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HOLOGRAPHIC TESTING OF TYRES

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ABSTRACT: One of new modern method for non-destructive evaluation of tyres is presented. By double exposure holographic technique the latent air separations between sword layers can be detected and by time-average holography the resonance frequency of inflated tyres may be measured.

1 Introduction

Existing methods of non-destructive testing of tyres include visual inspection, X-rays, ultrasonic, infrared techniques and also holography. Each method suffers one or more limitations rendering it to be either impractical or ineffective as an industrial inspection tool. This is why holography pays still as a laboratory method but, is not commonly used in industrial practice. Nevertheless development work and the testing of tyres has shown that the holographic method is the most reliable and sensitive method available for detection of the air separation [1], [2] and non-contact inspection of vibration characteristics of pneumatic tyres [3]. A laboratory holographic system for holographic tyre investigation was constructed at our University and realised for the rubber industry, e.g. the Barum-Continental Otrokovice Lmt.

The holographic systems consist from the holographic table of the size 250 x 160 cm which is vibrating isolated from the floor. This table is provided with the usual holographic system for holographic interferometry, with a rotating system and a holder of the inflated tyre. A lift mechanism of a vacuum dome is placed out of the holographic plate. A special holographic camera of our own construction for hologram recording with the external control and 50 mW He-Ne laser placed on the table enable the exposure time of several seconds. For shorter exposition the tyres are covered with a film of talc powder.

The internal defects (e.g. separations) are detected by the vacuum - inside method. A tyre, (spread at the beads) is placed over the holographic interferometr and both are sealed in a vacuum chamber (dome). The first exposition of a hologram is made at atmospheric pressure and the second after applying a slight vacuum. By the reconstruction process the tread, ply and liner separations appear as typical interference patterns over the internal part of tyre.

The vibration performances of tyres are studied by time-average holography [4]. Viewing the full sidewall of an inflated tyre enables the record of the periodic motion of the whole test object. The resonance frequencies and corresponding interferometric modal patterns which are typical for the different types of tyres give an important information about the vibration characteristics and the uniformity of tyres.

2 Holographic interferometry

Holography is an imaging method which permits the reconstruction of three dimensional images. Due to this fact holographic interferometry can measure the change in the shape of an object surface. Displace information is presented in the farm of interference fringes covering the reconstructed images.

When two holographic recordings of the same object are made in a single photographic emulsion with the object being slightly deformed or displaced between exposures, an observer sees a set of interference fringes superimposed over the image of the object. This method is known as double - exposure holographic interferometry.

Another method, time-average holographic interferometry, is used for an object under the dynamic excitation. A single hologram is made while the object is vibrating. The exposure time is much greater then the vibration period of the object, so that points of maximum displacement are displayed and compared.

For quantitative evaluation of the displacement vector $\Delta\vec{r}$ from holographic interferograms we are going out from the Fig. 1.

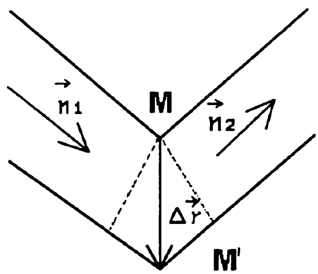

Fig. 1

Here the quantity $\vec{n}_1$ means the unit vector in the direction of illumination and $\vec{n}_2$ the unit vector in the direction of observation. The optical path difference is given by the relation

$$L = \Delta\vec{r}(\vec{n}_2 - \vec{n}_1) = N\lambda \tag{1}$$

where N is the number of interference fringes from the undeformed place on the object and λ is the wavelength of the light.

In praxis of non-destructive testing and vibration analysis of tyres only one component, e.g. the component in the normal direction to the object plane, is necessary to be known. When we arrange the direction of illumination and observation symmetrically to the object then the vector $\vec{n}_2 - \vec{n}_1$ gives the direction which is normal to the object plane ($\vec{n}_2 \approx -\vec{n}_1$, $|\vec{n}_2| = |\vec{n}_1| = 1$). Then from equation (1) the normal component of displacement vector $\Delta\vec{r}$ can be determined directly with high precision from the equation

$$\Delta r = N.\frac{\lambda}{2}. \tag{2}$$

3 Vacuum-inside method

To detect the previously mentioned types of separations a free uninflated tyre is spread at the beads and located on the rotating mechanism at the holographic table. The vacuum chamber is formed by LD dome put down on the table by a lift. The first hologram is recorded at atmospheric pressure and the second at partial vacuum of approximately to 10 kP. The optical system of the hologram recording is clear from the Fig. 2. The laser beam is reflected

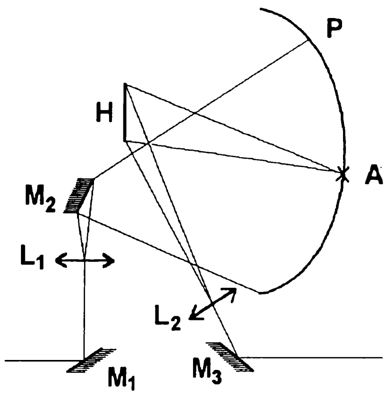

Fig. 2

by the mirror M_1 in the perpendicular direction and by the microscope objective L_1 and the mirror M_2 illuminates the inner part of the spread tyre. The diffusely reflected light from the tyre and the reference beam that illuminates the hologram directly (using mirror M_3 and lens L_2) form an interference field which is recorded on the hologram H.

The separation depth h and the displacement change Δr are in relation which can be expressed by the following approximate formula [6]

$$\Delta r = \frac{p}{E}\frac{D^4}{h^3}. \tag{3}$$

Here the other quantities express: diameter of the separation D, uniform pressure decrease p, and elastic modulus E. From the praxis is known that any separation whose diameter is greater than one-half of its depth is detectable. Separation detection sensitivity might appear to be improvable by increasing the pressure decrease (vacuum). However, this generally gives increased fringe frequency which results in difficulties when reading the interference pattern.

Typical separation under the tread simulated at a truck tyre is shown in the Fig. 3.

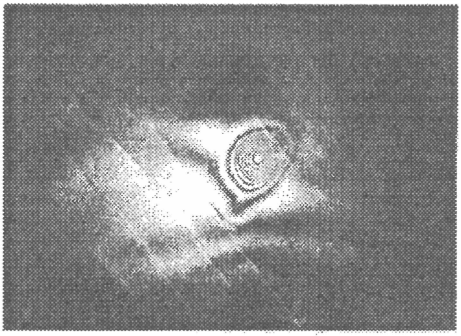

Fig. 3

4 Vibrations investigation

The vibration performances of tyres are studied by time-average holography. A single time exposure of the vibrating object is made while several hundred cycles of motion are executed. Sinusoidal periodic motion is the easiest to record since an object is near the extreme of its amplitude range during most of the exposure time. The resulting fringe pattern then displays as the double amplitude motion.

Fig. 4 is the time-average interferogram of a radial tyre vibrating in its basic (first-mode) resonance frequency while being excited radialy.

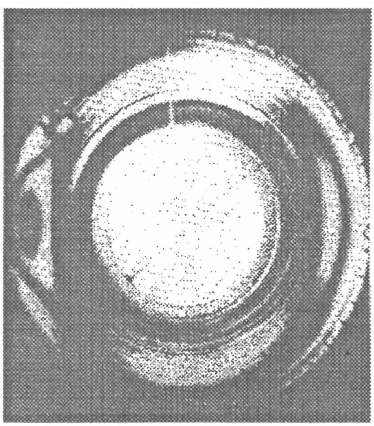

Fig. 4

Over-harmonic frequencies yield typical modal interference pattern which characterise the second, third and other radial vibration resonance [5].

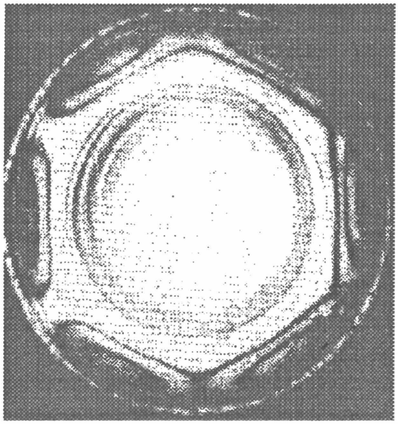

Fig. 5

Fig.5 demonstrated the third harmonic frequency of a perfect radial tyre. Non-uniformity of the tyre and loss of mass in consequence of using the tyre in service change the modal patterns that are characteristic for given resonance frequencies. This fact can be seen in Fig. 6.

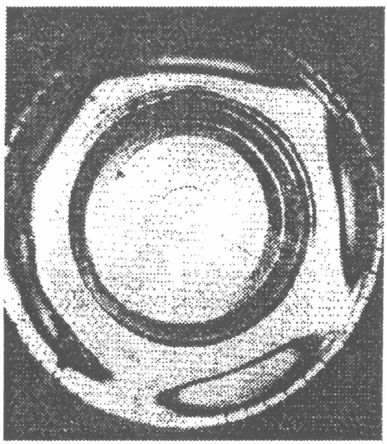

Fig. 6

While a continuous spectrum of frequencies is excited by the passage of a sharp bump trough the tyre contact patch (footprint), the primary disturbance frequency is

$$f = \frac{1}{T} = \frac{v}{l} \tag{4}$$

where T is the time of passage v the vehicle velocity, and 1 the contact length. For the first mode resonant frequency (59 Hz) and nominal footprint length $l = 25$ cm, the velocity $v = 53$ km/h which shows that a bumpy ride can be expected from radial tyres at city driving speeds. The resonant peak for bias ply tyres occurs at 140 Hz that means for 126 km/h. Passengers do not need to expect a bumpy ride disturbances at normal city speeds.

5 Conclusion

As it was mentioned above holography is still not a necessary inspection method in the tyre industry. That is why our laboratory system has been mainly used for testing the new developed types of tyres. Holographic process generally uses holographic film as recording material. Due to this fact holographic testing of tyres is not made in real time. In these days new interferometric methods are developed that video-technique is combined with computer-imaging system. By this way we can expect that holography will be applied in future also for the testing of industrial production of tyres.

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