STROBOSCOPIC CONTOUR PROJECTION

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1 INTRODUCTION

The use of contour or "fringe" projection as a means of measuring the shape of objects is a well established technique that has been developed to levels of high sophistication[1]. It has the advantage over techniques such as holography and speckle interferometry that the sensitivity is defined by the period of the contour lines and it has the advantage over scanning techniques that the whole surface under study can be measured at the same time.

This paper will describe its application to the study of vibrating reeds for musical instruments and enlarges upon material presented at this meeting in 2008[2]. However, the purpose is to illustrate how much can be achieved with minimal equipment and negligible outlay.

2 THE BASIC SCHEME

A collimated beam of light, preferably from a laser diode, passes through a grid of parallel opaque stripes and then obliquely onto the surface under study as shown in figure 1. This effectively generates a series of contour lines, where the contour interval is equal to the period of the grid. These may then be viewed from above and interpreted in the same way as the contour lines on a map to determine the shape of the surface. Furthermore, if we illuminate with a series of short pulses at the appropriate frequency we can observe stroboscopically the motion of a vibrating surface. The moving pattern may conveniently be recorded on video for subsequent analysis. Figure 2 shows the contour map of a bagpipe reed at the two extremities of its vibration.

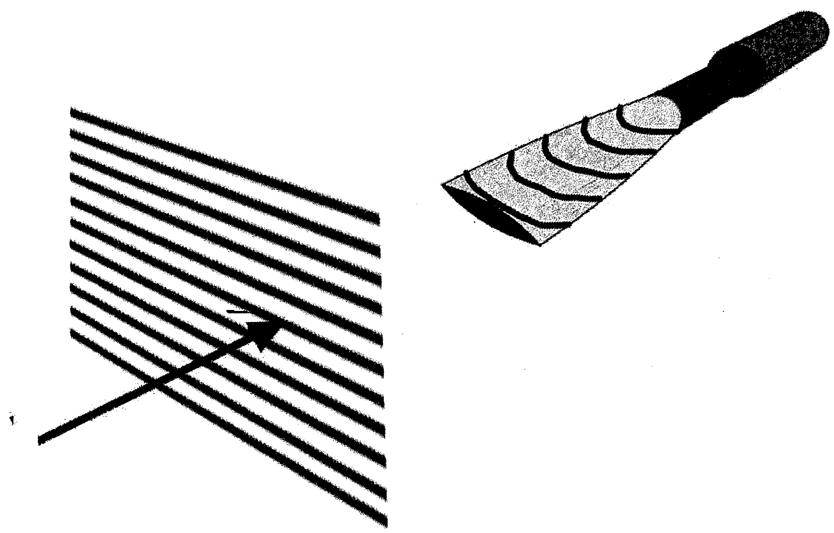

Figure 1 The projection of contour lines onto a surface.

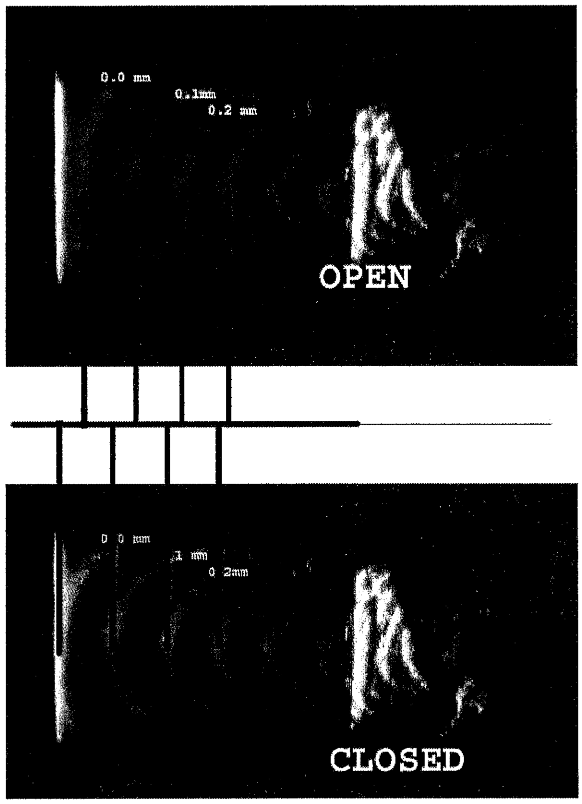

Figure 2. The displacement of projected contour lines at the extremes of vibration of a bagpipe reed.

3 THE GRID (text starts at 40mm from top of page)

The period of the grid will be dictated by the amplitude of the vibration one wishes to study, the accuracy required and the shape of the surface. If the period is equal to the amplitude of vibration one will observe a displacement of one contour and this would be a reasonable starting point. However, if the surface is highly curved this may generate too many lines in the field of view and these may be difficult to resolve and track . In this case a coarser grid would be chosen. The choice would also be affected by the nature of the surface. If it is too shiny the light will be specularly reflected and little will be scattered into the direction of observation. On the other hand, if it is too rough with large imperfections it may be difficult to establish the continuity of the lines. In effect the choice of period has to be determined empirically.

With modern computer printing equipment it is a relatively straightforward matter to produce an adequate grid with periods down to a millimetre or so. This has the advantage of great flexibility but for a more robust result with greater optical density it may be necessary to use standard or photographic printing techniques.

For periods greater than a couple of millimetres it is possible to make a grid of variable period by using the moiré pattern between two finer grids and varying their relative orientation.

For coarse grids the projection of the pattern may be thought of as each line casting a shadow onto the surface under study. However, for finer grids of a mm or less it becomes necessary to take account of diffraction[3]. The grid behaves as a diffraction grating which generates a series of wavefronts propagating at different angles Θ_n given by the grating equation (for normal incidence)

$$d \sin \Theta_n = n \lambda \qquad \text{Equation 1}$$

where d is the period of the grid and λ is the wavelength of light. Each pair of wave-fronts will now interact to form sinusoidal interference fringes with a period equal to that of the grid or integral fractions of it. The space beyond the grid is therefore filled with a series of interference fringes with an harmonic series of spatial frequencies. At certain distances Z_T from the grid these combine to form a Fourier synthesis of the original grid pattern. Z_T is known as the Talbot distance and is given by

$$z_T = \frac{2a^2}{\lambda}, \qquad \text{Equation 2}$$

The net result is that a clear image is formed at discrete distances from the grid and that between these images the contrast is poor. This is shown in figure 3 in which the pattern is projected obliquely onto a screen. Clearly it is important to position the surface under study at an appropriate distance from the grid.

Figure 3 Variation of contrast due to the Talbot effect.

If the grid had the form or a perfectly sinusoidal amplitude grating it would generate only two diffracted orders. These would then form sinusoidal interference fringes at all distances and the contour pattern would maintain its contrast throughout the illuminated volume. This is rather difficult to achieve in practice but some improvement may be obtained by printing a grid in with a sinusoidal variation of grey level.

4 ILLUMINATION

It is clear from equation 2 that the distances at which one obtains an image of high contrast varies with wavelength. So if one illuminates with a range of wavelengths contrast will be lost because at any given point there will be images that are not "in focus". For fine grids it is necessary to use a laser or laser diode. For coarser grids it may be possible to use a Light Emitting Diode. Both lasers, in the form of laser pointers, and LEDs are readily available at very low cost. They have been designed to be modulated at very high frequency and are therefore ideal light sources for stroboscopic illumination. Furthermore, since the light is emitted from a narrow junction, its distribution is naturally in the form of a wedge which again is ideally suited to oblique and highly anamorphic illumination. Unfortunately the manufacturers laser pointers and LEDs go to great lengths to design lenses which will compensate for the non-uniformity of illumination. So there may be some merit in polishing off these lenses.

The laser, collimating lens and grid may be mounted in a simple compact unit as shown in figure 4. In this case the laser came with a key-ring and various holograms. One of the hologram holders was adapted to take a small plastic beam expanding lens, the battery connections were replaced by a 3.5mm socket and the collimating lens was taken from a 50mm slide projector. The grid was printed on high transparency photographic film by a laser printer[4] and mounted on a rotatable mount for ease of alignment. (The clothes peg serves to operate the on-off switch)

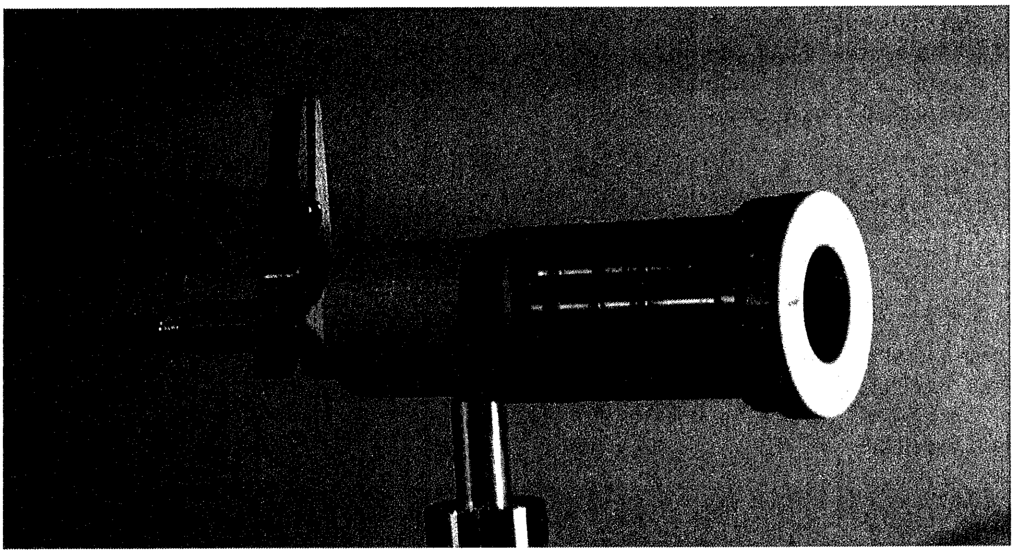

Figure 4 The illumination unit.

The electrical signal to drive the laser may be generated simply on a computer using standard audio editing software. In the present case the freely available "Audacity" was used. It has the facility for generating a square waveform of any desired frequency and this can simply be modified to a single spike. It is only necessary to do this for one period, as shown in figure 5, which can then be played repetitively to generate a signal in the form of a Dirac comb. The output may be fed via the headphone socket to an audio amplifier to drive the light source. The output frequency can be varied by selecting the required portion of the cycle before playing. It should be noted that it is advisable to disconnect the computer microphone before playing in order to avoid sound from the object under test being amplified and feeding into the driver signal. Sudden surges may prove fatal to laser diodes.

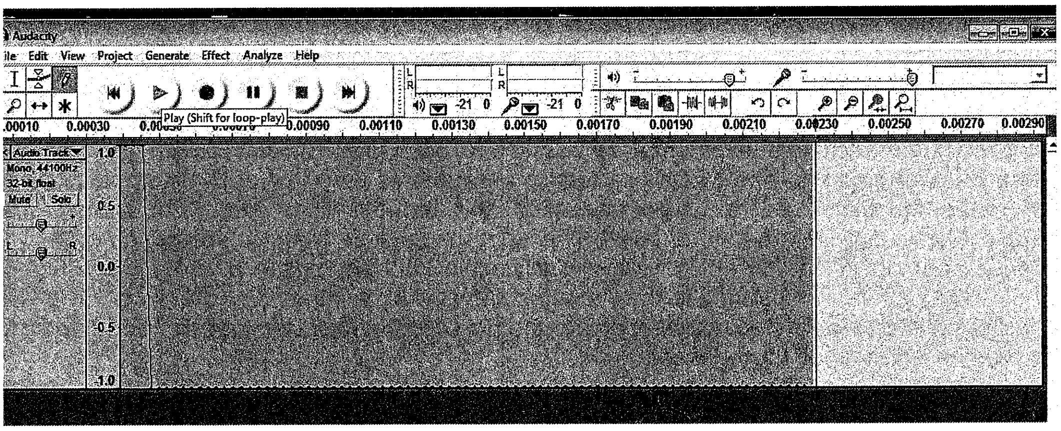

Figure 5 Generation of the driver signal using Audacity

5 ANALYSIS

A great deal can be learned from a visual inspection of the moving contour lines. One can identify nodal and anti-nodal regions and estimate the amplitude of vibration. This can be further quantified by measurement of individual frames of a video recording as shown in figure 2. Simply subtracting one image from another enables one to identify which areas have moved and which have remained stationary.

However, in order to gain maximum benefit from wealth of information that is available, more sophisticated image processing is required. Fortunately the images obtained are almost identical to those obtained in interferometry and automatic fringe analysis has been developed to a high degree. Unfortunately most interferometers now use phase stepping techniques which is not readily compatible with moving images but static analysis software does exist.

6 CONCLUSIONS

We have demonstrated the feasibility of stroboscopic contour projection as a technique for the study of surfaces vibrating at audio frequencies. We have applied this to the reeds of musical instruments but in principle it could be applied to a wide variety of applications. It has the advantage over certain other optical techniques that the sensitivity may be chosen at will and that the whole surface may be viewed at the same time. It also has the advantage that the components are readily available at very low cost.

7 REFERENCES

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