INVESTIGATION OF BELL CLAPPERS BEHAVIOUR ON BELL SOUND

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1.0 ABSTRACT

A bell radiates sound when a clapper excites it but the vibration of the clapper also produces sound at a lower magnitude. In addition, the vibrating clapper also causes double hits as it comes in contact with the bell. This study is aimed at investigating the effects of the vibrating clapper on the tonal quality produced by the bell and redesigns a clapper which will minimise the effects due to the vibration of the clapper. To achieve this, the clapper is modelled in ANSYS and experimental modal analysis is used to verify the results. Further redesign of the clapper will be done in ANSYS after the verification of the initial model. The original sound spectrum of the bell is used as comparison to the spectrum obtained by the excitation of a clapper to determine to the extend of disturbance caused by the clapper's vibration. Thus far, no extensive scientific research has been done on the effects of clapper's radiation of sound and vibrational characteristics on the tonal quality of the bell. This subject of research is in parallel with similar problems faced by musicians in instruments such as violins and pianos, where the quality of sound produced is interfered and drastically reduced by parasitic vibrations in members of the instrument.

KEYWORDS: ANSYS, Modal Analysis, Partial Tones, Vibration Modes, Clapper.

2.0 LITERATURE REVIEW

Most literatures on this subject have been concentrated on bells and only a limited amount has been on clappers. R. Perrin, T. Charnley and dePont[1] discovered that the quality of a bell depends upon the relative amplitudes and frequencies of the five lowest modes of vibration or musical partials of a bell. They have been able to relate these partials numerically according to their frequency ratios, namely 1, 2, 2.4, 3 and 4 respectively. Bell founders tuned the bell according to these five lowest partials. These partials are dependent on the shape and thickness of the bell. Thus, bell founders usually tune a bell by machining the inside of a bell to vary its thickness at different locations. There are various methods used to excite a bell. For this project, the bell provided is excited by a clapper hanging inside the bell.

The most significant research on clappers is by M.Grutzmacher, W.Kallenbach and E.Nellessen[2]. Part of their work touches on the influence of mass, material and clapper shape on the sound of the bell. One of the variables that influence the sound of a bell is the contact time of the clapper on the bell. In their work, it is concluded that increasing the mass of the clapper, decreasing the fall height and decreasing the elastic module of the clapper will increase the contact time, which in turn has the effect of weakening the higher partials and strengthening the lower partials of the bell tone. This project investigates the effect the vibration frequencies of the clapper has on the bell tone by varying the geometry of the clapper to change its natural frequency.

3.0 THEORETICAL WORK

Due to the complex shape of the clapper, an attempt to model it in classical mathematical model failed. Thus, the clapper was modelled using finite element software, ANSYS. A meshed model of the clapper is shown in Figure 1. Results from the Finite Element Analysis are shown in Section 5, Analysis of Results.

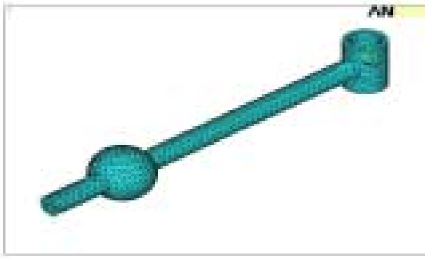

Figure 1: Meshed Clapper in ANSYS

4.0 EXPERIMENTAL STUDY

The experimental study involves determining: the natural frequency of vibration of the clapper through experimental modal analysis; collecting the sound spectrum of the bell excited by various methods; and investigation into the effects and existence of double hits caused by the vibration properties of the clapper.

4.1 Experimental Modal Analysis

To perform the modal analysis, ME'scope VES from Vibrant Technology, Inc is coupled with SignalCalc® ACE, a PC based dynamic dual spectrum analyser from Data Physics Corporation. Initially, the clapper is modelled in ME'scope VES and is grided and numbered as shown in Figure 2. For the purposes of this project, the "single point excitation" method often referred to as mobility measurement is applied. An impact hammer is used as an excitation source at different points along the grided clapper and an accelerometer is used to measure the response at a single point. The spectrum analyser is used to collect the transfer function from the impact hammer and accelerometer. The transfer function is then imported by ME'scope VES and further analysed to obtain the natural frequencies and the animation of the vibration modes. The experimental set-up is as shown in Figure 3.

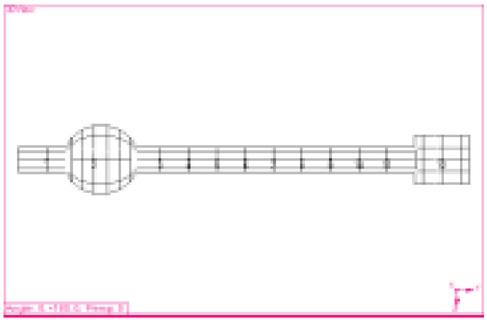

Figure 2: Modal Analysis of Clapper.

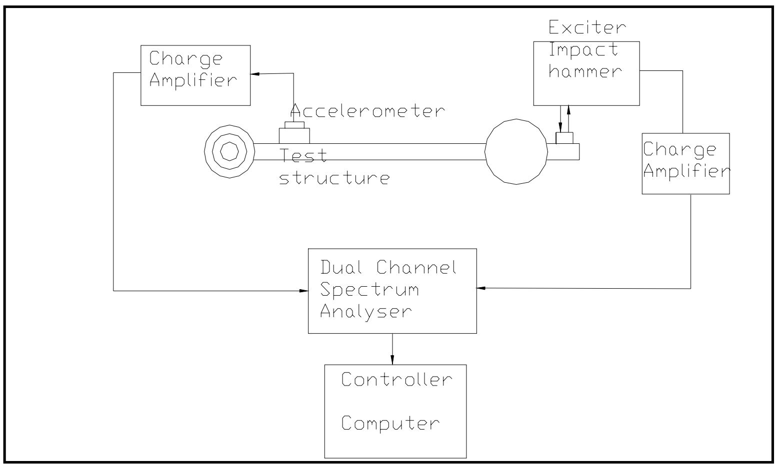

Figure 3: Experimental Set-up of Modal Analysis.

Two boundary conditions for the clapper were investigated in this project, namely free-free and the hinged free boundary conditions. The hinged-free condition is to model the clapper when it is installed in the bell. A frame was designed and manufactured by the departmental workshop for the purposes of simulating the boundary conditions required. To simulate the free-free boundary condition, which requires the clapper to be suspended in space, a suspension system consisting of elastic or ‘bungy’ cords, is shown in Figure 4 is designed. Another system designed to hinge the clapper is shown in Figure 5.

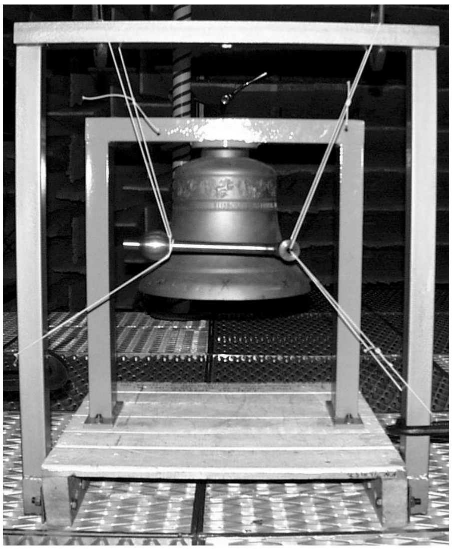

Figure 4: Free-free Condition.

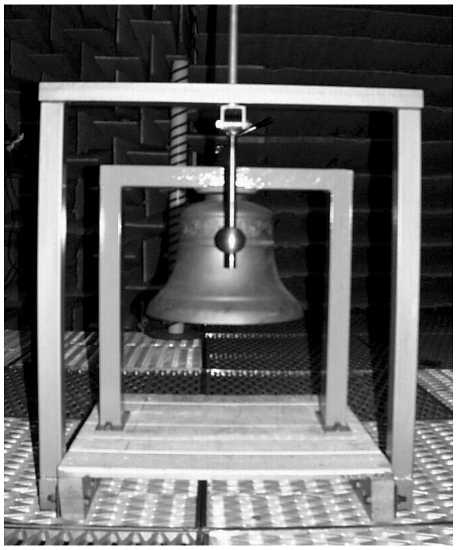

Figure 5: Hinged-free Condition.

4.2 Sound Spectrum of the bell

To be able to design a “better” clapper for the bell in term of its musical tone, the sound spectrum of the bell is obtained and used as a benchmark. The bell was excited using several different sources such as impact hammer, rubber hammer and clapper at different configurations. The power spectrum was collected for the range of 0 Hz to 5000 Hz using SignalCalc® ACE in order to observe the first 5 partial tones and the higher modes which are undesirable. One weakness in the methods used is that the magnitude of the tones obtained cannot be used for direct comparison and needs to be normalised for further analysis. Even though the impact hammer was used and the input force can be measured, the results obtained cannot be directly compared, as the force input of the other exciters cannot be measured. The experimental set-up used is as shown in Figure 6.

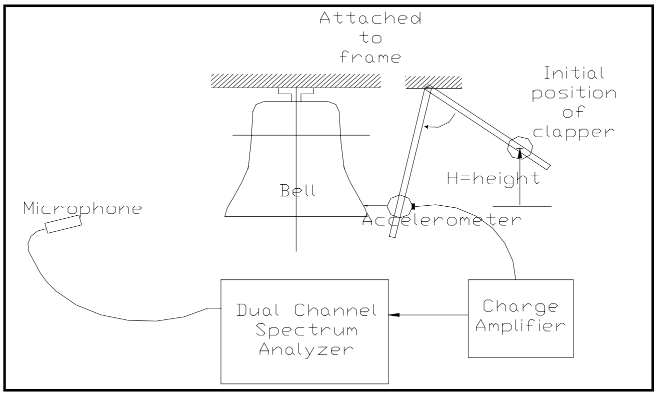

Figure 6: Experimental Set-up for Obtaining Sound Spectrum of Bell.

4.3 Contact Time and Double Hit

The contact time between the clapper and the bell has been shown to have a great influence on the sound spectrum of the bell[2]. The method used to obtain the contact time is to measure the acceleration profile and deduce the contact time from it. The experimental set-up is shown Figure 7.

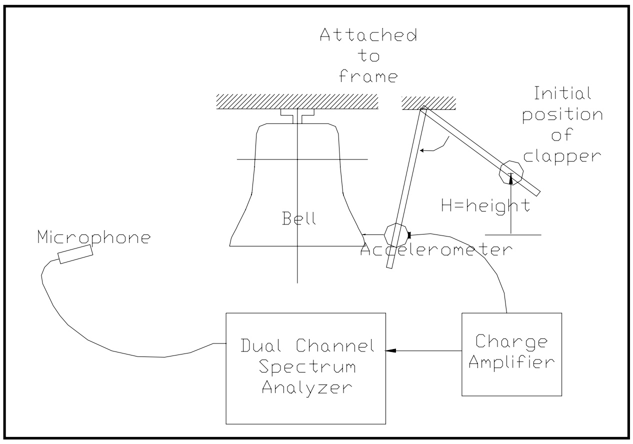

Figure 7: Experimental Set-up for Obtaining the Acceleration Profile of Clapper.

The height of the clapper release point is varied to obtain a set of readings for comparison and analysis. In M.Grutzmacher, W.Kallenbach and E.Nellessen's[2] work, it is mentioned that the height of the clapper release point will have an influence on the contact time. The existence of double-hits was deduced from the same set of data.

5.0 ANALYSIS OF RESULTS

5.1 Comparison Between Modal Analysis and ANSYS

The results obtained from ANSYS and experimental modal analysis as shown in Table 1 and Table 2. The discrepancies between the numerical and experimental results occurred because the ANSYS model assumed a perfect entity with perfect boundary conditions. An example of the top mode of vibration is shown in Figure 8 and side vibration mode in Figure 9.The differences were minimised by varying the material properties of the clapper in ANSYS because the material properties are not ideally uniform or as quoted in handbooks and the geometry may not be as perfect as modelled in ANSYS. This method was able to account for the differences to an accuracy of 10% for all cases except for the modes in the hinged-free condition on the side direction. The main reason for the large difference is mainly due to the experimental set-up. It is suspected that the frame and the method of attachment did not provide a sufficiently stiff boundary condition.

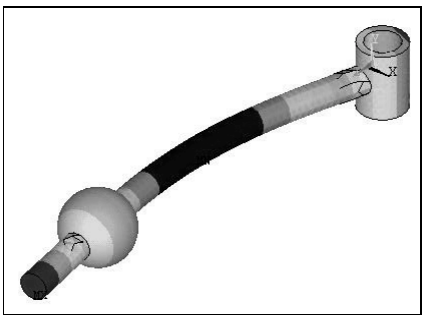

Figure 8: Top Mode Vibration

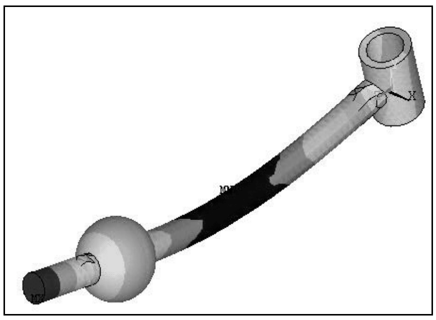

Figure 9: Side Mode Vibration

Mode Number	Theoretical (ANSYS, Hz)	Experimental (Hz)	Direction of Vibration
1	666.80	661.20	Side
2	673.89	661.53	Top
3	1565.20	-	Torsional
4	1949.20	1896.00	Side
5	1977.70	1889.00	Top

Table 1: Comparison for Free-Free Boundary Condition

Mode Number	Theoretical (ANSYS, Hz)	Experimental (Hz)	Direction of Vibration
1	96.03	599.24	Side
2	602.93	634.32	Top
3	759.19	-	Torsional
4	962.41	1185.00	Side
5	1936.70	1875.00	Top

Table 2: Comparison for Hinged-Free Boundary Condition.

5.2 Sound Spectrum of Bell

The sound spectra obtained showed that by using a softer material to excite the bell, the magnitudes of the lower partial tones are increased and the partial tones after the 5^{th} are virtually eliminated because the contact time was increased. The results from the impact hammer and the clapper are of the same magnitude and thus, it can be concluded that the impact hammer excites the bell in a similar fashion to a clapper. The results obtained were in accordance with M.Grutzmacher, W.Kallenbach and E.Nellessen's[2] work. The sound spectrum also confirmed that the partial tones of the bell were in a ratio as mentioned in M.Grutzmacher, W.Kallenbach and E.Nellessen's[2] work. In this bell, the first partial tone is at 587 Hz. Since the input force cannot be measured directly, the resultant magnitude of the tones are normalised to the first partial as in Table 3. The ratios for partials in each bell are separately tuned by bell founders to obtain different musical properties. There is no set of ideal ratios as bells are tuned for different purposes and different ratios.

Method of Excitation	Normalised Magnitude				
	1^{st} Partial	2^{nd} Partial	3^{rd} Partial	4^{th} Partial	5^{th} Partial
Impact Hammer	1.0000	2.6075	1.1816	0.6757	5.6047
Rubber Hammer	1.0000	1.7864	0.6681	0.2019	0.6687
Clapper	1.0000	2.4243	0.9600	0.5798	4.9936

Table 3: Normalised Magnitudes of the Partial Tones.

5.3 Contact Time and Double Hit

Initial results did not show any double hit had occurred. This may be due to the insufficient accuracy of the experimental set-up. Further fine-tuning and improvements will be made to the experimental set-up to increase its accuracy before a conclusion can be reached.

6.0 DISCUSSIONS

The discrepancies between the results in ANSYS and experimental modal analysis have been confined to an error of 10% by a slight adjustment of material properties of the clapper, which is perfectly logical as the material of the clapper may not be as pure and uniform as assumed. The modulus of elasticity of brass used is 101GPa, which was not varied, as it did not have much effect on the results. For mild steel, the modulus of elasticity was quoted at 207GPa and it was varied between 190GPa and 210GPa. The final value that provided the best estimation was at 197GPa. However, this could not account for the differences in the side vibration mode of the hinged-free boundary condition. It is believed that the experimental set-up could not provide a sufficiently stiff frame for the side vibration modes. To counter the problem, additional weight can be added to stiffen up the frame or alternatively the frame can be replaced by clamping the clapper and its holder to a heavy table. The magnitudes of the sound spectrum of the bell obtained are relative because the force used to excite the bell cannot be measured without affecting the spectrum. Thus, the magnitudes are normalised to the first mode to enable comparisons. Initial results obtained are in accordance with literature. The acceleration profile of the clapper obtained did not indicate any double hit. However, the results will be further scrutinised and the experimental set-up improved to be certain of the results obtained.

7.0 CONCLUSIONS

As soon as the discrepancies have been all accounted for, further redesigning of the geometry of the clapper will be done in ANSYS to obtain its desired natural frequency. The aim is to modify the clapper geometrically by removing portions of the clapper bar to minimise the higher intrinsic tones of the bell. The characteristics of the bell are in accordance with the results obtained from literature.

8.0 FUTURE WORK

Since this study only varied the geometry of the clapper, other variables such as material properties of the clapper, was not coupled with it. It might be worthwhile to do a further study on it. Furthermore, the bell itself was not extensively studied. It might be possible to redesign the bell and the clapper to obtain the desirable tones. The effects of sound field and sound diffusion of the bell chamber could be studied to further improve the bell tones.

9.0 REFERENCE

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