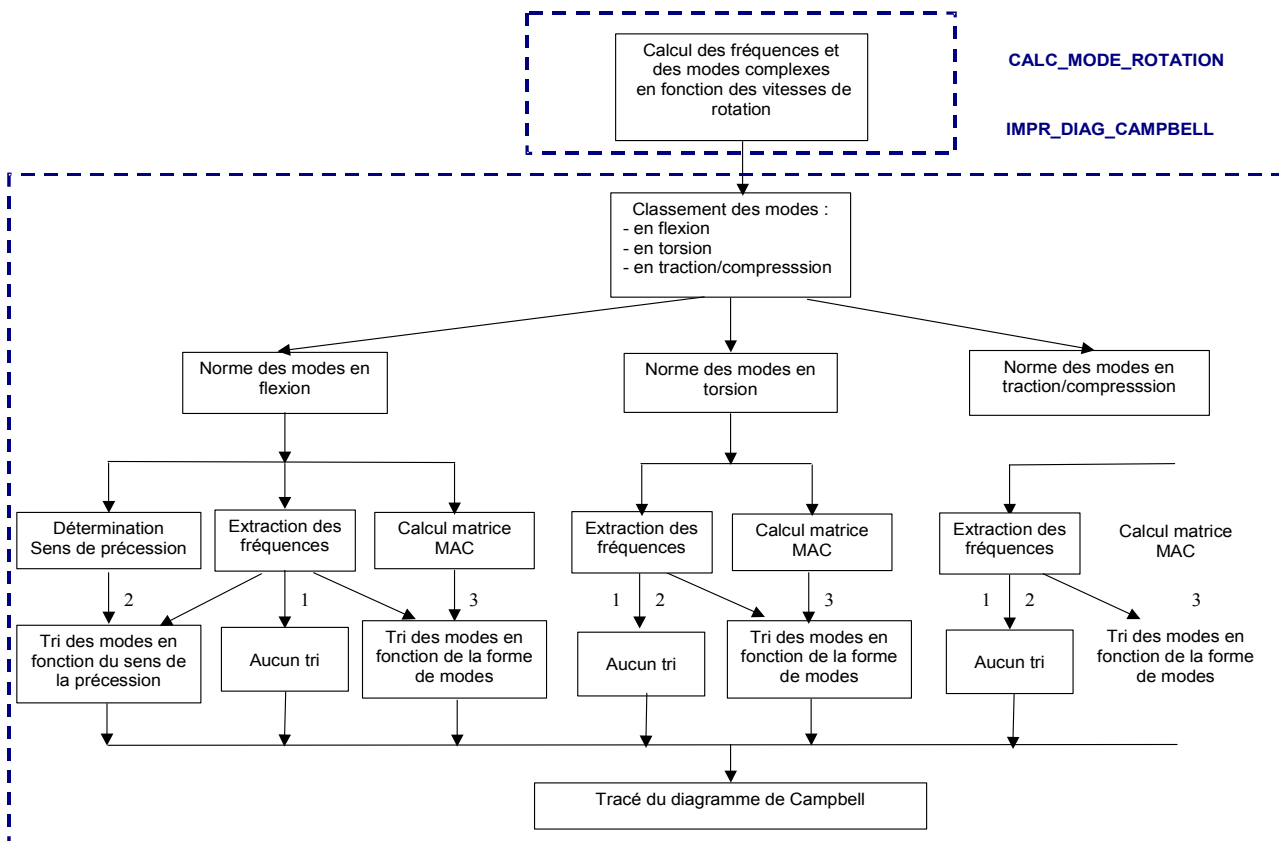


Figure 2-a- has: Flow chart of the diagram of Campbell

The three methods of follow-up of the modes are:

- pas de sorting,
- sorting of the frequencies gradually,
- sorting by the form of the modes

## 3 Algorithm

After the calculation of the frequencies and complex modes of the system, the list 'MODES' of `mode_meca_c` of the data input the macro one is one. The algorithm is presented below:

- Classification of the modes 'MODES' in inflection, torsion and traction/compression:
  - Extraction of the modes in inflection
  - Normalizes the modes in inflection
  - Extraction of the modes in torsion
  - Normalizes the modes in torsion
  - Extraction of the modes in traction/compression
  - Normalizes the modes in traction/compression
- Extraction of the frequencies
  - Frequencies in inflection
  - Frequencies in torsion
  - Frequencies in traction/compression
- Initialization of the plugboards of the frequencies, the filling of these tables corresponds to the method of follow-up of the modes 'Not of `SORTING`', following L' order of the mode such as it is in the concepts `mode_meca_c`.
- Calculation of direction of the direct or opposite precession<sup>1</sup> for the modes in inflection at each number of revolutions, fact in two ways different according to the choice of the type from calculation from the precession:
  - `PREC_GOR` : The identification of the precession is according to the sign of the greatest orbit in a mode (Precession direct, Precession reverses)
  - `PREC_MOY` : The identification of the precession will be done according to the sign of the sum of the signs of all the orbits
  - Filling of the table of the direction of precession `SENS`
- Follow-up of the modes:
  - If the type of follow-up of the modes is `TRI_PREC_MOD`, i.e. sorting of the frequencies gradually according to the direction of the precession. It requires the calculation of the axes of the orbits and the evaluation of the direction of course of the orbits. The identification of the precession will be done according to the sign of the greatest orbit or the sign of the sum of the signs of all the orbits. The frequencies are then classified in two groups (direct precession and opposite precession). In each group the frequencies are classified by order ascending for each number of revolutions. Each curve of the diagram of Campbell connects the points according to the number of revolutions respecting the order of ranking in each group ( $i^{\text{eme}}$  frequency of the group  $p$  (speed  $\Omega_p$ ) with  $i^{\text{eme}}$  frequency of the group  $p+1$  (speed  $\Omega_{p+1}$ ) etc).
    - Plugboard in updated inflection
  - If the type of follow-up of the modes is `TRI_FORM_MOD`, i.e. sorting by the form of the modes. The sorting of the frequencies according to the form of the modes requires the calculation of the matrix of MAC correlation of the modes. The comparison of the modes is done then as follows: each mode (on the basis of the number of the largest revolutions) is compared to other modes number of preceding revolutions by going the maximum of correlation. This comparison makes it possible to

<sup>1</sup>The direct precession (respectively opposite) corresponds if the orbit of the rotor is described in even direction that (respectively the direction opposed to) the rotation of the tree.

plot for each mode the curve of evolution of its frequency according to the number of revolutions to constitute the diagram of Campbell.

- Plugboard in updated inflection
  - Plugboard in updated torsion
  - Plugboard in traction/updated compression.
- 
- Layout of the diagram of Campbell
    - Layout of the diagram of Campbell of the modes in inflection
    - Layout of the diagram of Campbell of the modes in torsion
    - Layout of the diagram of Campbell of the modes in traction/compression.
- 
- Layout of the right-hand sides of slopes  $S$  and determination of the points of intersection (critical velocities).

## 3.1 Classification of the modes

The rotation of the rotor is done according to the axis  $Z$  (it is the condition of use correct of `IMPR_DIAG_CAMPBELL`).

After the calculation of the modes in rotation at various speeds, one gets the results:

- modes in inflection characterized by displacements in translation  $DX$ ,  $DY$  and in rotation  $DRX$  and  $DRY$
- modes in torsion characterized by displacements in rotation  $DRZ$
- modes in traction/compression characterized by displacements in translation  $DZ$ .

Initially, the modes are classified according to these three categories.

For each mode, following calculations are carried out:

- 1) Total standard  $N_{tot}$

$$N_{tot} = \sqrt{\sum |DX|^2 + |DY|^2 + |DZ|^2 + |DRX|^2 + |DRY|^2 + |DRZ|^2}$$

- 2) Report in inflection  $N_{flexion}$

$$N_{flexion} = \frac{\sqrt{\sum |DX|^2 + |DY|^2 + |DRX|^2 + |DRY|^2}}{N_{tot}}$$

- 3) Report in torsion  $N_{torsion}$

$$N_{torsion} = \frac{\sqrt{\sum |DRZ|^2}}{N_{tot}}$$

- 4) Report in traction/compression  $N_{longi}$

$$N_{longi} = \frac{\sqrt{\sum |DZ|^2}}{N_{tot}}$$

The classification of the modes is done as follows:

- [1] For the modes in inflection:  $N_{flexion} > N_{torsion}$  et  $N_{flexion} > N_{longi}$
- [2] For the modes in torsion:  $N_{torsion} > N_{flexion}$  et  $N_{torsion} > N_{longi}$
- [3] For the modes in traction/compression:  $N_{longi} > N_{flexion}$  et  $N_{longi} > N_{torsion}$

If the system comprises a solid mass (body of self-supporting quality), it is possible that there exist mixed modes (three at the same time). In this case, one applies the same method as above.

From the modal starting base `MODES`, three modal bases are thus extracted:

- 1) `MODEf` : containing the modes in inflection

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- 2) *MODEt* : containing the modes in torsion
- 3) *MODEl* : containing the modes in traction/compression

For the modal bases *MODEf* and *MODEl* , the standardisation is done compared to largest of the components of translation ( $DX, DY, DZ$ ).

For the modal base *MODEf* , the standardisation is done compared to largest of the components of rotation ( $DRX, DRY, DRZ$ ).

The extraction and the standardisation of the modes of the structure are done via the operators `EXTR_MODE` and `NORM_MODE`, respectively.

## 3.2 Calculation of the direction of precession for the modes in inflection

### 3.2.1 Concepts

The modes in rotation are defined by the ellipses in each node.

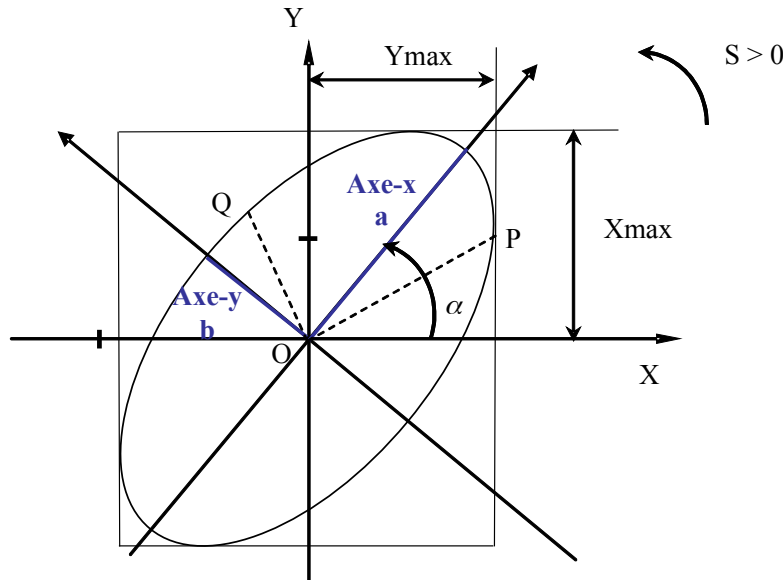


Figure 3.2-a: Ellipses defining the modes

For a given mode and each node, there are displacements in translation  $DX, DY$  with:

$$DX = (X_R, X_I), |DX|^2 = |X_R|^2 + |X_I|^2$$

$$DY = (Y_R, Y_I), |DY|^2 = |Y_R|^2 + |Y_I|^2$$

4 cases are possible:

- 1) If  $|DX|^2 + |DY|^2 \approx 0$  there is no ellipse, then  $a=0, b=0, \alpha=0, S=0$
- 2) If  $|DX|^2 \approx 0$  there is no ellipse, the trajectory is along the axis  $Y$  , then  $a=0, b=|DY|, \alpha=0, S=0$
- 3) If  $|DY|^2 \approx 0$  there is no ellipse, the trajectory is along the axis  $X$  then  $a=|DX|, b=0, \alpha=90^\circ, S=0$
- 4) If  $|DX|^2 \neq 0$  and  $|DY|^2 \neq 0$  then one can calculate the precession  $S$  for each node.

Displacements  $u$  according to  $X$  and  $v$  according to  $Y$  this node will be following form:

*Warning : The translation process used on this website is a "Machine Translation". It may be imprecise and inaccurate in whole or in part and is provided as a convenience.*

$$u = X_R \cos(\omega t) - X_I \sin(\omega t) , v = Y_R \cos(\omega t) - Y_I \sin(\omega t)$$

### 3.2.2 Determination of the direction of course

During one period of vibration, the ellipse perhaps traversed in the positive or negative direction (direct or opposite precession).

1) with  $\omega t = 0$  the axis of the rotor is at the point  $P$

2) with  $\omega t = \frac{\pi}{2}$  the axis of the rotor is at the point  $Q$

The preceding relations make it possible to calculate the components of the vectors  $\vec{OP} = \begin{pmatrix} X_R \\ Y_R \\ 0 \end{pmatrix}$  and

$\vec{OQ} = \begin{pmatrix} -X_I \\ -Y_I \\ 0 \end{pmatrix}$ . The sign of the vector product  $\vec{OP} \wedge \vec{OQ} = \begin{pmatrix} 0 \\ 0 \\ Y_R X_I - Y_I X_R \end{pmatrix}$  indicate the direction of the

course or precession (positive or negative).

For each node, we have the results in maximum amplitude, IE.:

$$u : XMAX = \sum X_R^2 + X_I^2 \text{ and } v : YMAX = \sum Y_R^2 + Y_I^2$$

For a mode, there are two manners of determining the direction of precession:

- **PREC\_GOR** : The identification of the precession is done according to the sign of the greatest orbit in a mode (direct Precession, opposite Precession).
- **PREC\_MOY** : The identification of the precession will be done according to the sign of the sum of the signs of all the orbits.

At exit the table **SENS** is filled for the directions of precession of all the modes at all the number of revolutions. This table makes it possible to follow the modes of inflection with the method **TRI\_PREC\_MOD**. It also makes it possible to determine the direction of precession on the diagram of Campbell according to the code of color defined in the instruction manual of the order **IMPR\_DIAG\_CAMPBELL**.

### 3.3 Calculation of the MAC matrices enter bases of two-speed modes of rotation

For the sorting of the modes by comparison of form, one calculates the coefficients of correlation (MAC matrix) between the modes two successive number of revolutions of indices. The operator is used **MAC\_MODES** for

- to calculate the MAC matrix between two successive modal bases of inflection.
- to calculate the MAC matrix between two successive modal bases of torsion.
- to calculate the MAC matrix between two successive modal bases of traction/compression.

### 3.4 Sorting according to the direction of the precession

It is about a method of follow-up of the modes by sorting of the frequencies gradually with checking of the direction of precession. The modes are classified in two groups according to the direction of precession (direct mode of precession, opposite mode of precession). The follow-up is then carried out in each group according to the order of the modes. One starts the follow-up by the last number of revolutions of number **NBV** and last mode **NFREQf** of this speed (cf. [Figure 3.4-a]).

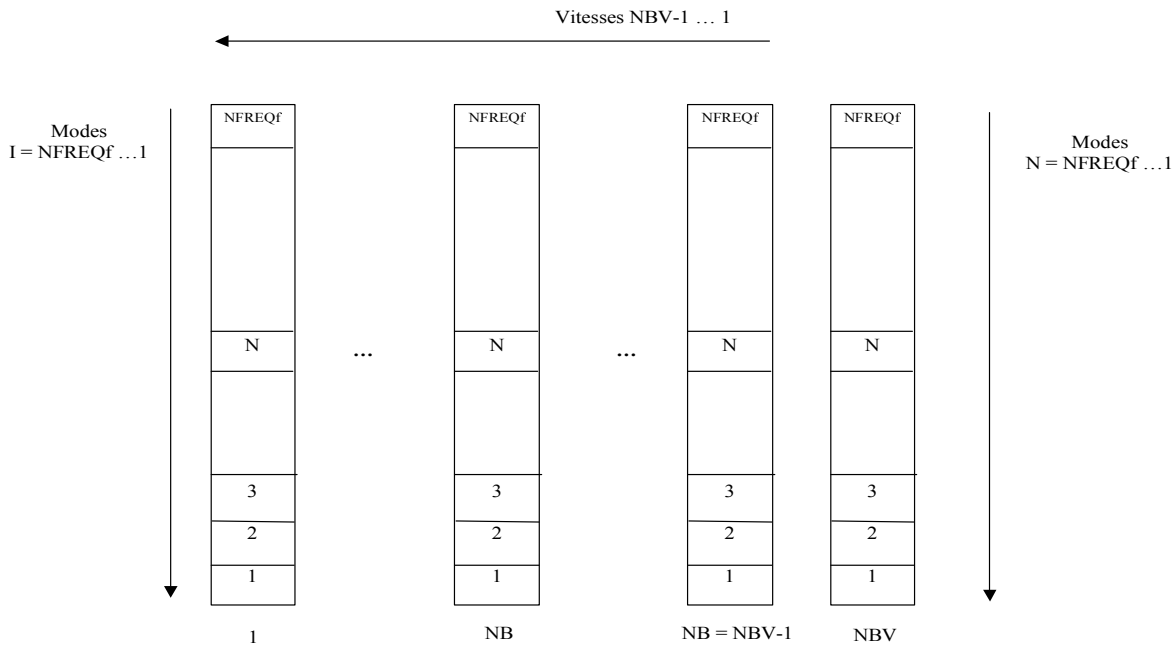


Figure 3.4-a-4-a: Sorting according to the direction of precession

## 3.5 Sorting according to the form of the mode (MAC)

This method of follow-up of the modes by comparison of form, requires the calculation of the matrix of MAC correlation of the modes two successive number of revolutions, to see paragraph 3.3.

One starts the follow-up by the last number of revolutions of number  $NBV$ . For each mode a number of revolutions given  $IVI$ , one seeks a mode number of preceding revolutions  $IVI - 1$  who makes the maximum of coefficient of correlation. One fills out the plugboard with the value of the number of the mode selected (cf. [Figure 3.5-a]).

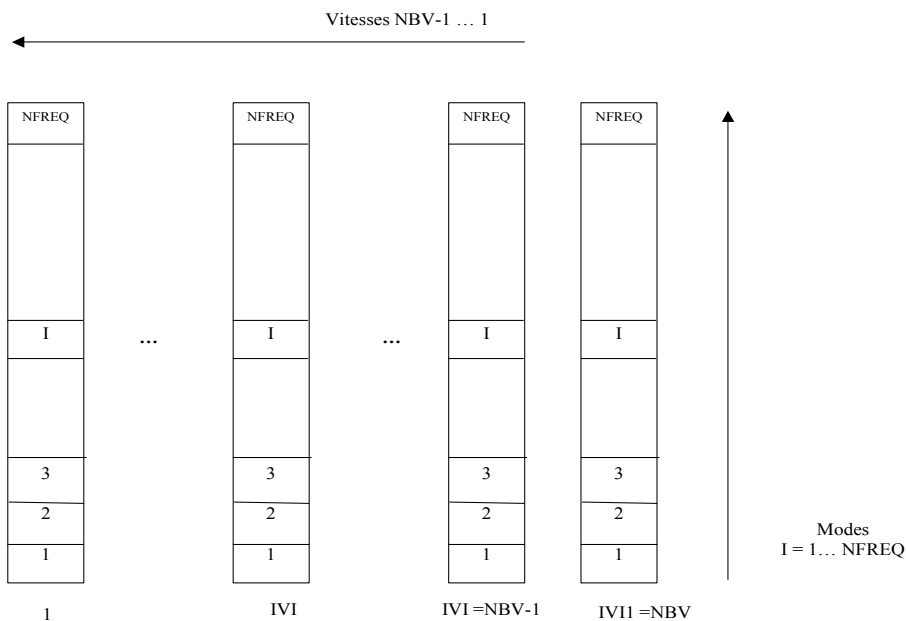


Figure 3.5-a: Sorting according to the form of the mode

This follow-up is made separately for the three categories of modes in inflection, torsion and traction/compression.



# Code\_Aster

Version  
default

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Titre : Post-traitement de calculs de lignes d'arbres : di[...]  
Responsable : HASSINI Mohamed-Amine

Date : 08/11/2013 Page : 9/10  
Clé : R7.10.03 Révision :  
5143af11b6a6

## 4 References

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1. ROTORINSA, Software of finite elements intended to envisage the dynamic behavior of rotors in inflection, LaMCoS UMR5259, INSA-Lyon.
2. MR. LALANNE, G. FERRARIS, " Rotordynamics Prediction in Engineering ", Second Edition, Wiley, 2001.

## 5 Features and checking

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Macro-orders `CALC_MODE_ROTATION` and `IMPR_DIAG_CAMPBELL` are checked by the following tests:

SDLL124	Diagram of Campbell of a beam with 3 discs subjected to the gyroscopy	[V2.02.124]
SDLL125	Diagram of Campbell of a beam with 2 nonsymmetrical discs and 2 stages	[V2.02.125]
SDLL129	Diagram of Campbell of a beam with 3 discs and 2 of the stages with variable characteristics according to the number of revolutions	[V2.02.129]

## 6 Description of the versions of the document

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Version Aster	Author (S) Organization (S)	Description of the modifications
10,1	M.Torkhani- EDF-R&D/AMA	Initial text