THE PHYSICS OF TIBETAN SINGING BOWLS

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ABSTRACT

Singing bowls are traditionally made in Tibet, Nepal, India, China and Japan. Although the name qing has been applied to lithophones since the Han Chinese Confucian rituals, more recently it also designates the bowls used in Buddhist temples. In the Himalaya there is a very ancient tradition of metal manufacture, and bowls have been handcrafted using alloys of several metals - mainly copper and tin, but also other metals such as gold, silver, iron, lead, etc. - each one believed to possess particular spiritual powers.

There are many distinct bowls, which produce different tones, depending on the alloy composition, their shape, size and weight. Most important is the sound producing technique used - either impacting or rubbing, or both simultaneously - the excitation location, as well as the hardness and friction characteristics of the exciting stick (called puja, frequently made of wood and eventually covered with a soft skin). Today, tibetan bowls are used essentially for ceremonial and meditation purposes. Nevertheless, these amazing instruments are increasingly being used in contemporary music.

Quite recently, some researchers got interested in the physical modelling of singing bowls, using waveguide synthesis techniques for performing numerical simulations [1-3]. Their efforts have been aimed particularly at achieving real-time synthesis. Therefore, understandably, several aspects of the physics of these instruments do not appear to be properly clarified in the currently published results. For instance, to our best knowledge, influence of the radial and tangential vibratory motion components of the bowl shell -and their dynamical coupling – have been ignored in the simulation literature. Also, how these motion components relate to the travelling position of the puja contact point is not clear, at the present time.

Details of the contact/friction interaction formulations have been seldom provided, and the significance of the various contact/friction parameters has not been asserted. On the other hand, experiments clearly show that beating phenomena arises even for near-perfectly symmetrical bowls, an important aspect which the published modelling techniques seem to miss (although beating from closely mistuned modes has been addressed -not without some difficulty [3]- but this is a quite different aspect).

Therefore, one may state that several important aspects of the excitation mechanism in singing bowls still lack clarification.

In this paper, we extend to the axisymmetrical tibetan bowls our basic techniques of physical modelling, already successfully used in previous papers concerning plucked and bowed strings [4-7] as well as impacted and bowed bars [7-10]. Our approach is based on a modal representation of the unconstrained system - here consisting on two orthogonal families of modes of similar frequencies and shapes. The first modeshapes have significant radial and tangential components, which are prone to be excited by the normal and frictional contact forces between the bowl and the travelling puja. Normal and tangential interaction forces are projected on the modal basis and a time-step integration of the modal differential equations is performed using an explicit algorithm. Then the physical motions at the contact location (and any other selected points) are obtained by modal superposition, from which the interaction forces can be computed, and the integration proceeds. Details on the specificities of the contact and frictional formulations used in our simulations are given in the paper.

An experimental modal identification has been performed for three different tibetan bowls, the main results of which are supplied. Then, we produce an extensive series of nonlinear numerical simulations, for both impacted and rubbed bowls. We show the influence of the contact/friction parameters on the produced sounds. Concerning the excitation of singing bowls, it becomes clear that - for suitable friction parameters, and for adequate ranges of the normal contact force Fn and tangential rubbing velocity Vt of the puja - an instability of the second shell mode (e.g., the first "elastic" mode, with 4 azimuthal nodes) arises, with an exponential increase of the vibration amplitude until saturation by nonlinear effects is reached. Our computations show that, concomitantly, the unstable mode also spins at the angular velocity of the puja Wp = Vt / R (where R is the bowl radius).

When the self-excited motion settles-in, the bowl/exciter travelling contact point lays in a node of the radial component of the rotating unstable mode, which corresponds to an anti-node of the tangential component. As a consequence, for the listener (or any fixed transducer), the singing bowl behaves as a rotating quadropole, with spinning velocity Wp. Because Wp is always much smaller than the frequency of the unstable ("singing") mode, the sound will be perceived as beating phenomena (at four times the Wp frequency) - even for a perfectly symmetric bowl. The envelopes of the beating normal and tangential motion components are out-of-phase. However, for a perfectly symmetric bowl, no beating at all is observed at the moving excitation point.

As for bowed strings and bowed bars, the effectiveness of the self-excitation mechanism increases when the static and dynamic friction coefficients are further apart. Concerning the influence of the normal contact force and tangential velocity of the exciter, we show that - for given friction parameters - only specific ranges of Fn and Vt lead to steady self-excited responses. Interestingly, the transient durations increase with Vt and decrease at higher values of Fn. On the other hand, the motion amplitudes of self-excited regime increase almost linearly with Vt, but are almost independent of Fn. Because of the intimate coupling between the radial and tangential shell motions, the effective bowl/puja contact force is not constant, but also oscillates. Indeed, when the tangential velocity increases beyond some limit value, the normal vibration amplitude becomes high enough for the contact between the bowl and the puja to disrupt in an intermittent manner, and the system starts to "ring" due to chaotic impact/friction chattering (an effect well known to every bowl player, but which we have not yet seen documented in simulation results). Because this limit velocity increases with Fn (and also because transients become shorter), it appears that - within a reasonable range – higher contact forces enable an easier control of the bowl playing. We conclude with an illustration of the dynamical behaviour of impacted and rubbed bowls when they have less-than-perfect shapes - a very common occurrence – for which slight differences in the frequencies of orthogonal mode pairs arise, leading to a different kind of beating phenomena.

From our computations, sounds and animations have been produced. Many aspects of the bowl responses highlighted in our simulations have been observed in preliminary qualitative experiments. As a concluding note, the computational methods presented in this paper can be easily adapted for the dynamical simulation of glass harmonicas, by simply changing the modes of the computed system, as well as the contact and friction parameters.

REFERENCES

[1] P. Cook, "Real Sound Synthesis for Interactive Applications", A. K. Peters, Natick, Massachusetts, USA (2002).

[2] S. Serafin, C. Wilkerson, J. Smith III, "Modeling Bowl Resonators Using Circular Waveguide Networks", Proceedings of the 5th International Conference on Digital Audio Effects (DAFx-02), Hamburg, Germany (2002).

[3] D. Young, G. Essl, "HyperPuja: A Tibetan Singing Bowl Controller", Proceedings of the Conference on New Interfaces for Musical Expression (NIME-03), Montreal, Canada (2003).

[4] J. Antunes, M. Tafasca, L. Borsoi, "Simulation des Régimes Vibratoires Non-Linéaires d'Une Corde de Violon", Bulletin de la Société Française de Mécanique, Nº 2000-3, pp. 193-202 (2000).

[5] J. Antunes, L. Henrique, O. Inácio, "Aspects of Bowed-String Dynamics", Proceedings of the 17th International Congress on Acoustics, (ICA 2001), Roma, Italy (2001).

[6] O. Inácio, "Largeur d'Archet et Régimes Dynamiques de la Corde Frottée" , Actes du 6e Congrès Français d'Acoustique (CFA 2002), Lille, France (2002).

[7] O. Inácio, L. Henrique, J. Antunes, "Nonlinear Dynamics and Playability of Bowed Instruments: From the Bowed String to the Bowed Bar", Proceedings of the Eleventh International Conference on Computational Methods and Experimental Measurements (CMEM 2003), Halkidiki, Greece (2003).

[8] O. Inácio, L. Henrique, J. Antunes, "Dynamical Analysis of Bowed Bars", Proceedings of the 8th International Congress on Sound and Vibration (ICSV8), Hong Kong, China (2001).

[9] O. Inácio, L. Henrique, J. Antunes, "Simulation of the Oscillation Regimes of Bowed Bars: A Nonlinear Modal Approach", Communications in Nonlinear Science and Numerical Simulation, Vol. 8, pp. 77-95 (2003).

[10] L. Henrique, J. Antunes, "Optimal Design and Physical Modelling of Mallet Percussion Instruments", Actes du 6e Congrès Français d'Acoustique (CFA 2002), Lille, France (2002). Also in Acta Acustica (2003, in print).