

A Determination of the Kinematic Quantities of a Rotating Object by Digital Image Correlation Method

Martin Hagara*, Róbert Huňady, Pavol Lengvarský

Department of Applied Mechanics and Mechatronics, Technical University of Košice, Faculty of Mechanical Engineering, Košice, Slovakia

*Corresponding author: martin.hagara@tuke.sk

Received October 08, 2013; Revised October 14, 2013; Accepted November 21, 2013

Abstract In this contribution an experimental determination of kinematic quantities of an automobile cooling fan by its rotational movement is described. The displacements of the fan surface were captured by two - cameras high-speed correlation system. The obtained data exported from some chosen points were for the purposes of post-processing imported into Matlab. For a verification of the reached results the second independent experimental method was used – the determination of the cooling fan rotational frequency was performed by a digital-optic tachometer.

Keywords: high-speed digital image correlation, motion analysis, kinematic quantities

Cite This Article: Martin Hagara, Róbert Huňady, and Pavol Lengvarský, “A Determination of the Kinematic Quantities of a Rotating Object by Digital Image Correlation Method.” *American Journal of Mechanical Engineering* 1, no. 7 (2013): 289-292. doi: 10.12691/ajme-1-7-27.

1. Introduction

Three-dimensional digital image correlation method belongs to the group of noncontact optic methods, which nowadays fully engages into the conception of measurement principles with high sensitivity and accuracy [1,2]. It is based on the comparison of digital images obtained from at least two CCD cameras during the investigated object movement or loading [Figure 1](#).

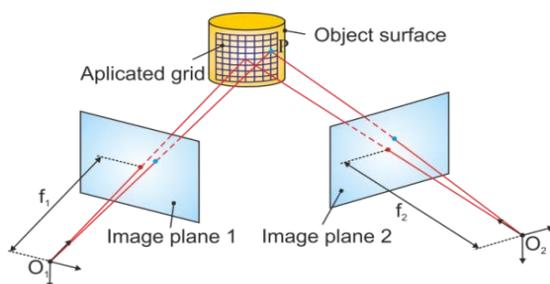


Figure 1. Stereoscopically located CCD cameras of a 3-D digital image correlation system

There are two forms of digital image correlation systems – a low-speed system and a high-speed one. It is possible to use the first mentioned only by low sampling frequencies (maximally several fps). Such a system mostly contains the objectives with higher resolution and thus it is suitable for the deformation analyses [3].

A high-speed correlation system with smaller objectives resolution can be used for the analyses, by which high sampling frequency is necessary. A common sampling frequency of the high-speed systems is several thousand fps and therefore they primarily serve as a tool for motion analyses, vibration analysis [4], modal analyses [5], drop tests [6], crash tests or fracture mechanics.

Displacements in two perpendicular directions x and y are investigated by the using of pseudo-affine transformations (1), (2) of the nodal points of user defined virtual grid [4]:

$$x_t(a_0, a_1, a_2, a_3, x, y) = a_0 + a_1x + a_2y + a_3xy \quad (1)$$

$$y_t(a_4, a_5, a_6, a_7, x, y) = a_4 + a_5x + a_6y + a_7xy \quad (2)$$

Where x_t, y_t are the transformation coordinates and $a_0, a_1, a_2, \dots, a_7$ are the transformation parameters.

The strain fields are subsequently determined by the analysis of local facets curvatures [Figure 2](#).

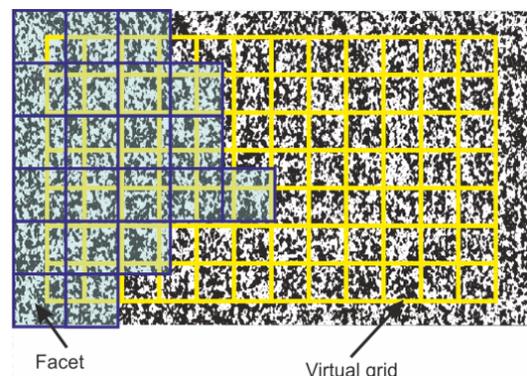


Figure 2. Object surface with random pattern, facets and virtual grid

2. Motion Analysis of A Rotating Object

The purpose of the analysis was to capture, evaluate and utilize the displacements of a rotationally moving object. The measurement object was a cooling fan of the automobile Skoda Felicia [Figure 3](#).



Figure 3. Investigated Skoda Felicia cooling fan

The fan was fixed to a wooden support stand and actuated by a power supply.

The measurement performed by the high-speed digital image correlation system Q-450 Dantec Dynamics was intent on the fan start, movement by certain immediate angular velocities and free after-running as well, which happened after the power supply switch-off.

2.1 Image Correlation System Configuration and Settings

For the acquisition of the moving object displacements it was needful to perform a dynamic measurement with sufficient sampling frequency. By the use of spray colors a stochastic black and white pattern required for the right correlation of the images was created on the fan rotating parts. Configuration of the high-speed correlation system used for the measurement is depicted in Figure 4.



Figure 4. Configuration of the 3-D image correlation system with investigated cooling fan

The experiment was captured by the high-speed CCD cameras SpeedSense 9070 with the image resolution of 1280x800 px. In consideration of the limited inner memory of the cameras and the aim of the experiment to capture the whole process from fan start to its stop it was necessary to find a convenient sampling frequency and acquisition time.

The sampling frequency was set to 2500 fps. The acquisition time was adjusted after the observation of the fan start and after-running duration to 8 s. Our idea was to capture ca. the first five seconds after the power supply switch-on, whereby the remaining time of 3 s should serve as a sufficient reserve for the acquisition of fan after-running.

The apertures of the objectives were adjusted to f-number of 22, by which the maximal depth of focus was attained. The exposure time of both cameras was set to the highest allowable value of 399 μ s. Cameras fields of view are visible in Figure 5.

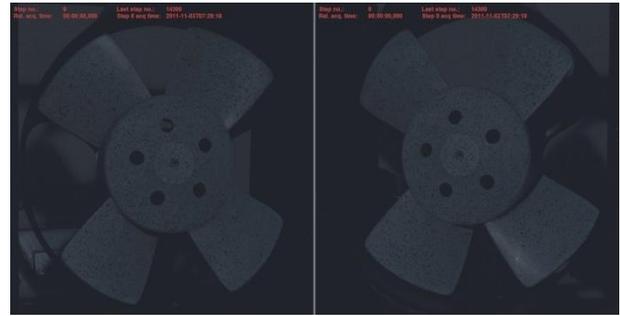


Figure 5. The cameras fields of view

The system captured 20000 images from both cameras.

For the reasons of using only two - cameras correlation system, by which the fan side parts could not be captured and only one powerful source of white light, which caused some unwanted reflections or shades on the fan surface, five segregate regions depicted in Figure 6 were selected and evaluated.



Figure 6. Five evaluated regions of cooling fan

3. The Results of the Analysis

The first step for the next data post-processing was the acquirement of the displacements fields evaluated by the operating correlation systems Dantec Dynamics software Istra 4D. In this software the own coordinates system with the origin determined in a green point (see Figure 7) was defined. Direction X is represented by a virtual flowline of the origin with the point depicted by a light-blue color. It caused, that two of the fan blades were turned into a vertical position.



Figure 7. New coordinates system defined in the software Istra 4D

As the software Istra 4D does not allow to select points with exactly defined position, three virtual gauges (in a form of points) were chosen approximately on the line depicted in Figure 8 by a yellow color. Their displacements in time were imported into Matlab for the next processing.

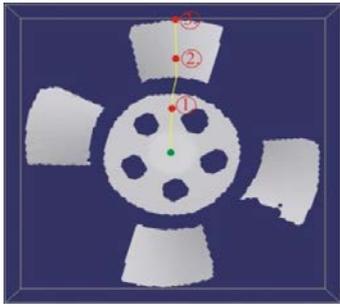


Figure 8. Three virtual gauges defined approximately on one line

Time dependences of the particular points displacements in X direction and Y direction as well can be seen in Figure 9 and Figure 10.

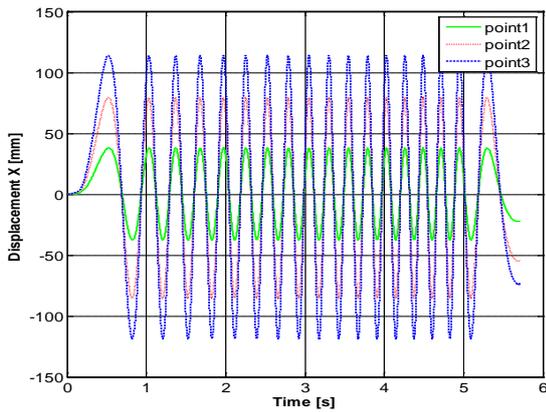


Figure 9. Time dependences of displacements X of particular points obtained by DIC

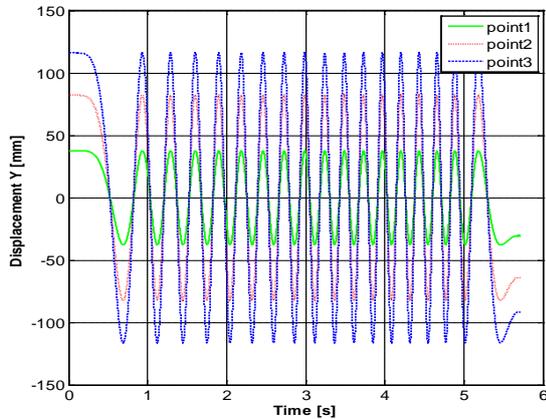


Figure 10. Time dependences of displacements Y of particular points obtained by DIC

The trajectories of selected points are depicted in the following Figure 11.

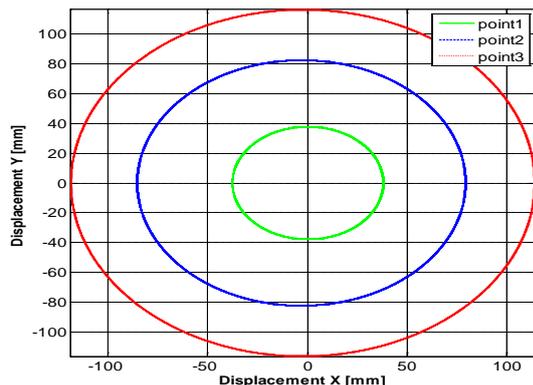


Figure 11. Trajectories of the particular points obtained by DIC

Subsequently a script created in Matlab serving for visualization of the particular points mean velocities in time was used. The simple script algorithm consists of the following parts:

1. creation of the matrix of rotation angle $\phi = \arctg(\mathbf{Y} / \mathbf{X})$;
2. creation of the elements of rotation radius matrix $R_i = \sqrt{X_i^2 + Y_i^2}$;
3. definition of the elements of rotation angle variation matrix $\Delta\phi_i = \phi_i - \phi_{i+1}$;
4. creation of the elements of angular velocity variation matrix $\Delta\omega_i = \Delta\phi_i \cdot f_s$, where f_s is a sampling frequency;
5. creation of the mean velocity matrix elements defined as $\Delta v_i = \Delta\omega_i \cdot R_i$;
6. graphical visualization of the time dependences of rotation angle variation Figure 12 and mean velocity Figure 13 as well of particular points.

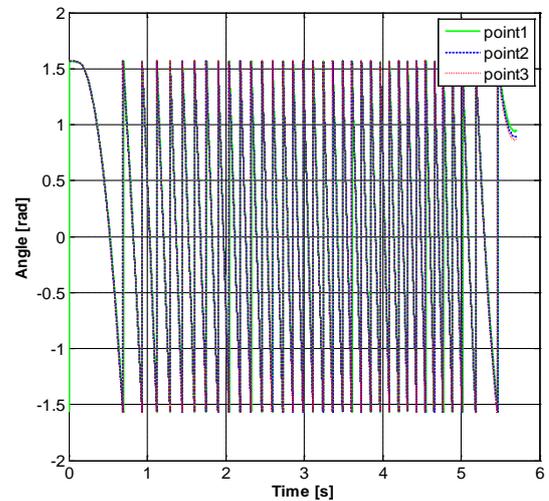


Figure 12. Time dependences of the rotation angle of particular points

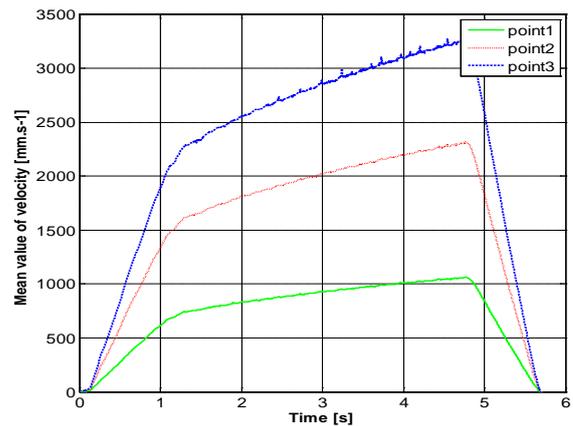


Figure 13. Time dependences of the mean value of velocities of particular points

The noise occurring in the mean value of the third point velocity is caused by a correlation error growing with the increasing velocity of particular points.

Pursuant to Euler's theorem the mean values of angular velocities of three examined points were determined. Subsequently by the use of

$$n = \frac{\omega}{2\pi} \tag{3}$$

the mean values of rotational frequency in fixed time intervals $\Delta T=1/f_s$ were computed. A graphical visualization of the time dependence of the mean values of rotational frequency can be seen in Figure 14.

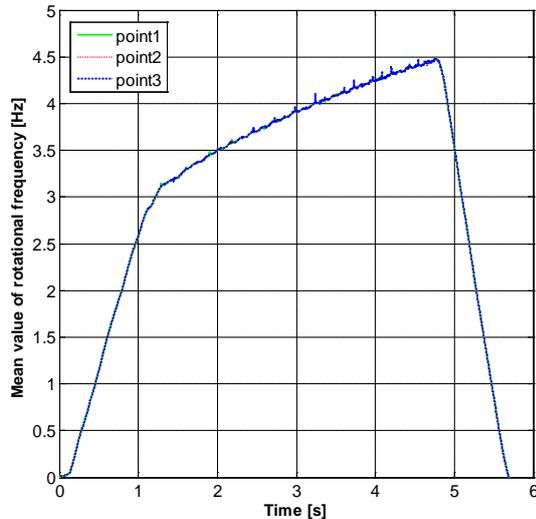


Figure 14. Time dependences of mean values of rotational frequency obtained for particular points by DIC

It was necessary to verify such obtained results by the use of an independent method. The primary aims of verification were formulated as find the proofs, that:

- the fan velocity is still growing during the examined time interval from 0 s to 4.77 s,
- in time point of ca. 1.2 s the acceleration of the fan is changed,
- rotational frequency reaches in every time point a value, that is corresponding to the real value.

The verification of the obtained results was performed by digital-optic tachometer Almemo. The apparatus consisted of a measuring LEDsonde Almemo FU A919-2 and a measuring device Almemo 2390-8 Figure 15.

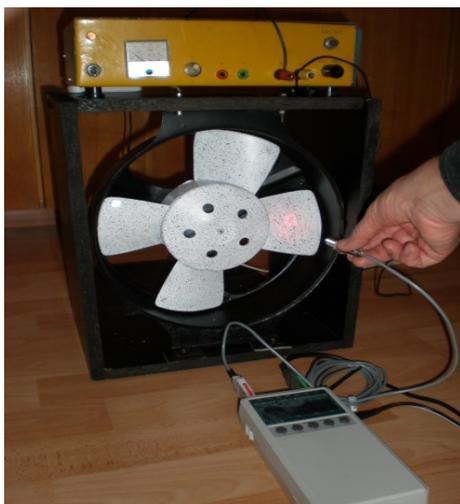


Figure 15. The Almemo apparatus used for the results verification

The principle of this device is based on the tracking of visible ray of red light (660nm) emitted and reflected back to the LED sonde from the object surface where a reflex element is bonded. The behavior of rotational frequency in time captured by this optic method can be seen in Figure 16.

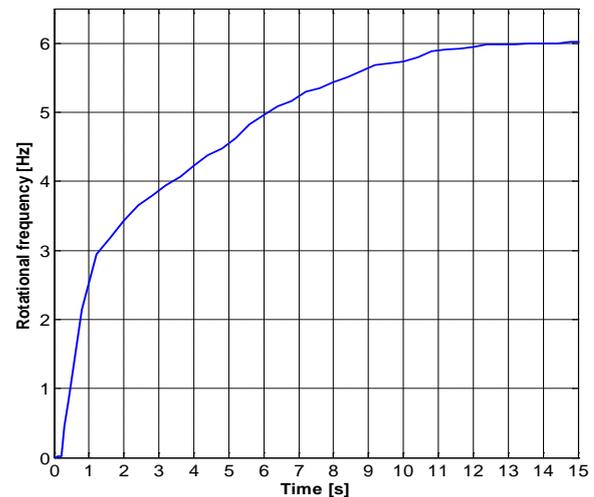


Figure 16. Time dependences of mean values of rotational frequency obtained by Almemo

The time dependences of velocities and rotational frequencies suggest that the fan has rotated with an accelerated movement in the whole captured process. The decrease of the acceleration after 1.2 s could be caused by the increase of a resistance force. The state of a dynamic equilibrium was achieved after 12 s from the fan start by the measurement with Almemo.

4. Conclusion

The digital image correlation is a practical modern optical method serving for the examination of rotating objects kinematics quantities. A big advantage is that it provides the data about these quantities in each investigated object surface point.

The user should be very careful by the options of sampling frequency and acquisition time because of a limitation, that the higher velocities, the higher correlation errors.

Acknowledgement

The work has been accomplished under the projects VEGA 1/0937/12 and KEGA 021TUKE-4/2013.

References

- [1] Trebuňa, F., Šimčák, F., *Príručka experimentálnej mechaniky*, TypoPress, Košice, 2007.
- [2] Sutton M.A., Ortu J-J., Schreier H.W., *Image Correlation for Shape, Motion and Deformation Measurements*, Springer Science + Business Media, LLC New York, 2009.
- [3] Chen F., Chen X., Xie X., Feng X., Yang L., "Full-field 3D measurement using multi-camera digital image correlation system," *Optics and Lasers in Engineering*, 51, 1044-1052, 2013.
- [4] Siebert T., Wood R., Splithoff K., "High Speed Image Correlation for Vibration Analysis," in *7th International Conference on Modern Practice in Stress and Vibration Analysis*, IOP Publishing, 2009.
- [5] Trebuňa F., Huňady R., Bobovský Z., Hagara M., "Results and Experiences from the Application of Digital Image Correlation in Operational Modal Analysis," *Acta Polytechnica Hungarica*, 10 (5), 159-174, 2013.
- [6] Trebuňa F., Hagara M., Huňady R., "Strain Fields Identification of Chosen Cycling Helmets Types by Their Impact Loading," *Acta Mechanica Slovaca*, 16 (2), 22-30, 2012.