Modelization of the turbulent excitations

Summarized:

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

Contents

1 Principle of computation

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

The computation of the dynamic response of a system with 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 operator MODE_ITER_SIMULT [U4.52.03],
2) one defines then the characteristics of the studied configuration, for taking into account of the phenomenon of fluid-structure coupling, using operator DEFI_FLUI_STRU [U4.25.01]. This operator allows for example to inform the profiles velocity associated with the excitation zones fluid, 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 operator CALC_FLUI_STRU [U4.66.02]. One has in output a modal base for each rate of flow,
4) the definition of the turbulent excitation is done then by a call to operator DEFI_SPEC_TURB [U4.44.31]. The modelizations available are the following ones:
   - spectrums of type “correlation length”, specific of the configurations of standard “the tube bundle under transverse flow”, for the application to vibrations of tubes of GV. The key words corresponding factors are SPEC_LONG_COR_1, SPEC_LONG_COR_2, SPEC_LONG_COR_3 and SPEC_LONG_COR_4. These spectrums are preset; however, the user can adjust the parameters of them. This part is developed with the paragraph [§2.2],
   - models turbulent excitation distributed. The factor key word corresponding is SPEC_FONC_FORME. The excitation spectrum is defined by its decomposition on a family of shape functions while providing, on the one hand an interspectral matrix, and on the other hand a list of shape functions associated with this matrix. The concepts [interspectrum] 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],
   - models localised turbulent excitation. The factor key word corresponding is SPEC_EXCI_POINT. He is in the case of used an excitation spectrum associated with one or more specific forces and moments. The definition of the excitation is done then while providing:
     - an interspectral matrix of excitations (the concept [interspectrum] 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 turbulent projection of the excitation spectrum previously defined, on the basis of the structure modal base under flow, is then carried out using operator PROJ_SPEC_BASE [U4.63.14].

1.2 Computation of the response to the turbulent excitation: frequential resolution

1.2.1 Introduction

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

1) computation of the interspectrums of modal excitations,
2) computation of the interspectrums of modal response,
3) recombination on physical base.

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 Computation of the interspectrums of modal excitations

the interspectrums of modal excitations $S_{QiQj}(f, U)$ are determined by turbulent projection of the excitation spectrum on the basis of the mechanical system modal base (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 Computation of the interspectrums of modal response

the interspectrums of modal displacements $S_{qiqj}(f, U)$ result then from the interspectrums 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 $H_i^*(f, U)$ the combined complex of the transfer transfer function of $H_i(f, U)$ the mechanical system considered indicates. Being given a frequency f and a rate of flow U, the transfer transfer function $H_i(f, U)$ of the mechanical system for the mode i is defined by:

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

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

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

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

where $|H_i(f,U)|^2$ indicates the square of the modulus of $H_i(f,U)$

1.2.4 Recombination on physical base

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

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

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

The recombination on physical base is carried out using 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 , is expressed as follows:

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

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

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

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

1.3 Computation of the response 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 interspectral

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

1.3.2 Generation of the random modal excitations

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

1.3.3 Modification of a modal base and projection

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

1.3.4 Definition of the obstacles

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

1.3.5 Dynamic resolution

The computation transient dynamics for the mode $i(1 \le i \le N)$ is carried out using a diagram of numerical integration with 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 $M_{ii}, C_{ii}\,\text{et}\,K_{ii}$ the mass, generalized damping and stiffness indicate respectively associated with i the ème mode; $q_i(t)\,\text{et}\,Q_i(t)$ indicate respectively the generalized displacement and the excitation associated with i the ème mode.

1.3.6 Projection of Ritz

the restitution on physical base is carried out using a projection of Ritz:

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

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

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

2 Models of turbulent excitation applicable to telegraphic structures

2.1 general Principles

2.1.1 Assumptions

One supposes that the induced linear excitation on the structure telegraphic by the turbulence of flow can be modelled in the form of a gaussian ergodic steady process random of average null. This turbulent excitation thus is entirely characterized by its **density interspectral** $S_f(x_1, x_2, \omega)$, where x_1 and x_2 are two unspecified points of the beam and w indicates the pulsation. The turbulent excitation applied to structure is thus characterized by its density interspectral S_f .

Moreover, it is supposed that the turbulent forces are independent of the motion of 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 Computation of the interspectrums of modal excitations

One indicates by $f_t(x, s)$ the 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). One makes the additional and $H1$ following $H2$ assumptions:

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

$H2$. The statement of $f_t(x, s)$ does not depend on the origin of the excited zone x_e ; that is translated par. $f_t(x, s) = f_t(x - x_e, s)$

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

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

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

Where ρ the density of the fluid indicates, U is the mean velocity of flow of the fluid, D and D_h are respectively the diameter of structure and the hydraulic diamtere, C_f represents the adimensional coefficient of turbulent force, x is the current X-coordinate of a point of the beam, x_e indicates the X-coordinate of the origin of the excited zone, L_e represents 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, v is the kinematical viscosity of the fluid, finally "" Re indicates the Reynolds number.

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

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

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

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

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

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

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

densities interspectrals 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 response of structure;
Φ_t : interspectrum of C_f enters α_1 and α_2 ;
$f_r=\frac{fD}{U}$: reduced frequency.

Note:

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

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

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

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

the statement of the autospectrums of modal excitations is similar:

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

2.2 Spectrums of type “correlation length”

2.2.1 Key words

the key words SPEC_LONG_COR_i factors (i varying from 1 to 4) of operator DEFI_SPEC_TURB [U4.44.31] give access spectrums of type “correlation length”. These spectrums, 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 interspectral

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

$$S_i(x_1, x_2, \omega)=S_0(\omega)\,\varphi_0(x_1, x_2) \qquad \textbf{éq 2.2.2.1 - 1}$$

In this statement, $S_0(\omega)$ represents the autospectrum of turbulence and $\varphi_0(x_1, x_2)$ indicates a function of spatial correlation defined by:

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

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

Four analytical statements are available in operator DEFI_SPEC_TURB [U4.44.31]. These statements 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 Modelization of the spectrum of turbulence by a statement with separate variables

- general Case

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 the degree of the base of the shape functions indicates φ_n and Φ_n is a function independent of the variable of space. These two functions are stored in data base and can be selected by the user.
The autospectrums 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:
$$L_{ni}^2=\int_0^1\int_0^1\varphi_n(\alpha_1,\alpha_2)\cdot\phi_i(\alpha_1 L_e+x_e)\,\phi_i(\alpha_2 L_e+x_e)\cdot d\alpha_1\,d\alpha_2$$ **éq 2.2.2.2 - 3**

the principle of computation is the following: one first of all calculates the values of L_{ni}^2 by carrying out the computation of the double integrals; one calculates then $\Phi_n(f_r,\mathrm{Re})$ for all the values of N; one obtains finally the statement 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 cas particulier of the study of the tubes of GV corresponds to a cas particulier of the general case presented previously while posing $Ns=1$. The interspectrum 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 the correlation length of the turbulent forces represents 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 spectrums of autocorrelation of modal excitations, in the case of profiles constant velocity and density, are given by:

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

with:

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

éq 2.2.2.2 - 6

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

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

éq 2.2.2.2 - 7

Where D is the diameter of 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 flow, $S\left(f_r\right)$ is one spectral concentration of separate excitation the mean velocity of flow U, x_1 and x_2 are the curvilinear abscisses of two points of observation on the tube, $\rho_e\left(x\right)$ is the profile of density of the fluid along the tube, $U_e\left(x\right)$ is the profile velocity transverse of flow along the tube and λ_c indicates correlation length.

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

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

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

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

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

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

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

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

$$S_{QiQj}(f,U)=\left(\frac{1}{2}\rho U^2 D\right)^2 . \frac{D}{U} S(f_r) \int_{x_e}^{x_e+L_e}\int_{x_e}^{x_e+L_e} \exp\left(-\frac{|x_2-x_1|}{\lambda_c}\right) \rho_e(x_1)\rho_e(x_2)U_e^2(x_1)U_e^2(x_2)\phi_i(x_1)\phi_j(x_2)dx_1 dx_2$$ **éq 2.2.2.2 - 10**

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

$$S_{QiQj}(f,U)=\frac{1}{4}\rho^2 U^3 D^3 L_e^2 S(f_r)\times\int_0^1\int_0^1 [\exp\left(-\frac{|x_2-x_1|}{\lambda_c}\right) r(\alpha_1 L_e+x_e) r(\alpha_2 L_e+x_e) u^2(\alpha_1 L_e+x_e) u^2(\alpha_2 L_e+x_e)\phi_i(\alpha_1 L_e+x_e)\phi_i(\alpha_2 L_e+x_e)]\ d\alpha_1 d\alpha_2$$

éq 2.2.2.2 - 11

Where $S(f_r)$ the spectrum of turbulence represents, 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 flow.

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

- Multiple cases of excitation zones

If there exist several excitation zones, one introduce the following additional notations:

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

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

K indicating the nombre total of excitation zones, the average transverse velocity on all of the excitation zones is defined by:

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

If V_{gap} is the velocity intertube at the entrance of GV (the beach velocities retailers is defined in CALC_FLUI_STRU [U4.66.02] using key word VITE_FLUI), one carries out the one second standardization; the transverse velocity in a point x located in the excitation zone 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 standardization, the arithmetic mean transverse velocity on all the excitation zones 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 computation interspectrums of modal excitations, carried out by the operator PROJ_SPEC_BASE [U4.63.14], is done by adding the contributions with each excitation zone 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:

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

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

is:

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

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 statement of the interspectrums 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 statements of the spectrums available for the user the various analytical statements of the spectrums available in operator `DEFI_SPEC_TURB` [U4.44.31] are the following ones:

- `SPEC_LONG_COR_1`

Each velocity U_i defined by the user by discretizing the beach velocities $\left[U_{\min} - U_{\max}\right]$ 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 velocity realised on the excitation zone "" k , and the mean velocity on all of the excitation zones.

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

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

The excitation spectrum turbulent associated with the zone "" k and 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} of this vector is provided by the statement:

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

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 excitation spectrum turbulent are written:

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

  values by default of the parameters are the following ones:

$$\phi_0=1.5\cdot10^{-3}$$
$$\beta=2.7$$
$$f_{rc}=0.1$$

- `SPEC_LONG_COR_3`

  the excitation spectrum turbulent 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:

$$\phi_0=5\cdot10^{-3}$$
$$\beta=0.5$$

  if not

$$\phi_0=4\cdot10^{-5}$$
$$\beta=3.5$$

- `SPEC_LONG_COR_4`

  the excitation spectrum turbulent is written:

$$S(f_r)=\frac{\phi_0}{f_r^{\beta}\rho_v^{g}}$$ **éq 2.2.2.2 - 15**

  with:

$$\phi_0=\frac{1}{6.8\cdot10^{-2}}10^{\phi}$$

The other parameters are defined by:

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

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 indicates the mean velocity of flow. The values of the coefficients of the polynomial τ_v are the following ones:

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

2.3 Model turbulent excitation distributed

2.3.1 The factor key word

Key words SPEC_FONC_FORME of operator DEFI_SPEC_TURB [U4.44.31] allows to define an excitation spectrum by its decomposition on a family of shape functions. The user has the possibility of defining the spectrum by providing an interspectral matrix and a list of associated shape functions. The concepts [interspectrum] 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 shape functions

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

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

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

The density interspectral of turbulent excitation between two points of 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 spatial distribution is unspecified.

2.3.3 Put 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 shape functions 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 telegraphic structure, the shape functions are a priori vectors with two components.
One thus informs, by convention in a `table_fonction`, two shape functions , 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

the shape functions φ_k are the first 12 modal deformed shapes of bending of structure identified in experiments, distributed according to the two orthogonal directions with the principal axis of the beam. The general analytical statement of these deformed shapes 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} indicate wave numbers, 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 constant real coefficients characteristic of the shape function considered.

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

This family of shape functions 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 telegraphic structure, turbulence being uncorrelated between these two directions.
The interspectral matrix $\left[S\alpha_k \alpha_l\right]$ identified on model GRAPPE1 is thus a matrix of size 12×12, made up 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 interspectrums. 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 interspectral matrix 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*** *. All the data characterizing these excitations thus represent* ***246 real coefficients (*** $[60+63]\times 2$ ***)*** *.*

2.3.3.3 Projection of the excitation on modal base

One notes:

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

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

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

the interspectrums of modal excitations $S_{Q_i Q_j}(\omega)$ applied to structure are written then:

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

For each mode i of structure, the 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

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

is:

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

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

Note:

1) *The functions $\varphi_k(x)$ represent, in practice, the modal deformed shapes 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, the 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 structure are carried out.*

2.4 Model localised turbulent excitation

2.4.1 The factor key word

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

- an interspectral matrix of excitations (the concept [interspectrum] 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.

He 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 **the instantaneous linear density of the turbulent forces** $f_t(x,t)$ can be **broken up on a family of shape functions** $\varphi_k(x)$ in the following way:

$$f_t(x,t)=\sum_{k=1}^{K}\varphi_k(x)\alpha_k(t)$$ **éq the**

2.4.2-1

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

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

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

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

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

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

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

2.4.3 Put 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:

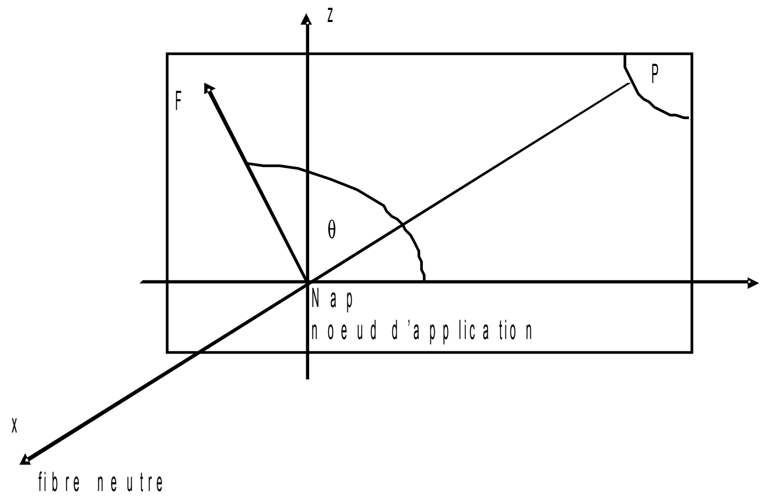
- list nodes of application of the forces and specific moments,
- nature of the excitation applied in each node (force or moment),
- direction of the excitation applied in each node.

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

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

One a: $\mathbf{n}_{\mathrm{k}}=\begin{pmatrix}0\\ \cos\cdot\left(\theta_k\right)\\ \sin\cdot\left(\theta_k\right)\end{pmatrix}$ and $\mathbf{n}_{\mathrm{m}}$ definite in a similar way.

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



Appear 2.4.3.1 - has: Definition of the direction of application

the generalized excitation associated with i the ème mode of 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 represents the length of the beam and $\phi_i(x)$ the deformed shape of the mode i , one obtains, taking into account the statement [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 computation of the interspectrums of modal excitations leads then to:

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

Note::

When the user defines the excitation spectrum turbulent, it must inform the interspectral matrix of the specific excitations whose terms intervene above. ***This matrix has as a dimension*** $K+M$ ***(number of 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 structure. The linear density of this excitation has as a statement:

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

Where ρ is the density of the fluid, U is the mean velocity of flow, D_h is the hydraulic diamtere, 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.
The quantities ρ U , D_h and L_p make it possible to dimension the excitation.

In substituent the statement [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 uncorrelated, the computation of the interspectrums of modal excitations lead 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 statement, D is the diameter external of structure, $S_{F_tF_t}(s_r)$ and $S_{M_tM_t}(s_r)$ respectively represent the adimensional autospectrums of force and moment identified on model GRAPPE2. Operator `PROJ_SPEC_BASE` [U4.63.14] calculates the interspectrums of modal excitations according to the relation [éq 2.4.3.2 - 3] above.

Note:

1) *Adimensional autospectrums 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 ratios 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 respectively indicate the hydraulic diamtere and the diameter external of structure; 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 adimensional autospectrums.*

2) *The adimensional autospectrums $S_{F_t F_t}(s_r)$ 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, rod of centered or offset command), all the data characterizing excitations GRAPPE2 thus represent **24 real coefficients.***

3 GAY

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2) S. GRANGER, N. GAY: Software FLUSTRU Version 3. Note principle. HT32/93/013/B

3) L. PEROTIN, MR. LAINET: Integration of a general model of turbulent excitation in *the 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
04/07/09	*A. ADOBES, L. VIVAN (EDF-R&D/MFTT, CS)*	