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DIGITAL IMAGE COMPARATOR FOR EXPERIMENTAL ANALYSIS OF DEFORMATIONS

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Abstract. Optical methods of deformation measurements represent one of the oldest and the most widespread area of experimental mechanics. The optic methods of strain measurements are generally-interferometry, stereo image analysis and digital image analysis. The above-mentioned optical methods are of particular importance for deformation analysis in microstructures and microobjects, where they are the only possible experimental tools. The basis of the stereoscopic technique of deformation measurements is the taking of pair stereoscopic photographs of objects, using the time base principle, i.e. photographs of objects before and after the deformation under the entirely same conditions are taken. The further step in stereoimage method of the strain analysis is the stereocomparation of the pair of images. Up to now we have used for it the analog apparatus ZEISS-Stecometr. The paper which is presented describe a digital system of reading and comparation of the pairs of stereoimages.

1. Introduction

Optical methods of deformation measurements represent one of the oldest and the most widespread area of experimental mechanics. The furthest and the most frequently used principle of optical methods is interference [1], and almost a hundred years old history has the stereoscopic principle [2]. Newer are photomethods applying image analysis to calculate coordinates of identification points fields [3].

The above-mentioned optical methods are of particular importance for deformations analyses in microstructures and microobjects, where they are the only possible experimental tool. Evolution of optical methods of deformations measurements in the field of experimental micromechanics commences at the end of 1980s. In the field of interferometry there are contributions of Sciammarella [4], and Michel and Kühnert [5]. Stereoscopic method was employed by Davidson [6], and Berka and Růžek [7]. Image analysis of microidentification point structures was worked-in-progress by Allais [8] and Fischer [9].

At present, the best sophisticated and the most frequently used method in this area is the interferation micro-moire' technique of D. Post [10]. In our country, Václavík and Minster [11] are working with this technique. Advantage of it is the full-surface scan of deformations field and the high accuracy, reached by using grids pairs with the density of 1200 lines/mm, positioned both in the interferometer and also in the measured object. Development of the technique was influenced also by the rapid evolution of image analysis and digital technique, enabling measurement in the real time.

Evolution of the stereoscopic method of deformation analysis is connected with the overall development for evaluation of pairs stereoscopic photographs. This results from the fact that taking photographs and their analysis does not take place simultaneously. With regards to specific conditions of taking ground photographs by using special cameras, the evaluation systems are equipped with the high resolution scanners that markedly enhance purchase and operating expenses of these systems, and thus they become hard available. Users of stereoscopic measurement technique, who can work with digital image recording, gained by CCD camera or scanning electron microscope, therefore try to create on-line system enabling record, processing and comparation of images obtained by the time base method. The system described in the following contribution is a digital image of the hitherto used analog system for recording and evaluation of stereoscopic photographs pairs, that was referred to on the previous conferences EAN [12].

2. The deformation analysis by the stereoimage technique

The basis of stereoscopic technique of deformation measurements is the taking of stereoscopic objects photographs pairs, using the time base principle, i.e. photographs of objects before and after the deformation under the entirely same conditions. To fulfil this requirement, it is necessary not only for the image-taking apparatus, a microscope in our case, but also for the CCD camera to ensure, by their external (sample and apparatus position) and also internal (magnification stability, orientation) a reproducibility of photographs with accuracy attributed on the deformation measurement accuracy. This can be different according to the nature of solved problem (elastic or plastic deformation). According to it, it is also necessary to choose an appropriate method. Taking into consideration deformation measurements in the vicinity of the agreed plasticity limit of steel, having a size of 0.2 % with accuracy 10 %, i.e. value of $\Delta\varepsilon$ = 0.02 %, the requirement follows on the accuracy of the couple of stereoscopic photographs evaluation of undeformed specimen, obtained by the time base method. It means that after the first image processing, the specimen is undertaken to all necessary measurement operations, and then the second image is performed. Found values of fictive deformations represent faults of measurements that must be lower than the required value of 10 % of plasticity limit. Deviations may result from:

– differences in the position and microscopic identity of sample surface in its taking out and reloading into the vacuum microscope chamber

– differences in the resetting of microscope electronic regime during exchange or the switching the device off.

To minimize these deviations, it is necessary, regardless the type of a microscope, to choose such a method that will limit changes in the setting of device parameters, used in the first photographs processing, at maximum. This is the question of keeping the working distance and set magnification, whose deviations are equal to a relative error in their deformations measurements. Errors in the measured deformation can be caused also by overfocusing and higher differences in the brightness and contrast setting, which change dimensions of microobject image and thus conditions of the photographic comparison.

Further group of errors is connected with the quality of image recording, both photographic and digital. In case of the stereocomparation, besides identity of microsurface images, it is also internal resolution of stereocomparator Δl, which at device ZEISS Stecometr is 2 μm. The necessary precision in the deformation measurement equal to $\Delta\varepsilon$ = 0.0002 is reached at the photographic distance of compared points $\underline{1}$ equal to $\Delta l/\Delta\varepsilon$ = 2/0.0002 = 1.10 μm. At the smaller points distance, the error is bigger than presumed 10 %.

At digital system of evaluation of a stereoscopic pair of photographs, the accuracy of a points position is measured mainly by the resolution at which the image is taken.

3. The reading and image processing - system TESCAN

TESCAN has developed a device for digitization, preprocessing and recording of electron microscopic image. Hardware of the device is composed of personal computer, digital generator of scan signal and acquisition device of video signal, positioned on the special developed card in the ISA computer bus and converters units D/A and A/D in the separate box, where there are the circuits for an option of input analog signal, signal filters, power supplies and auxiliary circuits.

Signal for electron beam sweeping in the microscope tube is generated in the computer in the digital form. According to the generation principle, it is necessary to resolve fast and slow raster scanning. In the fast raster scanning mode - called "fast" in the program - the step signal is generated mainly by hardware tools - everything is subordinate to reaching the maximum speed of raster scanning. Sweeping is not synchronized with the power supply. This mode serves to the rapid scanning of specimen and to the microscope setting.

In the slow raster scanning mode, the time of duration of electron beam in each image element (and thus the speed of raster scanning) is changed sequentially. Five slow speeds is preprogrammed altogether, the quickest of which is called "middle", and it is possible to follow also the slowly changing image. The others are then called "slow" and serves to reach the best quality stationary image. Quality image improvement, i.e. increasing of ratio signal/noise, is reached by two effects. As far as the electron beam remains longer in each image element, then the statistic noise lowers in the genesis and the prime processing of image signal with the time prolongation root (interaction of electrons with a specimen, generation of signal electrons, their transformation on photons in the scintillator and back conversion on the photomultiplier cathode are stochastic processes). Next effect affecting the ratio signal/noise improvement is compression of width of the transmitted frequency band necessary for the real transmitting of all details in the image.

At all slow speeds of raster scanning (including "middle") is the start of each row synchronized with the certain phase of the power supply. Thus, the dominant interference component is suppressed, because disturbing magnetic field in the tube vicinity (if it exists here) causes the certain image distortion, but not the loss of resolution.

Generated sweeping signal is then, in the D/A converters units, transformed from the digital form onto the analog signal, and in the output circuit, it is possible to set its polarity, amplitude and ss level suitable for an appropriate type of microscope (between -10 and +10V). The basic setting of system magnification is carried out here in order that the operating field of system may be concordant with the original field of electron microscope .

Analog video signal generated and strengthened in the microscope is brought via input switching circuits into an A/D converter. Even four signal from different detectors from the microscope is possible to transfer into the input circuits, and one of them to choose for display by means of the program. In the A/D converter, the analog video signal is converted onto the digital form simultaneously with the filtration - all higher frequencies that are not necessary for real image signal transmission are reduced, and thus the image noise is reduced. Digital video signal is then via special interface, located on the same card in the computer as a generator of sweeping, brought into the computer video memory and - as far as an operator commands by means of the control program - the image is set also on the chosen memory medium.

The entire process of sweeping and image acquisition is controlled by the program that operates in the Window 95 environment and uses the standard image format BMP. The program includes also procedures for image preprocessing - brightness and contrast manipulation, image focusing and noise reducing. Program offers ample possibilities in the software calibration field of image magnification on the basis of known objects and measuring of formations in the image.

The big attention in the program creation has been also payed to the comfortable and users-friendly storage system, which enables quick scanning, copying and opening of stored images by means of "album" of their miniatures, sorting according to the data in the head stored with each image etc. Program enables to make images with the resolution of 256x256 up to 4096x4096 of image elements (pixels).

The researchers payed an extraordinary attention to the problem of necessary resolution (i.e. fineness of the raster step) and its fitting with the other requirements on the system. These requirements are rather controversial. As mentioned above, improvement of the signal/noise ratio is possible to reach by the duration of electron beam in each pixel, while in order to reach the higher resolution of optical microscope system, it is necessary to operate with "thinner" and unfortunately less intensive electron beam. Increasing of requirement on the duration in each pixel and simultaneously increasing of numbers of pixels in the given image leads to the disproportionate prolongation of time for one image - above the level, which is usually guaranteed by producers for stability of their devices and after all above the time acceptable for an operator. Thus, the probability is increased that during the long time of photo performing , a random failure of power supply or a shake etc. may happen, which is displayed by the image error. For example, in the size magnification of units of thousands and image division onto the 4096x4096 pixels, which is a requirement for microdeformation measurement with the above mentioned accuracy, at the microscopes with thermoemission electron gun is the time necessary for one pixel about 200 μs, which at 4096x4096 pixels represents the time of image processing 60 minutes. During this time, defocusing of image may happen as well as its shifting by device drift or a change of brightness. When solving this problem, the procedure has been developed, which enables in the lower resolution raster regime (as a basic raster regime we consider resolution 512x512 pixels) to choose a window of the chosen size (using the multiple of two), to place this window on the chosen object decisive for microdeformations evaluations, and then to scan the image in this window with the very fine raster scanning, which corresponds to 4096 image elements on the row throughout the whole image. Thus, scanned chosen parts of image are screened on the display with the full resolution, and can be used for evaluation of microdeformations by digital comparator.

In conclusion, it is necessary to add that the proposed system requires the best quality computer hardware. The necessity is the high quality resolution monitor and a graphic card with the memory 4 MB, fixed disc with the high capacity, or further tools for recording of digitized images sets.

4. The digital comparation of stereoimages - system COMPARAT

To evaluate a stereoscopic pair of raster electron microscope images, the software system has been developed. The system enables an operation with images up to maximum dimension of 2048x2048 pixels. Both compared images are displayed simultaneously on the computer display in complementary colours. The high sensitivity of the human eye on the change of colour tone, which is near to neutral gray, is utilized. Changes in images are shown as garish colour changes. A user marks in an interactive way a certain amount of points corresponding each other in the both images. Thus, the relative shifts in these points are determined. The absolute shifts are possible to determine only after the precise matching of both compared images. Three following methods are possible to employ.

1) The precise matching of compared images is guaranteed by the technical solution of experiment. In this case, relative shifts are considered as absolute ones. In practice, it is very difficult to find such a technical solution.

2) During images scanning, it is guaranteed that both images have the same scale, i.e. magnification of the raster electron microscope is in both images identical. In this case, such a translation and rotation of the second of the images pair is searched in order that the sum of deviation quadrates in the users tagged points was minimal. Practically it is carried out in such a way that both images are placed into the complex numbers plane and linear transformation

$$w = a.z. + b$$

is searched, where a, b are complex constants and abs (a) = 1 is valid. After the linear transformation with required attributes has been found, the second of the images is transformed. Shifts between marked point in the first image and transformed second image are considered to be absolute.

3) This method is used then, when it is not possible to guarantee that compared images have the same scale. In this case, such a translation, rotation and homotetie (a scale change) is searched in order that the sum of deviation quadrates in the points marked by the user may be minimal. Analogously with the item 2), the linear transformation is searched in

the complex plane with the difference that abs (a) need not to equal to 1. It is possible to employ this method only if we accept an assumption that the size of surfaces has not been changed by deformation. After the linear transformation with required attributes has been found, the second of the images is transformed. Shifts between marked points in the first image and transformed second image are considered to be absolute.

After the absolute shifts have been found, the conform scan, determined by the absolute shifts in the set points is searched. This display is then employed for shifts matrix generation in the sufficiently dense grid of points. For images of 2048x2048 pixels, the grid with the step of 64 pixels is applied. This matrix of shifts is an output of the comparator. The system has also a possibility of graphic output in which the shifts vectors are plotted in the nodal points of a grid. To reach the maximum possible accuracy of printing on all possible types of printers, the system TEX has been chosen. The comparator generates automatically the source set for TEX, and therefore it is sufficient to translate this set using some of the TEX version (quite sufficient is the version Plain TEX) and print out. When employing laser printers 300 dpi or some better, the printing accuracy is comparable or better than an error caused by discretization of the image processed by the comparator.

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