INTERNAL FLUID INFLUENCE ON THE DYNAMIC BEHAVIOUR OF THE RESONANCE BOX OF THE GUITAR

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ABSTRACT
The vibrational behaviour of the guitar box has been studied attending to the influence of the internal gas. In this sense the box has been filled with air, helium and krypton. The problem has been approached in two ways: experimental, through the modal analysis technique, and calculated, by means of the finite element method. The dependence of the vibration patterns, natural frequencies and dynamic response on the mechanical characteristics of the fluid has been established. Likewise the study confirms the numerical model developed in order to describe the structure-fluid interaction.

1. INTRODUCTION

In string instruments, resonance boxes amplify and filter the string vibration and accordingly determine the final sound to a great extent. In previous works we have studied the vibrational dynamics of the guitar box by means of experimental measurements and numerical calculations [1]. Now we show that the inner fluid determines the vibrational response of the resonance box and prove the adequacy of the numerical model to the aim, the fluid – structure coupling including the role of the sound hole. We have carried out a comparative study of the vibrational behaviour of the guitar box filled with different fluids: helium, air and krypton, by means of the modal analysis method [2] and the finite element method [3]. In this way the influence of the fluid type on the vibration patterns, natural frequencies and frequency response of the instrument together with the participation factors of the uncoupled modes (wooden structure and inside fluid) on the coupled modes can be analysed.

2. EXPERIMENTAL

2.1 Modal Analysis

The modal analysis technique has been applied to the resonance box filled with helium, krypton and air in order to compare their respective effects on the dynamical behaviour. Among the available applications, the Frequency Response Function (FRF) was chosen. As for the boundary conditions, the ribs were fixed by means of polyurethane foam to a metallic mould, in order to prevent the soundboard and back plate perimeters from moving in the analysed frequency band.

2.2 Numerical Model

The numerical model is based on the finite element method: a guitar box model (whose geometrical design and material parameters were similar to the real one) was developed from its individual components till the assembled box. [1] On the other hand the inside fluid was separately studied introducing a new procedure [4] that allows the sound hole role to be included through a length correction to the opening thickness.

What has been said above allowed us to obtain the uncoupled vibration modes corresponding to the wooden structure and to the three inside fluids. On these uncoupled modes, the modal coupling method was successively applied to calculate the vibration patterns and natural frequencies of the coupled modes due to the fluid – structure interaction. Together with the normal modes the numerical results include the participation factors of the uncoupled modes in the coupled modes. Therefore besides the prediction of the vibrational behavior this numerical study contributes to the analysis of the experimental data.

3. RESULTS AND DISCUSSION

3.1 The Internal Fluid Modes By The Finite Element Method

Figure 1 shows the lowest modes corresponding to the three gases, the different correction lengths that takes up the effects of the radiation and of the external medium can be appreciated. As can be seen frequencies and patterns differ depending on the gas. Regarding to frequency values they are closely related to the mechanical (density and bulk modulus) parameters. Geometrical patterns have in common that A0 is not a pure Helmholtz mode since the sound pressure does not feature a constant distribution. Although the results show an in-phase vibrational behavior they also reveal a different value for the sound pressure all over the cavity. This fact is more evident in the case of krypton whereas helium case is closer to the ideal even pressure distribution. The pressure values corresponding to different gases are not comparable, in this mode and in the rest, because the modes have been independently normalized, being the pressure distribution of each mode the only significant. Thus pressure differences between upper and lower part of the box are of 25% for helium, 60% for air and 80% for krypton.

The vibrational patterns corresponding to the upper modes A1, A2 … are similar in the three cases, and can be found in [4]. Therefore the size and shape of the cavity determine the stationary waves patterns, and the type of fluid has no influence on them. Frequencies are shown in Table 1. As was to be expected the highest frequencies correspond to helium, the lightest gas. The frequencies of the acoustic modes of air and krypton are in the same range of those of the structural modes; this fact makes easier the low-frequency coupling. On the other hand the coupling for helium is possible only through A0 mode since the rest of acoustic frequencies are over 1 kHz.

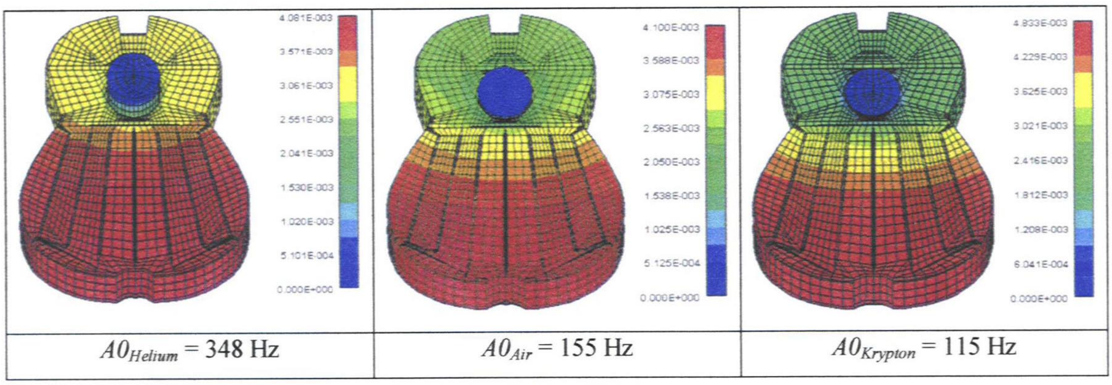

Figure 1: Calculated patterns and frequencies of mode A0 corresponding to the three gases considering the cavity as rigid

	A0	A1	A2	A3	A4	A5
Helium	348 Hz	1150 Hz	1587 Hz	2087 Hz	2238 Hz	2857 Hz
Air	155 Hz	418 Hz	545 Hz	718 Hz	771 Hz	981 Hz
Krypton	115 Hz	287 Hz	356 Hz	471 Hz	505 Hz	640 Hz

Table 1: Frequency values corresponding to the six lowest modes of the rigid cavity filled with helium, air and krypton

3.2 Coupled Modes

As it was demonstrated in a previous paper [1], the air contained in the box allows the connection between soundboard and back plate, giving rise to the modes of the box. Moreover it acts as an added mass because the natural frequencies decrease in comparison with those of the structural modes. Furthermore the interaction between structural and acoustical modes depends on the vibrational character of the structural modes, for example, some modes are unable to couple and therefore appear only in one part – soundboard or back –; this is the case of the transversal flexural modes.

So the choice of the three gases was due to their physical properties, basically their densities, looking for their influence on the final behaviour of the instrument. On the one hand the results will allow us to validate the whole process, and on the other hand the comparative study will stress the nature of the coupling.

As an example, figure 2 shows the calculated and measured vibration patterns, natural frequencies and quality factors of eight lowest modes of the box with the ribs fixed, filled with krypton.

Figure 3 shows the uncoupled modes forming this coupled mode by means of the participation factors.

In Table 2 the frequency and quality factors values are presented for the three gases. It can be seen that experimental and calculated modes are similar and appear in the same order. Mode TB(4) was predicted in the case of Krypton and air, but it was not experimentally detected.

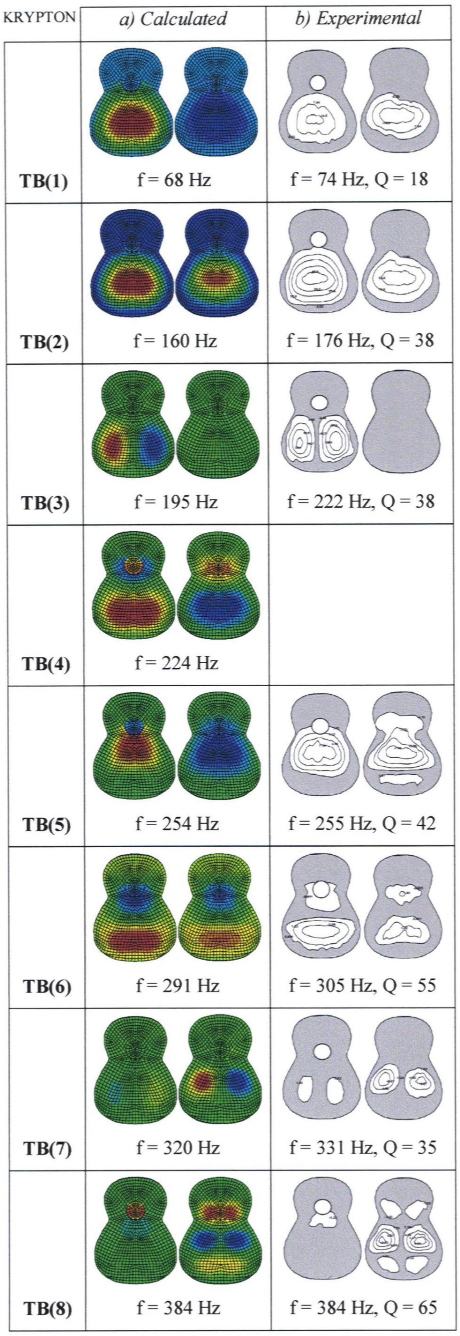

Figure 2: Vibration patterns corresponding to the guitar box filled with krypton

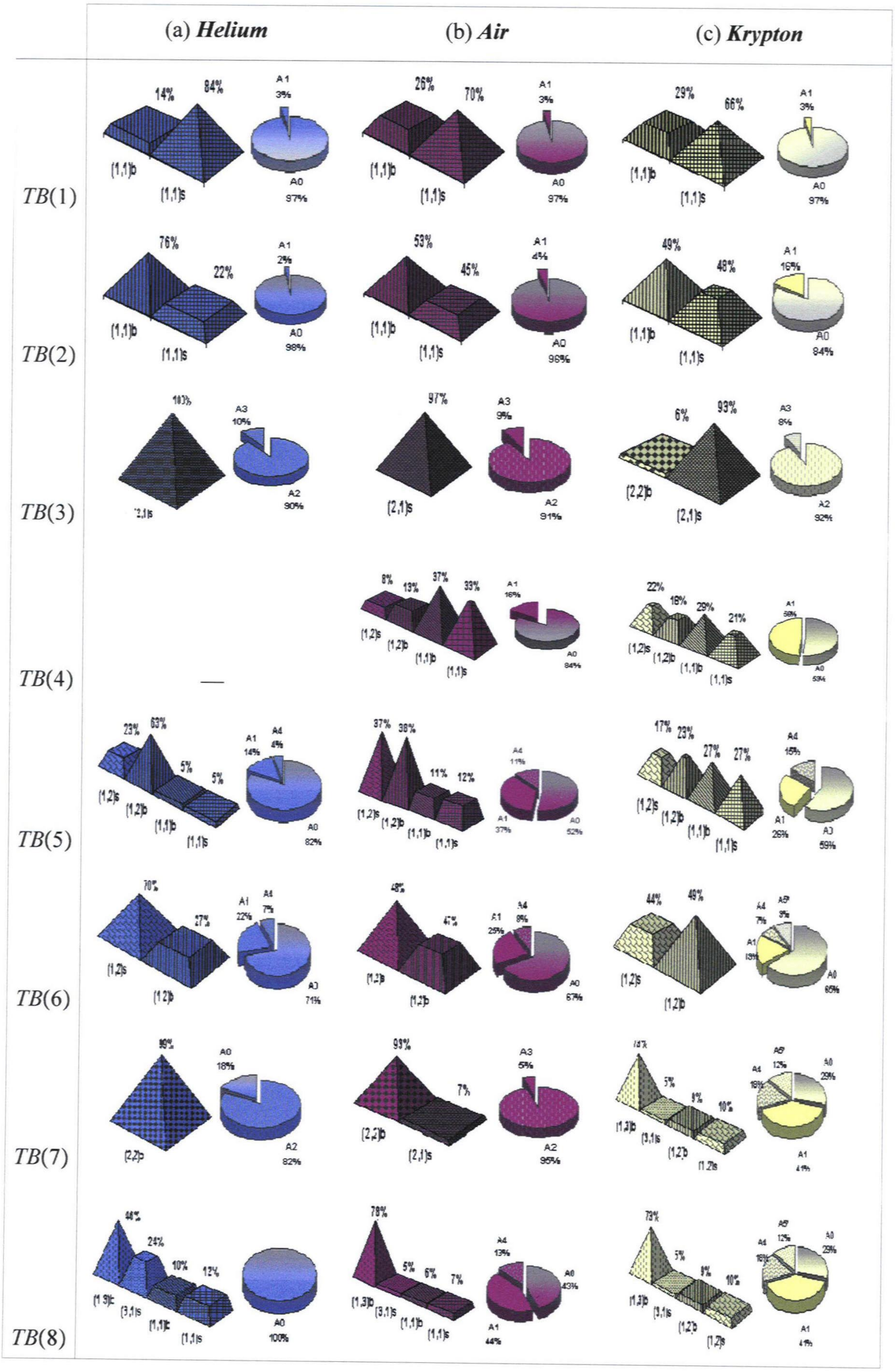

Figure 3: Participation factors of the uncoupled modes (structural and acoustic) on the coupled modes of the guitar box

	Helium		Air		Krypton	
	Calculated	Experimental	Calculated	Experimental	Calculated	Experimental
TB(1)	128 Hz	142 Hz, Q= 34	91 Hz	101 Hz, Q= 25	68 Hz	74 Hz, Q= 18
TB(2)	170 Hz	189 Hz, Q= 30	162 Hz	180 Hz, Q= 31	160 Hz	176 Hz, Q= 38
TB(3)	215 Hz	246 Hz, Q= 35	210 Hz	239 Hz, Q= 37	195 Hz	222 Hz, Q= 38
TB(4)	*	*	242 Hz	*	224 Hz	*
TB(5)	287 Hz	296 Hz, Q= 20	259 Hz	282 Hz, Q= 50	254 Hz	255 Hz, Q= 42
TB(6)	292 Hz	333 Hz, Q= 37	290 Hz	323 Hz, Q= 58	291 Hz	305 Hz, Q= 55
TB(7)	352 Hz	391 Hz, Q= 28	332 Hz	372 Hz, Q= 42	320 Hz	331 Hz, Q= 35
TB(8)	396 Hz	439 Hz, Q= 22	373 Hz	393 Hz, Q= 50	384 Hz	384 Hz, Q= 65

Table 2: Frequency and quality factor values corresponding to the guitar box in the three cases

4. CONCLUSIONS

The finite element and the modal analysis methods have been applied to the guitar box filled with three gases in order to study in depth its vibrational behavior, emphasizing the fluid – structure coupling and the influence of the type of fluid. The results allow us to draw some conclusions about the fluid - structure coupling, the dynamic behavior of the guitar box and the appropriate methodologies to approach complex vibrating system:

- Concerning to the acoustic modes
  - The six lowest acoustic modes of the guitar box present the same pattern independently of the type of fluid, for the three studied gases
  - The pressure distribution inside the box is the same for the three gases in all the modes excepting the Helmholtz resonance
  - In the Helmholtz resonance, the pressure field is nearly uniform in the case of helium, and presents a strong gradient pointing to the upper part of the cavity in the case of krypton, being the air halfway between them. So A0 pattern depends on the fluid density, and the denser is the gas, the more different is this mode from the pure Helmholtz resonator
- Concerning to the dynamic behaviour of the resonance box
  - The type of fluid determines the modal patterns and frequencies of the whole resonance box
  - Since A0 mode is present at whatever mode with soundboard – back interaction via fluid, its frequency and pressure pattern determine the coupling with the structural modes. In this sense the Helmholtz mode determines the coupled modes to a great extent
  - The frequencies and patterns corresponding to A1, …A5 modes have an influence on their coupling with the structural modes
  - The experimental measurements show that quality factor is a very sensitive parameter to type of inside fluid
- Concerning to the methodology
  - Combining modal analysis and finite element method is adequate to analyse different structural designs and their effect on the dynamical response of the resonance box.
  - Furthermore the developed finite element model proves to be valid for studying the dynamic fluid – structure coupling in whatever mechanical system including cavities connected to the outside

5. REFERENCES

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