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LASER EXTENSOMETER USING STUCK FOIL-EMBOSSED DIFFRACTION GRATING
LASEROVÝ EXTENZOMETR S VYUŽITÍM LEPENÉ DIFRAKČNÍ MŘÍŽKY

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The stuck foil-embossed diffraction grating has been developed for the use in moiré interferometry. Another application of the grating is described in the article forming one beam laser extensometer. The main aim of the contribution is description of the grating production, the laser extensometer design and derivation the theory.

Keywords: Laser, laser extensometer, diffraction grating, strain gauge.

The drawback of methods using diffraction gratings like moiré interferometry, grating interferometry etc. is the replication process for obtaining the object measuring grating, which is difficult and time consuming. The development of new method for ready-to-use diffraction gratings was the aim of presented work. The time-consuming grating replication on the object is going to be replaced by direct sticking of the pre-produced grating.

The modified technology of embossed holography has been used for production of specimen grating. The parameters of surface of specimen grating are similar to the surface relief of rainbow holograms. The principle of this production method is embossing of nickel copy of the grating relief to the polymer foil. The nickel original grating is prepared by the electroforming technology from master grating at photoresist photosensitive layer. The embossing process of the production of specimen gratings is a process based on rotary replication of production shim into polymer foil under high temperature and pressure. The typical structure of the foil used for embossed holography is a sandwich construction. Embossed foil is coated by required adhesive and it is laminated to backing paper.

Strain measurement using laser extensometer is one of fields, where developed grating can be used.

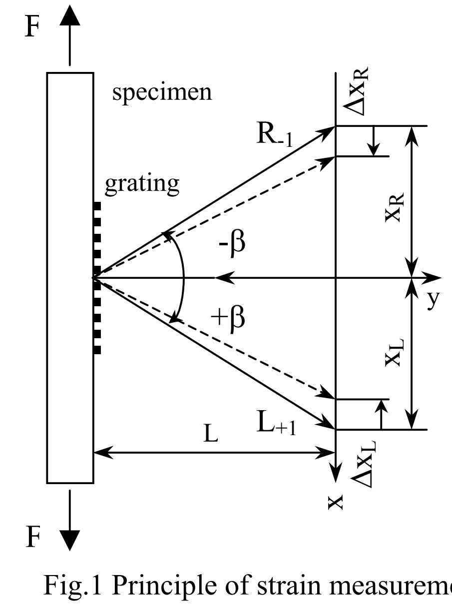

Fig.1 Principle of strain measurement

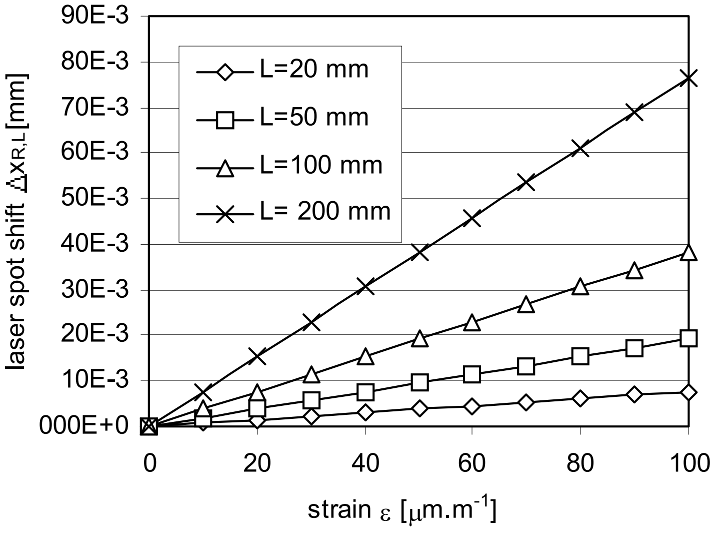

Fig.2 Sensitivity of strain measurement

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Let the specimen is illuminated with non-expanded laser beam in normal direction to its surface. Let the specimen surface is glued with foil diffraction grating. In that case the laser beam is diffracted to two +1, -1 diffraction orders, which propagate with angle $+\beta, -\beta$ to the specimen normal according to the grating equation

$$\sin\beta = \pm\lambda \cdot f = \pm\frac{\lambda}{p} \ , \tag{1}$$

where β corresponds to the diffracted beam angle, λ to the laser wavelength, f to the spatial frequency of the grating and p to the grating pitch. The distance in the image plane between laser spot and the normal axes $x_{L,R}$ can be determined according relation

$$x_{L,R} = L \cdot tg\beta = \frac{L \cdot \lambda}{\sqrt{p^2 - \lambda^2}} \ . \tag{2}$$

Loading the specimen, the grating pitch and the diffracted angle β are changed. Then the strain ε can be calculated from the spot position changes Δx_L, Δx_P at the image plane by derivation the equation (2)

$$\varepsilon = \frac{\Delta p}{p} = -\frac{(\Delta x_L - \Delta x_R)\cdot(p^2 - \lambda^2)^{\frac{3}{2}}}{2L \cdot \lambda \cdot p^2} \ . \tag{3}$$

The relation between the strain ε and laser spot movement $\Delta x_{L,R}$ is seen from the curves in the Fig.2.
The easy set up according Fig.1 is sensitive to specimen translation along the z-axes and its rotation about two in plane and one out-of-plane axis. It is insensitive to the rigid body in-plane movement. New set up, which compensates all misalignment errors, has been developed and is show in Fig.3.

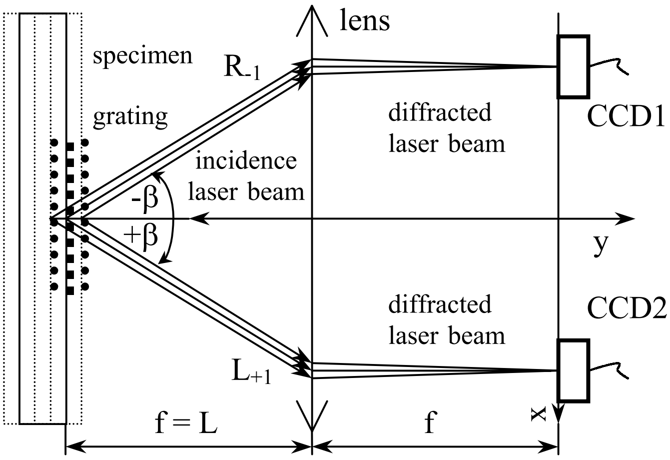

Fig. 3 Laser extensometer proposed design

The specimen is situated approximately in the object focus plane of the image lens. Two CCD sensors are placed in the image focus plane, to be able to record the both in plane diffraction beam spot movements. The main error of the laser spot movement due translation of the specimen in z direction $(\Delta x_L - \Delta x_R).2L.tg\beta$ is compensated in this arrangement, because the parallel set of diffracted beams is always directed to the same point in the focus image plane.
Measuring the movement of the laser spot also in the y direction Δy_L, Δy_R compensates the sensitivity to rotations about x and z axes by recalculation the measured values Δx^*_L, Δx^*_R using the relation

$$\Delta x_{L,R} = \Delta x^*_{L,R} \cdot \sqrt{1 + \frac{(\Delta y_L + \Delta y_R)^2}{L^2}} + \left[\frac{L \cdot \lambda}{\sqrt{p^2 - \lambda^2}} - \sqrt{\frac{L^2 \cdot \lambda^2}{p^2 - \lambda^2} - \frac{(\Delta y_L - \Delta y_R)^2}{4}}\right] \tag{4}$$

The effect of rotating the specimen about y axis can be compensated using equations, obtained by solving (1) for tilted grating using the sum of laser spot translations $(\Delta x_L + \Delta x_R)$, which is not presented here.

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