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VIBRO-ACOUSTICS ANALYSIS OF A MEDICAL XRAY SOURCE: HYBRID APPROACH COMBINING EXPERIMENT AND FEA/BEA MODELING

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ABSTRACT
A vibro-acoustics analysis of a medical X-Ray source is presented. As the X-Ray source noise is generated by the interactions between the internal rotor and its bearing which are very complicated to describe, the analysis is carried out by using an hybrid approach combining experimental data measured on the system and an elasto-acoustics FEA/BEA model. This methodology, already applied for automotive and aerospace domains, uses RAYON® solver integrated in the MCAE environment of I-DEAS™. Firstly, an inverse procedure is applied to determine an equivalent source model as a set of internal forces derived from vibration measurements in running condition and the elasto-acoustic model. Secondly, the BEA model and the source previously found are used to compute the radiated noise. Experimental and numerical results of both vibrations and radiated noise are finally compared. Such approach yields to a vibro-acoustics model capable to help for the path noise analysis and for the numerical modification analysis which have been applied to lead to several noise reduction improvements on the X-Ray source.

1 - INTRODUCTION

The development of Medical systems based on X-RAY sources are mainly driven by mechanical, high voltage electrical and optical constraints needed to insure the best result for medical diagnosis. But acoustic annoyance generated by such system becomes an emergent constraint regarding hospital and community regulation as well as patient comfort during the exposure analysis. As the major noise generator in the X-RAY source is due to the rotational motion of the rotor interacting with its bearing, one way to reduce the noise concerns the bearing itself for which GEMS works continuously. The other way is to decrease vibration-acoustic path from the bearing to the external casing. In the latest case, the vibro-acoustic analysis of such system remain an hard task as the X-RAY structure is complex, involving in one hand a lot of interacting components and the other hand initial vibration source difficult to describe. Up to now, major improvements are found by using experiments on prototyped solutions.

This paper presents an investigation carried out on the X-RAY source in order to evaluate capabilities of the numerical modeling approach which could offer a more efficient way to analyze the vibro-acoustic behavior of the X-RAY source and to help for design improvements.

The methodology used, have been already successfully applied for automotive and aerospace domains [1,2] and take advantage of FEA/BEA capabilities of the RAYON® solver developed by STRACO which is integrated as the I-DEAS Vibro-acoustics task in the MCAE environment of I-DEAS™ [3].

This methodology is based on an hybrid approach combining both experimental data measured on the system in running condition and a numerical vibro-acoustic FEA/BEA model. Firstly an inverse problem is solved in order to determine an equivalent set of forces which represents the unknown efforts induced by the bearing. This problem involves both acceleration spectra measured over the X-RAY source Casing and the numerical transfer function provided by the FEA/BEA model. Secondly, both vibration responses and radiated noise are derived from the FEA/BEA model and the force spectra. Some results are proposed and discussed in this paper.

2 - XRAY SOURCE DESCRIPTION

The XRAY source, presented on the figure 1, is composed by an internal insert, the XRAY generator, mounted in a full of oil casing. The internal insert is made of a glass balloon which contains a static cathode mounted on the balloon top side and the rotating anode positioned on the balloon queue side. A deep vacuum is preserved in the insert. The insert queue is covered by the stator.
In running conditions, the bearing which maintained the anode rotor during its motion generates the major part of vibrations which propagate along the insert and its support, and then along the oil and the casing to induce the external noise radiation.

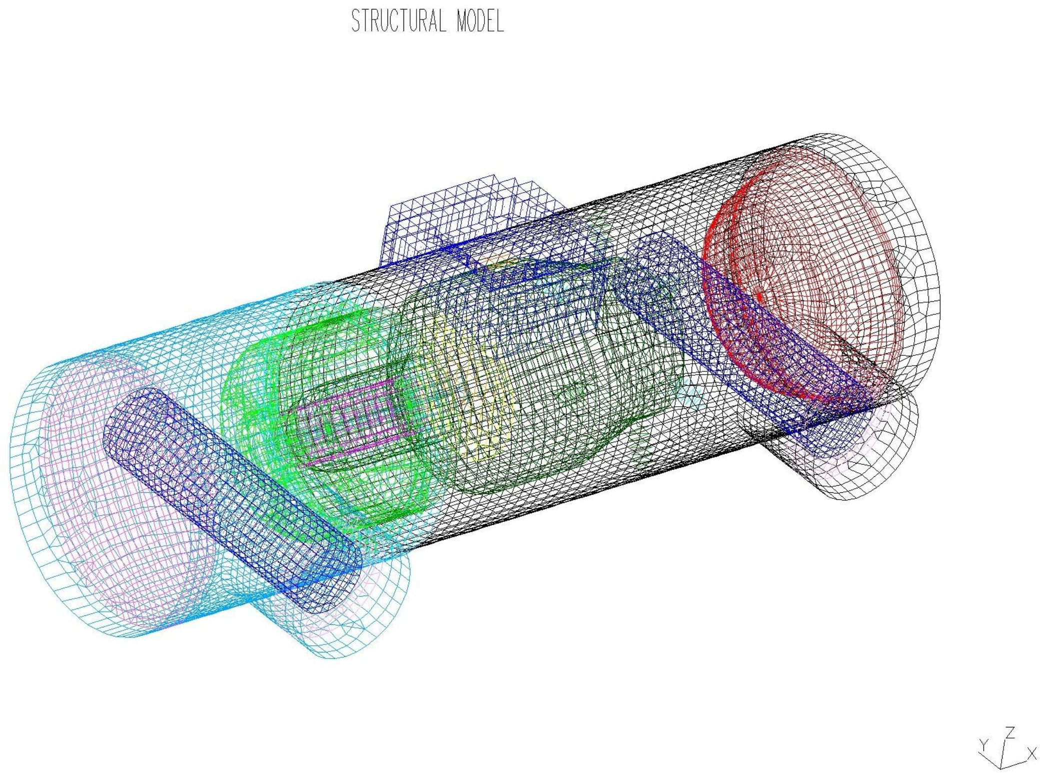

Figure 1: XRAY source model.

3 - MODELING AND EXPERIMENTAL PROCEDURES

In order to analyze the vibro-acoustic behavior of the XRAY source an hybrid approach involving both a vibro-acoustic FEA/BEA model and an experimental analysis has been performed. The analysis have been carried out to cover frequency range up to 4,5 KHz.

3.1 - Experiments

The experiments have been conducted on an actual XRAY source in order to provide data needed for: the vibro-acoustic analysis, the model refinement, the inverse problem force characterization and the model validation. In such way, acceleration spectra on 60 points distributed over the XRAY source casing as well as the near field radiated pressure and intensity have been measured in running condition. Complementary information concerning the XRAY source modal analysis has been derived from Acceleration/Force transfer functions measured by exciting the casing with a shaker.

3.2 - FEA/BEA model

The XRAY source model is build according to a variational formulation developed in the RAYON software which couples the Finite Element model of the XRAY source structure in vacuum by using NASTRAN software [4] and the internal Boundary finite element model by using RAYON which represents the oil within the casing (uncompressible assumption is assumed).
The elasto-acoustics behavior of the assembled system is driven by the hydro-elastic modes corresponding to the eigen-value problem given by Eq 1:

$$\left[K_s - \omega^2 \left(M_s + M_a\right)\right] \Psi_{as} = 0 \tag{1}$$

where K_s and M_s describe the FEA stiffness and mass matrices of in vacuum and M_a is the added mass describing the oil effect on the structure. This problem is solved by using a modal scheme involving around 200 in vacuum structural modes and yields 168 hydro-elastic modes to cover the frequency range of interest.
Casing vibration responses are then given by solving the excited system in which internal forces related to the bearing are introduced.

3.3 - Inverse problem force characterization
As these forces are unknown, an inverse problem involving both experimental accelerations measured on the XRAY source casing and the vibro-acoustic model is solved as summarized in fig. 2. An equivalent force model composed of 6 translation and rotation forces acting on the anode axis is assumed. Transfer functions between each force and measured acceleration location (H_{ij}) coming from the model and the measured acceleration spectra ($\gamma_i^{\exp}$) provided by the experiments in running condition, are combined in a least square minimization procedure (Eq. 2) to deduce unknown force spectra F_j.

$$F_j \text{ which minimizes } : \sum \left\| \gamma_i^N - \gamma_i^{\exp} \right\|$$
$$\text{where } \gamma_i^N = \sum H_{ij} F_j$$

Results are then evaluated by comparing synthesized acceleration derived from the model and those measured.

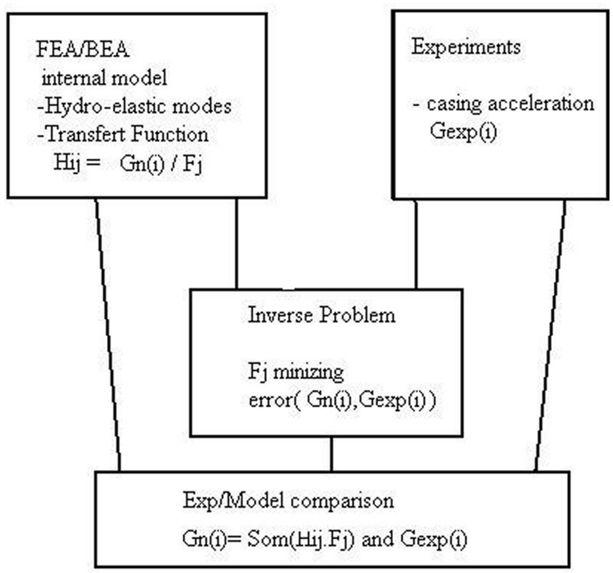

Figure 2: Inverse problem procedure.

3.4 - External noise radiation
Finally radiated noise is derived by using the external BEA XRAY source model excited by the acceleration found in the previous step. In this case, air coupling reaction on the XRAY source vibrations is supposed to be negligible. The numerical procedure is conducted in two step: firstly, transfer functions between radiated pressure and each internal force are computed, secondly the final pressure responses are synthesized by combining transfer functions to the force spectra previously determined.

4 - RESULTS AND CONCLUSION
As presented in figure 3, the modeled acoustic pressures radiated by the XRAY source matches reasonably well the global tendency of the experimental result. But discrepancies within the range of 6 to 10dB are registered. They are mainly caused by two problems:

- as the XRAY source is a resonant system which is controlled by light damped modes, force characterization and dynamic responses are very sensitive to the accuracy of the structural model which needs to be more refined than the one used.
- the source model, composed by only 6 forces, is certainly not sufficient to control efforts induced by the bearing.

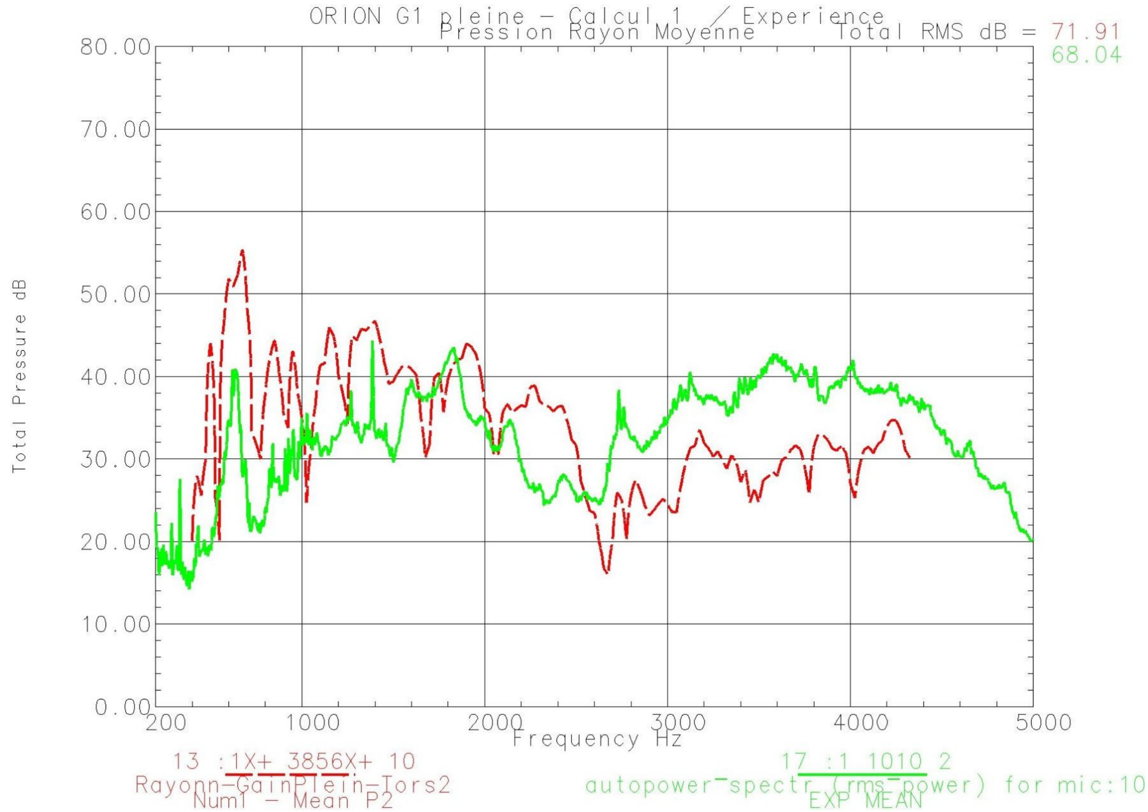

Figure 3: Radiated pressure comparison; exp. (solid), model (dashed).

Nevertheless, the modeling approach results remains interesting and sufficient to evaluate the influence of particular components and to investigate design improvements to reduce the noise. For instance, the oil effect is figured in fig. 4. These results for which tendency have been verified by experiments, show that the noise path is controlled in low frequency by the structure path and above 1,5 KHz, by the oil path.

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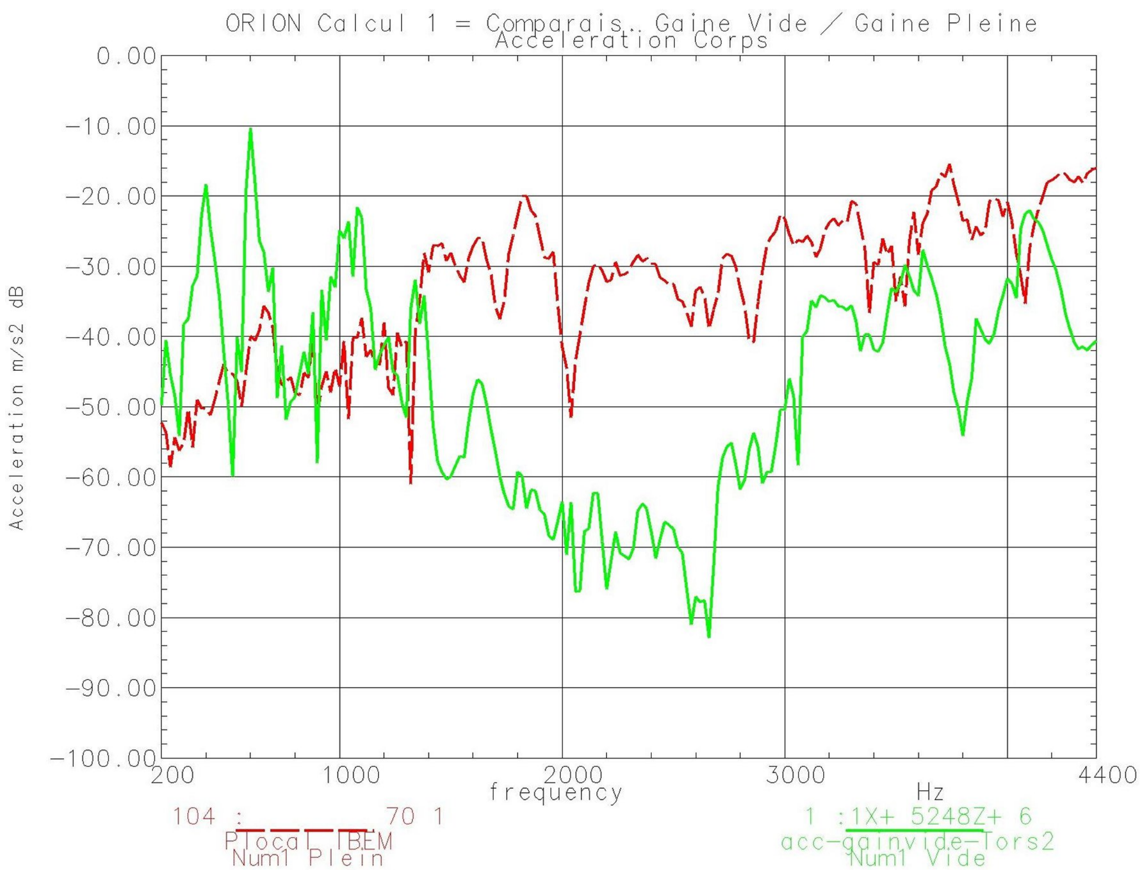

Figure 4: Model comparison; with oil (dash), without oil (solid).