712. Using the high-speed camera as measurement device in the dynamic material tests

Artur Iluk
Wrocław University of Technology, Faculty of Mechanical Engineering
E-mail: *artur.iluk@pwr.wroc.pl*

(Received 28 September 2011; accepted 14 February 2012)

Abstract. The application of the original optical image recognition program Edge for measurement and analysis of the displacement and strain rate during a dynamical test on the flywheel device was presented in the paper. Examples of image recognition analysis on a movie taken by high-speed camera Phantom v12 were used, in connection with the software, as dynamical videoextensometer. The results showed that the previously assumed constant velocity of the lower end of specimen during flywheel device test is not true.

Keywords: high-speed camera, flywheel device, videoextensometer, dynamic.

Introduction

Precise measurement of displacement or deformation is very important for various kinds of experiment where strain rate is relatively high. It is especially significant for finding out a dissipation of energy during impact and for determining dynamic characteristics of materials during high speed deformation. Dynamic character of process causes, that the measurement of displacements is quite difficult and range of available method of its measurement becomes narrow. Some methods are by its nature to slow, other ones introduce to experiment sensors with significant mass, which inertia can make the results useless. The optical methods utilizing laser devices [1, 2] and various kinds of force and acceleration sensors are popular [3].

The following criteria for method evaluation are utilized:

- spatial resolution,
- temporal resolution,
- quality of results.

The use of high speed camera for measurement of deformation was tested. This kind of equipment recently achieved great improvement in speed of recording, so instead of traditional use for documentation of run of test [4], it becomes a useful measurement device for high-speed experiments [5]. One of the goals of experiment was the estimation of usefulness of high-speed photography for measurement purposes.

Material test

Material test example is the dynamic tension test on a flywheel device. This device utilizes the one bar method – a variation of Split Hopkinson Bar device. The main goal of experiment is to determine the dynamic characteristics of material for strain rate in range up to 3000 s^{-1}.

For the one bar method it is necessary to know the history of velocity of lower part of a specimen [6]. It can be assumed, that because of very high inertia of the hammer, this velocity is constant and equal to circumferential velocity of the hammer.

Two methods of displacement measurement have been used:

- precise measurement of rotational velocity of the hammer by an encoder,
- high speed camera Phantom v12, working at rate 82 kHz

A view of specimen on flywheel device is presented on figure 1.

The frame rate 82 kHz was relatively low, but a larger field of view has been selected to observe all elements of device and specimen. The movement of markers at the both ends of working area of specimen has been traced on the movie.

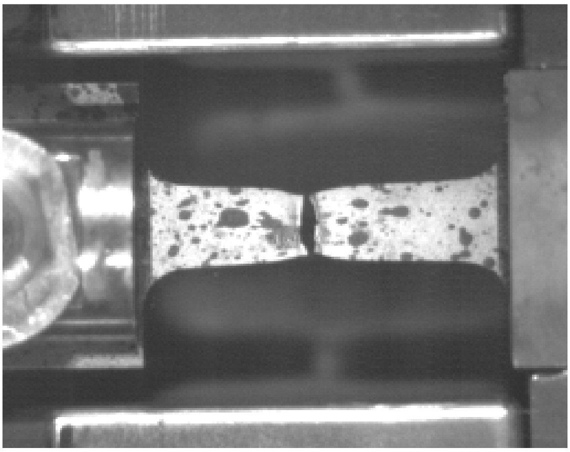

Fig. 1. A view of specimen on flywheel device at frame rate 82 kHz

Image analysis

To use the slow-motion movie as a source of information demand the specialized software to image analysis. In this area two programs were checked: commercial system TEMA dedicated to objects tracking in 2D and 3D space and software developed by author especially for purpose of tracking moving edges in 2D space.

The TEMA software is equipped in various algorithms to track different kinds of objects:

- correlation (Digital Image Correlation - DIC),
- quadrant symmetry (pattern with two symmetry axes),
- center of gravity of irregular shape,
- edge intersection,
- corner.

Example view of tracked image in TEMA is shown in the figure 2.

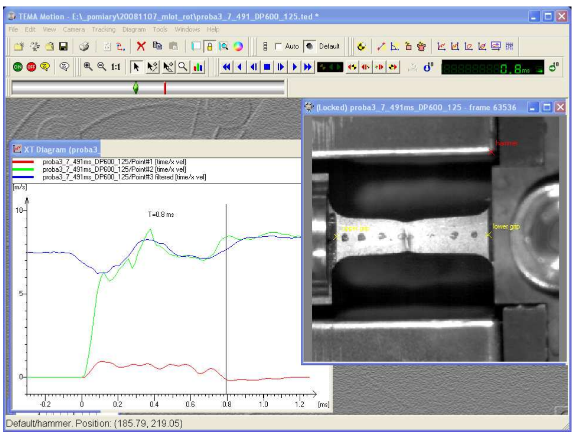

Fig. 2. Example view of TEMA tracking positions of markers on specimen in dynamic tension test

Unfortunately, there is no tracker algorithm to track vertical or horizontal movement of straight edge, which is the most useful for measurement of displacement and velocity of different parts of the specimen. Digital image correlation tracking algorithm demands a random pattern on the specimen which is not as well defined as a straight contrastive edge marker. For this reason special tracking software were developed for tracking edge movement. Example view of program was shown in the figure 3.

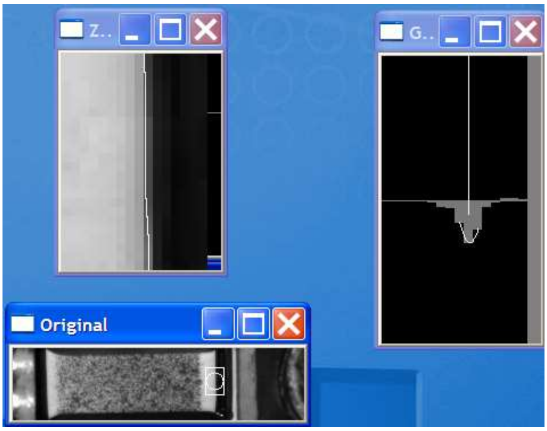

Fig. 3. View of author's contrastive edge tracking program Edge v2.1 during work

Tracked sample (lower picture), detected with subpixel accuracy edge (upper left), luminance gradient in single point on the edge (upper right).

Tracking algorithm used in the EDGE program gives results with subpixel accuracy. Practically achieved resolution is on the level 0.1 of pixel. Because algorithm is tracking position of the edge in multiple points along its length, digital image noise can be compensated by averaging on the edge length. As result of such averaging, more stable results can be achieved without filtering of the results.

Result discussion

The analysis of the results from camera revealed, that assumption of constant velocity of lower part of specimen is not true. Rotational velocity of the hammer is in fact constant, but because of significant inertia of lower grip, this grip is bouncing elastically from hammer at the moment of hit, and the resultant velocity of lower part of specimen is higher than velocity of hammer. Precise measurement of this velocity enables to perform a correction of the received characteristics of dynamic material behavior. An example of velocity history obtained from flywheel test is shown in figure 4.

A spatial and temporal resolution of results is acceptable in this case, but velocity of impact was relatively low (about 15 m/s) while device can work up to 50 m/s. For higher impact speed, higher frame rates have to be used. In the table 1 available frame rates and corresponding spatial and temporal resolutions are presented.

Conclusion

Comparison of various methods of displacement measurement shows, that using a high speed camera in connection with software to image analysis is very useful tool especially for experiments, where desired spatial resolution is not very high.

The main advantages of this method are:

- possibility of multi point and 2D measurement (3D with 2 cameras),
- temporal resolution up to 1us at low spatial resolution (Phantom v12),

- spatial resolution up to approximately 24000 points (at low speed),
- short setup time of an experiment,
- visual documentation of an experiment.

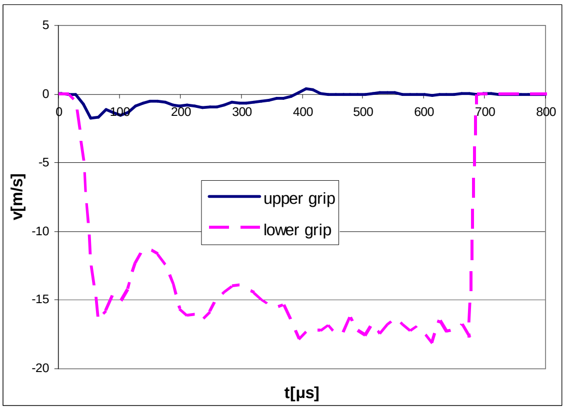

Fig. 4. An example of velocity history obtained from a flywheel test

Table 1. The spatial and temporal resolutions for selected frame rates

strain rate [1/s]	frame rate [fps]	*dt* [µs]	*du* [µm]	spatial points	temporal points
250	684000	1,46	5,86	478	547
500	684000	1,46	5,86	478	274
1000	684000	1,46	5,86	478	137
250	490196	2,04	2,93	956	392
500	490196	2,04	2,93	956	196
1000	490196	2,04	2,93	956	98
250	264970	3,77	1,25	2240	212
500	264970	3,77	1,25	2240	106
1000	264970	3,77	1,25	2240	53

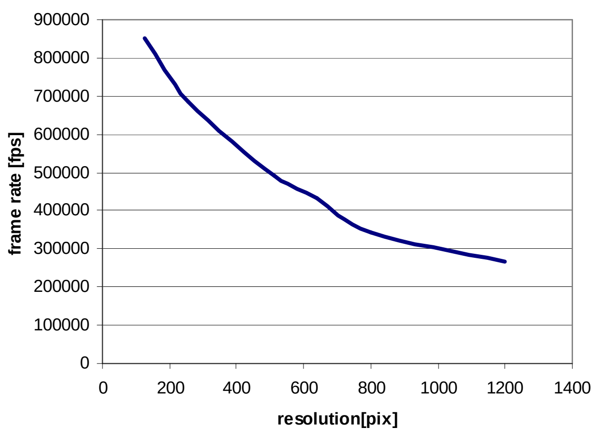

Fig. 5. The dependency between a spatial and temporal resolution for Phantom v12 high-speed camera

The specific feature of the method is that user can fluently set the parameters of the recording between two states:

- high spatial and low temporal resolution,
- low spatial and high temporal resolution.

The dependence between a spatial and temporal resolution is presented on the figure 5. In case of fast tension test on the flywheel, the high-speed camera can generate useful results for low and moderate velocity of impact. For high velocity, a contradiction between a spatial and temporal resolution of this kind of device become unacceptable. Additionally for high temporal resolution, the most significant problem becomes a lightning. For highest frame rate exposition time is below 1 μs, so bright and stable light is necessary.

References

[1] **Swantek S. D., Wicks A. L., Wilson L. T.** An Optical Method of Strain Measurement in the Split Hopkinson Pressure Bar, APS Meeting Abstracts, 2001.

[2] **Llorca F.** Application of Ultra High Speed Optical Measurements to the Study of Metals Viscoplasticity under Very High Dynamic Mechanical Loading. SPIE Conference Series, 2003, p. 490-495.

[3] **Tobota A., Kopczyński A., Karliński J.** Axial Crushing of Monotubal and Bitubal Circular Foam-Filled Sections, Journal of Achievements in Materials and Manufacturing Engineering, Vol. 22, 2007, p. 71-74.

[4] **Lambert M., Froustey C., Charles J. L., Lataillade J. L.** High Strain Rate Testing of Aluminium Alloy & High Speed Photography, Journal de Physique IV (Proceedings), Volume 110, Issue 1, September 2003, p. 543-549.

[5] **Lee Richard J., Joshi Vasant S.** Use of High-Speed Photography to Augment Split Hopkinson Pressure Bar Measurements of Energetic Materials, AIP Conference Proceedings, Vol. 620, p. 860-863.

[6] **Uenishi A., Yoshida H.** Material Characterization at High Strain Rates for Optimizing Car Body Structures for Crash Events, Nippon Steel Technical Report No. 88, 2003.