A new modal synthesis program: OSCAR

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1 INTRODUCTION

Among CASTEM 2000 tools, OSCAR is devoted to dynamic analysis through modal synthesis. Typically, for performing dynamical analysis, for instance, vibration or seismic calculation, it is usually possible to retain the modes in the low frequency range. Also, the main advantage of modal synthesis is the drastic reduction of degrees of freedom. Modal analysis can be used when the sub-structures remain elastic and have only small displacements. This is a satisfactory assessment for most vibration calculations. More over, modal analysis can deal with problems involving localized nonlinearities. In such a case, sub-structure vibration modes are calculated apart from nonlinear phenomena. Then structural motion is projected on the modes which are coupled by describing the non linear behaviour links.
Relatively inexpensive, numerical simulations in non-linear dynamics can be performed with OSCAR either to analyse the behaviour of real systems or to validate simplified models, such as linear equivalent ones.
It is an efficient way of investigating the influence of non-linear links on global vibratory behaviour of structures.

- Resolution algorithm

The Devogelaere-Fu dynamic algorithm described in reference [4] was chosen for OSCAR. With this explicit time-intagration operator, strong non-linearities can be computed without any iteration. This algorithm was proved to be particularly efficient for solving impact problems of loosely supported vibrating tubes.
Sub-structures free modes are computed. The motion of the global structure is projected on the basis of these modes. The projection time functions $\alpha_n(t)$ represent the new degrees of freedom of the system. The number of modes to be retained for calculation is strongly connected with the behaviour law of the linking elements.
The following system is solved:

$$\ddot{\alpha} + M^{-1} C \dot{\alpha} = M^{-1} (-K\alpha + F_{ex} + F_e)$$

where:
M diagonal matrix for generalized masses

K diagonal matrix for generalized stiffnesses
C diagonal matrix for modal damping
F_{ex} vector of external generalized forces
F_e vector of linking forces
α vector of modal projections.

The main features of the algorithm can be given as follows: the solution at time t_{m+1} is extrapolated from the configuration at time t_m under the assumption that the structures are in equilibrium under the effect of internal, external and linking forces calculated at time t_m:

$$\alpha_{m+1} + M^{-1} C \alpha_{m+1} = - M^{-1}(K \alpha_m + F_{exm} + F_{em})$$

Then linking forces are calculated according to the behaviour laws of the various connections elements:

$$F_{em+1} = \mathcal{L}(X_{m+1}, \dot{X}_{m+1}, \ddot{X}_{m+1})$$

where: $X_{m+1} = \Phi \alpha_{m+1}$ Φ modal matrix
is the displacement obtained by modal recombination. These forces, by imposing linking relations, ensure equilibrium of sub-structures at time t_{m+1}.
Of course, this time-discretization scheme is conditionnaly stable. The integration time step must not exceed a critical value which is about half the period of the highest order mode that was retained in the modal basis. This critical value depends as well on the type of link which is used. But, the time step necessary for sufficiently accurate results is always lower than the calculated critical value.

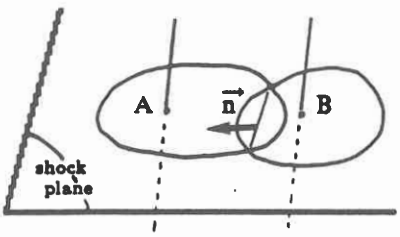
- Connections implemented into OSCAR

The links could generate some forces which can be linears or non-linears in nature, conservatives or dissipatives, or destabilizing. Today, three connections are available:

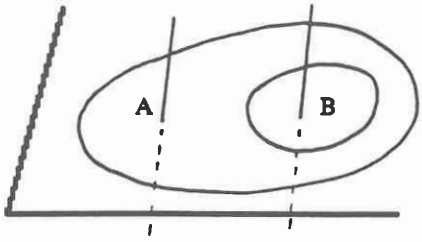
a) Shocks

In vibratory analysis, the influence of small impacts is studied. The important parameters come from the overall behaviour of the impact: dominant resonance frequency and average impact force. A simplified description of the local dynamic behaviour of the impact is sufficient provided that average effects are correctly represented. In this description, the evolution of the shock phenomenon is not detailed. Only the quasi-static effect of neglected modes is kept. Hence, the shock can be represented by an equivalent spring. For instance, the main elastic effect in the case of pipe transverse impact is given by the section ovalization which represents the elastic effect of the transversal modes.
Two types of shock models are implemented:

- impact for which the normal to the contact surface keeps along a constant previously defined direction.
- impact for which the normal to the contact surface belongs to a constant plane: for instance, this method is devoted to impacts between concentric or separated sub-structures with parallel axis. A cross section of the beam is associated with each shock point.



separated sub-structures



concentric sub-structures

In both cases, if an impact occurs at a shock point, forces proportional to the penetration of the two bodies are applied at this point along the normal of the contact: $F_n = k\ e\ n$.

b) Friction

In most of the impacts between sub-structures, the contact surfaces are sliding along each other. Then the friction causes the most important loss of energy.
When sliding is important, it is necessary to calculate the tangential forces. Here, the Coulomb's law of friction is used for that purpose.
As long as the sub-structures are in contact, the relative velocity of impact surfaces is calculated. Then:

- if sliding occurs, a friction force is applied. This force is proportional to the modulus of the normal force and directly opposite to the relative velocity,
- if not, the bodies may be considered to roll upon another as if hinged and the reaction coming from this non-slipping condition is calculated.

Sliding ends when relative velocity changes sign. It begins when the non sliding reaction is greater than a threshold proportional to the normal force modulus.
However, coefficients of friction for impact phenomena are not well known and consequently they rest either upon pure hypothesis or upon corresponding values for non-collision processes. Figures 1, 2 and 3 show an impacting beam.

c) Weir fluid discharge

A fluidelastic instability was discovered during test operations of SUPERPHENIX 1 LMFBR Reactor (see ref. 2). The instability is due to energy bringing by discharge to the fluid-structures system constitued by the flexible weir shell and adjoining thin fluid collectors.
The interaction fluid-structure modes are coupled by the weir discharge, and then, exchange energy between themselves.
The modelization of the weir effect is realized by flow and forces sources localized at the top of collectors.
At the weir top, the flow source is given by:

$$q_{d_t} = g^{1/2} z^{3/2}$$ where Z is the free surface position of the weir.

At the bottom collector, the flow source is retarded with regard to the discharge at the weir top by a time τ. τ is the time taken for the fluid to fall the distance between the collector levels.

$$q_{d_b} = q_d\ (t - \tau)$$

Moreover, the flow impact creates the force:

$$F = - q_d\ (t - \tau)V$$ where V is the flow velocity.

This model allows to estimate the vibratory level when a steady state is reached by the effect of non-linearities. Figures 4, 5 and 6 display a typical calculation results of OSCAR.

CONCLUSION

Various non-linear theoretical models can take place in OSCAR formalims. The computation have been found relevant to calculate the behaviour of complex systems and to predict steady state amplitude or average values. This type of code have proved to be very user friendly and presents a large adaptability to various dynamic problems.

REFERENCES

[1] AXISA F., ANTUNES J., VILLARD B. (1986)
Overview of numerical methods for predicting flow induced vibration and wear of heat exchange tubes.

[2] AITA S., BENASSIS T., GUILBAUD D., GIBERT R.J. (1987)
Fluidelastic instability of a flexible weir, non linear analysis Cranfield (ENGLAND) to be presented at flow induced vibrations conference.

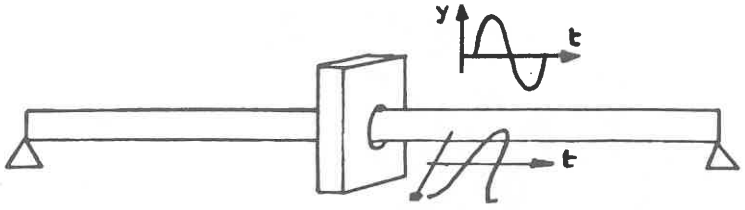


Figure 1. Friction impacts of a tube in a circular support plate

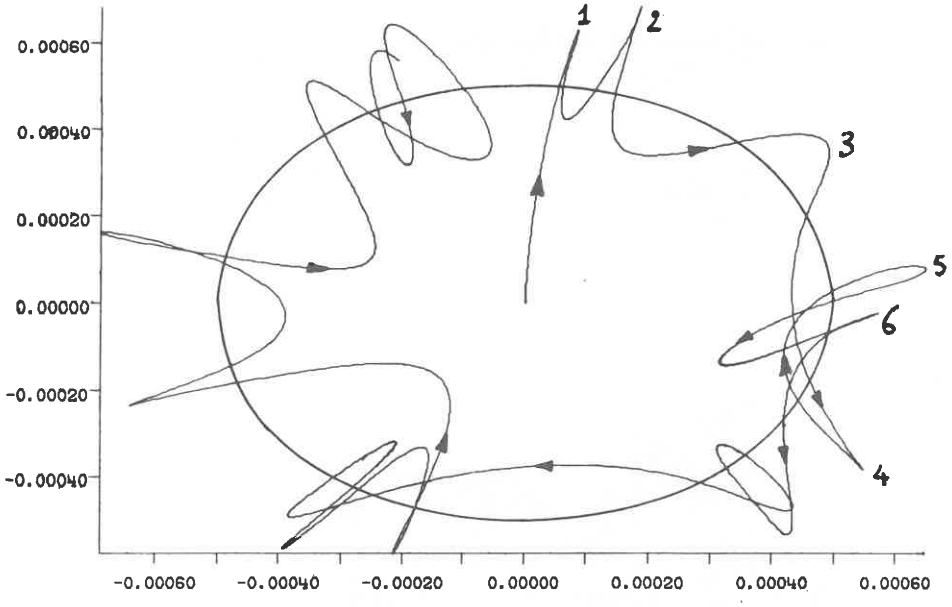


Figure 2. Trajectory of the tube center during a period of the excitation.

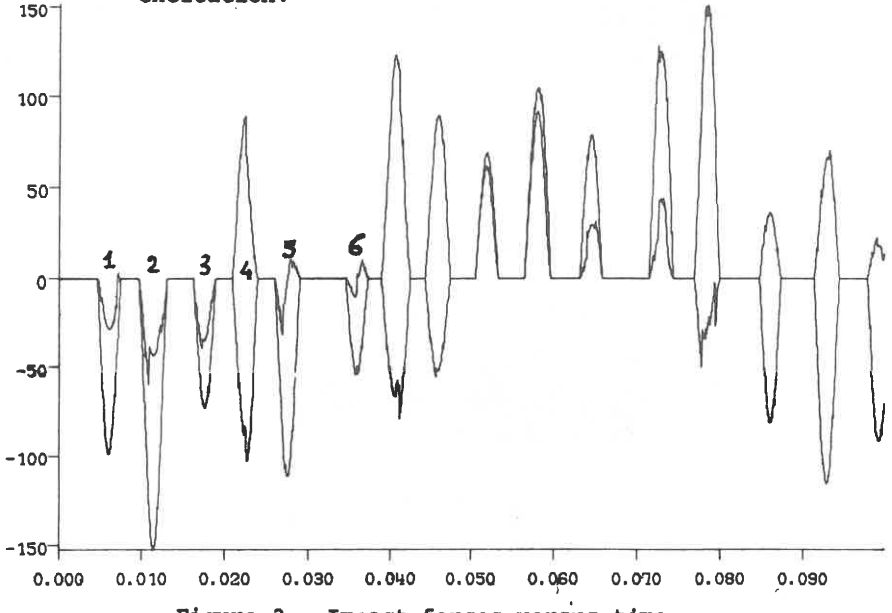


Figure 3. Impact forces versus time.

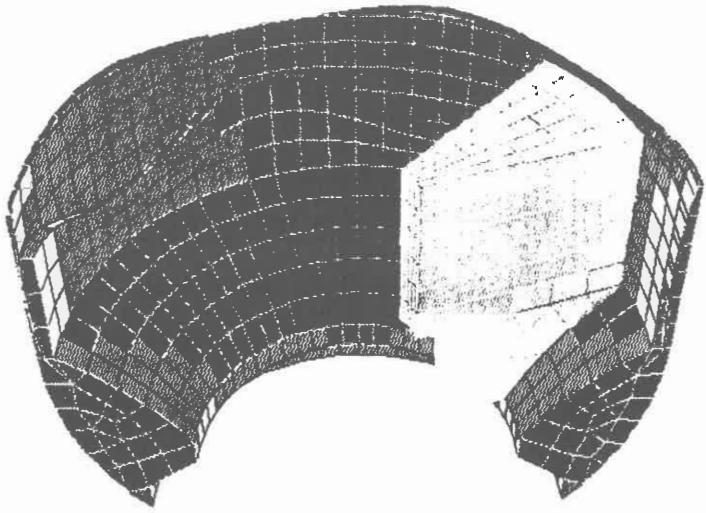


Figure 4. Sloshing mode of Superphenix weir (n=5).

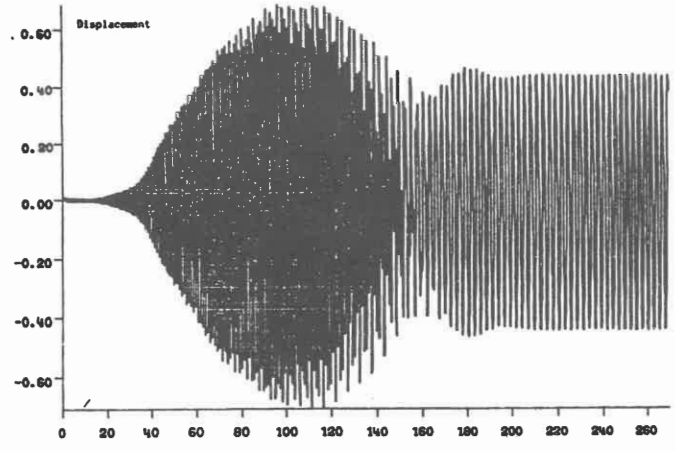


Figure 5. Instability growing and installation in case of two conflicting modes of different nature (sloshing and fluidelastic).

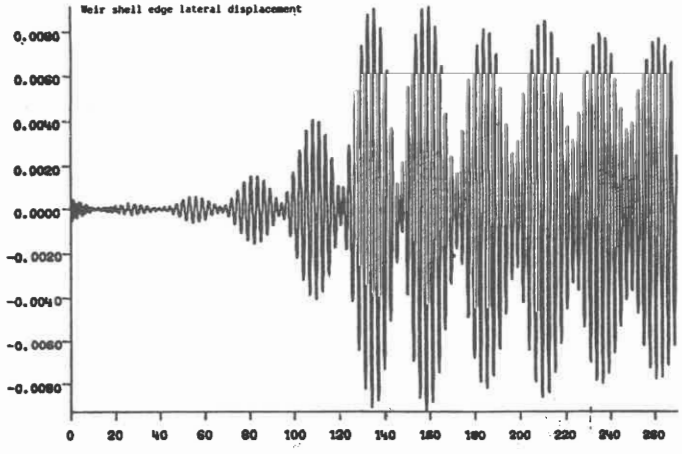


Figure 6. Instability growing and installation in case of two conflicting instable modes of same nature (sloshing).