RBDO analysis of dynamic contact inside the piezoelectric engine

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Introduction

The generation of a progressive wave of volume imposes the respect of geometrical constraints and mechanics relating to the periodicity of the structure of the engine. Under normal conditions of operation, the engines are subjected to: (i) an axial static loading of pre-stressing actuating of the axial and radial deformations stator and rotor, (ii) a dynamic excitation of the stator, involving deformations of inflection out-plan which, while being propagated in the volume of the stator, create by drive, a rigid displacement of the rotor's body et (iii) efforts of contact and friction static and dynamic to the interface of contact between the stator and the coating of friction.

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- Efforts of contact and friction static and dynamic to the interface of contact between the stator and the coating of friction.

The aim of this study is to propose a numerical modelling by the finite element method of the mechanical behaviour of piezoelectric engine SHINSEI USR 60 pennies dynamic loading taking into account the contact without friction by using the reliability analysis.

Contact problems are treated using an augmented Lagrangian approach to identify the candidate contact surface and contact stresses [1] and the dynamic treatment is solved using a time integration scheme.

The stochastic role of each parameter of design in the default risk is highlighted. For this analysis of reliability of the structure, we propose a coupling direct mechanic-reliability between the augmented Lagrangian method to solve the contact, developed on a computer code by finite elements, and probabilistic method FORM [2].

By introducing a risks unit with the mechanical problem, we evaluate the probability that the constraints of contact in the coating of friction exceed a value threshold safety and limit the lifespan initially envisaged when designing engine introducing safety criteria in the optimization procedure.

Reliability design optimization

The ultimate goal of design under uncertainty is to reach an optimum in terms of total cost. In principle, an optimum balance between structural system reliability and other conflicting societal goals must be obtained. This is a difficult task. Traditionally, the solution of the RBDO model is achieved by alternating reliability and optimization iterations. This approach leads to low numerical efficiency, which is disadvantageous for engineering applications on real structures. In order to avoid this difficulty, the hybrid RBDO methods are proposed. In the same direction, we propose the dynamic hybrid method. The efficiency of this method is showed in [3].

Dynamic Hybrid method :

The solution of the above nested problems leads to very large computational time, especially for large-scale structures. In order to improve the numerical performance, the hybrid approach consists in minimizing a new form of the objective function $F(\mathbf{x},\mathbf{y})$ subject to a limit state and to deterministic as well as to reliability constraints:

$$\begin{array}{lll} \text{min} & : & f(\mathbf{x}).d_\beta(\mathbf{x},\mathbf{y},t) \\ \textit{subject to} & : & G(\mathbf{x},\mathbf{y},t)\le 0 \\ & : & d_\beta(\mathbf{x},\mathbf{y},t)\le \beta_c(t) \qquad \forall t\in[0\ \ T] \\ \textit{and} & : & g_k(\mathbf{x},t)\le 0 \end{array}$$

In the case $t=0$ (static problem), $d_\beta(\mathbf{x},\mathbf{y})$ is the distance in the hybrid space between the optimum and the design point, $d_\beta(\mathbf{x},\mathbf{y})=d(\mathbf{u})$. The minimization of the function $F(\mathbf{x},\mathbf{y})$ is carried out in the Hybrid Design Space (HDS) of deterministic variables $\mathbf{x}$ and random variables $\mathbf{y}$.

An example of this HDS is given in figure 1, containing design and random variables, where the reliability levels d_β can be represented by ellipses in case of normal distribution, the objective function levels are given by solid curves and the limit state function is represented by dashed level lines except for $G(\mathbf{x},\mathbf{y})=0$. We can see two important points: the optimal solution P_x^* and the reliability solution P_y^* (i.e. the design point found on the curves $G(\mathbf{x},\mathbf{y})=0$ and $d_\beta=\beta_t$).

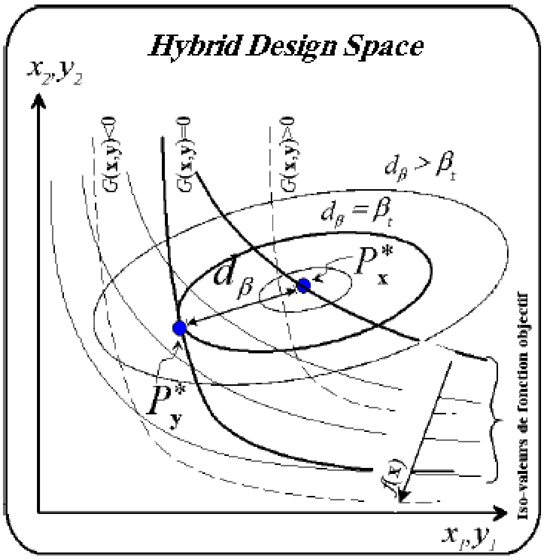

Figure 1. Hybrid Design Space in the case t = 0.

Frequencies Hybrid Method (FHM) :
The response of a structure to a dynamic excitation depends, to a large extent, on the first few natural frequencies of the structure. Excessive vibration occurs when the frequency of the dynamic excitation is close to one of the natural frequencies of the structure. In designing most structures, it is often necessary to restrict the fundamental frequency or several of the lower frequencies of the structure to a prescribed range in order to avoid severe vibration. The hybrid formulation will not be able in its traditional formulation to determine the critical region about eigen-frequency.
A new formulation was developed within the framework of calculations into dynamic excitation. The goal of this development is to seek the dangerous frequencies bands relative to different eigen-frequencies. The principal idea is to seek more than only one point of design. The frequencies band critical is limited by a lower limit and an upper limit. These two points are sought for each iteration.

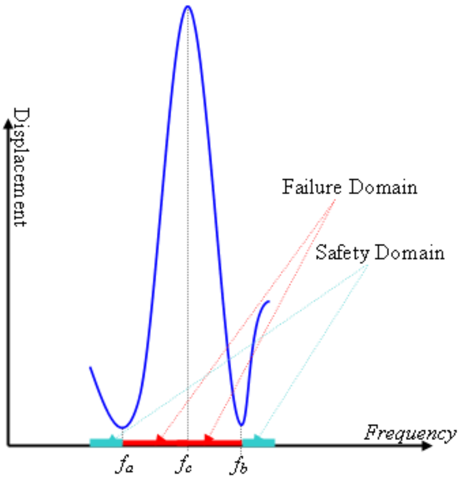

Figure 2. Displacement and eigen-frequency

Formulation : The new formulation of frequencies problem:

$$\begin{aligned} \min_{x,y} \; &: F(\mathbf{x},\mathbf{y}) = f(\mathbf{x}).d_{\beta_1}(\mathbf{x},\mathbf{y}).d_{\beta_2}(\mathbf{x},\mathbf{y}) \\ \textit{subject to} \; &: G(\mathbf{x},\mathbf{y}) \le 0 \\ &: g_k(\mathbf{x}) \le 0 \\ \textit{and} \; &: d_{\beta_1}(\mathbf{x},\mathbf{y}) \ge \beta_t \\ &: d_{\beta_2}(\mathbf{x},\mathbf{y}) \ge \beta_t \end{aligned}$$

Numerical Results

In this example, we present a study on the Reliability design optimisation one stator and rotors of a piezoelectric engine with annular progressive wave SHINSEI USR 60 , which will be subjected to the constraint stress [4]. The body force F_{ext} on the SHINSEI USR 60 engine, is transmit to the rotor circumferential and punctually done at the ratio $R=21.10^{-3}\,m$ with the value 140 N. The mechanical characteristics of different material and geometry are given in tables 1 and 2.

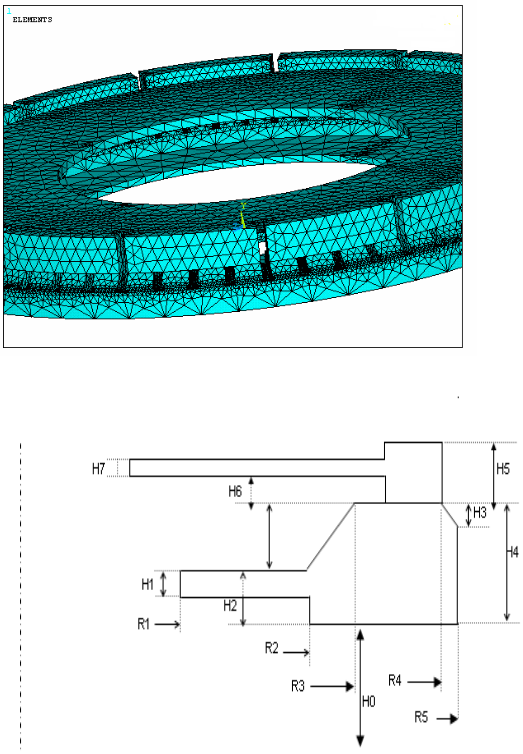

Figure 3. Finite elements and dimensions of stator and rotor.

Param.	H0	H1	H2	H3	H4	H5	H6
(mm)	0.5	0.6	1.2	1	4.2	3.2	1.3
Param.	H7	R1	R2	R3	R4	R5	
(mm)	2.1	16.5	22.5	25	29	30	

Table 1. Geometry characteristics

Rotor		Stator	
E *(MPa)*	ρ *(Kg/m^3)*	E *(MPa)*	ρ *(Kg/m^3)*
27000	2700	123000	8250

Table 2. Mechanical characteristics

Variable	CRBDO *(facteur de sécuritè1.5)*	
	Design Point	*Optimum Solution*
H0	0.52195×10^{-3}	0.53998×10^{-3}
H2	0.11563×10^{-2}	0.12749×10^{-2}
H3	0.66719×10^{-3}	0.99276×10^{-3}
H5	0.32564×10^{-2}	0.24628×10^{-2}
H6	0.12530×10^{-2}	0.13973×10^{-2}
H7	0.20121×10^{-2}	0.20821×10^{-2}
Stress	0.23564×10^{9}	0.23530×10^{9}
Reliability index	3.6	-------------

Variable	RHM	
	Design Point	*Optimum Solution*
H0	0.57767×10^{-3}	0.71853×10^{-3}
H2	0.11494×10^{-2}	0.13036×10^{-2}
H3	0.87807×10^{-3}	0.11079×10^{-3}
H5	0.25716×10^{-2}	0.23572×10^{-2}
H6	0.80493×10^{-3}	0.87639×10^{-3}
H7	0.14356×10^{-2}	0.13696×10^{-2}
Stress	0.2358×10^{9}	0.1560×10^{9}
Reliability index	3.8	----

Table 3. Results of RBDO in stator and rotor

Table 3 shows the RBDO results when using the different distribution laws. After having optimized the structure, the resulting CRBDO can' the required reliability level but the reliability concept into the optimization process in RHM satisfies the reliability constraint.

Variable	*Design Point (a)*	*Optimum Solution*	*Design Point (b)*
R2	22.211×10^{-3}	21.214×10^{-3}	20.76×10^{-3}
R3	25.59×10^{-3}	23.959×10^{-3}	25.4×10^{-3}
R4	29.66×10^{-3}	27.925×10^{-3}	28.33×10^{-3}
H1	0.428×10^{-3}	0.562×10^{-3}	0.678×10^{-3}
H2	1.345×10^{-3}	1.483×10^{-3}	1.549×10^{-3}
H3	1.5×10^{-3}	1.318×10^{-3}	1.66×10^{-3}
H4	3.66×10^{-3}	3.435×10^{-3}	3.489×10^{-3}
β	3.65×10^{-3}	-------	3.6
Frequency *[KHz]*	37.2	39.5	41

Table 4. Results of RBDO in stator

Table 4 shows the FHM results, the solution redefine a new interval [*37.2, 41*] Hz of functioning motor piezoelectric and satisfying a required reliability index (see table 4). In practical cases, we cannot know if the given interval is large or small, this depends on the engineering experience, but the FHM model is a good tool to control it.

CONCLUSION

The coupling of the two aspects "optimization" and "reliability" in only one formulation through traditional model RBDO, allowed a good improvement for the results of deterministic optimization. This improvement is due to the catch in consideration as of the reliability beginning like constraint in order to carry out one to balance between the robustness and the cost of the design to against bets one is to oblige to solve two problems of optimization, which costs much. However, hybrid method RBDO includes in its architecture the deterministic and random parameters in only one hybrid space. This space allows simultaneous control as well as the good control of all the parameters of the problem. The time-variant reliability-based optimization is very interesting in the design for cost-effective, durability and lifetime management of engineering system; it's the Dynamic Hybrid Method. These advantages motivated us in order to improve this method for search of the failure critical region about eigen-frequency; it's the Frequencies Hybrid Method.

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