Modeling of the turbulent excitations

Summary:

One describes the modeling of the turbulent excitations available in *Code_Aster* and the way in which these last are taken into account in a calculation of dynamics. The turbulent excitations are characterized by a spectral concentration of efforts, specified using the operator `DEFI_SPEC_TURB` [U4.44.31]. Their taking into account in a calculation of dynamics is done by projection of the spectrum on the basis of modal structure which one wants to calculate the answer. The operations of projection are carried out using the operator `PROJ_SPEC_BASE` [U4. 63.14].

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1 Principle of calculation

1.1 Determination of a modal base of the system under flow and projection of the excitation

The calculation of the dynamic response of a system to a turbulent excitation induced by a fluid flow is carried out by respecting the following stages:

1) initially, one calculates the modal base of the system except flow using the operator CALC_MODES [U4.52.02],
2) one defines then the characteristics of the studied configuration, for taking into account of the phenomenon of coupling fluid-structure, using the operator DEFI_FLUI_STRU [U4.25.01]. This operator allows for example to inform the profiles speed associated with the zones of fluid excitation, for configurations of standard "the tube bundle under transverse flow". He produces a concept of the type [type_flui_stru] intended to be used by the operators implemented downstream in the command file,
3) the modal characteristics of the system under flow are then calculated using the operator CALC_FLUI_STRU [U4.66.02]. One has at exit a modal base for each rate of flow,
4) the definition of the turbulent excitation is done then by a call to the operator DEFI_SPEC_TURB [U4.44.31]. Modelings available are the following ones:
   - spectra of type "length of correlation", specific of the configurations of standard "the tube bundle under transverse flow", for the application to the vibrations of tubes of Steam Generator. The keywords corresponding factors are SPEC_LONG_COR_1, SPEC_LONG_COR_2, SPEC_LONG_COR_3 and SPEC_LONG_COR_4. These spectra are preset; however, the user can adjust the parameters of them. This part is developed with the paragraph [§2.2],
   - model of turbulent excitation distributed. The keyword factor corresponding is SPEC_FONC_FORME. The spectrum of excitation is defined by its decomposition on a family of functions of form while providing, on the one hand a matrix interspectrale, and on the other hand a list of functions of form associated with this matrix. Concepts [interspectre] and [function] associated must be generated upstream. In the case of the component "control rod", the user can also use a preset spectrum of turbulence, identified on model GRAPPE1. This part is developed with the paragraph [§2.3],
   - model of localised turbulent excitation. The keyword factor corresponding is SPEC_EXCI_POINT. It is used in the case of a spectrum of excitation associated with one or more specific forces and moments. The definition of the excitation is done then while providing:
     - a matrix interspectrale of excitations (the concept [interspectre] associated must be generated upstream),
     - the list of the nodes of application of these excitations,
     - the nature of the excitation applied of each one of these nodes (force or moment),
     - directions of application of the excitations thus defined.

   This part is developed with the paragraph [§2.4].

5) The projection of the spectrum of turbulent excitation previously definite, on the basis of modal structure under flow, is then carried out using the operator PROJ_SPEC_BASE [U4.63.14].

1.2 Calculation of the answer to the turbulent excitation: frequential resolution

1.2.1 Introduction

The calculation of the frequential response of the structure or the system coupled fluid-structure is done in three stages:

1) calculation of the interspectres of modal excitations,
2) calculation of the interspectres of modal answer,
3) recombination on the physical basis.

Initially, one introduces for each mode the transfer transfer function of the mechanical system (structure alone or system coupled fluid-structure). Each of the three stages above is then detailed.

1.2.2 Calculation of the interspectres of modal excitations

Interspectres of modal excitations $S_{QiQj}(f,U)$ are determined by projection of the spectrum of turbulent excitation on the basis of modal mechanical system (structure alone or system coupled fluid-structure). This stage of projection is detailed in paragraph [§2] for the various models applicable to telegraphic structures.

1.2.3 Calculation of the interspectres of modal answer

Interspectres of modal displacements $S_{qiqj}(f,U)$ result then from the interspectres of modal excitations $S_{QiQj}(f,U)$ using the following relation:

$$S_{q_i q_j}(f,U) = H_i^*(f,U) S_{QiQj}(f,U) H_j(f,U)$$ **éq 1.2.3-1**

where $H_i^*(f,U)$ indicate the combined complex of the transfer transfer function $H_i(f,U)$ mechanical system considered. Being given a frequency f and a rate of flow U, the transfer transfer function $H_i(f,U)$ mechanical system for the mode i is defined by:

$$H_i(f,U) = \frac{1}{M_i \omega_i^2 \left(-\left(\frac{f}{f_i}\right)^2 + 2j\xi_i \left(\frac{f}{f_i}\right) + 1 \right)}$$ **éq 1.2.3-2**

where M_i indicate the modal mass of the mode i, ω_i and f_i indicate respectively, at the speed U, the pulsation and the Eigen frequency of the mode i, ξ_i indicate, at the speed U, the reduced damping of the mode i, and J indicate the complex number such as $J^2 = -1$.
The calculation of the interspectres of modal displacements starting from the interspectres of modal excitations and of the transfer transfer functions is carried out using the operator `DYNA_SPEC_MODAL` [U4.53.23].

One deduces in particular from [éq 1.2.3-2] the relation binding the autospectres of modal displacements to the autospectres of modal excitations:

$$S_{qiqi}(f,U)=|H_i(f,U)|^2 S_{QiQi}(f,U) \qquad \textbf{éq 1.2.3-3}$$

where $|H_i(f,U)|^2$ indicate the square of the module of $H_i(f,U)$

1.2.4 Recombination on physical basis

Being given a rate of flow U , the interspectre of physical displacement $S_{u_1u_2}(x_1,x_2,f)$ at the points of X-coordinates x_1 and x_2 , at the frequency f , is obtained by modal recombination. This operation is written:

$$S_{u_1u_2}(x_1,x_2,f)=\sum_{i=1}^{N}\sum_{j=1}^{N}\phi_i(x_1)\,\phi_j(x_2)\,S_{q_iq_j}(f,U) \qquad \textbf{éq 1.2.4-1}$$

Where N indicate the number of modes of the base; $\phi_i(x_k)$ is the component at the point of discretization x_k deformation of i ème mode following the direction of space considered.

The recombination on physical basis is carried out using the operator `REST_SPEC_PHYS` [U4.63.22]. The direction of space considered is specified at the time of the call to this operator.

1.2.5 Statistical elements

The modal variance $\sigma_i^2(U)$, associated at the speed U , expresses itself as follows:

$$\sigma_i^2(U)=2\int_0^\infty S_{q_iq_j}(f,U)\,df \qquad \textbf{éq 1.2.5-1}$$

At the rate of flow U , value RMS $\sigma_{RMS}(x)$ of answer in a point x structure is given by:

$$\sigma_{RMS}(x)=\sqrt{\sum_{i=1}^{N}\phi_i^2(x)\,\sigma_i^2(U)} \qquad \textbf{éq 1.2.5-2}$$

Where N indicate the number of modes of the base and $\phi_i(x)$ is the component at the point x deformation of i ème mode following the direction of space considered.
This operation is carried out by the operator `POST_DYNA_ALEA` [U4.84.04].

1.3 Calculation of the answer to the turbulent excitation: temporal resolution

The temporal resolution proceeds according to the sequence of the following operations:

1.3.1 Factorization of the density interspectrale

The operator GENE_FONC_ALEA [U4.36.05] the factorization of the density interspectrale of modal excitations realizes $S_{QiQj}(f, U)$, before application of the method of Monte Carlo.

1.3.2 Generation of the random modal excitations

The operator GENE_FONC_ALEA [U4.36.05] generates random modal excitations $Q_i(t)$ by carrying out pullings by the method of Monte Carlo. The operator RECU_FONCTION [U4.32.03] allows to recover each evolution $Q_i(t)$.

1.3.3 Modification of a modal base and projection

The operator MODI_BASE_MODALE [U4.66.21] the modal base of the structure in substituent to the initial characteristics modifies those obtained for a rate of flow considered.
The operator PROJ_MATR_BASE [U4.63.12] the projection of the matrices of mass and stiffness allows assembled on the new modal basis previously definite.

1.3.4 Definition of the obstacles

The definition of the geometry of the obstacles is carried out, if necessary, using the operator DEFI_OBSTACLE [U4.44.21].

1.3.5 Dynamic resolution

Transitory dynamic calculation for the mode $i(1 \le i \le N)$ is carried out using a digital diagram of integration with the operator DYNA_TRAN_MODAL [U4.53.21].

$$M_{ii}\ddot{q}_i(t)+C_{ii}\dot{q}_i(t)+K_{ii}q_i(t)=Q_i(t) \quad \textbf{éq 1.3.5-1}$$

Where $M_{ii}, C_{ii}\,\mathrm{et}\,K_{ii}$ the mass, generalized damping and stiffness indicate respectively associated with i ème mode; $q_i(t)\,\mathrm{et}\,Q_i(t)$ indicate respectively the generalized displacement and the excitation associated with i ème mode.

1.3.6 Projection of Ritz

The restitution on physical basis is carried out using a projection of Ritz:

$$\mathbf{U}(\mathbf{x}, t)=\sum_{i=1}^{N} \mathbf{u}_{\mathrm{i}}(\mathbf{x})q_i(t) \quad \textbf{éq 1.3.6-1}$$

$\mathbf{U}(\mathbf{x}, t)$ indicate the assembled vector of physical displacements; $\mathbf{u}_{\mathrm{i}}(\mathbf{x})$ is the defining assembled vector i ème modal form and $q_i(t)$ generalized displacement following it i ème mode.

This last operation is carried out using the operator REST_GENE_PHYS [U4.63.31].

2 Models of turbulent excitation applicable to the telegraphic structures

2.1 Principles generals

2.1.1 Assumptions

It is supposed that the linear excitation induced on the telegraphic structure by turbulence of the flow can be modelled in the form of a stationary process random ergodic Gaussian of worthless average. This turbulent excitation thus is entirely characterized by its **density interspectrale** $S_f(x_1, x_2, \omega)$, where x_1 and x_2 are two unspecified points of the beam and w indicate the pulsation. The turbulent excitation applied to the structure is thus characterized by its density interspectrale S_f .

Moreover, it is supposed that the turbulent forces are independent of the movement of the structure. The turbulent excitation is identified in experiments on a model of reference. It is then applicable to any real component in geometrical similarity with the model of reference.

2.1.2 Calculation of the interspectres of modal excitations

One indicates by $f_t(x, s)$ linear density of turbulent excitation exerted on the beam; x is the current X-coordinate of a point of the beam and s the complex pulsation (variable of Laplace). The additional assumptions are made $H1$ and $H2$ following:

$H1$. The excited length L_e is lower than the overall length L beam.

$H2$. The expression of $f_t(x, s)$ does not depend on the origin of the excited zone x_e ; that results in $f_t(x, s) = f_t(x - x_e, s)$.

In this case, one can express the linear density f_t in the following form:

$$f_t(x, s) = \frac{1}{2} \rho U^2 D \cdot C_f \left(\alpha, \frac{D}{D_h}, \frac{D}{L_e}, s_r, \mathrm{Re} \right) \qquad \textbf{éq 2.1.2-1}$$

with: $\alpha = \dfrac{x - x_e}{L_e}$ $\quad s_r = \dfrac{sD}{U}$ $\quad \mathrm{Re} = \dfrac{UD}{u}$

Where ρ indicate the density of the fluid, U is the mean velocity of flow of the fluid, D and D_h are respectively the diameter of the structure and the hydraulic diameter, C_f represent the adimensional coefficient of turbulent force, x is the current X-coordinate of a point of the beam, x_e indicate the X-coordinate of the origin of the excited zone, L_e represent the excited length, α is the reduced variable of space, s is the complex pulsation (variable of Laplace), s_r is the reduced complex pulsation, ν is the kinematic viscosity of the fluid, finally “ Re “the Reynolds number indicates.

By geometrical assumption of similarity of the real component with the model of reference, one obtains:

$$f_t(x,s)=\frac{1}{2}\rho U^2 D\cdot C_f(\alpha, s_r, \mathrm{Re})$$ **éq 2.1.2-2**

Thus, the modal turbulent excitation $Q_i(s)$ can be written in the field of Laplace (assumption $H2$):

$$Q_i(x)=\int_{x_e}^{x_e+L_e} f_t(x,s)\phi_i(x)dx=L_e\int_0^1 f_t(\alpha L_e, s)\phi_i(\alpha L_e+x_e)d\alpha$$ **éq 2.1.2-3**

where $\phi_i(x)$ is the component of i ème modal deformation according to the direction of space in which acts the turbulent excitation.

By means of the expression [éq 2.1.2-2], one deduces:

$$Q_i(s)=\frac{1}{2}\rho U^2 DL_e\int_0^1 C_f(\alpha, s_r, \mathrm{Re})\phi_i(\alpha L_e+x_e)d\alpha$$ **éq 2.1.2-4**

The densities interspectrales of modal turbulent excitations are expressed then in the form:

$$S_{Q_iQ_j}(f,U)=\left(\frac{1}{2}\rho U^2 DL_e\right)^2\frac{D}{U}\int_0^1\int_0^1 \Phi_t(\alpha_1,\alpha_2,f_r,\mathrm{Re})\phi_i(\alpha_1 L_e+x_e)\phi_j(\alpha_2 L_e+x_e)d\alpha_1 d\alpha_2$$

éq 2.1.2-4

with $1\le i,j\le N$, where N is the number of modes selected to determine the answer of the structure;
Φ_t : interspectre of C_f enter α_1 and α_2 ;
$f_r=\frac{fD}{U}$: reduced frequency.

Note:

In what follows, the assumptions are preserved $H1$ and $H2$ and one notes $I_{ij}(f_r,\mathrm{Re})$ the integral:

$$I_{ij}(f_r,\mathrm{Re})=\int_0^1\int_0^1 \Phi_t(\alpha_1,\alpha_2,f_r,\mathrm{Re})\phi_i(\alpha_1 L_e+x_e)\phi_j(\alpha_2 L_e+x_e)d\alpha_1 d\alpha_2$$ **éq 2.1.2-5**

Using this notation, the interspectres of modal excitations are written:

$$S_{Q_i Q_j}(f, U) = \left(\frac{1}{2}\rho U^2 D L_e\right)^2 \frac{D}{U} I_{ij}(f_r, \mathrm{Re})$$ **éq 2.1.2-6**

The expression of the autospectres of modal excitations is similar:

$$S_{Q_i Q_i}(f, U) = \left(\frac{1}{2}\rho U^2 D L_e\right)^2 \frac{D}{U} I_{ii}(f_r, \mathrm{Re})$$ **éq 2.1.2-7**

2.2 Spectra of type “length of correlation”

2.2.1 Keywords

The keywords factors SPEC_LONG_COR_i (i varying from 1 with 4) of the operator DEFI_SPEC_TURB [U4.44.31] give access spectra of type “length of correlation”. These spectra, specific of the configurations of standard “the tube bundle under transverse flow”, are preset but the user can adjust the parameters of them.

2.2.2 Definition of the model

2.2.2.1 Density interspectrale

In the case of spectra of type “length of correlation”, the density interspectrale characterizing the turbulent excitation is supposed to be able to be put in a form at separable variables such as:

$$S_i(x_1, x_2, \omega) = S_0(\omega)\,\varphi_0(x_1, x_2)$$ **éq 2.2.2.1 - 1**

In this expression, $S_0(\omega)$ represent the autospectre of turbulence and $\varphi_0(x_1, x_2)$ indicate a function of space correlation defined by:

$$\varphi_0(x_1, x_2) = \exp\cdot\left(\frac{-|x_2 - x_1|}{\lambda_c}\right)$$ **éq 2.2.2.1 - 2**

where x_1 and x_2 the X-coordinates of two points of observation indicate and λ_c represent the length of correlation.

Four analytical expressions are available in the operator DEFI_SPEC_TURB [U4.44.31]. These expressions correspond each one to a particular representation of $S_0(\omega)$.

The user defines a spectrum of turbulence by choosing one of these analytical forms, of which it can adjust the parameters.

2.2.2.2 Modeling of the spectrum of turbulence by an expression with separate variables

- Case general

The function Φ_{tt} introduced into the relation is modelled by a form with separate variables:

$$\Phi_t(\alpha_1,\alpha_2,f_r,\mathrm{Re})=\sum_{n=1}^{N_s}\varphi_n(\alpha_1,\alpha_2)\,\Phi_n(f_r,\mathrm{Re})$$ **éq 2.2.2.2 - 1**

Where N_s indicate the degree of the base of the functions of form φ_n and Φ_n is a function independent of the variable of space. These two functions are stored in the database and can be selected by the user.
The autospectres of modal excitations are given by [éq 2.1.2-7] while introducing:

$$I_{ii}(f_r,\mathrm{Re})=\sum_{n=1}^{N_s}L_{ni}^2\cdot\Phi_n(f_r,\mathrm{Re})$$ **éq 2.2.2.2 - 2**

with: $$L_{ni}^2=\int_0^1\int_0^1\varphi_n(\alpha_1,\alpha_2)\cdot\phi_i(\alpha_1L_e+x_e)\,\phi_i(\alpha_2L_e+x_e)\cdot d\alpha_1\,d\alpha_2$$ **éq 2.2.2.2 - 3**

The principle of calculation is the following: one calculates the values first of all of L_{ni}^2 by carrying out the calculation of the double integrals; one calculates then $\Phi_n(f_r,\mathrm{Re})$ for all the values of N; one obtains finally the expression of $S_{Q_iQ_i}(f,U)$ using the equation [éq 2.1.2-4].

- Typical case: model used for the tubes of steam generator

The typical case of the study of the tubes of Steam Generator corresponds to a typical case of the case general introduced previously while posing $Ns=1$. The interspectre of turbulent excitation between two points of reduced X-coordinates α_1 and α_2 is then given by:

$$\Phi_t(\alpha_1,\alpha_2,f_r,\mathrm{Re})=\exp\left(-\frac{|\alpha_1-\alpha_2|}{\lambda_c}\cdot L_e\right)\cdot\Phi(f_r,\mathrm{Re})$$ **éq 2.2.2.2 - 4**

where λ_c represent the length of correlation of the turbulent forces and L_e is the excited length. In general, one takes λ_c about 3 to 4 times the diameter external of the tube.

The spectra of autocorrelation of modal excitations, in the case of profiles constant speed and density, are given by:

$$S_{QiQi}(f,U)=\left(\frac{1}{2}\rho U^2DL_e\right)^2\cdot\frac{D}{U}I_{ii}(f_r,\mathrm{Re})$$ **éq 2.2.2.2 - 5**

with:

$$I_{ii}(f_r,\mathrm{Re})=\Phi(f_r,\mathrm{Re})\int_0^1\int_0^1 .\exp\left(-\frac{|\alpha_2-\alpha_1|}{\lambda_c}L_e\right).\phi_i(\alpha_1 L_e+x_e)\phi_i(\alpha_2 L_e+x_e).d\alpha_1 d\alpha_2$$

éq 2.2.2.2 - 6

In the case general of profiles of density and unspecified rate of flow, one a:

$$S_{QiQj}(f,U)=\left(\frac{1}{2}D\right)^2\cdot\frac{D}{U}S(f_r)$$
$$\int_{x_e}^{x_e+L_e}\int_{x_e}^{x_e+L_e}\exp\left(-\frac{|x_2-x_1|}{\lambda_c}\right)\cdot\rho_e(x_1)\rho_e(x_2)\cdot U_e^2(x_1)U_e^2(x_2)\phi_i(x_1)\phi_i(x_2)dx_1 dx_2$$

éq 2.2.2.2 - 7

Where D is the diameter of the structure, L_e is the length of the excited zone, x_e is the X-coordinate of the origin of the excited zone, U is the mean velocity of the flow, $S(f_r)$ is a spectral concentration of separate excitation the mean velocity of the flow U, x_1 and x_2 are the curvilinear X-coordinates of two points of observation on the tube, $\rho_e(x)$ is the profile of density of the fluid along the tube, $U_e(x)$ is the profile speed transverse of the flow along the tube and λ_c indicate the length of correlation.

The adimensional profiles of density and transverse speed of the external flow are in the following way defined :

$\rho_e(x)$ indicating the evolution of the density of the external fluid along the immersed zone L_{imm} tube, one indicates by ρ density of the external fluid realised on the immersed part of the tube :

$$\rho=\frac{1}{L_{imm}}\int_{x_{imm}}^{x_{imm}+L_{imm}}\rho_e(x)dx$$ **éq 2.2.2.2 - 8**

One indicates by $r(x)$ adimensional profile of density such as $\rho_e(x)=\rho\cdot r(x)$.

$U_e(x)$ indicating the evolution rate of flow of the external fluid over the excited length L_e tube, one indicates by U rate of flow of the fluid realised over the excited length of the tube:

$$U=\frac{1}{L_e}\int_{x_e}^{x_e+L_e}U_e(x)dx$$ **éq 2.2.2.2 - 9**

One indicates by $u(x)$ adimensional profile transverse speed of the external flow, such as $U_e(x)=U\cdot u(x)$.

By introducing the average sizes and the adimensional profiles into the expression [éq 2.2.2.2 - 7], one obtains:

$$S_{QiQj}(f,U)=\left(\frac{1}{2}\rho U^2 D\right)^2.\frac{D}{U}S(f_r)\int_{x_e}^{x_e+L_e}\int_{x_e}^{x_e+L_e}\exp\left(-\frac{|x_2-x_1|}{\lambda_c}\right)$$
$$\rho_e(x_1)\rho_e(x_2)U_e^2(x_1)U_e^2(x_2)\Phi_i(x_1)\Phi_j(x_2)dx_1dx_2$$ **éq 2.2.2.2 - 10**

After having noted $\alpha=\frac{x-x_e}{L_e}$, it comes:

$$S_{QiQj}(f,U)=\frac{1}{4}\rho^2U^3D^3L_e^2S(f_r)\times\int_0^1\int_0^1[\exp\left(-\frac{|x_2-x_1|}{\lambda_c}\right)r(\alpha_1L_e+x_e)r(\alpha_2L_e+x_e)$$
$$u^2(\alpha_1L_e+x_e)u^2(\alpha_2L_e+x_e)\Phi_i(\alpha_1L_e+x_e)\Phi_i(\alpha_2L_e+x_e)]\ d\alpha_1d\alpha_2$$

éq 2.2.2.2 - 11

Where $S(f_r)$ represent the spectrum of turbulence, definite according to a reduced frequency f_r (Strouhal number). For a tube in interaction with a transverse flow, f_r is written:

$$f_r=\frac{fD}{U}$$

where f is the dimensioned frequency, D is the diameter of the tube and U is the mean velocity of the flow.

The double integral of the expression [éq 2.2.2.2 - 11] is evaluated by the operator `PROJ_SPEC_BASE` [U4.63.14].

- Case of multiple zones of excitation

If there exist several zones of excitations, the following additional notations are introduced:

The zone of excitation k being located by its X-coordinate of beginning x_k and its length L_k , one notes $U_k(x)$ profile speed transverse of the fluid flow on the level of this zone. Average transverse speed on the zone of excitation k is then given by:

$$\bar{U}_k=\frac{1}{L_k}\int_{x_k}^{x_k+L_k}U_k(x)dx$$

One of deduced the adimensional profile transverse speed, standardized on the zone k :

$$u_k(x)=\frac{U_k(x)}{\bar{U}_k}$$

K indicating the full number of zones of excitation, the average transverse speed on the unit of the zones of excitation is defined by:

$$\bar{U}=\frac{1}{K}\sum_{k=1}^{K}\bar{U}_k$$

If V_{gap} is the speed intertube at the entrance of Steam Generator (the beach speeds retailers is defined in `CALC_FLUI_STRU` [U4.66.02] using the keyword `VITE_FLUI`), one carries out one second standardisation; transverse speed in a point x located in the zone of excitation k is given by:

$$V_k(x)=V_{gap}\frac{U_k(x)}{\bar{U}}=V_{gap}\frac{\bar{U}_k}{\bar{U}}u_k(x)$$

Thanks to this standardisation, the arithmetic mean transverse speed on all the zones of excitation is equal at the speed inter-tube; one has indeed:

$$\frac{1}{K}\sum_{k=1}^{K}\left(\frac{1}{L_k}\int_{x_k}^{x_k+L_k}V_k(x)dx\right)=V_{gap}$$

The calculation of the interspectres of modal excitations, realized by the operator `PROJ_SPEC_BASE` [U4.63.14], is done by adding the contributions with each zone of excitation according to the relation:

$$S_{Q_iQ_j}\left(f,V_{gap}\right)=\left(\frac{1}{2}D\right)^2\sum_{k=1}^{K}\left(\frac{D}{\bar{V}_k}\times L_{ij}^k\times S\left(f_r^k\right)\right)$$

with:

$$\bar{V}_k=V_{gap}\times\frac{U_k}{\bar{U}}\quad\text{and}\quad f_r^k=\frac{fD}{\bar{V}_k}$$

and $L_{ij}^k=\int_{x_k}^{x_k+L_k}\int_{x_k}^{x_k+L_k}\exp\left(\frac{-|x_2-x_1|}{\lambda_c}\right)\rho_e(x_1)\rho_e(x_2)V_k^2(x_1)V_k^2(x_2)\phi_i(x_1)\phi_i(x_2)dx_1dx_2$

that is to say:

$$L_{ij}^k=\bar{V}_k^4\times\int_{x_k}^{x_k+L_k}\int_{x_k}^{x_k+L_k}\exp\left(\frac{-|x_2-x_1|}{\lambda_c}\right)\rho_e(x_1)\rho_e(x_2)u_k^2(x_1)u_k^2(x_2)\phi_i(x_1)\phi_i(x_2)dx_1dx_2$$

One poses:

$$l_{ij}^k=\int_{x_k}^{x_k+L_k}\int_{x_k}^{x_k+L_k}\exp\left(\frac{-|x_2-x_1|}{\lambda_c}\right)\rho_e(x_1)\rho_e(x_2)u_k^2(x_1)u_k^2(x_2)\phi_i(x_1)\phi_i(x_2)dx_1dx_2$$

The expression of the interspectres of modal excitations becomes then:

$$S_{Q_iQ_j}\left(f,V_{gap}\right)=\left(\frac{1}{2}D\right)^2\sum_{k=1}^{K}\left(\frac{D}{\bar{V}_k}\times\bar{V}_k^4\times l_{ij}^k\times S\left(f_r^k\right)\right)$$

from where:

$$S_{Q_iQ_j}\left(f,V_{gap}\right)=\frac{1}{4}D^3\times\sum_{k=1}^{K}\left(\bar{V}_k^3\times l_{ij}^k\times S\left(f_r^k\right)\right)$$

- Analytical expressions of the spectra available for the user

Various analytical expressions of the spectra available in the operator DEFI_SPEC_TURB [U4.44.31] are the following ones:

- SPEC_LONG_COR_1

Each speed U_i defined by the user by discretizing the beach speeds $\left[U_{\min} - U_{\max}\right]$ explored is initially standardized in the form U_i^{kn} by applying the equation:

$$U_i^{kn} = U_i \frac{\bar{U}^k}{\bar{U}}$$

where $\overline{U}^k$ and $\overline{U}$ respectively indicate the speed realised on the zone of excitation " k ", and mean velocity on the unit of the zones of excitation.

A Reynolds number “local” R_e^{ik} , associated with the zone “ k “and at the speed U_i is then calculated starting from the local characteristics of the flow:

$$\mathrm{Re}^{ik} = \text{-}\frac{U_i^{kn} \cdot D}{\nu}$$

The spectrum of turbulent excitation associated with the zone “ k “and at the speed U_i is given in the shape of a vector S^{ik} , having as many components as of points used to discretize the frequential interval $\left[f_{\min} - f_{\max}\right]$, support of the excitation. j - ième component S_j^{ik} this vector is provided by the expression:

$$S_j^{ik} = \frac{\Phi_0}{\left(1 - \left(\frac{f_{rj}^{ik}}{f_{rc}}\right)^{\beta/2}\right)^2 + 4\epsilon^2 \left(\frac{f_{rj}^{ik}}{f_{rc}}\right)^{\beta/2}}$$ **éq 2.2.2.2 - 12**

f_{rj}^{ik} is provided by:

$$f_{rj}^{ik} = \frac{f_j D}{U_i^{kn}}$$

where:

f_j is the value of frequency associated with the j-ième component in the discretization with the frequential interval $\left[f_{\min} - f_{\max}\right]$, f_{rc} is a cut-off frequency being worth 0.2; Φ_o , β , ϵ depend amongst Reynolds according to the equations provided in table Ci - below:

R_e^{ik}	f_o	β	ϵ
$\left]-\infty; 1.5 10^4\right]$	2.83504 10^{-4}	3	0.7
$\left]1.5 10^4; 3.5 10^4\right]$	$1.3 \cdot 10^{-4} \left(\begin{array}{l} 20.42 - 14.10^{-4} \cdot R_e^{ik} - 9.81 \cdot 10^{-8} \cdot R_e^{ik^2} + 11.97 \cdot 10^{-12} \cdot R_e^{ik^3} \\ -35.95 \cdot 10^{-17} \cdot R_e^{ik^4} + 34.69 \cdot 10^{-22} \cdot R_e^{ik^5} \end{array} \right)$	Idem	Idem
$\left]3.5 10^4; 5 10^4\right]$	Idem	4	0.3
$\left]5 10^4; 5.5 10^4\right]$	$50.18975 \cdot 10^{-4}$	Idem	Idem
$\left]5.5 10^4; +\infty\right]$	Idem	4	0.6

- SPEC_LONG_COR_2

The spectrum of turbulent excitation is written:

$$S(f_r)=\frac{f_0}{1+\left(\frac{f_r}{f_{rc}}\right)^{\beta}}$$ éq 2.2.2.2 - 13

The values by default of the parameters are the following ones:

$$\Phi_0=1.5\cdot 10^{-3}$$
$$\beta=2.7$$
$$f_{rc}=0.1$$

- SPEC_LONG_COR_3

The spectrum of turbulent excitation is written:

$$S(f_r)=\frac{\Phi_0}{f_r^{\beta}}$$ éq 2.2.2.2 - 14

with:

$$\Phi_0=\Phi_0(f_{rc})$$
$$\beta=\beta(f_{rc})$$

The values by default of the parameters are the following ones: f_{rc} = 2

If $f_r\le f_{rc}$, one a:

$$\Phi_0=5\cdot 10^{-3}$$
$$\beta=0.5$$

if not

$$\Phi_0=4\cdot 10^{-5}$$
$$\beta=3.5$$

- SPEC_LONG_COR_4

The spectrum of turbulent excitation is written:

$$S(f_r)=\frac{\Phi_0}{f_r^{\beta}\rho_v^{g}}$$ éq 2.2.2.2 - 15

with:

$$\Phi_0=\frac{1}{6.8\cdot 10^{-2}}10^{\Phi}$$

The other parameters are defined by:

$$\phi = A t_v^{0.5} - B \tau_v^{1.5} - C \tau_v^{2.5} - D \tau_v^{3.5}$$
$$\beta = 2$$
$$\gamma = 4$$

τ_v indicate the rate of vacuum; ρ_v is the volume throughput defined by $\rho_v = \rho_m U$; ρ_m is the mass throughput and U indicate the mean velocity of the flow. Values of the coefficients of the polynomial in τ_v are the following ones:

$$A = 24.042$$
$$B = -50.421$$
$$C = 63.483$$
$$D = 33.284$$

2.3 Model of turbulent excitation distributed

2.3.1 Keywords

The keyword factor SPEC_FONC_FORME of the operator DEFI_SPEC_TURB [U4.44.31] allows to define a spectrum of excitation by its decomposition on a family of functions of form. The user has the possibility of defining the spectrum by providing a matrix interspectrale and a list of associated functions of form. Concepts [interspectre] and [function] must then be generated upstream. In the case of the component “control rod”, the user can also use a preset spectrum of turbulence, identified on model GRAPPE1.

2.3.2 Decomposition on a family of functions of form

The model of turbulent excitation distributed supposes that **instantaneous linear density of the turbulent forces** $f_t(x,t)$ can be **broken up on a family of functions of form** $j_k(x)$ of dimension K in the following way:

$$f_t(x,t) = \sum_{k=1}^{K} \varphi_k(x) \alpha_k(t) \qquad \textbf{éq 2.3.2-1}$$

Coefficients $\alpha_k(t)$ at every moment define the decomposition of the turbulent excitation on the family of functions of form.

The density interspectrale of turbulent excitation between two points of the telegraphic structure of X-coordinates x_1 and x_2 is written then:

$$S_f(x_1, x_2, \omega) = \sum_{k=1}^{K} \sum_{k=1}^{K} \varphi_k(x_1) \varphi_l(x_2) S\alpha_k \alpha_l(\omega) \qquad \textbf{éq 2.3.2-2}$$

This formulation makes it possible to take into account an excitation whose space distribution is unspecified.

2.3.3 Setting in equations

2.3.3.1 Application of a turbulent excitation distributed

The length of application L is characterized in an intrinsic way by the field of definition of the functions of form associated with the excitation. The enforcement zone is determined by the data of the name of the node around of which it is centered.
x_n indicating the X-coordinate locating this node, the turbulent excitation is imposed on the field $\left[x_n - L/2, x_n + L/2\right]$.
The turbulent excitation being able to be, in addition, developed in a way correlated in the two directions $\mathbf{Y}$ and $\mathbf{Z}$ orthogonal with the axis of the telegraphic structure, the functions of form are a priori vectors with two components.
One thus informs, by convention in one `table_fonction`, two functions of form, first is associated with the direction $\mathbf{Y}$ and the other with the direction $\mathbf{Z}$. Each of the two functions is defined on the interval $[0, L]$.

2.3.3.2 Turbulent excitation identified on model GRAPPE1

Functions of form φ_k are the first 12 modal deformations of inflection of the structure identified in experiments, distributed according to the two orthogonal directions with the main axis of the beam. The general analytical expression of these deformations is the following one:

$$\vec{\varphi}_k(x) = \begin{pmatrix} \varphi_{Yk}(x) \\ \varphi_{Zk}(x) \end{pmatrix}$$ **éq 2.3.3.2 - 1**

with:

$$\varphi_{Yk}(x) = A_{Yk}\cdot\cos\left(\frac{n_{Yk}}{L}x\right) + B_{Yk}\cdot\sin\left(\frac{n_{Yk}}{L}x\right) + C_{Yk}\cdot ch\left(\frac{n_{Yk}}{L}x\right) + D_{Yk}\cdot sh\left(\frac{n_{Yk}}{L}x\right)$$ **éq 2.3.3.2 - 2**

$$\varphi_{Zk}(x) = A_{Zk}\cdot\cos\left(\frac{n_{Zk}}{L}x\right) + B_{Zk}\cdot\sin\left(\frac{n_{Zk}}{L}x\right) + C_{Zk}\cdot ch\left(\frac{n_{Zk}}{L}x\right) + D_{Zk}\cdot sh\left(\frac{n_{Zk}}{L}x\right)$$ **éq 2.3.3.2 - 3**

where n_{Yk} and n_{Zk} numbers of waves indicate, L is the length of application of the excitation and the coefficients A_{Yk}, B_{Yk}, C_{Yk}, D_{Yk}, A_{Zk}, B_{Zk}, C_{Zk}, D_{Zk} are real coefficients constant characteristic of the function of form considered.

The first 6 functions of form are associated with the direction $\mathbf{Y}$ and A_{Zk}, B_{Zk}, C_{Zk}, D_{Zk} are thus worthless, for $1 \leq k \leq 6$.
The 6 last functions of form are associated with the direction $\mathbf{Z}$ and A_{Yk}, B_{Yk}, C_{Yk}, D_{Yk} are thus worthless, for $7 \leq k \leq 12$.

This family of functions of form is thus characterized by $5 \times 12 = 60$ real coefficients.

The turbulent excitation identified on model GRAPPE1 is homogeneous in the two orthogonal directions with the axis of the telegraphic structure, turbulence being décorrélée between these two directions.

The matrix interspectrale $\left[S\alpha_k\,\alpha_l\right]$ identified on model GRAPPE1 is thus a matrix of dimension 12×12 , constituted by two identical diagonal blocks of dimension 6:

$$\left[S\alpha_k\,\alpha_l\right]=\begin{bmatrix}\left[S_o(\omega)\right] & [0]\\ [0] & \left[S_o(\omega)\right]\end{bmatrix}$$

By square property of symmetry, this matrix is entirely defined by the data of the triangular part higher (or lower) of $\left[S_o(\omega)\right]$, that is to say 21 interspectres. For each one of them, the characteristic parameters are the level of plate, the cut-off frequency and the slope of the spectrum beyond this frequency.

The matrix interspectrale of turbulent excitation identified on model GRAPPE1 is thus characterized by 63 real coefficients (3×21).

Note:

Excitations GRAPPE1 are available to ***two flows of reference*** *. The whole of the data characterizing these excitations thus represents* ***246 real coefficients (*** $[60+63]\times 2$ ***)*** *.*

2.3.3.3 Projection of the excitation on modal basis

One notes:

$\phi_i(x)=\begin{pmatrix}DY_i(x)\\ DZ_i(x)\end{pmatrix}$ i - éme deformed modal of the structure.

Are β_{ik} coordinates of i - éme deformed modal of the structure on the basis as of functions of form $\varphi_k(x)$:

$$\phi_i(x)=\sum_{k=1}^{K}\beta_{ik}\cdot\varphi_k(x) \qquad \textbf{éq 2.3.3.3 - 1}$$

Interspectres of modal excitations $S_{Q_iQ_j}(\omega)$ applied to the structure are written then:

$$S_{Q_iQ_j}(\omega)=\sum_{k=1}^{K}\sum_{k=1}^{K}\beta_{ik}\cdot\beta_{jl}\cdot S_{\alpha_k\alpha_l}(\omega) \qquad \textbf{éq 2.3.3.3 - 2}$$

For each mode i structure, coefficients β_{ik} are given by integrating the equation [éq 2.3.3.3 - 1] prémultipliée by the functions φ_j , on the scope of application of the excitation. One obtains as follows:

$$\int_{x_0-L/2}^{x_0+L/2}\varphi_j(x+L/2)\cdot\phi_i(x)\cdot dx=\sum_{k=1}^{K}\beta_{ik}\cdot\int_{x_0-L/2}^{x_0+L/2}\varphi_j(x+L/2)\cdot\varphi_k(x+L/2)\cdot dx$$

$$\int_{x_0-L/2}^{x_0+L/2} \varphi_j(x+L/2)\cdot\phi_i(x)\cdot dx=\sum_{k=1}^{K}\beta_{ik}\cdot\int_0^L \varphi_j(x)\cdot\varphi_k(x)\cdot dx \quad \forall(i,j)$$ **éq 2.3.3.3 - 3**

For each i , the equation [éq 2.3.3.3 - 3] is written in matric form:

$$\left[a_{jk}\right]\cdot\left(\beta_{ik}\right)=\left(b_{ij}\right)$$ **éq 2.3.3.3 - 4**

with:

$$a_{jk}=\int_0^L \varphi_j(x)\cdot\varphi_k(x)\cdot dx$$

that is to say:

$$a_{jk}=\int_0^L \left(\varphi_{Yj}(x)\cdot\varphi_{Yk}(\varphi)+\varphi_{Zj}(x)\cdot\varphi_{Zk}(x)\right)\cdot dx$$

and

$$b_{ij}=\int_{x_0-L/2}^{x_0+L/2} \varphi_j(x+L/2)\cdot\phi_i(x)\cdot dx$$

that is to say:

$$b_{ij}=\int_{x_0-L/2}^{x_0+L/2} \left(DY_i(x)\cdot\varphi_{Yj}(x+L/2)+DZ_i(x)\cdot\varphi_{Zj}(x+L/2)\right)\cdot dx$$

The resolution of each linear system of equations leads to β_{ik} .
The calculation of the scalar products is carried out in the operator PROJ_SPEC_BASE [U4. 63.14].

Note:

1) *Functions $\varphi_k(x)$ represent, in practice, the modal deformations raised on the model. The system (), with dominating diagonal, is thus well conditioned. In particular, when the telegraphic structure model has a homogeneous linear density, functions $\varphi_k(x)$ are orthogonal and the matrix $\left[a_{jk}\right]$ is diagonal.*
2) *Tests comparing the scope of application of the excitation with the field of definition of the structure are carried out.*

2.4 Model of localised turbulent excitation

2.4.1 Keywords

The keyword factor SPEC_EXCI_POINT of the operator DEFI_SPEC_TURB [U4.44.31] is used in the case of a spectrum of excitation associated with one or more specific forces and moments. The user can define the spectrum while providing:

- a matrix interspectrale of excitations (the concept [interspectre] associated must be generated upstream),
- the list of the nodes of application of these excitations,
- the nature of the excitation applied of each one of these nodes (force or moment),
- directions of application of the excitations thus defined.

It can also use a preset spectrum of turbulence, identified on model GRAPPE2.

2.4.2 Bases

The model of localised turbulent excitation is a typical case of the model of turbulent excitation distributed. Thus, one supposes just as in paragraph [§2.3.2] that **instantaneous linear density of the turbulent forces** $f_t(x,t)$ can be **broken up on a family of functions of form** $\varphi_k(x)$ in the following way:

$$f_t(x,t)=\sum_{k=1}^{K}\varphi_k(x)\alpha_k(t) \qquad \textbf{éq 2.4.2-1}$$

Coefficients $\alpha_k(t)$ at every moment define the decomposition of the turbulent excitation on the family of functions of form.

The density interspectrale of turbulent excitation between two points of the telegraphic structure of X-coordinates x_1 and x_2 is written then:

$$S_f(x_1,x_2,\omega)=\sum_{k=1}^{K}\sum_{l=1}^{K}\varphi_k(x_1)\cdot\varphi_l(x_2)\cdot S_{\alpha_k\alpha_l}(\omega) \qquad \textbf{éq 2.4.2-2}$$

The characteristic of the model of localised turbulent excitation is due to **specificity of the functions of form** $\varphi_k(x)$:

$\varphi_k(x)=\delta\left(x-x_k\right)$ allows to represent one **specific force** applied to the point of X-coordinate x_k

$\varphi_k(x)=\delta'\left(x-x_k\right)$ allows to represent one **specific moment** applied to the point of X-coordinate x_k

$\delta\left(x-x_k\right)$ and $\delta'\left(x-x_k\right)$ indicate respectively the distribution of Dirac and the derivative of the distribution of Dirac at the point of X-coordinate x_k .

Taking into account the specificity of the functions of form, the projection of a turbulent excitation localised on modal basis is much simpler than in the case general (excitation distributed), since one can analytically calculate the expression of the projected excitation.

2.4.3 Setting in equations

2.4.3.1 Application of a localised turbulent excitation

A turbulent excitation applied to a structure telegraphic and made up by forces and specific moments are considered. This excitation is entirely characterized by the following data:

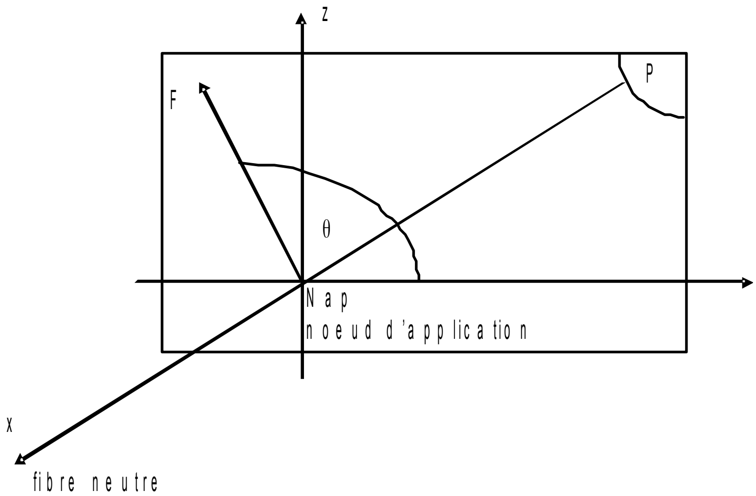
- list of the nodes of application of the forces and specific moments,
- nature of the excitation applied in each node (force or moment),
- direction of the excitation applied in each node.

Ainsi $$\mathbf{f}_t(x,t)=\sum_{k=1}^{K} F_k(s)\cdot\delta\left(x-x_k\right)\cdot\mathbf{n}_k-\sum_{m=1}^{M} M_m(s)\cdot\delta'\left(x-x_m\right)\cdot\mathbf{n}_m$$ **éq 2.4.3.1 - 1**

is the expression of a located turbulent excitation, characterized by K forces and M specific moments, applied respectively to the nodes of X-coordinates x_k and x_m in the directions $\mathbf{n}_k$ and $\vec{\mathbf{n}}_m$.

One a: $\mathbf{n}_k=\begin{pmatrix}0\\ \cos\cdot\left(\theta_k\right)\\ \sin\cdot\left(\theta_k\right)\end{pmatrix}$ and $\mathbf{n}_m$ defined in a similar way.

θ represent the azimuth giving the direction of application of the force (or the moment) in the plan P orthogonal with neutral fibre with the node of application, such as defined in figure [2.4.3.1 Figure - has] Ci - below:



2.4.3.1 figure - has: Definition of the direction of application

The generalized excitation associated with i ème mode of the structure, $Q_i(s)$, being defined by:

$$Q_i(s)=\int_0^L \phi_i(x)\cdot\mathbf{f}_t(x,t)\cdot dx$$ **éq 2.4.3.1 - 2**

where L represent the length of the beam and $\phi_i(x)$ deformation of the mode i , one obtains, taking into account the expression [éq 2.4.3.1 - 1]:

$$Q_i(s)=\sum_{k=1}^{K} F_k(s)\cdot\phi_i(x_k)\cdot\mathbf{n}_\mathrm{k}-\sum_{m=1}^{M} M_m(s)\cdot\phi_i(x_k)\cdot\mathbf{n}_\mathrm{m}$$ **éq 2.4.3.1 - 3**

The calculation of the interspectres of modal excitations leads then to:

$$\begin{aligned}S_{Q_iQ_j}(s)=&\sum_{k_1=1}^{K}\sum_{k_2=1}^{K}\boldsymbol{S}_{\boldsymbol{F}_{k_1}\boldsymbol{F}_{k_2}(\boldsymbol{s})}\left(\phi_i(x_{k_1}).\mathbf{n}_{\mathrm{k}_1}\right).\left(\phi_j(x_{k_2}).\mathbf{n}_{\mathrm{k}_2}\right)\\&+\sum_{k_1=1}^{K}\sum_{m_2=1}^{M}\boldsymbol{S}_{\boldsymbol{F}_{k_1}\boldsymbol{M}_{m_2}(\boldsymbol{s})}\left(\phi_i(x_{k_1}).\mathbf{n}_{\mathrm{k}_1}\right).\left(\phi_{j'}(x_{m_2}).\mathbf{n}_{\mathrm{m}_2}\right)\\&+\sum_{m_1=1}^{M}\sum_{k_2=1}^{K}\boldsymbol{S}_{\boldsymbol{M}_{m_1}\boldsymbol{F}_{k_2}(\boldsymbol{s})}\left(\phi_i'(x_{m_1}).\mathbf{n}_{\mathrm{m}_1}\right).\left(\phi_j(x_{k_2}).\mathbf{n}_{\mathrm{k}_2}\right)\\&+\sum_{m_1=1}^{M}\sum_{m_2=1}^{M}\boldsymbol{S}_{\boldsymbol{M}_{m_1}\boldsymbol{M}_{m_2}(\boldsymbol{s})}\left(\phi_i'(x_{m_1}).\mathbf{n}_{\mathrm{m}_1}\right).\left(\phi_{j'}(x_{m_2}).\mathbf{n}_{\mathrm{m}_2}\right)\end{aligned}$$ **éq 2.4.3.1 - 4**

Note:

When the user defines the spectrum of turbulent excitation, it must inform the matrix interspectrale specific excitations whose terms intervene above. ***This matrix has as a dimension*** $K+M$ ***(many forces and specific moments applied).***

2.4.3.2 Turbulent excitation identified on model GRAPPE2

The turbulent excitation identified on model GRAPPE2 is represented by a resulting force and a moment, applied in the same node following the two orthogonal directions to the axis of the structure. The linear density of this excitation has as an expression:

$$\mathbf{f}_t(x,s)=\frac{1}{2}\rho U^2 D_h\left[L_p\cdot F_t(s_r)\cdot\delta(x-x_0)-L_p^2\cdot M_t(s_r)\cdot\delta'(x-x_0)\right]\begin{pmatrix}0\\0\\1\end{pmatrix}$$ **éq 2.4.3.2 - 1**

Where ρ is the density of the fluid, U is the mean velocity of the flow, D_h is the hydraulic diameter, L_p is the thickness of the plate of housing (corresponding to the excited length), x_0 is the X-coordinate of the point of application of the excitation, $s_r=\frac{s\cdot D}{U}$ is the reduced complex frequency, $F_t(s_r)$ and $M_t(s_r)$ are the adimensional coefficients representing the resulting force and the moment.
Sizes ρ , U , D_h and L_p allow to dimension the excitation.

In substituent the expression [éq 2.4.3.2 - 3] in the relation [éq 2.4.3.1 - 4] defining the modal excitation $Q_i(s)$, one obtains:

$$Q_i(s)=\frac{1}{2}\rho U^2 D_h\left[L_p\cdot F_t(s_r)\cdot\phi_i(x_0)\cdot\begin{pmatrix}0\\0\\1\end{pmatrix}+L_p^2\cdot M_t(s_r)\cdot\phi_i'(x_0)\cdot\begin{pmatrix}0\\0\\1\end{pmatrix}\right]$$ **éq 2.4.3.2 - 2**

The specific force and the moment identified on model GRAPPE2 being décorrélés, the calculation of the interspectres of modal excitations leads finally to:

$$S_{Q_iQ_j}=\left(\frac{1}{2}\rho U^2 D_h\right)^2\frac{D}{U}\cdot\quad\left[L_p^2\cdot\phi_i(x_0)\cdot\begin{pmatrix}0\\1\\1\end{pmatrix}'\phi_j(x_0)\cdot\begin{pmatrix}0\\1\\1\end{pmatrix}\cdot S_{F_tF_t}(s_r)\right.$$
$$\left.+L_p^4\cdot\phi_i'(x_0)\cdot\begin{pmatrix}0\\1\\1\end{pmatrix}'\phi_j'(x_0)\cdot\begin{pmatrix}0\\1\\1\end{pmatrix}\cdot S_{M_tM_t}(s_r)\right]$$ **éq 2.4.3.2 - 3**

In this expression, D is the diameter external of the structure, $S_{F_tF_t}(s_r)$ and $S_{M_tM_t}(s_r)$ the adimensional autospectres of force and moment represent respectively identified on model GRAPPE2. The operator `PROJ_SPEC_BASE` [U4.63.14] calculates the interspectres of modal excitations according to the relation [éq 2.4.3.2 - 3] above.

Note:

1) *Autospectres adimensional GRAPPE2 are usable to simulate the behavior of any structure in similarity with the model; one then utilizes the geometrical parameters structural feature to dimension the excitation. Model GRAPPE2 having been built in similarity with the configuration engine, the following reports are fixed and characteristic of this geometry:*

$$\frac{D_h}{D} \text{et} \frac{L_p}{D}$$

It is pointed out that D_h and D the hydraulic diameter and the diameter external of the structure indicate respectively; L_p is the thickness of the plate of housing, corresponding to the excited length.
***The data of ρ , $\mathbf{U}$ and $\mathbf{D}$ is thus sufficient to dimension in a univocal way the turbulent excitation** starting from the autospectres adimensional.*

2) *Adimensional autospectres $S_{F_t F_t}(s_r)$ and $S_{M_t M_t}(s_r)$ one and the other being defined by three real coefficients (level of plate, reduced frequency of cut and slope beyond this frequency), only six constants make it possible to characterize the adimensional turbulent excitation identified on model GRAPPE2.*
*Four configurations having been studied (ascending flow or going down, stem of centered or offset order), the whole of the data characterizing excitations GRAPPE2 thus represents **24 real coefficients.***

3 Bibliography

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3) L. PEROTIN, MR. LAINET: Integration of a model general of turbulent excitation in *Code_Aster* : specifications. HT32/96/003/A

4 Description of the versions of the document

Version Aster	Author (S) Organization (S)	Description of the modifications
07/04/09	*A. ADOBES, L. VIVAN (EDF-R&D/MFTT, CS)*	