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The Methodology for Realization of Smartphone Drop Test Using Digital Image Correlation

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Abstract The paper deals with the description of methodology for performing of drop test of smartphones using high-speed digital image correlation method. This method allows capturing the impact of the phone at high sampling frequencies and thus the stresses in each surface point can be computed. The measurement was realized in laboratory conditions, in which the phone was fallen down from the height of one meter, which is a distance, which the mobile phones are dropped out from the being's hand. Five different possibilities of the phone impact were investigated. The acquired results are in a form of deformation as well as von Mises stress computed in chosen locations of the touchscreen area.

Keywords: *drop test, stress analysis, digital image correlation, smartphone*

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1. Introduction

The influence of impact to the certain object can be investigated from different causes. There are a lot of tests performed, especially in automotive industry, serving for investigation what the impact evocates with being's body, or what to do to improve the protection of human health. The results are then evaluated and if they do not pass the criteria defined by safety norms, thus they are used as source materials for optimization of this state. E.g. Haddadin et al. [1] in their contribution describe the impact test, which was carried out using standard automobile crash-test facilities at the ADAC (German Automobile Club). They described the injuries caused by sharp edges occurring by unexpected rigid frontal impacts. By their research several injury mechanism and so called Severity Indices were evaluated. Berg et al. [2] performed seven sled tests to simulate frontal collisions at speeds around 50 km/h involving unbelted human cadavers in a standard sitting position. Using restraint system in a form of full-size airbag and knee pads the accelerations were measured and injuries were discussed.

The effect of cycling helmet for the protection of human skull is also well-known. Trebuňa et. al [3] described in their paper, which deformation of cycling helmets and overloading of the human head occur during impact of the wooden head model with helmet from two meters' height. The consequences of impacts can be analyzed also by contact sports. E.g. Svoboda et al. describe in their contributions [4,5] an effect of the combat sports athletes impact on human's head.

Also various technical devices belonging to the common equipment of human being have to pass the given criteria of drop tests. To the group of portable electronic devices, that can be relatively easily damaged by the impact, are included tablets, USB discs or any electronic components, which they are consisted of. We cannot be oblivious of mobile phones, by which an accidental drop in daily life is probably the most common cause of failure. The forces causing the damage of these devices depend on the drop height, material, weight, shape orientation at impact surface and several other factors.

The finding of location with maximal level of stress after impact of electric devices to the ground demands use of more sensors allowing recording quantities by their dynamic loading. For that reason, the drop tests or impact tests are mostly simulated using various numerical methods, especially by finite element method. To the objects, which are due to impact tests most often analyzed, printed circuit boards (PCB) can be assigned [6]. Lim and Low [7] examined the drop impact response of portable electronic products at different impact orientations and drop heights. Seah et al. [8] carried out the research on the mechanical response of PCBs inside portable consumer electronic products, which were subjected to drop impact.

The mobile phones were investigated by Kim and Park [9]. They studied the reliable drop/impact simulation for a cellular phone using the explicit code LS-DYNA. Wang et al. [10] proposed a practical platform and simulation tool for drop tests. They assessed that already a small angle variation (±5°) may result in up to 36% difference in predicted stress. Liu and Li [11] presented the impact study of a new cell phone design with split steel bands. The finite element model of the cell phone was created in

ANSA and analyzed with LS-DYNA. The investigated quantity was the integrity of the split band, the stresses occurring in the cover glass and LCD layers were evaluated numerically and the shock absorbing performance of different visco-elastic pads attached on camera was compared in details.

As the authors department disposes of wide range of full-field measuring techniques, authors aim was to realize an experimental study and describe the methodology for smartphone drop test using modern optical non-contact method of high-speed digital image correlation.

2. Description of the Measuring System

The system Q-450 Dantec Dynamics is a high-speed digital image correlation device, allowing from practical point of view a wide range of applications. Currently, in regard to the ability for high-speed recording, it is used especially by testing and developing of airbags, in motion analysis, crash tests, drop tests, by investigation of crack propagation, fatigue life assessment or validation of various numerical models. Its user facility allows to configure it in different ways and thus use it e.g. in vibration analysis or in determination of the modal parameters of structures. The flexible construction of the system allows its use also in large-size aerial, automotive as well as railway machines.

The correlation system Q-450 (Figure 1) consists of two high-speed cameras utilizing CMOS sensors. The cameras dispose of two identical objective lenses, serving for the setup of essential image parameters of the field of view.

The type of used objective lenses depends on the specific conditions of given experiment, i.e. in the case of need it is possible to focus the object by the use of lenses with different focal lengths. To the correlation system belongs also a powerful source of stable white light, serving for ensuring of optimal light conditions. Its use is necessary particularly in high-speed measurements with extremely short exposure time.

All the functions of the system are controlled via powerful notebook. The cameras are connected to the computer through LAN interface. The synchronization of the cameras is ensured by external analog-digital convertor with eight channels, by which it is able to setup the external triggers, or just capture the output signals from various sensors and measuring devices. There is also a set of calibration targets of different sizes, used for the system calibration.

Figure 1. The high-speed digital image correlation system Q-450 Dantec Dynamics

A large dynamic range of the system allows measure displacements from micrometers up to tenths of centimeters, whereby the system combines high resolution with highly precise temporal resolution. The accuracy and the sensitivity of the measurement depend on the field of view, which size can be set by the user. The maximal length of acquisition interval is limited by the internal memory capacity of the cameras.

The correlation system, used for experimental investigation of smartphone impact, consists of two high-speed cameras SpeedSense 9070, which allow to realize measurement at sampling frequency up to 3140 fps by full resolution. Mentioned correlation system disposes of 16 GB of internal memory for image acquisition.

For the evaluation of the results in a form of deformation and stress two software applications were used. The process of image correlation was realized in Istra4D - software delivered with correlation systems Dantec Dynamics. The results in a form of deformation were imported into Matlab in order to calculate and visualize equivalent stress in chosen locations.

3. Drop Test of a Smartphone Using High-Speed Digital Image Correlation System

The measurement, which aim was to describe the methodology for mobile phone drop test, was performed on a model Nokia 500 RM-750 (see Figure 2), which front surface was sprayed with white background color and black speckles in order to get a high-contrary random pattern (Figure 3) important for proper image correlation.

Figure 2. The smartphone type Nokia 500 RM-750 used for experiment

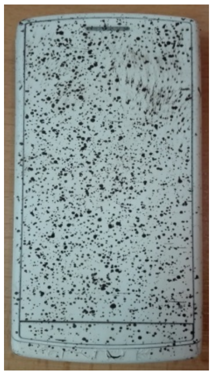

Figure 3. The speckle pattern created on the analyzed smartphone surface

Figure 4. Configuration of the cameras with testing stand

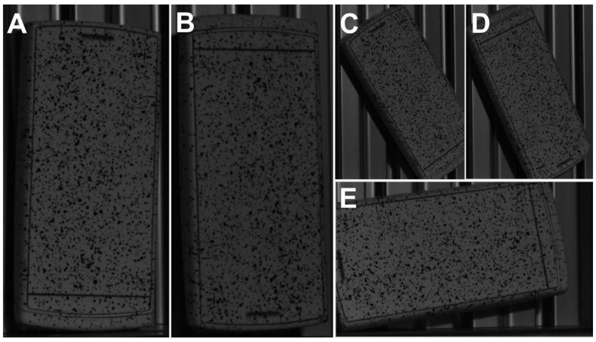

Figure 5. Five investigated types of smartphone impacts to the ground

The measurement was realized in laboratory conditions, whereby the smartphone was falling down from the height of one meter (Figure 4), which is a distance common for the drop out of mobile phones from the being's hand.

The free fall of the smartphone was realized in such a way, that five different types of impacts of the phone to the ground (Figure 5) were investigated:

A. controlled impact to the smartphone's bottom edge,
B. controlled impact to the smartphone's upper edge,
C. controlled impact to the smartphone's left bottom corner,
D. controlled impact to the smartphone's right upper corner,
E. uncontrolled impact to the smartphone's lateral edge.

Each impact of the phone to the ground did not visibly destroy any part of the phone, therefore the drop test was realized five times with the same piece of smartphone.

Such an impact takes very short time. For that reason, the sampling frequency of the cameras had to be set as high as possible. On the other hand, the higher sampling frequency, the lower resolution. Thus it is necessary to find a compromise between the sampling frequency and resolution, by which the correlation can be accomplish in the right way. The measurement was realized under such conditions, that the sampling frequency was set to 13300 fps, which allows to capture images with resolution of 568x320 px. For the camera calibration a target with 9x9 fields of size 11 mm was used. Acquired calibration parameters are depicted in Figure 6.

The evaluation was realized by the facet size set to 10x10 px. On the evaluated object contour, concretely on the part of touch screen, four virtual gages were used. The first one, a line, served for the visualization of touchscreen out-of-plane deformation after impact. The next three ones, in a form of points, were used for computation of von Mises stress acquired in the upper (Point1), middle (Point2) as well as bottom (Point3) part of the touchscreen. Such types of gages, located in the same locations (Figure 7), were used in all the evaluations of performed measurements in order to compare obtained results.

Each line gage starts in a point denoted as Ls with relative position 0 mm and ends in a point L_F with relative position 85.2 mm. In Figure 8 – Figure 12 the temporal change of deformation in z direction as a function of relative position of each point of the line gage are depicted. It can be seen that deformation has a wave character.

In cases A-D only one impact of the phone to the ground was observed (in a time step denoted as Step1), in case E two impacts appeared (in Step1 and Step35). While in cases A-B the deformation wave reaches magnitude in ca. Step5, in cases C-D in Step10. The impact of the phone to the second corner in case E (see Figure 13) increased the amplitude of the decaying deformation wave rapidly again.

Intrinsic Parameters Camera Position 1 image:	
Focal length {x; y}:	{2827 ± 3; 2828 ± 3}
Principal point {x; y}:	{606 ± 7; 381 ± 5}
Radial distortion {r2; r4}:	{-0,123 ± 0,008; 1,03 ± 0,15}
Tangential distortion {tx; ty}:	{-0,0039 ± 0,0004; -0,0046 ± 0,0007}
Extrinsic parameters Camera Position 1 image:	
Rotation vector {x; y; z}:	{3,056 ± 0,002; -0,0083 ± 0,0009; 0,650 ± 0,004}
Translation vector {x; y; z}:	{23,0 ± 1,6; -2,7 ± 1,1; 600,0 ± 0,7}
Intrinsic Parameters Camera Position 2 image:	
Focal length {x; y}:	{2808 ± 4; 2810 ± 4}
Principal point {x; y}:	{599 ± 6; 385 ± 5}
Radial distortion {r2; r4}:	{-0,061 ± 0,010; 0,2 ± 0,3}
Tangential distortion {tx; ty}:	{-0,0031 ± 0,0004; -0,0033 ± 0,0007}
Extrinsic parameters Camera Position 2 image:	
Rotation vector {x; y; z}:	{-3,0307 ± 0,0018; -0,0171 ± 0,0009; -0,757 ± 0,003}
Translation vector {x; y; z}:	{-0,5 ± 1,3; -4,0 ± 1,0; 614,2 ± 0,8}

Figure 6. Calibration parameters used by the experiments

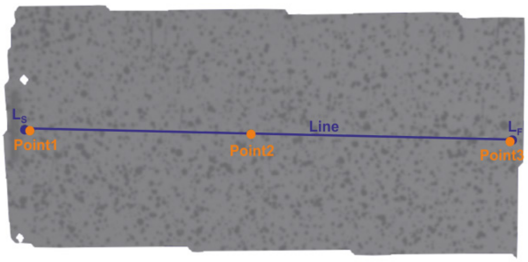

Figure 7. Virtual gages created on the evaluated smartphone surface

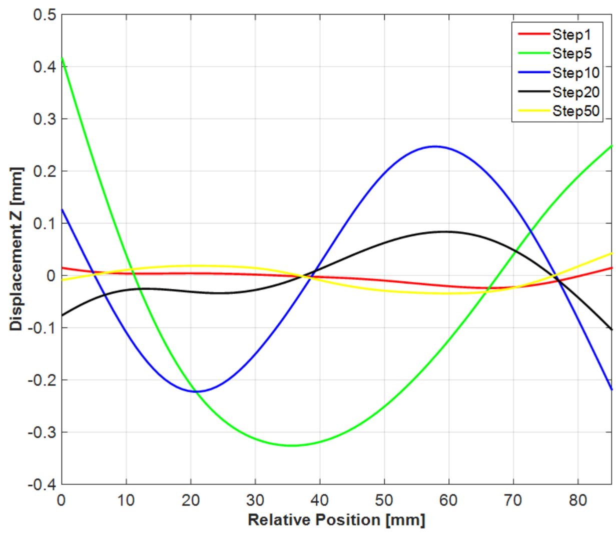

Figure 8. Temporal change of touchscreen deformation along the line gage in z direction by the impact of type A

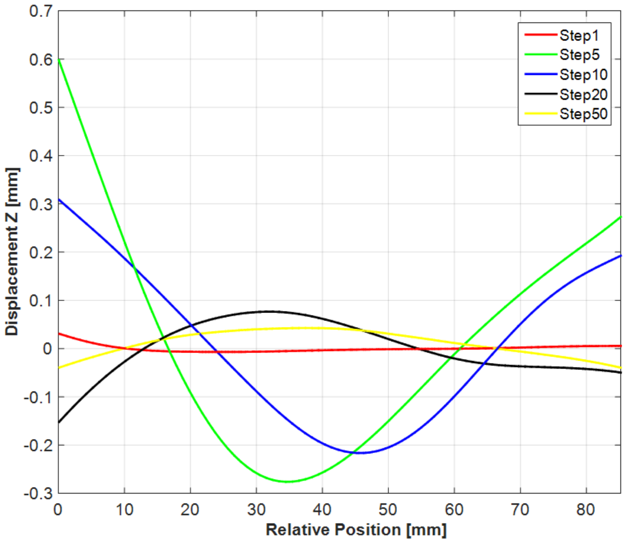

Figure 9. Temporal change of touchscreen deformation along the line gage in *z* direction by the impact of type B

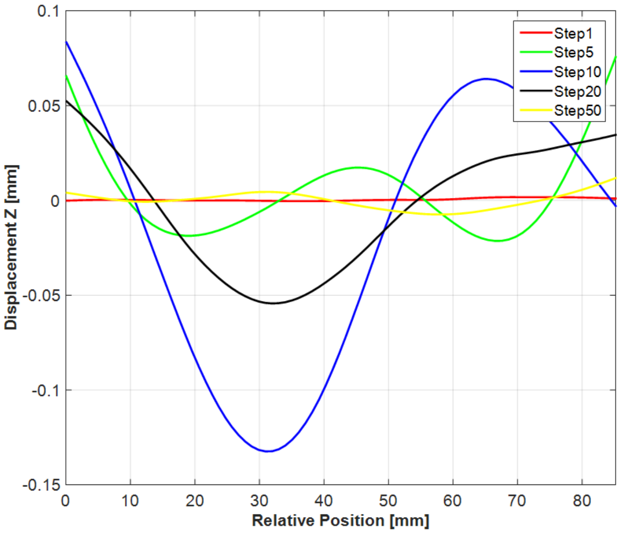

Figure 10. Temporal change of touchscreen deformation along the line gage in *z* direction by the impact of type C

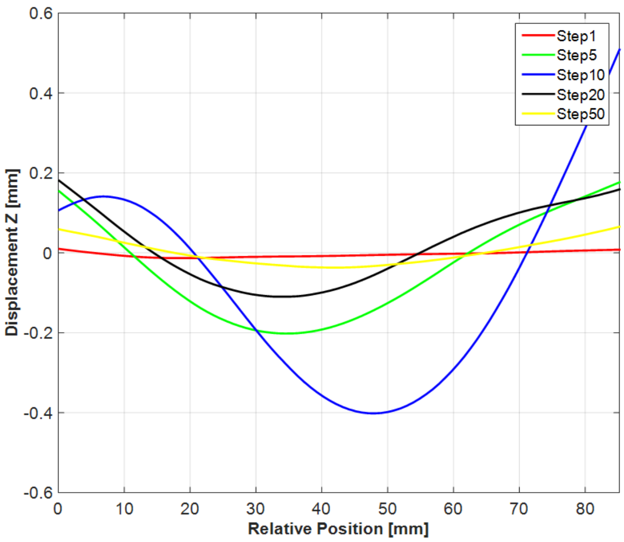

Figure 11. Temporal change of touchscreen deformation along the line gage in *z* direction by the impact of type D

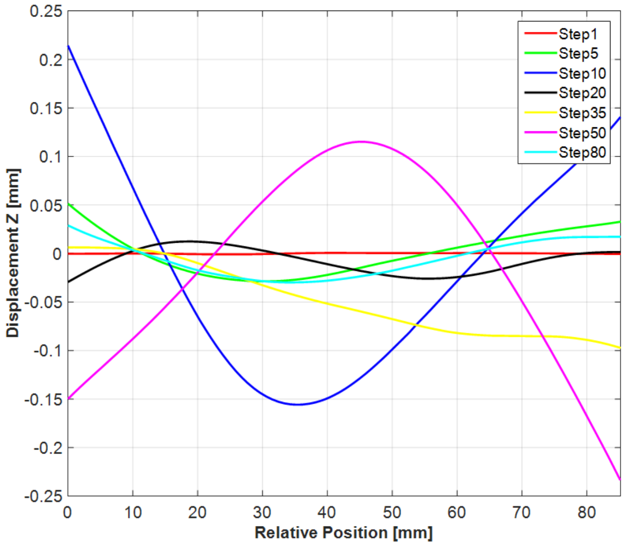

Figure 12. Temporal change of touchscreen deformation along the line gage in *z* direction by the impact of type E

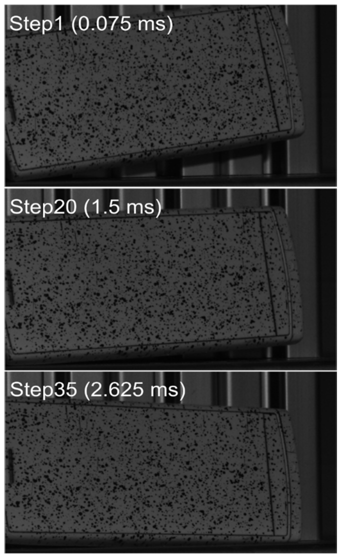

Figure 13. The impact of the second corner occurring in the impact type E

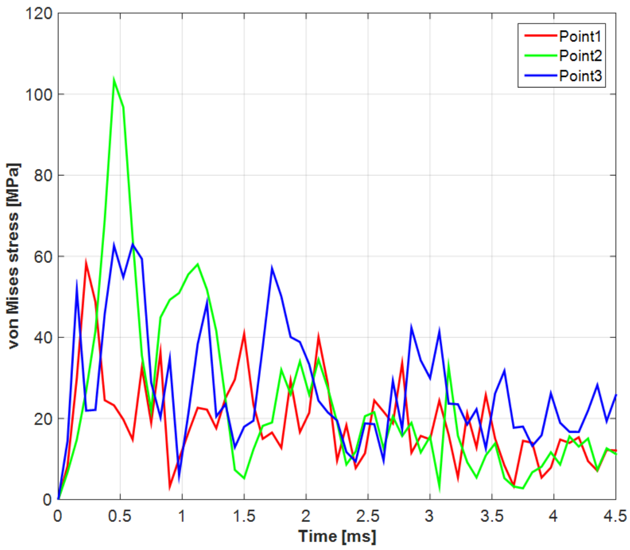

Figure 14. Course of Von Mises stress obtained in impact type A

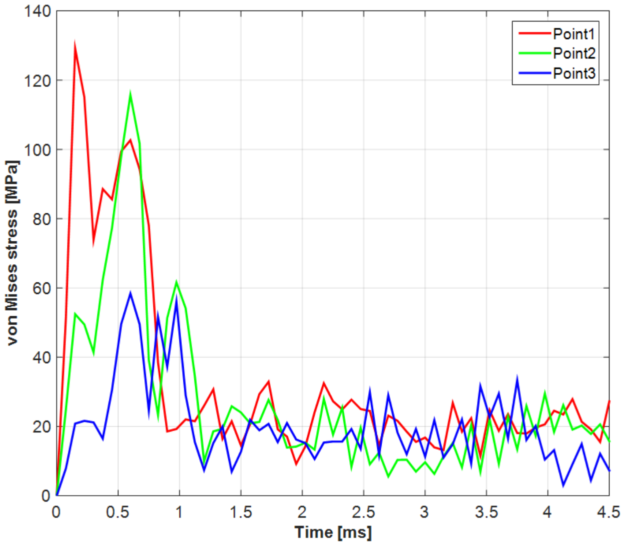

Figure 15. Course of Von Mises stress obtained in impact type B

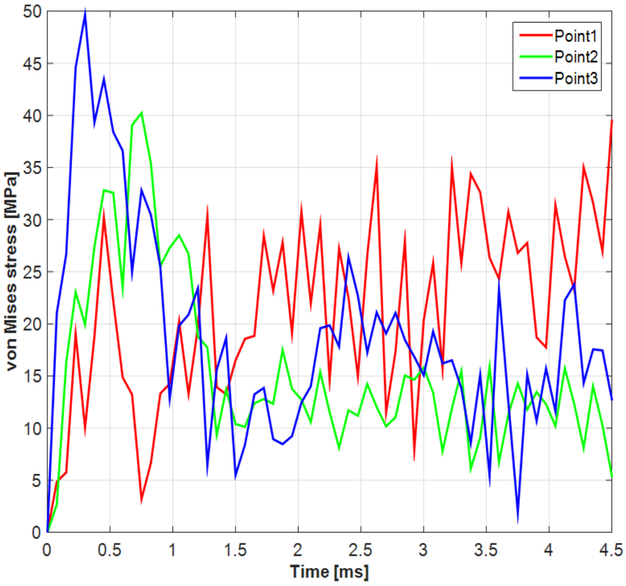

Figure 16. Course of Von Mises stress obtained in impact type C

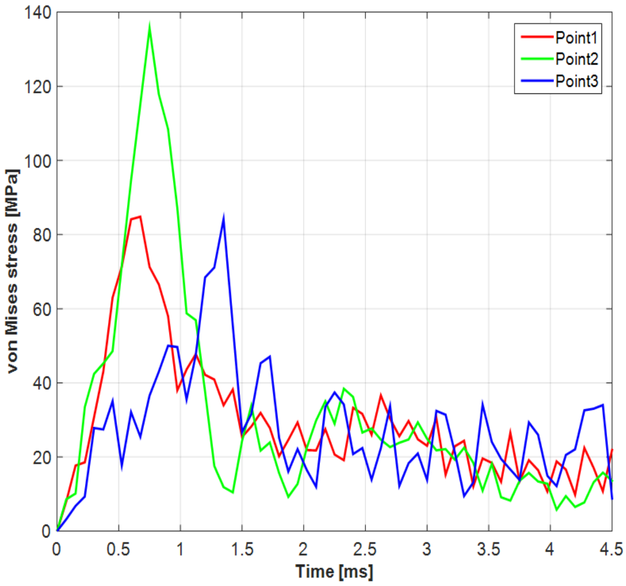

Figure 17. Course of Von Mises stress obtained in impact type D

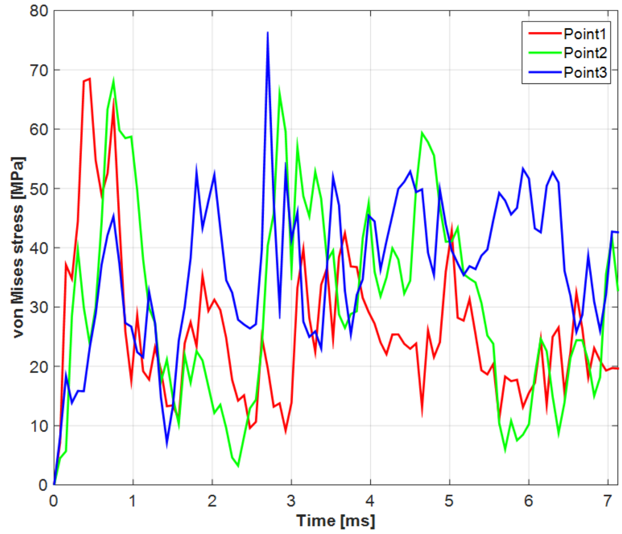

Figure 18. Course of Von Mises stress obtained in impact type E

Assuming linear behavior of the touchscreen material the equivalent stresses in point gages were computed. Considering elastic modulus of the touchscreen material equal to 64 GPa and Poisson ratio equal to 0.21, the courses depicted in Figure 14 – Figure 18 were acquired. In most cases the highest level of stress is observed in the middle part of the touchscreen and in case D reaches the maximal value of ca. 138 MPa. The most favorable seems to be the impact of the phone in case C, where the maximal stress reaches value of ca. 50 MPa. The second impact in case E does not markedly affect the levels of stress in the touchscreen.

4. Summary

Digital image correlation is a modern optical full-field method applicable in wide range of mechanical problems. The contribution describes an experimental methodology for investigation of smartphone impact testing, whereby the temporal change of deformation as well as von Mises stress in the touchscreen was investigated. For the realization of the experiment a correlation system Q-450 Dantec Dynamics was used.

The results of experiments should indicate the stresses and the deformation on the touchscreen surface and can be used for prediction, which type of smartphone's impact is the most dangerous. To register the peak value of stress it is necessary to capture the impact by the sampling frequency as high as possible. In present paper the values of equivalent stress in touchscreen area reach in two cases ca. 140 MPa, which is the maximal value acquired. Nevertheless, the smartphone did not allocate any outer damage.

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