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Vibration Modes of a C4 Handbell: Holographic Interferometry and Finite Element Analysis

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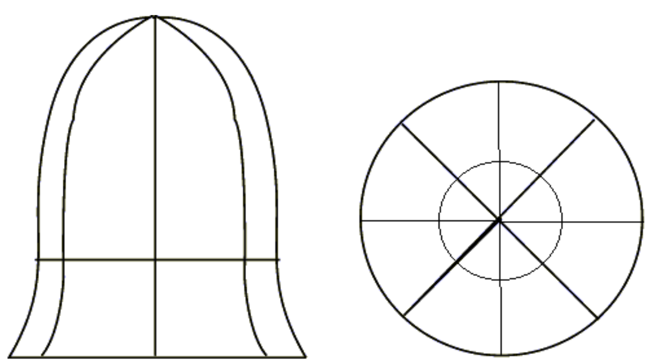
Abstract

Holographic interferometry was used to study the vibration modes of a C4 handbell. Holographic interferograms were made of four of the vibration modes of the bell. Finite element analysis was used to create a preliminary model of the bell. Keywords: Vibration Modes, Holography, Handbell, Finite Element Analysis, Interferometry

1. Vibration Modes

When a handbell is struck by its own clapper many modes of vibration are excited [1]. Each of these vibration modes is present at a different frequency, with different intensities depending on the pitch of the bell. By driving the bell with a mechanical vibrator at just one frequency at a time it is possible to isolate the vibration modes. Each vibration mode is designated by two numbers (*m*, *n*). These numbers correspond to the pattern of nodal lines on the bell. The diagram below shows the (4, 1) mode. There are four nodal diameters, *m*, shown in the top view and one nodal circle, *n*.



Side View Top View

Figure 1 Vibration mode diagrams of the (4,1) mode

2. Holography

Holography was used to study the modes of vibration of the bell. A hologram is created by the interference between two laser beams, the object beam and the reference beam, on holographic film plate, as in the following diagram [2].

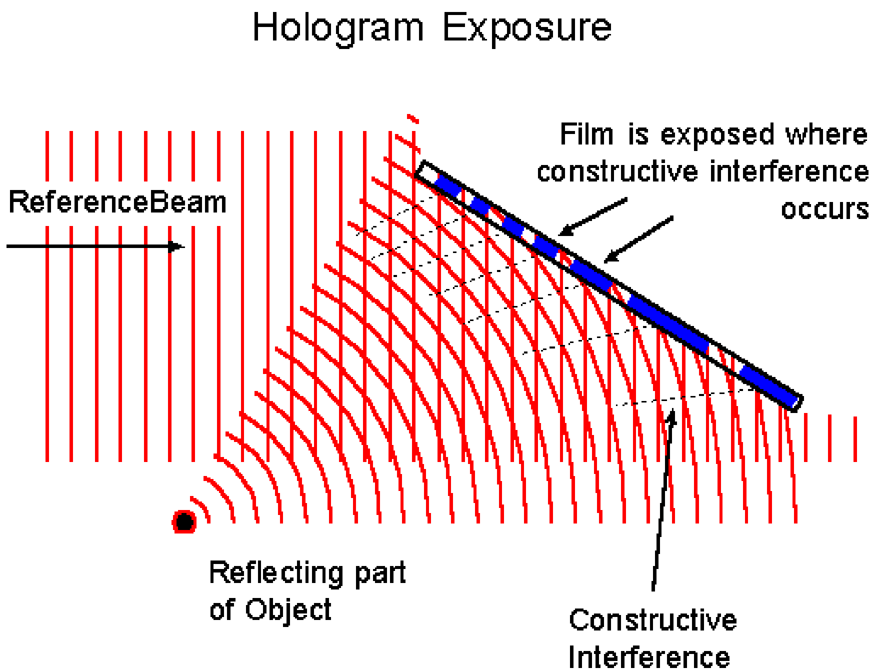


Figure 2 Hologram exposure

After the plate is exposed it must be developed. The developing process used in holography is very similar to the photographic developing process [3]. After developing, the hologram is viewed by illuminating the plate with the reference beam at the same angle as when it was exposed, as shown below. The plate acts as a complex diffraction grating. A curved wave front is created that appears to be emanating from the same point at which the object was originally located.

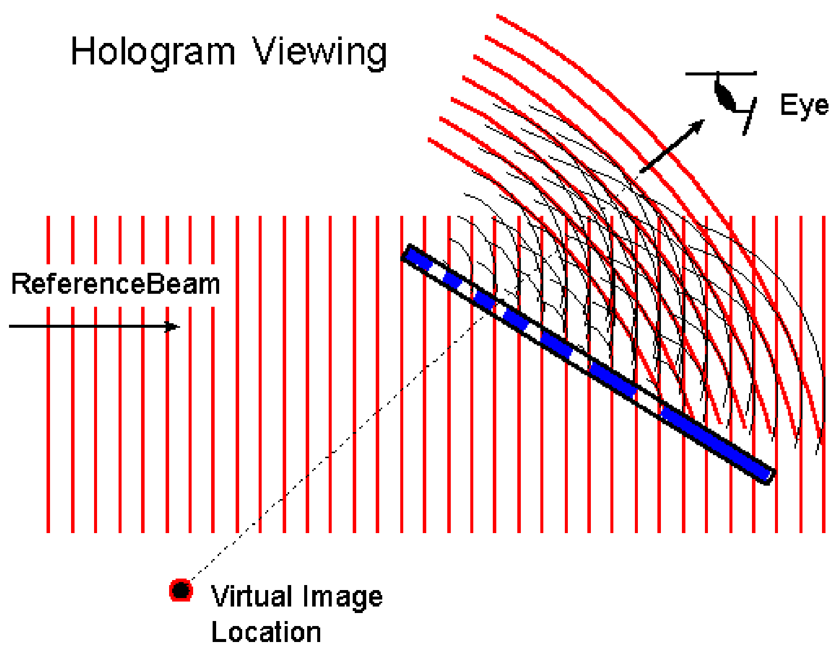


Figure 3 Hologram viewing

3. Holographic Interferometry

Holographic interferometry is the use of holographic techniques to create images of vibrating objects. As shown in the diagram below, the two extremes of vibration create two different exposures. Where the object hasn't moved the image will be bright, where the object has moved the image will be dark, except where it was moved an integral multiple of a wavelength of light.

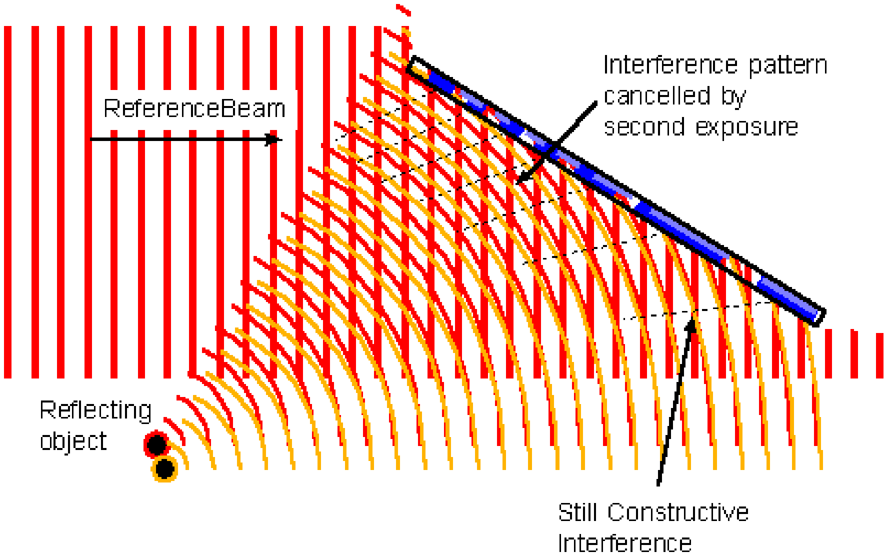


Figure 4 Holographic interferometry

Holographic interferometry is useful in the study of modes of vibration because of the patterns seen on the object in the hologram. Bright lines indicate the presence of nodal lines and dark rings indicate the presence of an antinode. This creates contour lines as seen below.

Figure 5 A picture of a hologram

4. Finite Element Analysis

Another technique used to study the bell was finite element analysis [4]. Finite element analysis uses a computer program to analyze a model of an object. We used a program called Femap [5].

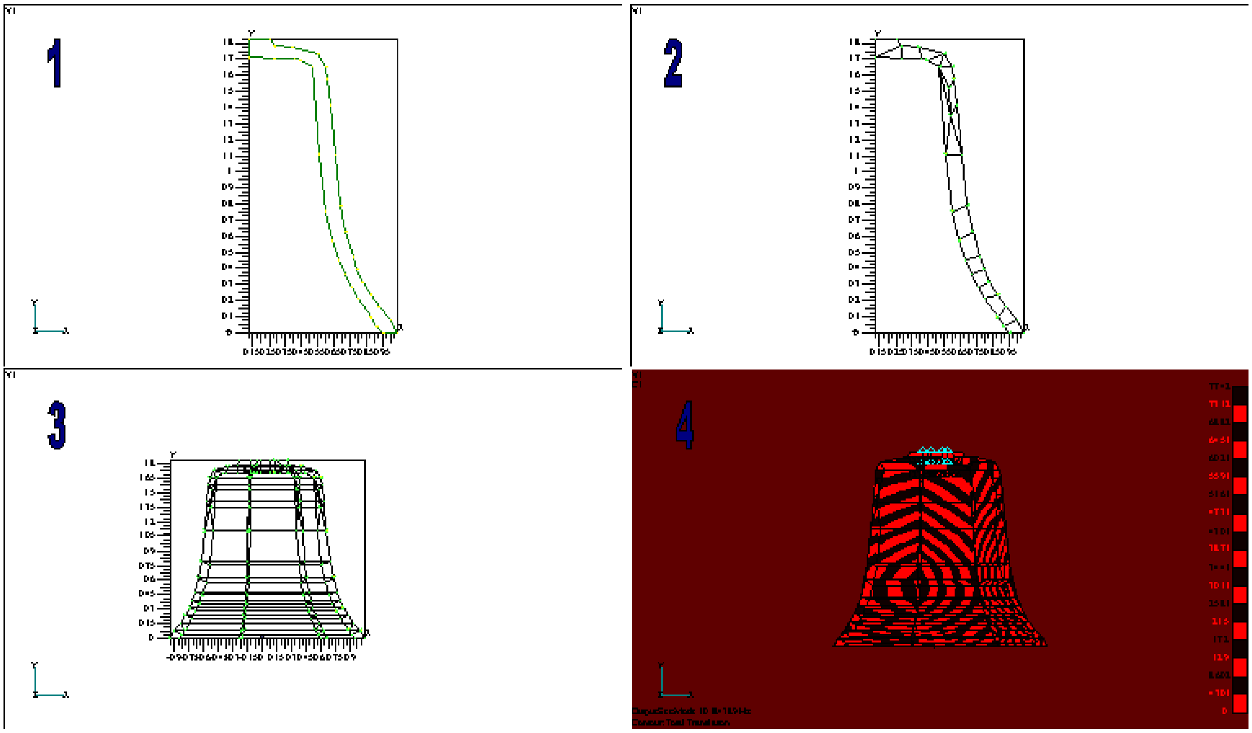


Figure 6 Model creation

The first step in finite element analysis is to create the model. An outline of a cross-section of the bell is made (1), this is then "meshed" (2). Meshing is the process of dividing the surface into elements. Each element has properties associated with it that are determined by the material of which the object is made. These elements are then revolved around an axis (3). The next step is the actual analysis. The program solves a set of differential equations for each element that describe how that element will react to certain forces; the solutions are then matched along the edges of each element. We can then see a visual representation of these solutions (4).

5. Experiment

We found the resonant frequencies of the bell by positioning a microphone close to the bell and connecting this to a digital oscilloscope. The oscilloscope performed a Fast Fourier Transform on the sound produced by the bell. By watching for peaks in the Fourier Transform we were able to determine the resonant frequencies to approximately a tenth of a Hertz. We found eighteen resonant frequencies. We made holographic interferograms at four of these.

In order to make the holograms we had to mount and drive the bell in such a way as to eliminate unwanted vibration. Below is a diagram of our mounting and driving system.

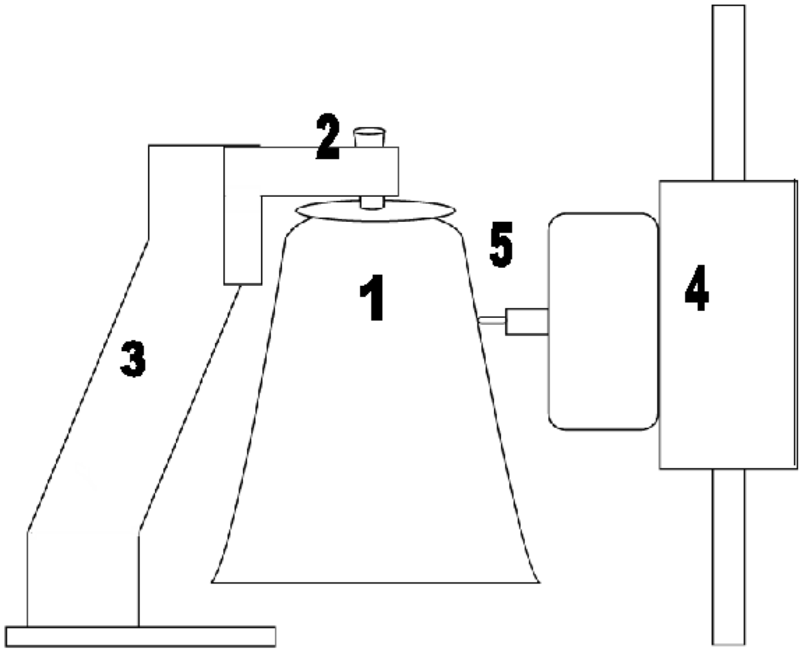


Figure 7 Bell mounting and driving setup

The bell (1) is bolted to a piece of aluminum (2), which is, itself, clamped to an aluminum mount (3) that is bolted to the optical table. The bell is driven by a mechanical vibrator (4) that is also bolted to the optical table, a nylon bolt (5) is attached to the vibrator and is what actually contacts the bell at 2 cm down from the corner of the bell.

Because the bell was too shiny to create a good hologram, we sprayed very thin layer of oil onto the bell and then dusted it with talcum powder. This made the bell bright, but not shiny.

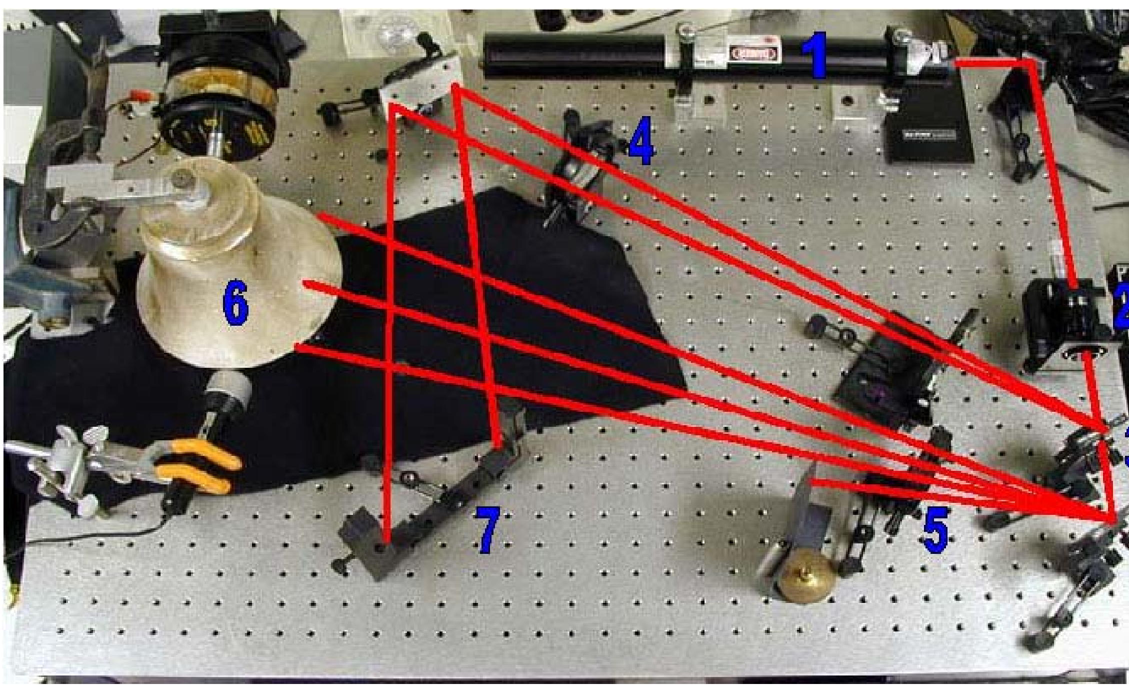


Figure 8 Setup used for the creation and viewing of holograms

The beam is emitted from the laser (1), it then goes through a spatial filter (2), which cleans up the beam and begins to spread it In the spatial filter the laser beam goes through a microscope objective and is focused onto a 15 micron pinhole, only the parallel parts of the beam make it through this pinhole. A five percent beamsplitter (3) splits the beam into a reference beam and an object beam. The reference beam goes through a lens (4) to spread it further. This spreading is needed to weaken the final intensity of the beam that hits the plate. The reference beam reflects off a mirror and hits the film plate directly. The object beam also goes through a lens (5) to spread it. This lens is needed to allow the object beam to illuminate the whole object. The object beam reflects off the object and onto the plate. The two beams interfere constructively and destructively on the film plate and expose it. (7). The film plate is developed, and we have a hologram.

The first holographic interferogram that we created was with the bell vibrating at a frequency of 261.8 Hz. To measure the amplitude of vibration we connected the driver to our oscilloscope and set it to an amplitude of 1 V peak to peak. To find our reference and object beam intensities we created a light meter that consists of a photo-cell connected to a very sensitive meter that measures current in nA. Our reference beam intensity was 200 nA and our object beam intensity was 25 nA. Because this ratio was too high we used a filter on the reference beam to cut it to only 90 nA. The hologram was exposed for 15 minutes, and after developing, we found that the image of the bell was not present. Because we could see other images in the hologram, we thought that it might be a coherence length problem. If the lengths of the reference beam and the object beam are not close enough, an image is not created. However, after changing the setup slightly, so that the beams would be closer to the same length, we made another hologram that had the same problem, no bell image. We decided then that we must have some extra vibration in the bell setup that was destroying the image. The aluminum post we used to mount our vibrator was only ¼ in. thick, and we hypothesized that we needed a stronger post. We made a post about twice as thick and tried another exposure. We also decreased the driving amplitude to 50mV peak to peak, and exposed it for 10 minutes. This resulted in a good image. The bell was vibrating in the (2,0) mode.

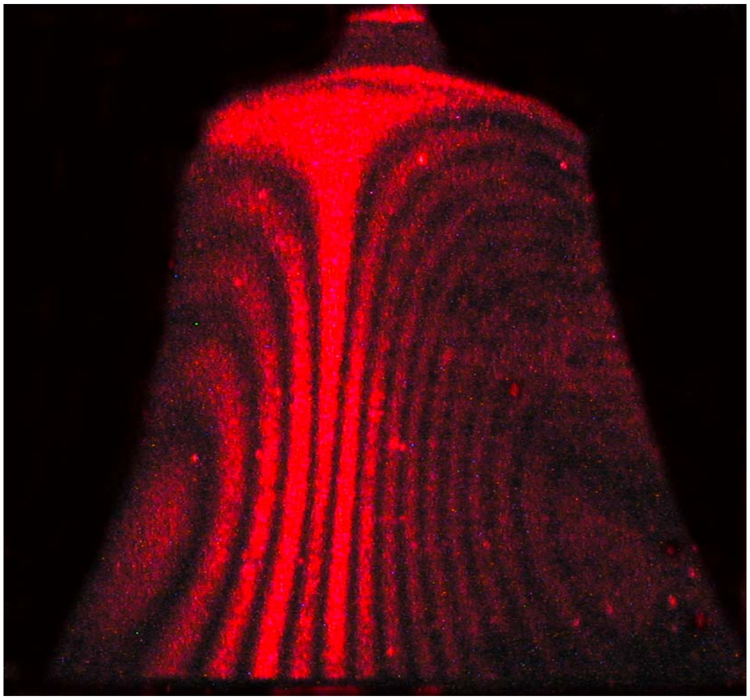


Figure 9 (2,0) mode

In the first hologram we made at the next frequency, 770.9 Hz, we set the driving amplitude to 50 mV peak to peak. The reference beam was at 100 nA and the object beam was at 20 nA. After developing we found that an image of the bell was there, but there were no lines on it. This meant that the driving amplitude was too small for the holographic technique to detect any vibration. We increased the amplitude to 700 mV and tried again, and got a good picture of the (3,0) mode.

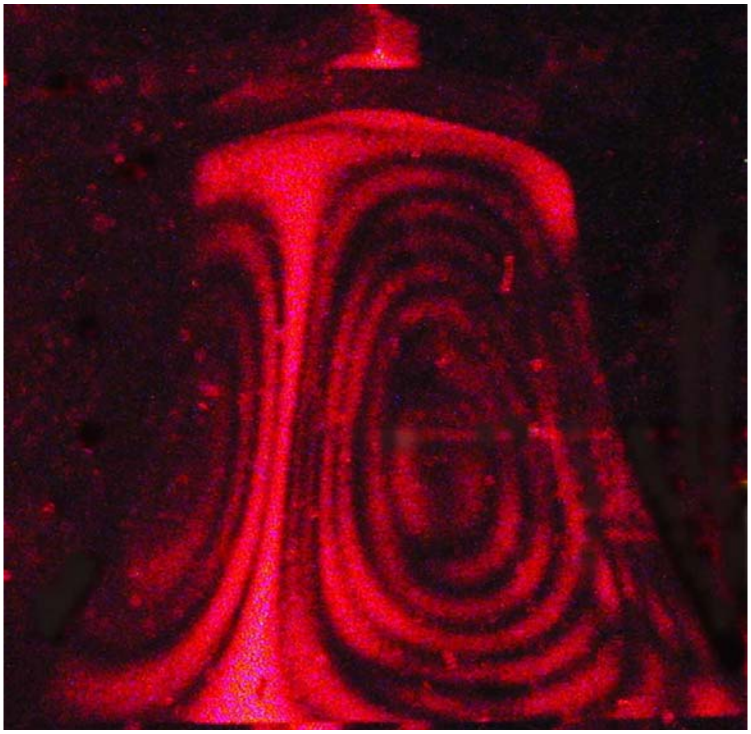


Figure 10 (3,0) mode

The next hologram was made with the bell vibrating at a frequency of 1334.5 Hz and an amplitude of 3 V. In order to get a brighter hologram, we increased the exposure time to 20 minutes. The resulting hologram showed the bell and showed the pattern of nodal lines, but there were too many nodal lines and they were too close together. We repeated the hologram later at an amplitude of 1 V and got a good result showing the (4,1) mode.

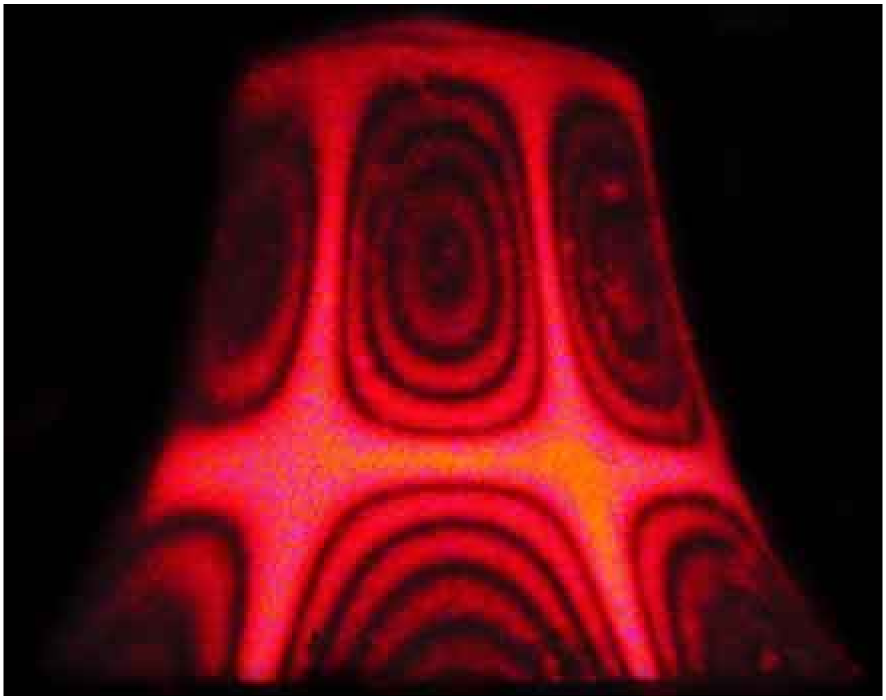


Figure 11 (4,1) mode

The last frequency we analyzed with this technique was 1250.6 Hz. The amplitude of vibration was 2.5 V. The resulting hologram showed the (3,1) mode, but had the same problem as the first hologram made at 1334.5 Hz. There were too many lines, but because we ran out of plates we were unable to create another hologram.

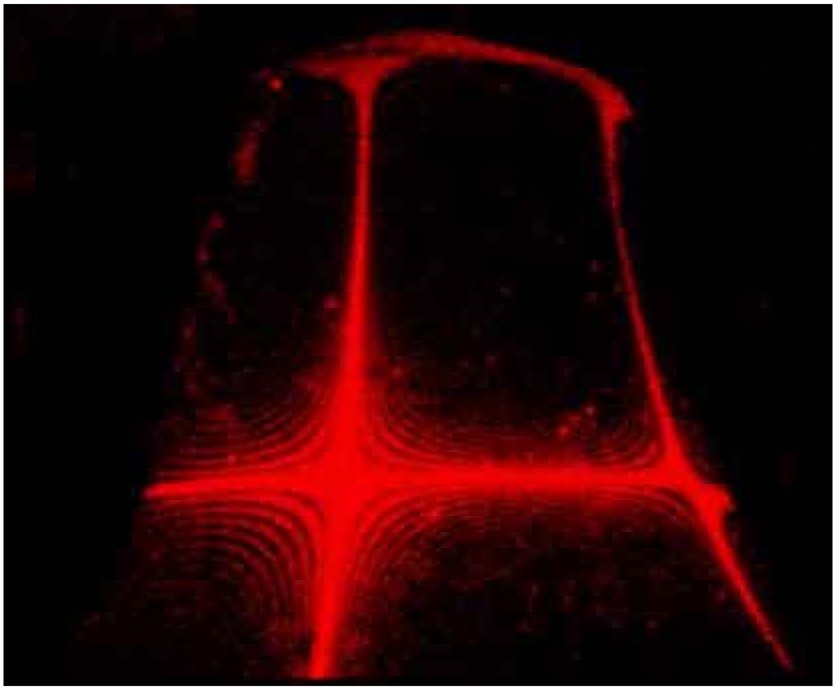


Figure 12 (3,1) mode

6. Future Plans

Eventually, we hope to have holographic interferograms of all the resonant frequencies that we found. We also hope to be able to make an accurate model that could be used to predict the behavior of the bell using the full version of Femap. The picture below shows the same mode of vibration for the computer model and the actual bell, but the frequency at which the model was being driven was much lower than the actual bell. More research needs to be done on the physical properties of the bell, as well as more accurate measurement.

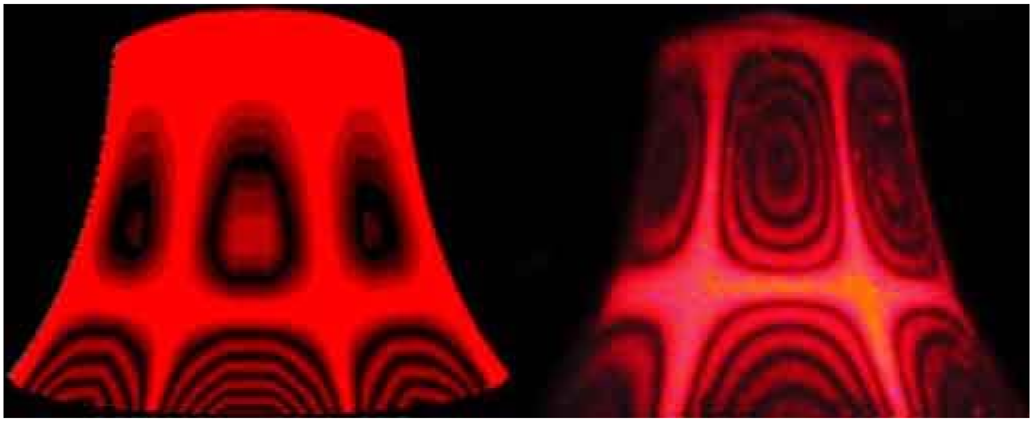


Figure 13 Comparison of FEA model and hologram

References

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(4) R. Young and I. MacPhedran, "Internet Finite Element Resources," http://www.engr.usask.ca/~macphed/finite/fe_resources/fe_resources.html, 2001.

(5) www.femap.com