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Použití optických metod pro diagnostiku dynamických přechodových charakteristik v lidské lebce

Optical methods in diagnostic of transient dynamic responses in human skull

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Abstract: *The paper deals with the study of stress wave propagation in a human skull. Impact was generated both focused ruby laser beam and exploding wires. Transient dynamic responses were studied by means of double pulse holointerferometry and laser interferometry. In the research was paid attention to the evaluation of stress wave propagation velocity and the results of both optical methods were compared. .The study assists in the design of useful medical solutions.*

Key words: **stress waves propagation, skull, exploding wire, double-pulse interferometry, laserinterferometry, hologram**

1. Introduction

The skull is supported on the summit of the vertebral column, and is of an oval shape, wider behind than in front. It is composed of a series of flattened or irregular bones which, with one exception (the mandible), are immovably jointed together. It is divisible into two parts: the cranium, which lodges and protects the brain, consists of eight bones, and the skeleton of the face, of fourteen bones.Fracture of the skull is classified as complicated, because may involve damage to vital organs. It may be caused by direct force, where force is applied sufficiently to cause the bone to fracture at the point of impact.

The measurement was provided on human skull (post morte) of an forty years old man fifty years after his death. The skull haven't mandible and suture squamous is damaged.

Optical methods suitable for studying dynamic state of stress are dynamic photoelasticity, moire interferometry, speckle interferometry, double-pulse holointerferometry and laserinterferometry. The last two mentioned methods were used in the experiment.

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2. Experiment

2.1 Double-pulse holointerferometry

Holographic interferometry is a method that can record three-dimensional deformation over an entire object surface. The holographic interferogram is a pattern consisiting of light and dark bands which seems to be superimposed on the object. This fringe pattern is converted phase information and is made by interference of the object and reference beam which are mutually coherent. Spacing and form of the interference fringes are indicative of the changes that have occurred in the shape or position of the object.

The holographic interferometry was used for studying of the stress waves propagation. Impact loading was generated by exploding wire and laser beam. The exploding wire enables to generate a short ($20\,\mu s$) and intensive pulse ($1500\,N$). The laser beam for impact loading was by means of beamsplitter, mirrors and converging lens focused on the skull. The beam causes a short mechanical and thermal impact of the skull. Both the generation by exploding wire and the laser beam is possible to synchronize with holographic record.

Glabella (the smooth flat portion of the frontal bone between the eyebrows) was chosen as the point of impact.
The skull is in motion during the holographic recording, therefore "double-pulse" mode was used. As the source of lights for holographic record and simultaneously for generation impact loading was employed pulse ruby laser with wavelength 694,3 nm, pulse duration 30 ns, pulse energy 0,4 to 0,6 Joules/pulse and double pulse separation is from 1 to $800\,\mu s$. The first holographic recording is taken before the shock waves are generated, the second exposure is initiated with the loading of the object. The synchronization between the arrival of the shock wave generated by the exploding wire and the instant of visualization was achieved by PIN diode.
The holointerferograms were reconstructed continuous-wave He-Ne laser with wavelenght 632,8 nm.

Optical schema for double-pulse holointerferometry is shown in Fig.1. From the ruby laser emanates light beam which is divided by beamsplitter **BS** into three, mutually coherent, beams. The first beam is used for the illumination of the object. It passes through the beamsplitter, reflects from mirror **M1** and after passing through the negative lens **O1** incidents on the skull. The second beam acts as reference beam. This beam is made diverging by the insertion of negative lens **O2** into his path and after reflection from mirror **M2** incidents on the hologram. The third beam incidents on the **PIN diode** which enables to synchronize shock wave generated and holographic record. The reference beam was adjusted to have approximately the same optical path length as the object beam.

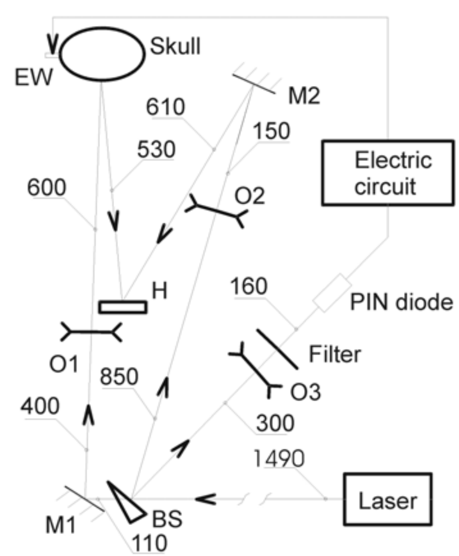


Fig.1. The optical schema for double-pulse holointerferometry

The holographic records were made for two pulse separations i.e. $60\,\mu s$ and $75\,\mu s$. In Fig.2.are given photos of the “double pulse“ holographic interferograms from which only a single state of change in the shape and position of the object can be studied.
The skull was situated with regard to hologram in two positions**.** In the Fig.2.a and the Fig.2.b the skull is depicted in the plan view (norma verticalis) and in the Fig.2.c and the Fig. 2.d in the side view (norma lateralis).

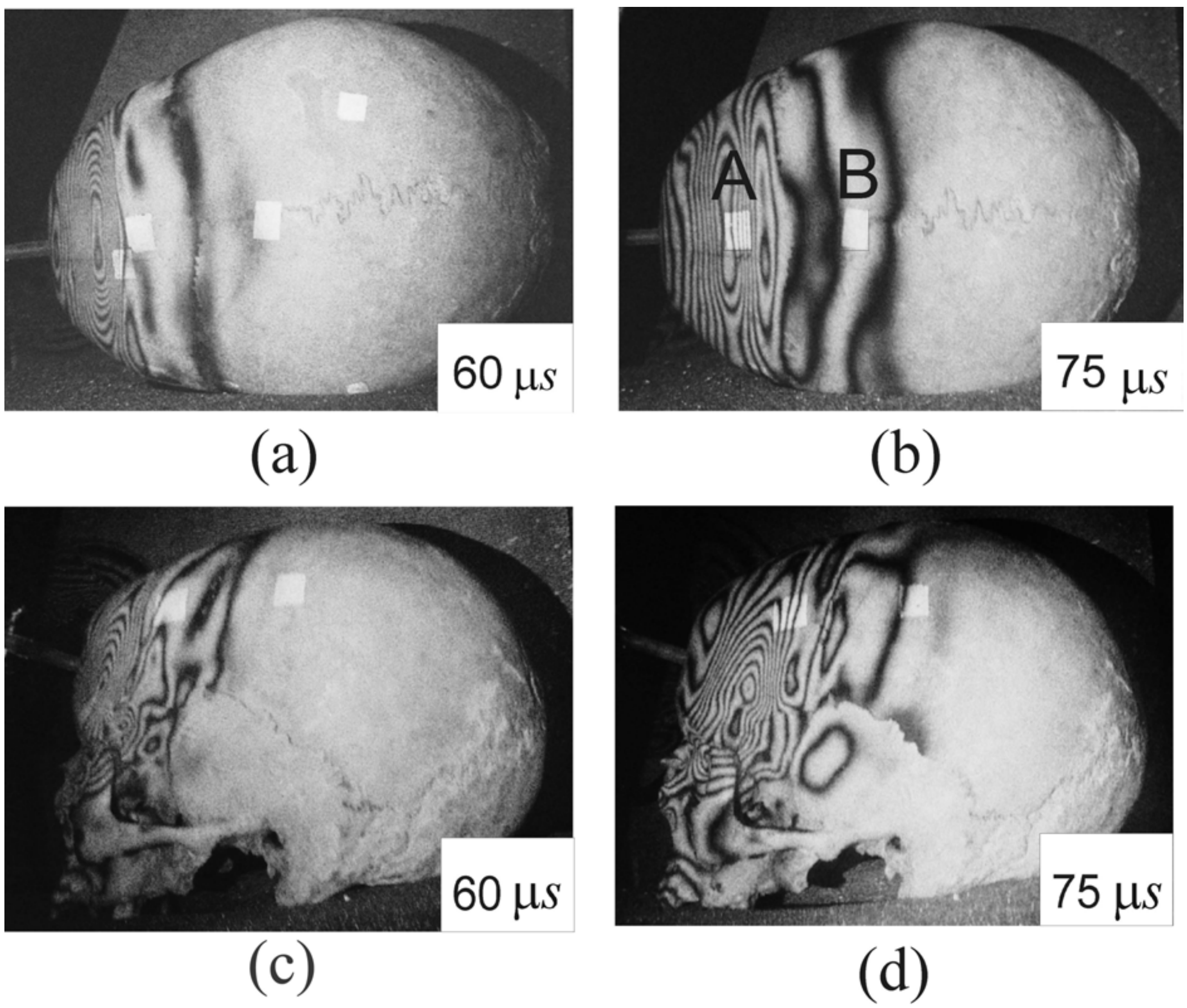


Fig.2. Holographic interferograms of the human skull

For the interferogram in Fig. 2.b was calculated vector displacement $\vec{d}$ of points on the surface of the object. If light travels a distance l_0 from the source to a point on the object and back to the observer before the object is deformed, it will travel a distance $l_0 - L$ after the object is deformed, where

$$L = \vec{d}\left(\vec{s}_0 + \vec{s}\right) = j \cdot \lambda \qquad (1)$$

$$\vec{d} \cdot \vec{c} = j \cdot \lambda \qquad (2)$$

and $\vec{s}_0, \vec{s}$ are unit propagation vectors of the light illuminating an object point and the light scattered towards the observer, respectively.
The notation j is interference order (fringe order) , λ is the wavelenght of the laser light and $\vec{c}$ is sensitivity vector.
Three observations must be made so that three independent vector components of $\vec{d}\left(d_x, d_y, d_z\right)$ will be determined. Therefore the magnitude of the component of $\vec{d}$ along the direction of $\vec{c}$ was calculated using equations

$$\left|\vec{d}\right| \cdot \left|\vec{c}\right| \cdot \cos\left(\vec{d}, \vec{c}\right) = j \cdot \lambda \qquad (3)$$

$$d_{\vec{c}} = \left|\vec{d}\right| \cdot \cos\left(\vec{d}, \vec{c}\right) = \frac{j \cdot \lambda}{\left|\vec{c}\right|} \qquad (4)$$

where $\left|\vec{c}\right| = 2$ and j are fringe order numbers to the bright fringes in Fig. 2.b. The fringe orders were determined by visual examination of a photo of the interferogram. The base has not moved, so was assigned the number $j = 0$ to the bright fringe which it covers.
In Fig.3 gives the relationship between the distance from the point of impact and the magnitude of $d_{\vec{c}}$.

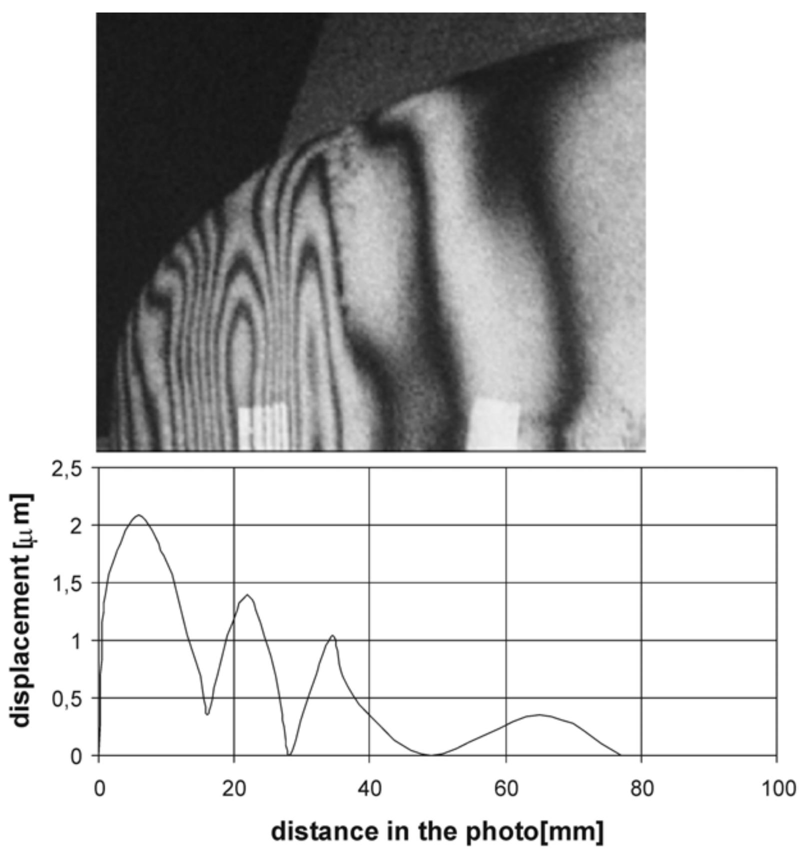


Fig.3. The relationship between the distance and displacement

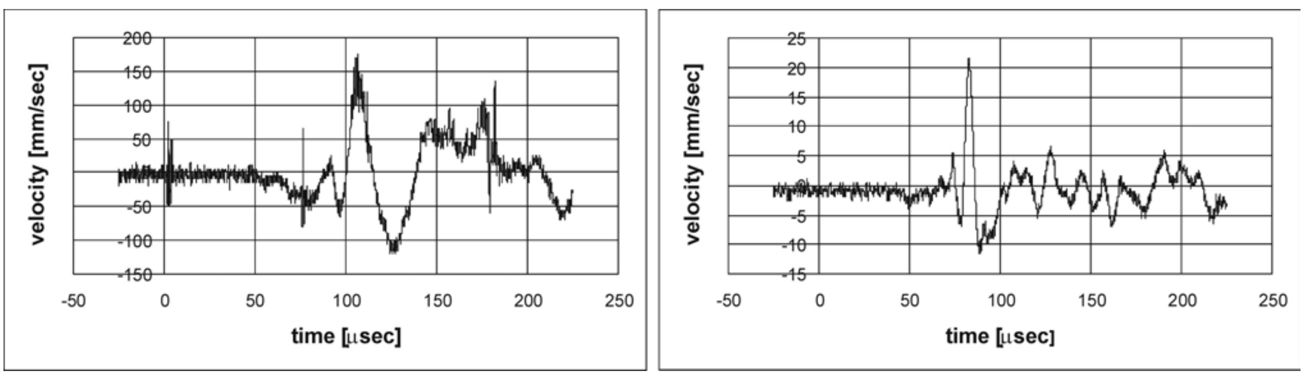
2.2 Laserinterferometry

Optical vibrometer is instrument for contactless measurement of vibration and displacement. The main components of vibrometer system are a laser interferometer and a controller processor. Laserinterferometry provides point-wise data. Vibrometer is instrument which measure surface motion from a remote position using interferometric techniques.

The measurement by laser vibrometr was done with double-pulse interferometry simultaneously. The velocity information was obtained e.g. at point B in Fig. 2b. The distance from the point of impact to the point B is 130mm. Fig.4a and Fig.4b shown relationship between the time and velocity of displacement at point B . Impact loading was generated by exploding wire (Fig.4a) and by laser beam (Fig.4b).

The wave front passes by point B after the lapse of 50 μs in Fig.4a and 46 μs in Fig.4b. It follows that velocity of stress waves propagation generated by exploding wire is 2600 m/s and by laser beam it is approximately equal to 2800 m/s.

Compare the two graphs in Fig.4a and Fig.4b. The values of velocity of displacement in Fig.4a are ten times greater than in Fig.4.b.



(a) **(b)**

Fig.4. The relationship between the time and velocity of displacement
(a) the exploding wire (b) the laser beam

3. Conclusion

The paper deals with the study of stress wave propagation in a human skull by means of two optical methods – double-pulse holointerferometry and laser interferometry. In the described experiment was investigated if and how holographic interferometry and laserinterferometry could be used to study the reaction of the skull bones to mechanical loading. The first mentioned method can record three-dimensional deformation over an entire object surface and other method is point-wise measuring method. The methods have established themselves as qualified methods for non-destructive testing and inspection.

Holographic interferometry provides data related to the shape of the object and data about the changes in the shape of the object, encoded in the fringe pattern. The relationship between the distance from the point of impact and the displacement was obtained by means of double-pulse interferometry. Unfortunately, the wavelenghts of the light emitted by the laser sources commonly employed for reconstruction of holograms differ from that of the Ruby laser. These differences lead to aberrattions in the reconstructed images [4].

The velocity of stress waves propagation in the human skull , which was subjected to a mechanical load, was investigated by means of laserinterferometry. The acquired results are comparable to results in [5], where a velocity range is written 2500-4700 m/sec.

It is important to choose a suitable manner of the generation of the mechanical loading while using extremely sensitive optical methods.

4. Acknowledgements

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