CHARACTERIZATION OF SHOCK ABSORBER DEFORMATION BY OPTICAL SURFACE DIGITIZATION

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ABSTRACT

The performance of shock absorbers has been tested in specific regulatory drop tests onto an unyielding target at the BAM drop test facility. Optical surface digitization methods have been used to measure, analyze and evaluate permanent deformations of shock absorbers more systematically. The measurement principle of the fringe projection technique used and its technical application to shock absorber research is explained in detail in this paper. Furthermore, examples of shock absorber testing results as well as final data visualization are presented.

INTRODUCTION

In the design approval assessment of packages for the transport and storage of radioactive material the design of shock absorbers is still important with respect to safety and optimization of package design. Shock absorbers and impact limiters are designed for a package to withstand hypothetical accident loads during transport and to suffer the maximum damage simulated in mechanical and thermal tests. Generally, the rate of permanent deformation of shock absorbers may indicate possible sufficient protection of the cask body and closure system. Knowledge about correct figures on impact limiter deformation is also essential for benchmarking of appropriate calculation methods. Different electrical and optical measurement methods have to be applied in experimental drop tests [1]. The fringe projection technique, in combination with close range photogrammetry, is especially suited to investigating shock absorber behavior by 3-D surface digitization.

Compared with common dimensional inspection tools, use of a round-about optical 3-D digitization of shock absorbers under drop test conditions gives a significant competitive edge:

- Complete documentation of 3-D shape
- Objective and quantitative damage analysis
- Target/actual-comparison with CAD model dimensional data
- Pre/post-comparison of real objects under load
- Surface based verification of FEM simulations
- Completely new and innovative 3-D measuring possibilities

Fig. 1 illustrates the complicated use of spirit level and folding ruler for distance measurement between a horizontal plane and the inside of a damaged shock absorber. The result contains subjective systematic errors and will be limited to single point measurements only. These restrictions will be overcome with the help of a digital shock absorber copy (Fig. 2).

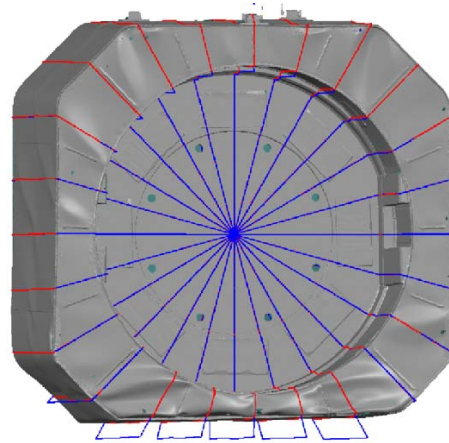**Figure 1. Manual length measurement in vertical projections**

Figure 2. Complete measured model with polygonal surface mesh and cross sections before and after impact

SHOCK ABSORBER DIGITIZATION BY PROJECTED FRINGE METHOD

The optical measurement method applied for surface digitization mainly consists of a fringe projecting sensor head. The sensor device is shown in Figure 3. A slide projector in the middle of the fixing bar projects light planes into the measurement volume. This space is observed by a stereo camera set-up. Cameras are positioned on a bar left and right of the projector. A more detailed sensor scheme is presented in Fig. 4.
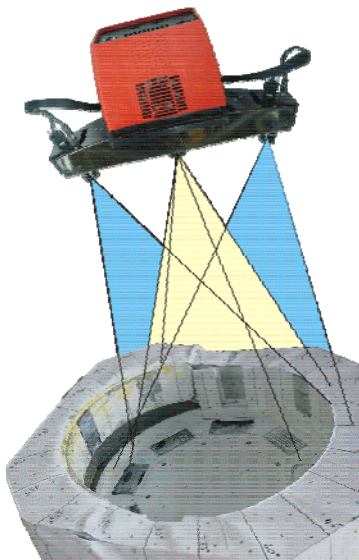

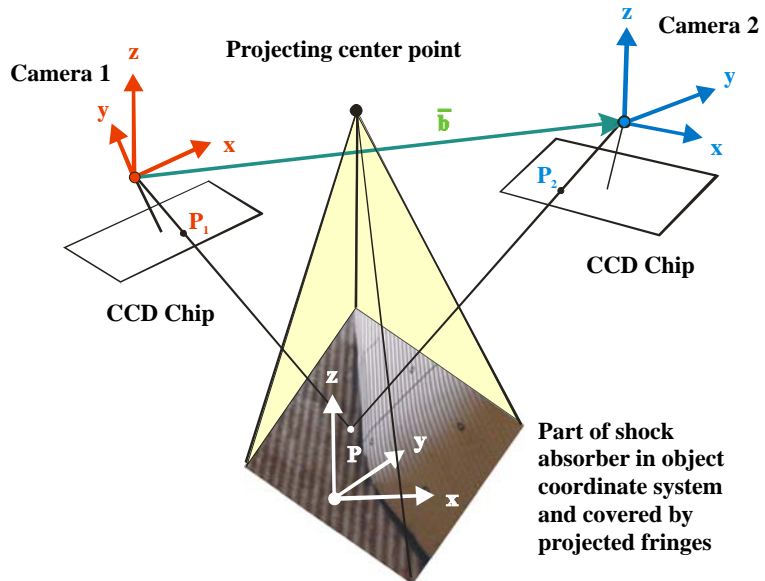**Figure 3. Sensor arrangement with object**

Figure 4. Principle of sensor measuring a single point 3-D coordinate

The following sequence of steps describes the principle of the applied projected fringe method:

Reference point system
It is obvious to conclude from Fig. 3 and 4 that each sensor view is independent of other views if there is no general referencing in 3-D space. Therefore, dot targets are stuck on the shock absorber surface to be digitized (visible in Fig. 1, 3 and 4). These dot targets are identified by close range photogrammetry and, thus, define the reference coordinate system, i.e. the object coordinate system [1]. The high photogrammetric accuracy in 3-D reference point coordinates of some 0.01 mm/m³ supplies an outstanding basis for further overall measurement uncertainty in round-about object digitizing.

Sensor calibration
The stereo camera set-up has to be calibrated for 3-D measuring capability. A calibration cross (see Fig. 5) or calibration plate with specially arranged coded dot targets has to be put in different viewing orientations to the sensors cameras. The following parameters are determined with the photogrammetric bundle adjustment method [1] applied to these different image couples: Correcting camera imperfections, defining a sensor coordinate system merging both camera coordinate systems 1 and 2 and, thus, creating a stereo model delivering for each identified surface point (see Fig. 4) its 3-D coordinate in the sensor coordinate system. After this calibration procedure the mechanical settings of the cameras and their relative orientation to each other should remain unchanged and stable in space.

Figure 5. Sensor calibration

Single sensor view
The projector projects light planes onto the surface. In Fig. 4 a sinusoidal structured and dense fringe system can be observed. At least 3 sequences of these fringes, phase shifted and slightly different in space frequency, are used to compute the interpolated definite number for each projected plane. This unique labeling of all surface positions enables the most accurate point identification in areas covered by projected fringes vertically oriented to the plane the two cameras are located in. Fig. 4 shows as an example point P. The identical (photogrammetricly homologous) point P detected in both stereo images enables its 3-D coordinate calculation with the calibrated stereo model described before. The great quantity of surface points visible at the same time by both cameras and having sufficient 3-D quality represents the point cloud of one sensor view, only. At the same time, the sensor determines by ellipse finding image processing the 3-D coordinates of reference points fixed additionally to the shock absorber surface. However, the sensor point cloud data is still arranged in the local sensor coordinate system.

Single view transformation into common object coordinate system
The sensor head is freely moveable on a mobile tripod around the shock absorber. Detected reference points in each sensor view are compared with reference 3-D point coordinates coming out from the photogrammetry. If relative reference point distributions are locally identical, the point cloud arising from the current sensor view will be matched into the right surface position. In this way, patch by patch will be added to create at least the complete round-about digital surface representation. Finally, the measured overall point cloud is transformed into a common object coordinate system (see Fig. 4).

Surface mesh creation

After acquiring this high-density 3-D point cloud a polygonal model should be created for further evaluations. All neighboring 3-D data points are now edge components of triangles defining the polygonal mesh adapted to the object's curvature. Therefore, it can be described mathematically by plane equations. This is, for example, an advantage for cross sectioning, 3-D surface comparisons, data analysis and visualization later on. Furthermore, the number of model points can be drastically reduced as a function of surface gradients.

RESULTS OF DROP TEST RESEARCH

Digital representation of real shock absorbers enables completely new and innovative possibilities in deformation analysis when compared to a 3-D coordinate measuring machine or other tools used so far:

- Larger scanned surface point density and better local resolution
- High potential accuracy of 3-D coordinates determination and relative object positioning
- Fast data acquisition of heavy objects
- No need for specifically constructed and manufactured measuring tools and mechanical means
- Flexible 3-D data evaluation using different geometricly primitive approximations and profiling cross sections
- Digital data storage of complete models allows new approaches and further analysis later on
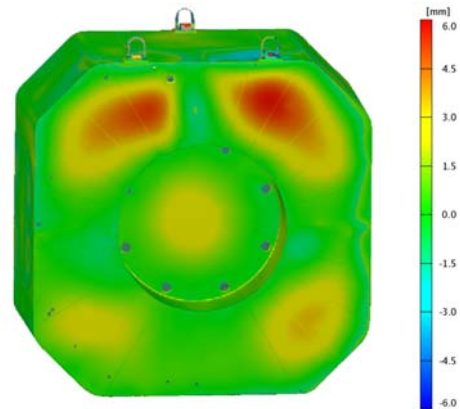
Figure 6. Shape comparison with CAD data

The following results are presented to illustrate these further measuring possibilities. Figures 6 and 7 describe color scaled surface deviation. The difference in model shape from the CAD model is small in scale (Fig. 6) but gives an idea of the extent of accordance between manufactured shock absorber and CAD model. Figure 7 permits an overview of large deformation areas. Quantitative interpretation should be done carefully if the surfaces to be compared are inclined too much to each other. In this case, vertical distances from the reference object's surface to the deformed one's cannot be correctly defined.

Digital models provide exact locations of cross sections in space. In Fig. 8 radially distributed cross sections spaced at 15° are used for distance measurements in certain planes of a deformed shock absorber. The combination of both measurement results - before and after drop tests - provides information of wall thickness changes in these selected cross sections.
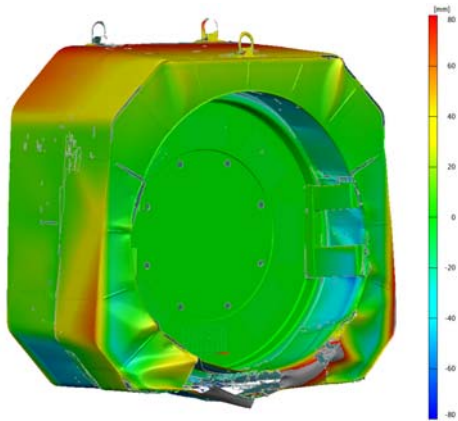
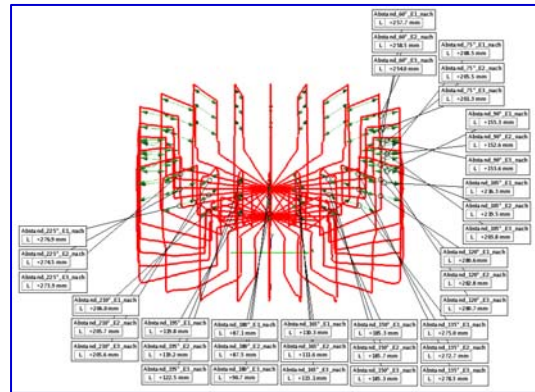**Figure 7. Shock absorber deformation due to drop test damage**

Figure 8. Multiple length measurements in cross sections

Another type of distance measurements is when 3-D measurements and CAD data are fused into a joint model. This approach saves time because the cask body between both shock absorbers only has to be partly digitized. Data combination can be done by fitting algorithms. In Fig. 9 the three on-axis cask data points P_1 to P_3 are pre-selected for inclination angle and change of distance determination relative to the unyielding foundation surface due to drop test deformation.
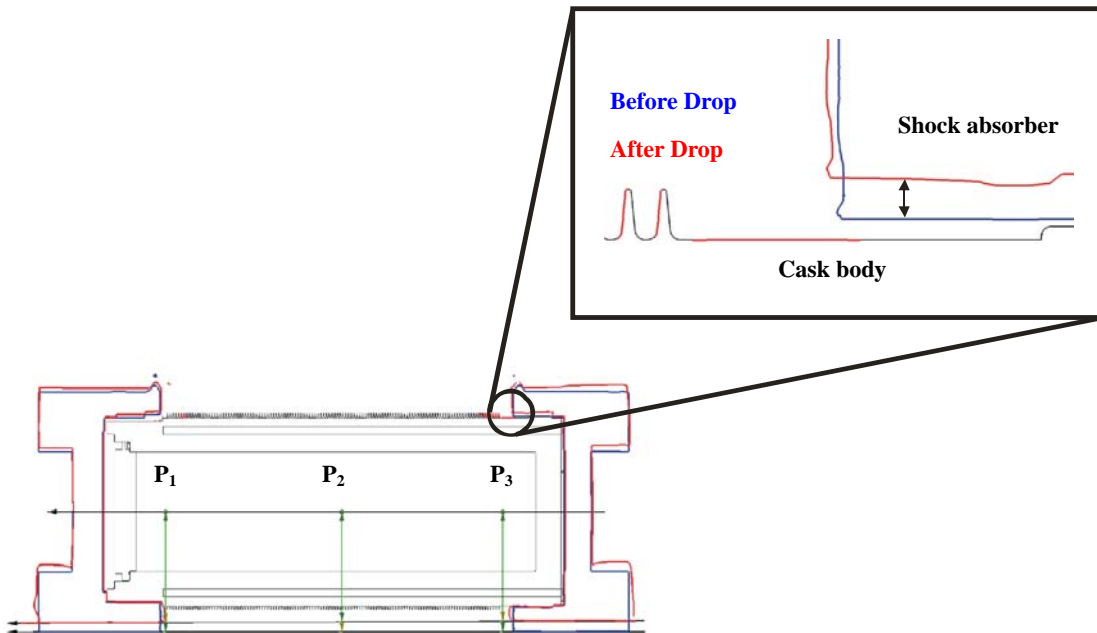

Figure 9. Cross section in drop test plane created from combined CAD cask and mesh model data of shock absorbers digitized before and after drop test

The change in gap length is shown in the extracted and detailed edge area of a shock absorber drawing. These measurements in almost unattainable object areas are hardly feasible without virtual data fusion. It is similar when measurements have to be conducted completely inside the object space. Figure 10 shows a deformed shock absorber after an inclined drop test on the cask edge. The 3-D cask data and oriented foundation plane are added in part for better clarity. The appropriate cross section in the drop plane is shown in Fig. 11. The plane parallel to the foundation goes directly through the edge point of the cask body base plate. Thus, it is possible to determine residual shock absorber wall thickness after drop test deformation. Figure 11 contains two schematically drawn parameters, the vertical and co-axial distances between the cask edge point and meshed external shock absorber surface.
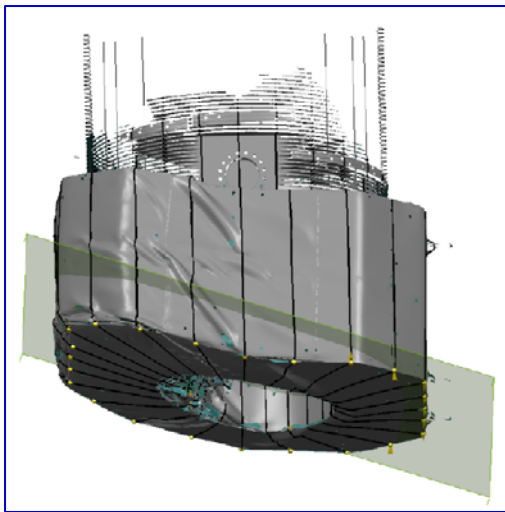

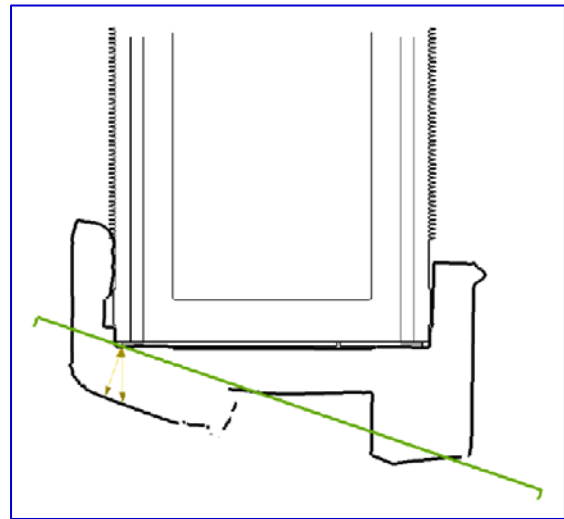**Figure 10. Deformed shock absorber model merged with cask data**

Figure 11. Cross section of inclined cask with shock absorber in drop plane

CONCLUSIONS

The applied optical measurement has successfully proved its excellent suitability for evaluation of a shock absorber's performance. New innovative possibilities like a comparison with 3-D reference CAD data, research of specific surface deviations caused by deformation and dimensional measures of the object under test conditions in cross sections or defined geometric stereoscopic pictures arise due to virtual object modeling.

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