Laser grating extensometer LES for whole-field strain analysis in fatigue

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ABSTRACT: *In the paper laser grating extensometer system LES for whole-field strain analysis in fatigue loading conditions was presented. The integration of laser grating extensometer with the fatigue machine makes possible fully automatic measurements of local displacements and strains in the variable loading conditions. In the laser grating extensometer system LES the moiré interferometry technique was used for displacement and strain measurement. Measurement sensitivity of up to 20nm can be obtained analysing the interference fringe pattern image. Automatic measuring mode makes supervisionless operation of the system possible in the case of long lasting investigations, mainly fatigue testing, and also other requiring a complex and long lasting loading and data recording program.*

INTRODUCTION

The state of stress and strain is one of the main factors deciding about fatigue life of structural parts and materials. Their strong concentrations accompanying to geometrical and structural notches are one of the most appearing causes of fatigue cracks in machine parts.

Very often in stress and strain investigations in specimen or real objects tested under time variable loading it is necessary to estimate their field distributions in fatigue crack initiation and propagation areas.

There are a lot of experimental methods that enable to measure strains in two-dimensional analysis area [1], but only a few of them can be applied in fatigue loading conditions and in plastic strain ranges. The laser grating interferometry (moiré interferometry) [2,3] is one of that methods. The following part of the paper describes designed, in co-operation of University of Technology and Agriculture in Bydgoszcz, Institute for Terotechnology in Radom and Warsaw University of Technology, the automated system of laser grating extensometer LES [4,5,6] for displacement and strain distributions measurements in time variable loading conditions and possibilities of its application in fatigue crack initiation and propagation investigations.

OPERATION PRINCIPLE OF LES SYSTEM

Automated system of laser grating extensometer LES is a modern measurement system that enables to estimate the displacement and strain distribution in cyclic loading conditions. Fig. 1 shows the complete configuration of the system including the LES measurement head, personal computer with software, drivers and the supply unit and the co-operating fatigue test machine.

The original computer code controls the work of complete system by means of National Instruments PCI-GPIB interface (for loading machine control), Matrix Vision MVDelta (or MVSigma) frame-grabber (for image acquisition) and Advantech PCI 1750 laboratory card (for stepping-motors, laser diodes and CCD camera control).

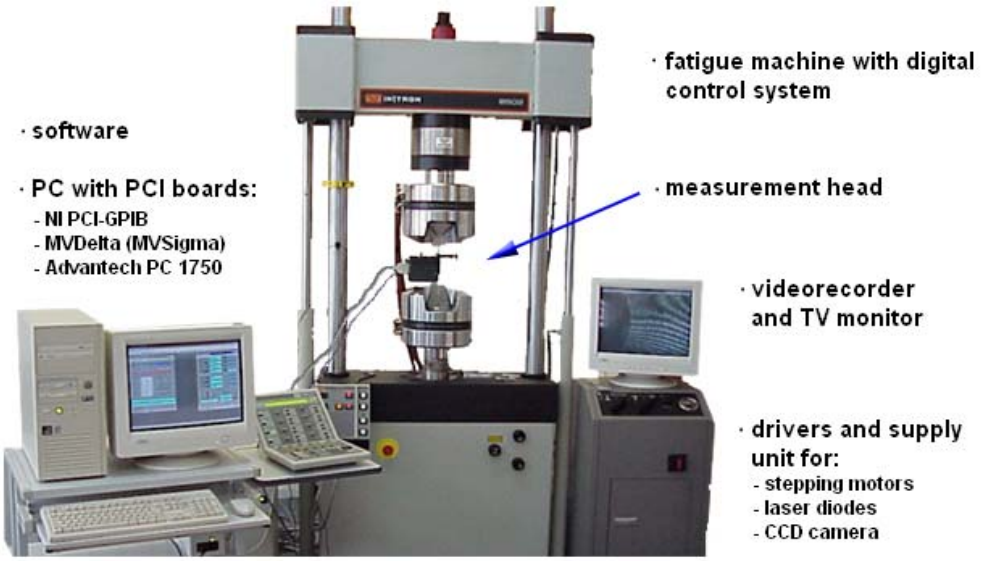

Figure 1: LES system configuration

Measurement head

The mechatronic measurement head (shown in Fig.2) is the main element of the system. The applied measurement displacement/strain techniques enables to conduct the measurement on flat or almost flat objects. The head fastening is carried directly on the object or through the intermediate elements in grips of the fatigue machine.

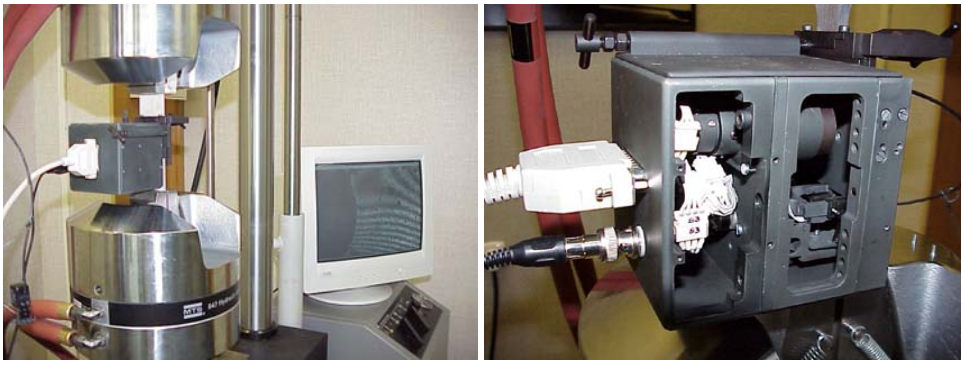

Figure 2: Measurement head

As it was mentioned above, the laser grating interferometry technique was applied to displacement and strains measurement. Its principle of working [2] was shown in Fig.3a. The method is one of the whole-field optical methods that enables to estimate two-dimensional displacement and strain distribution.

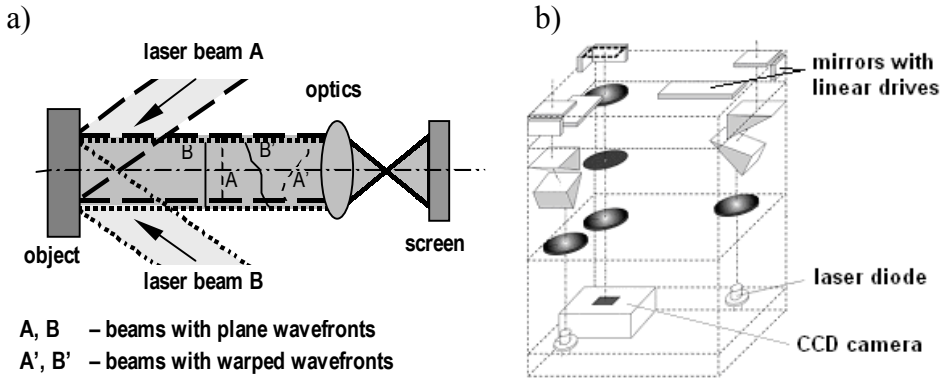

Figure 3: Principle of laser moiré (grating) interferometry technique (a) and functional scheme of measurement head (b)

In the method, two coherent laser beams light a specimen grating placed on tested object at angles of incidence equal plus the first and minus first grating diffraction angles. As a result of beams diffraction on the deformed, because of loading specimen grating, they propagate along the normal to the specimen surface and create the image of interference fringes, carried information on displacement of the object surface under the specimen grating.

Two independent measurement channels for two perpendicular directions *u* and *v* (Fig.3b) were applied in the LES head. Necessary adjustment connected with the measurement realisation are carried remotely by linear drives with the stepping-motors. Laser diodes are a source of the coherent light, and the fringes pattern is observed by a CCD camera. Fig.4 shows examples of image of interfernce fringe patterns for u and v analysis direction. In the presented examples the specimen grating was placed on the object with generated fatigue crack to analyse changes of strain distributions in the area of crack tip.

MEASUREMENT MODES

Designed and developed software owing to integration of the LES system with the fatigue machine, enables the automatic realisation of the measurement in two basic working modes: on-line and off-line.

On-line mode

The first work mode of the LES system consists in the local strain measurement on the pointed fragment of the specimen grating in the real time mode (on the fly) (Fig.5). It enables to measure the strain on a very small measurement gauge and record its value during the realisation of loading including the rest measurement signals (e.g. load, piston position, strain from external extensometer, etc.).

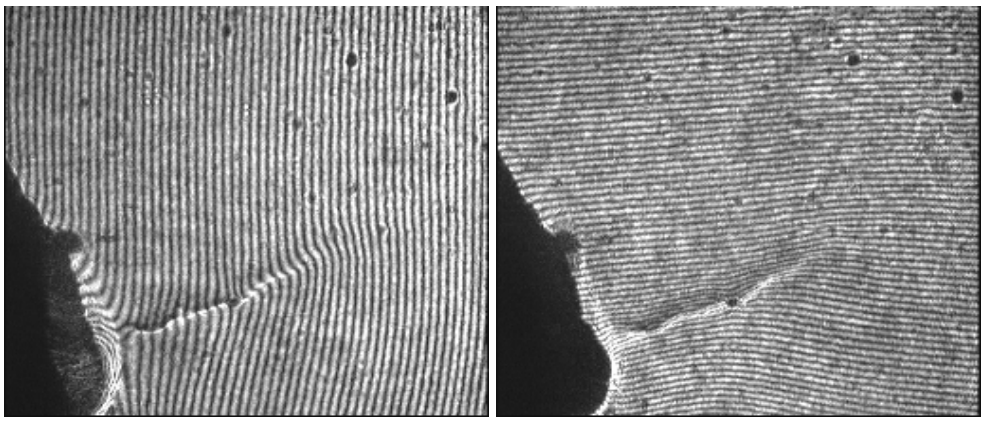

Figure 4: Fringes patterns for cracked specimen

Fig.6. shows an example of a course of the local strain value recorded for few following loading cycles in the flat specimen with a central hole in the crack initiation area.

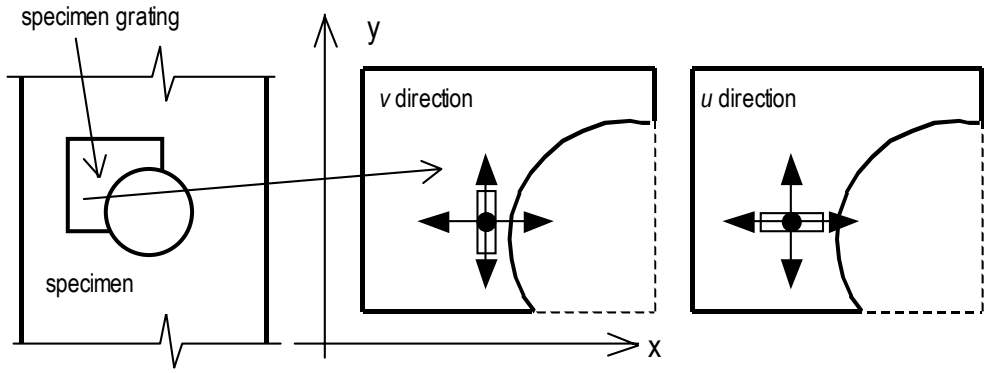

Figure 5: Local strains measurements in on-line mode

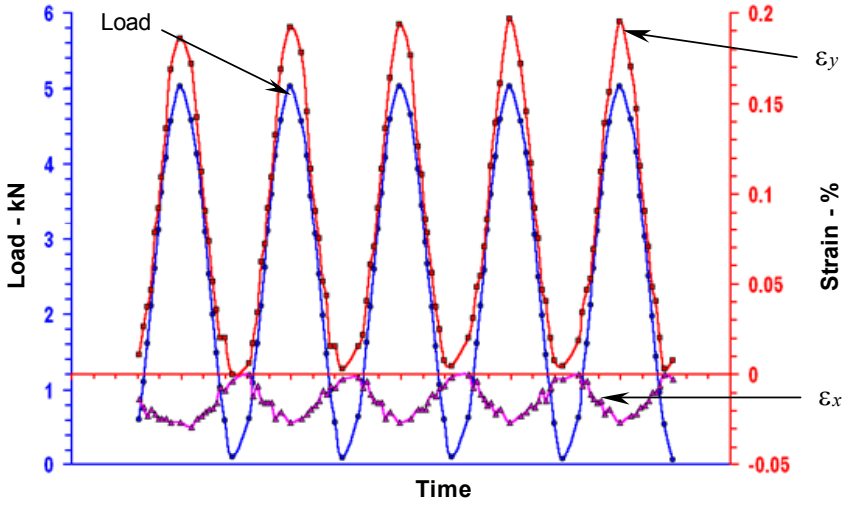

Figure 6: The example of on-line measurements of load and strains in flat specimen with hole in the following loading cycles

Off-line mode

The off-line mode consists to the automatic analysis of fringe patterns recorded during the test in order to estimate 2D displacement and strain

distributions. The analysis is processed for a pointed sequence of interference fringe images basing on a calculation sheme prepared by a user (Fig.7).

Fig.8 shows examples of displacement maps obtained for the notched flat specimen in following phases of a loading cycle.

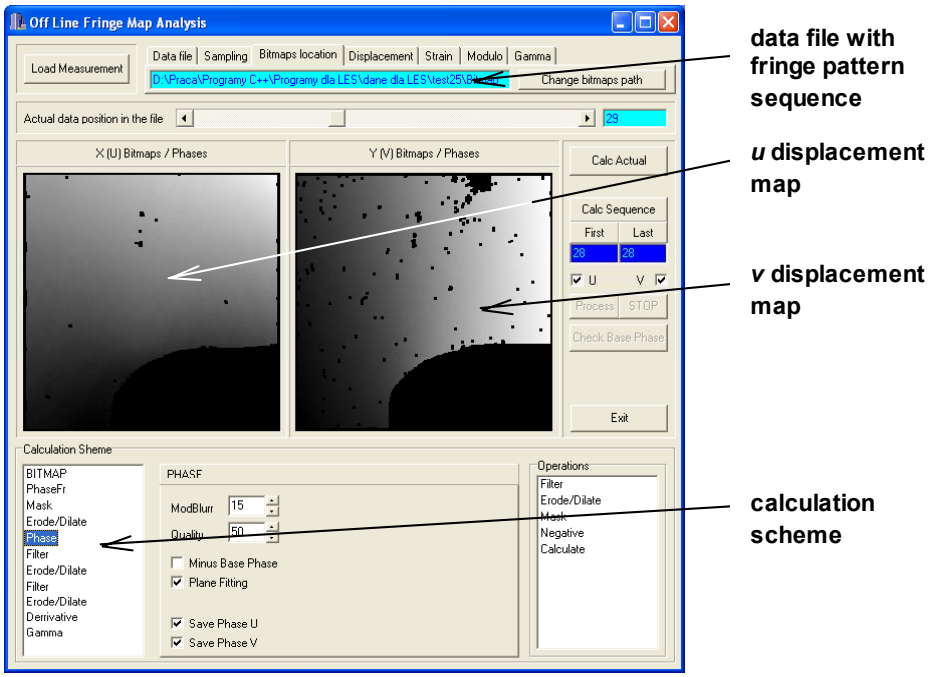

Figure 7: Off-line analysis

BASIC OPERATIONAL PARAMETERS OF LES

Measurement possibilities of the laser grating extensometer are connected with parameters of the applied laser diodes, frequency of a compensative and specimen gratings and resolution of CCD camera and the frame-grabber board. In the basic version of the LES head the base sensitivity is 417 μm/fringe, what enables obtaining the measurement sensitivity up to 20 nm and the measurement range about 35 μm.

The applied optical arrangement enables to measure in a sight area with dimensions about 3 x 4 mm on a crossed-line grating with dimensions up to 25 x 25 mm.

The measurement in the on-line mode takes place on a measurement

gauge which is 0.15÷0.35 mm length and about 0.03 mm width, whereas the frequency of the fringes image recording is up to 50 Hz (the CCiR system).

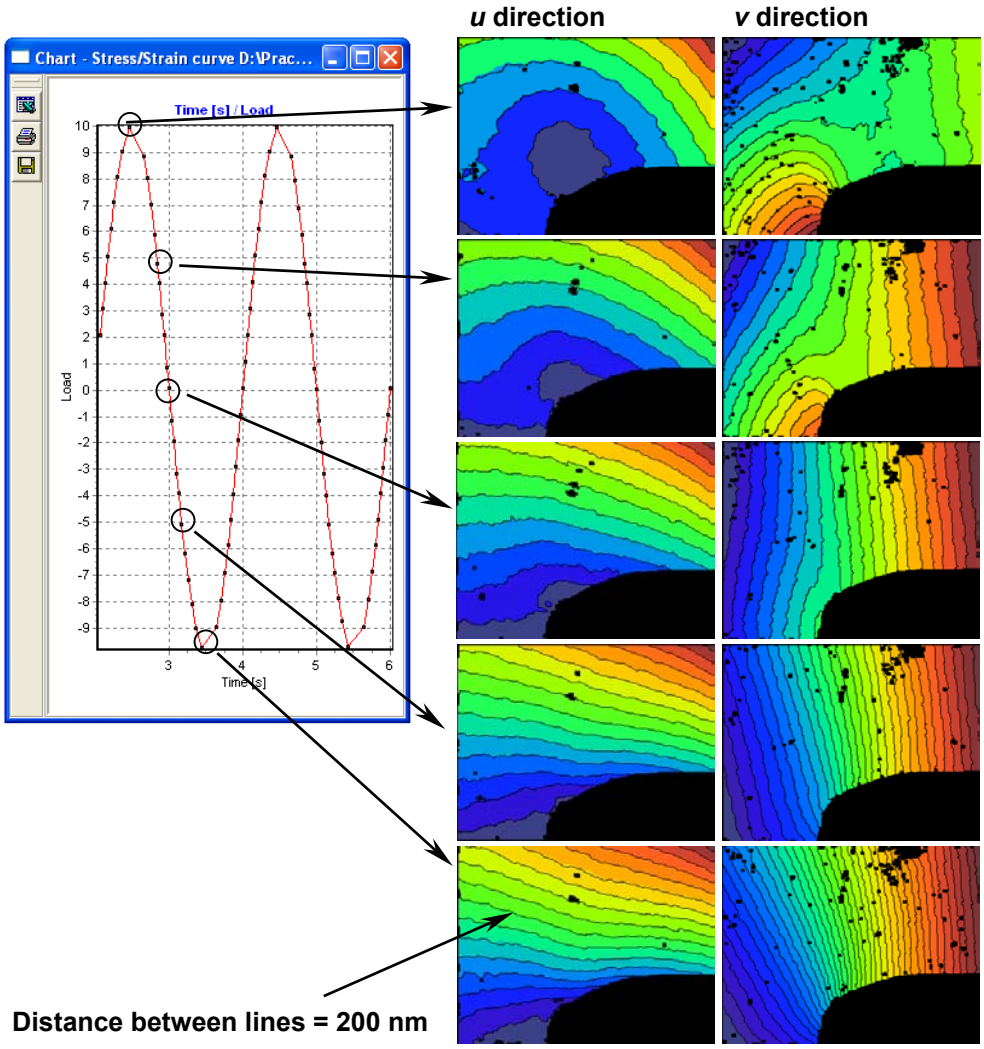

Figure 8: Displacement map for following phase of loading cycle

SYSTEM AUTHORS

The laser grating extensometer system was designed and developed in co-operation of a group of people from Institute for Terotechnology in Radom, Warsaw University of Technology and University of Technology

and Agriculture in Bydgoszcz:
- Tomasz Giesko, Andrzej Zbrowski, Tomasz Wójcicki – Institute for Terotechnology in Radom,
- Małgorzata Kujawińska, Leszek Sałbut, Robert Sitnik, Michał Józwik – Warsaw University of Technology,
- Józef Szala, Dariusz Boroński – University of Technology and Agriculture in Bydgoszcz.

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SUMMARY

The laser grating extensometer presented in the paper thanks to obtained operational parameters and automation of the measurement process is particularly useful in the investigations of the fatigue crack initiation and growth.

The automatic measurement mode enables the system to work without a supervision in long-lasting tests, the fatigue ones mostly, but also other tests that need complicated and long-lasting loading and data recording program.

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