Application of Shadow Moiré Method by Phase Shifting to Membranes Deformation Measurement

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Introduction. The paper deals with full-field and non-contact method to measure deformation of thin membranes, in order to characterise their behaviour in the range of large displacements. There is presented the optical method of shadow Moiré by phase shifting and its application at membranes deformation. The accuracy of the method is 0.01 mm. FEM and analytical studies have accompanied the experimental determinations to prove their reliability.

Theoretical considerations

It is known that thin membranes undergoing high deformations comparatively with their thickness have a nonlinear behaviour, their stiffness increasing significantly with the applied load. For this case the theory offers only an approximate solution which is restricted to a circular membrane shape. An exact solution implies knowing of the membrane surface equation, fact difficult to be examined, the equation degree modifies with the applied load (pressure).

Considering a clamped plate with constant thickness *h*, undergoing uniform pressure *p*, the maximum deflection w_0 can be expressed [1]:

$$w_0 = 0{,}662 \cdot R \cdot \sqrt[3]{\frac{pR}{Eh}} \qquad (1)$$

Where: *R* is the membrane's radius, *p* applied pressure, *E* Young's modulus, *h* membrane's thickness, and value of Poisson's ratio equals 0.3.

Experimental set-up

Shadow Moiré method is a known optical method for deformations analysis. Application of classical method to calculate displacements [2] using level curves can be applied successfully if the desired accuracy is about 0.1 mm. Study of the thin membranes having large deformations isn't enough accurate by this method.

If the phase shifting techniques is combined with shadow Moiré [3] the accuracy increase 10 times (up to 0.01 mm). The principle is presented in figure 1 and the experimental measuring set-up in figure 2.

The white light source projects the master grid with a pitch of 0.5 mm upon the analysed object (an aluminium circular membrane with thickness *h*=0.14 mm and radius *R*=60 mm). The master grid is fixed and the object can be displaced with a micrometric screw. If the object is observed through the master grid it can be seen the level curves relative to the grid plane.

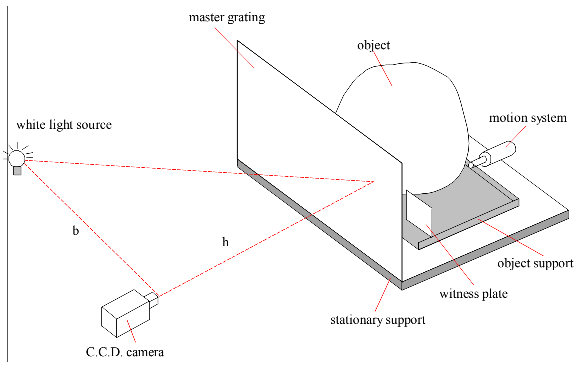


Figure 1

The interference fringes captured with a CCD camera were digitized with a frame grabber having a resolution of 512x512 pixels and 8 bit colour depth.

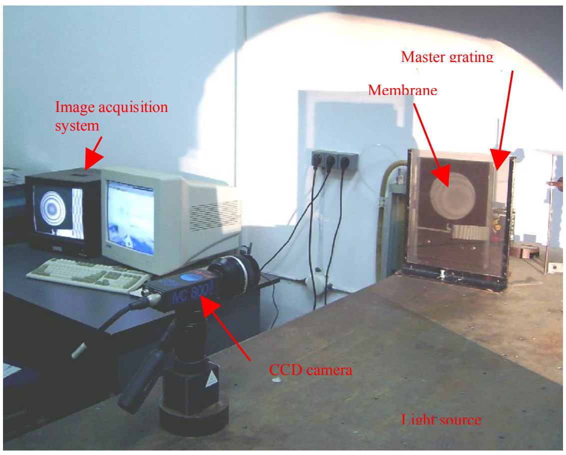
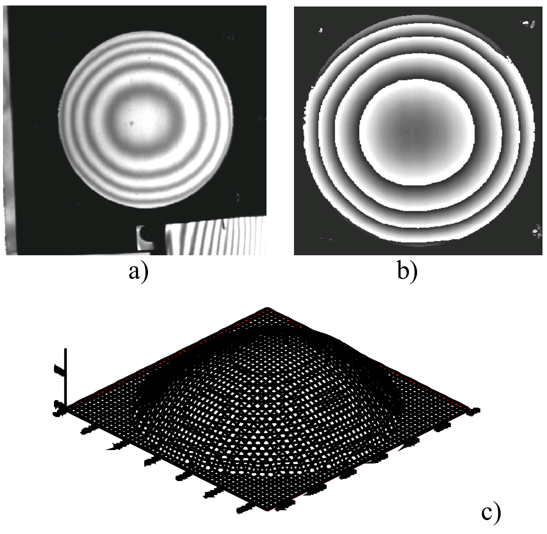


Figure 2

Near the object is placed a small witness plate necessary to accurate evaluation of the phase value between the shifted images. The computation was performed using OMBRE software developed by University of Poitiers, France [4].

Loading of the membrane was done with a small pump, applied pressure being measured with a calibrated glass tube in millimetres water column (mm H_2O).

To automatically compute the membrane's relief (deformed shape) three images of the level curves (Fig. 3a) phase-shifted with 120º are necessary. The software computes the phase distribution (Fig. 3b) and demodulates it (unwrapping). Introducing the set-up geometrical parameters (master grid pitch, distances between light source and CCD camera and light source to master grid) and correspondence pixels to mm the relief (deformation values with respect to the reference plane) of the membrane can be obtain. The data are represented as grey values or can be exported and represented with mapping software (Fig. 3c).



a) b) c)

Figure 3

Results

To plot the membrane's load-deformation curve six measuring steps were performed. The maximum pressure was limited by the measuring device (glass tube) and number of level curves which can be accurate resolved by the computation software.

The experimental results at very low pressure (< 50 mm H_2O) were affected by initial membrane shape which wasn't plane due to technical difficulties to stretch it in the loading device. For pressure values higher than 100 mm H_2O (9,8E-04 N/mm^2) the effect disappear and do not influence anymore the results.

For numerical (FEM), analytical and experimental studies the membrane load-displacement curve is presented in figure 4.

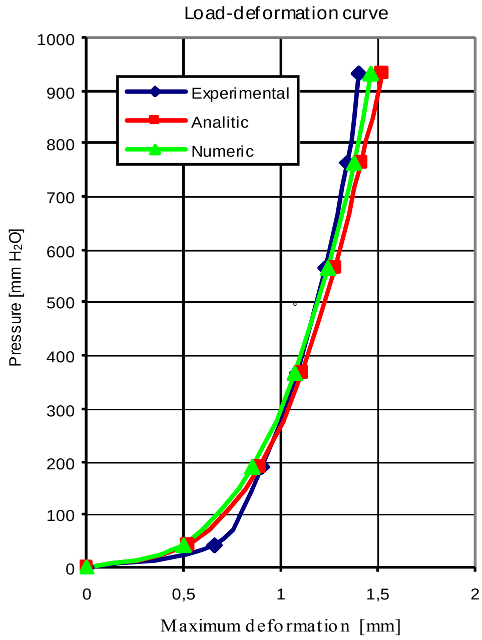


Figure 4

Conclusions

Application of shadow Moiré method by phase shifting technique proved to be a reliable experimental method to analyse the membranes deformations. It can be noticed a relative small error (< 5%) between experiment and FEM method.

The obtained results consist of start point for further investigations of membranes with complex shape or approximate known of the material constants.

References

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