APPLICATION NOTE

Multi-camera Metrology

Using multi-camera Digital Image Correlation (DIC) for complex materials, shapes and structures

Today's challenging test requirements

In Material Testing laboratories, optical imaging technologies are becoming more and more popular at the expense of strain gauges and other traditional labor intensive strain measurement methods.

- Report generation of measurement results in one single coordinate system, independent of the application and the number and setup of cameras
- Correlation of experimental measurement results with simulation data through standardized multidimensional data exchange formats

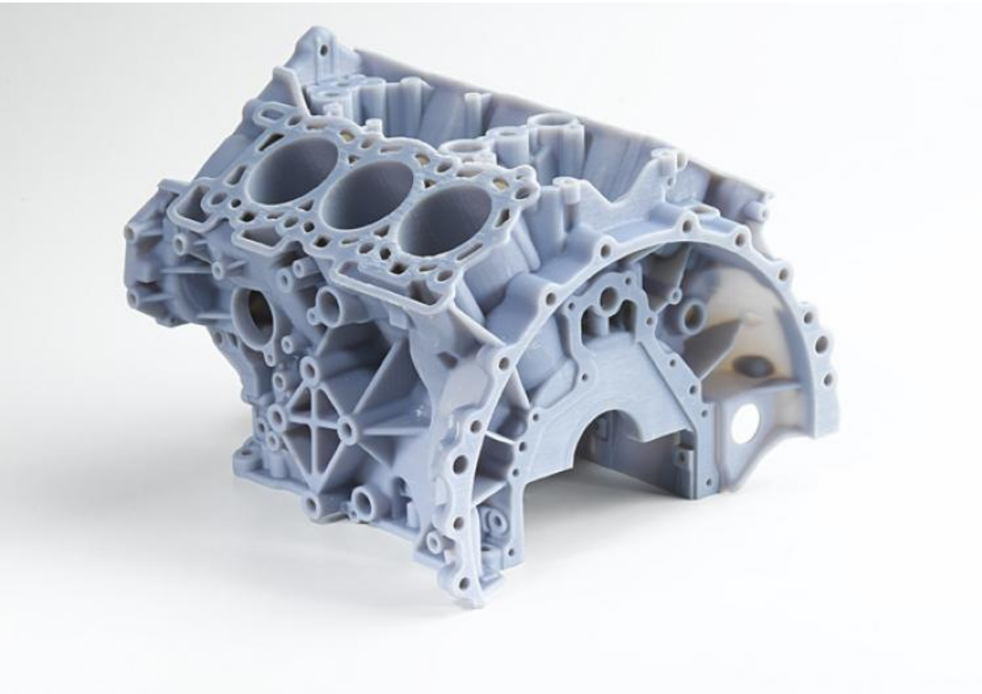


Figure 1 - 3D printed composite component

This trend is fueled not only by the requirement to produce measurement results most efficiently, but also by an ever-increased need for comprehensive measurement data. Such data is necessary to fully evaluate complex materials and structures with oftentimes anisotropic characteristics. In fact, today's Material Testing applications face challenges like:

- Testing of components with semi-flexible shapes and geometries
- Validation of material behaviors of components with very complex structures produced by additive manufacturing / 3D printing techniques

State-of-the-art 3D Digital Image Correlation systems can effectively address such challenges, making it a viable solution for Material Testing application throughout the value chain process, from Materials Research, over Product Development to Quality Control in production.

Optical measurement solution

Dantec Dynamics provides cost-efficient and innovative solutions for Material Testing and Structural Analysis of advanced materials and complex components.
The multi-camera DIC solution provides the unique ability to capture and analyze in one single measurement step the shape, deformation, strain and vibration of the component surfaces with multifaceted geometries even if such surface extends outside a single camera's field of view and requires multiple optical access points for full coverage.

Digital Image Correlation – a proven displacement and strain measurement technology

Digital Image Correlation (DIC) is a full-field, non-contact optical technique that measures surface deformation with micrometer resolution on almost any material and shape. Its flexible design suits a wide range of applications, from microscopic heat expansion measurements to monitoring of large scale civil engineering structures.

DIC is based on the recognition of a pattern of so-called speckles which are applied on the surface of the object to be measured. These speckles provide an optical "fingerprint" that is identifiable by software algorithms. Images taken in subsequent steps are correlated with a reference image which produces in result a deformation map.

Conventional 3D DIC systems with a pair of cameras come to its limit with complex geometries that can only be covered as long as the surface of the object remains in the field-of-view of the camera pair. As such, DIC is a great solution for measuring strain on surfaces that are flat or slightly curved. The inspection of special shaped objects with high radii, or the examination of sample thinning, is however almost impossible with conventional DIC systems as the area to be measured needs to be observed by both cameras. In order to circumvent the problem, one can stitch together deformation maps generated by DIC measurements produced in successive steps side by side. Such work-arounds are however less than ideal as the deformation on the intersections of the stitched images can only be approximated, potentially missing or misrepresenting crucial deformation data.

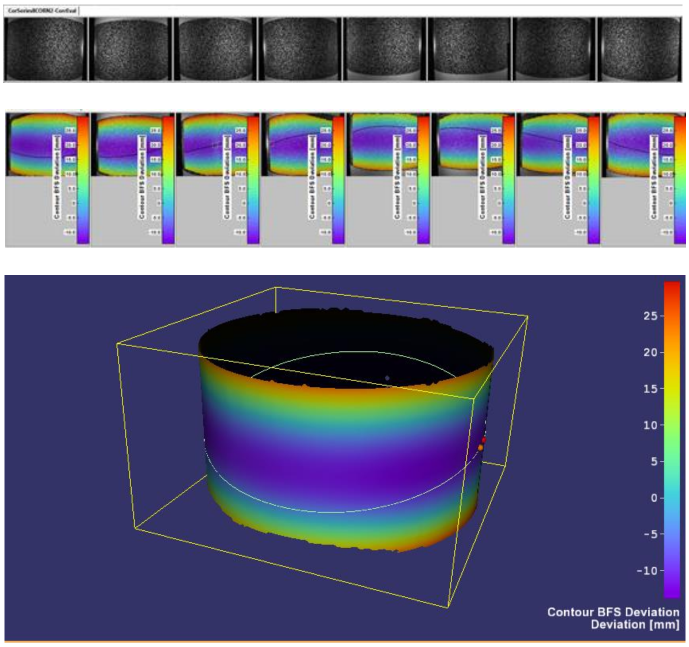


Figure 2 - Full-field evaluation of a cylindrical object with an 8 camera DIC System

Dantec Dynamics' multi-camera approach does solve this issue by employing simultaneously multiple cameras, arranged in any possible array as long as the field of view of the individual cameras overlaps in pairs. With such setup surfaces with high radii, corners, spheres, cylinders or even complete cubes can be evaluated in one coordinate system. Unlike conventional DIC systems, which approximate 3D measurements by stitching displacement data together, this unique multi-camera DIC solution provides many important benefits:

- No stitching of measurement data
- Increased accuracy on areas observed by several cameras
- No coordinate transformations required
- Easy calibration of all cameras simultaneously
- Flexible setup capable of accommodating any possible sample geometry

Unique multi-camera DIC algorithm

As per the principle of stereoscopic vision, 3D information can only be calculated on surface areas which are in the field of view of a pair of cameras. On non-planar surfaces, it can be complicated or even impossible to ensure a sufficient overlap of the field of view of two cameras. Properly positioning a third camera next to the two first cameras extends the overlapping field of views of any given camera pairs and, in addition, provides the means to evaluate curved objects or corners that can't be captured by a pair of cameras alone. On top of that, the accuracy of the deformation measurement will also be increased in the areas in which all three cameras' field of view overlaps.

The basic DIC principle remains the same whether two or more cameras are used. In fact, the "fingerprints" used for identification of the measurement points on the object surface are defined in the image of a reference camera.

The positions of these "fingerprints" are captured in the images of any cameras with overlapping field of view with the one of the cameras being the reference camera and their 3D position coordinates can be reconstructed. Figure 3 illustrates this process.

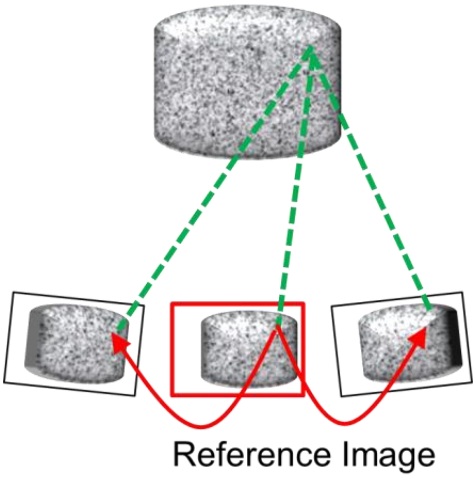


Figure 3 - Definition of facets in a conventional 3

The main drawback of this reference camera approach is, that the area which can be evaluated is still restricted by the field of view of the reference camera. Adding more cameras can extend the surface area which can be evaluated beyond the field of view of the reference camera.

A different process is however required to define further finger-prints on the object, outside the field of view of the reference camera.

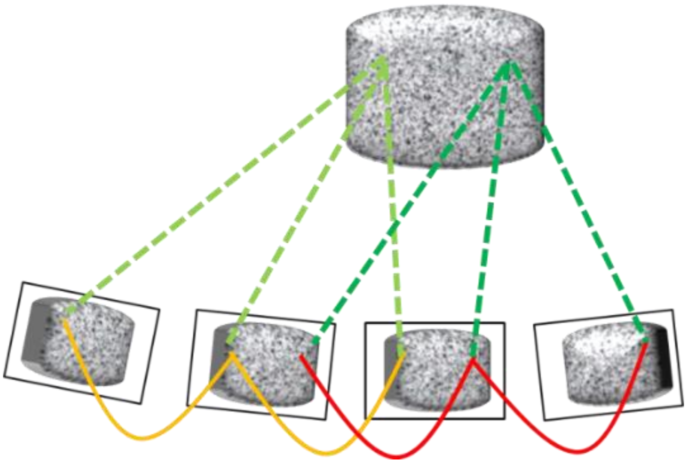


Figure 4 - Definition of facets in a multi camera DIC setup using the cluster approach

By using the so called **Cluster Approach for DIC systems**, the restrictions of using a reference camera can be overcome. To do so, the points to be evaluated can no longer be defined in a single reference camera's field of view but need to be specified on the object itself.

This way, every point on the object surface seen by at least a pair of two cameras can be evaluated. The principle of this approach is illustrated in figure 4.

The principle used for the 3D reconstruction of the object points is identical to the one used in conventional DIC.

By using the information of the projection parameter the pixel positions are projected back and the intersection of these projection lines define the 3D coordinates of the corresponding object point which make this process a holistic approach of the measured data in one 3D coordinate system.

The accuracy can even be increased with several cameras overlapping in their field of view.

Multi-camera setup using 4 cameras

By using a 4-cameras setup and the cluster approach, different configurations are possible. The following table summarizes principle arrangements of the cameras:

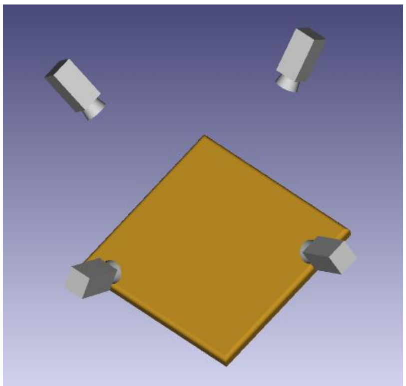
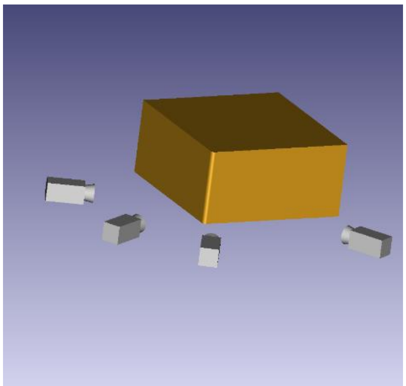
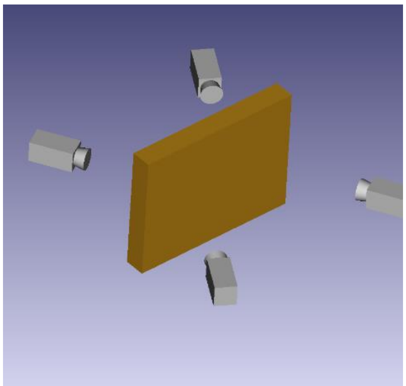
One side arrangement	Corner arrangement	Double side arrangement
		
All cameras see the object from one side • Increased accuracy • Extension of field of measurement	Cameras look at two adjacent sides and the corner • Measurement around a corner • Increased accuracy on the sides and at the corner	Cameras look at front- and back-side Simultaneous measure-ment of front and back side • Data in common coordinate system • Direct measurement of thinning

Table 1 - Principle configuration of a 4 camera multi camera setup

Example multi-camera corner setup – cardboard box

One example for the corner arrangement is the measurement of cardboard boxes under pressure load. The deformation of the adjacent sides and the corners are of importance. Since the load cycling is not reproducible, all measurement data need to be captured simultaneously. With Dantec Dynamics' DIC cluster approach, the entire 3D displacement information can be measured and analyzed, as explained above. Figure 5 shows the 3D model of the measured area with the amplitude of the displacement mapped as a result on the surface of the model.

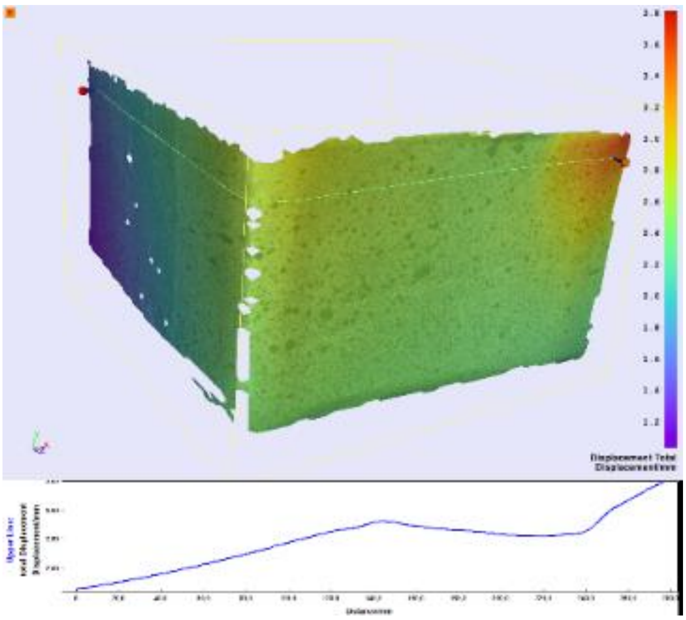


Figure 5 - Deformation of a cardboard box

Example double-side tensile testing

Using a classical 2-cameras configuration, the displacements and strain fields of a tensile test speciment under investigation can be determined. This means that one analyzes a component’s behavior only by observing one sole side. This approach is relatively accurate for simple materials but, as for inhomogeneous and anisotropic materials such as composites, the front and back side of the sample might behave differently. Thus, both sides should be measured independently, which gives access to the 2D front/back surface strains. Figure 6 displays the results of a measurement of a plastic sample during a tensile test. The upper two images show the calculated longitudinal strain in loading direction. This strain is overlaid on the raw imaged view of the cameras. The lower two images show the corresponding information for the back side of the sample. The red arrow indicates the direction of the load.

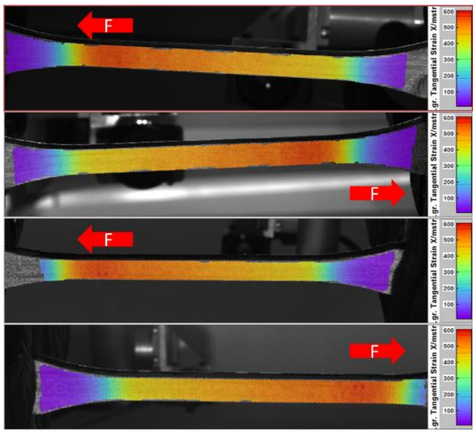


Figure 6 - Front and backside strain in loading direction tensile test sample

In Figure 7 the same results of this measurement is plotted as a 3D model. Both sides of the sample are visible on this model and the distance in-between them is equal to the thickness of the sample.
Using a point-gauge element on one side of the sample and its corresponding point on the other side, one can extract the behavior information at a particular position of the plastic object.
In the following Figure 8 the transverse elongation, the tensile test machine’s force and the longitudinal sample strain are plotted over time.[1]

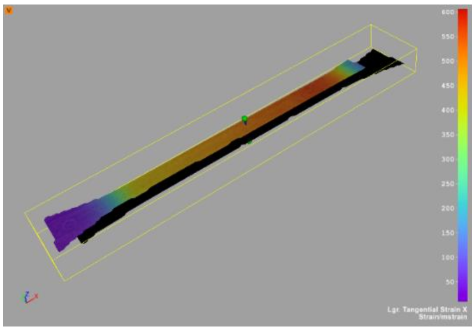


Figure 7 - Front and backside strain in loading direction tensile test sample as 3D model

The conventional front/backside tensile measurement method is only an approximation. As the sample thickness is calculated via a volume conversion. By combining a 4-camera DIC system with our cluster approach, the surfaces’ behavior and the relative position of these can be determined – hence the thickness data of the sample can also be computed. By analyzing the thickness changes as a function of the load, the strain in thickness direction can be calculated and can for instance be compared with the surface strain perpendicular to the direction of load. Figure 9 shows the change in thickness, the strain in the thickness’ direction and the strain on the surface perpendicular to the direction of load over the strain in loading direction.

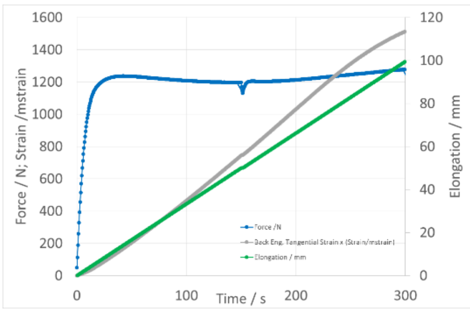


Figure 8 - Traverse displacement, force and strain in loading direction over time

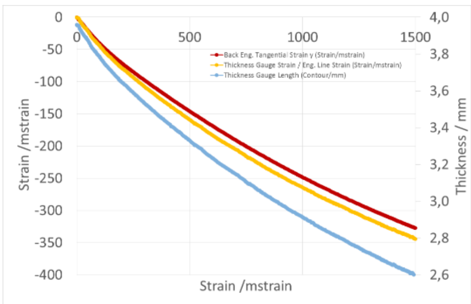


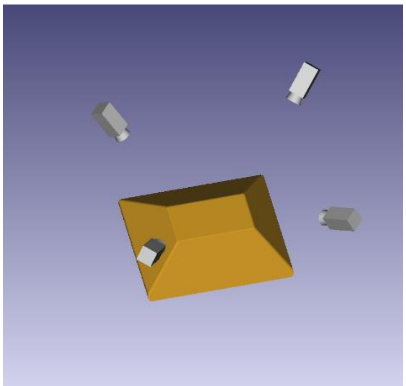
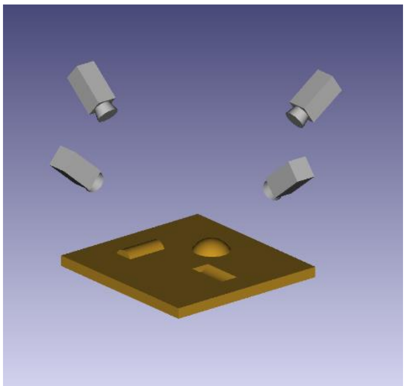
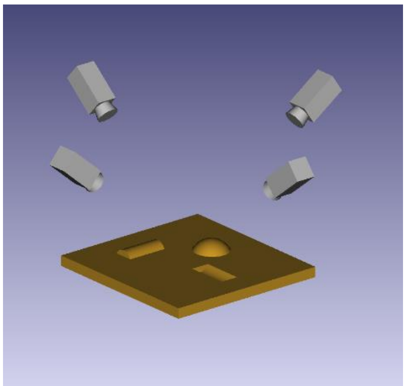
Figure 9 - Thickness changes, strain in thickness and perpendicular to direction of the load

[1] The dip in force is caused due to the test procedure, which has paused during about one second

Multi-camera single-side setups

Starting from the one side arrangement of the cameras, various configurations can be realized. Each has advantages in terms of flexibility and improvements of the measurable object geometry. A listing of some applications can be found in the following table.

Table 2 - Different applications of a 4 camera multi camera setup in one side arrangement

All side arrangement	Component testing	Concave objects
		
Cameras capture around the object • Full view of object • Measurement of discontinued areas	Cameras capture from different directions • Full view of object shape • Measurement of curvature and bulges	Cameras capture into the concave shape • 360° view of bowl shaped object • Measurement of entire shape

Example single-side component testing

Depending on the shape of the object under investigation and the requirements of the measurement, the use of a conventional 2 camera DIC system will typically not sufficient to capture enough of the object of interest. The contour does not allow a single camera viewing all of the surface, areas will be shadowed by the contour and shape of the object. In this situation our cluster camera approach can overcome these limitations. Especially for industrial measurement applications the geometry of the objects gets typically quite challenging. Areas of interest are often close to surface irregularities and a reliable analysis is required.

A comparison between a “standard” 2 camera DIC and a Multi Camera DIC using 4 camera is demonstrated in the next figures.

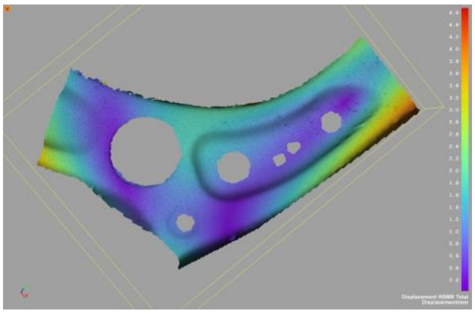


Figure 10 - Two camera DIC measurement limited to surface only, not showing shadowed areas.

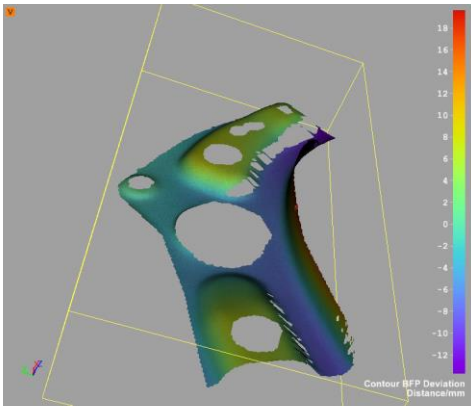


Figure 11 – Four camera DIC system showing component edges

Example single-side concave testing

A hemisphere is a geometrical shape which can be difficult to evaluate. The setup is as shown in table 2 concave objects. Four cameras capture the concave surface from the top. A single camera covers more than 90° of the hemisphere, each object point is viewed by at least 2 cameras and the complete surface can be measured by this multi-camera setup.

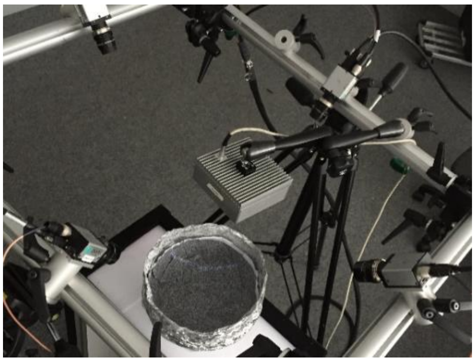


Figure 12 - Setup of multi-camera system for measurement of a hemisphere

A picture of a setup for the measurement of a half shell shows Figure 12. The object is a hemisphere of about 25 cm diameter and a 5 cm rim on top. This experiment demonstrates the feasibility of the system measuring the complete surface even with an irregular shape. A small pressure in vertical direction from the button causes a buckling of the inner surface. Figure 13 shows the reconstructed inner surface of the test object as a 3D model. The complete 360° of the surface is captured and can be reconstructed as a full model of the object. The magnitude of the displacement is mapped as color coded texture on the surface. A line along the circumference verifies the local buckling with positive and negative amplitude.

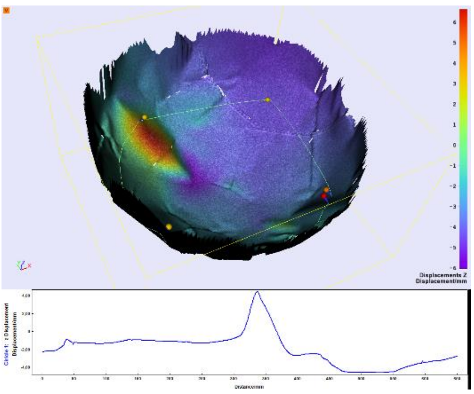


Figure 13 - Displacement of hemisphere object

Benefits of the Digital Image Correlation measurement solution

Save time/money

- Full-field, 3D quantitative analysis on displacements and strain. Unlimited data points.
- Non-contact measurement. Quick and easy setup.
- Fast and easy real-time calibration for all cameras at once.
- Eliminate the limits of point and two dimensional measurements irrespective of sample alignment and rigid body movements.

Explore innovative measurement techniques

- Measurement of any material/component with smooth or uneven surfaces in one coordinate system.
- Increased accuracy with multi-camera setups.
- Multi-camera setup also working for high-speed and vibration analysis applications.
- Investigate anisotropic material behavior.
- Explore advanced materials and structural testing areas with DIC, such as:
  - Strain measurement
  - Fatigue Testing
  - FEM validation
  - Vibration Analysis
- Stress determination by measurement of sample necking.
- Flexible measurement areas: from mm² to m² dimensions.
- Indication of measurement accuracy always available.
- Accuracies down below 1µm displacement for smaller areas.

Easy to use – Built-in "Sensor intelligence"

- Deformation, Displacements (x,y,z), Strains (exx, eyy, exy, e1, e2), etc.
- Material parameters: Poisson ratio and Young's Modulus.
- Vibration analysis and modal shape analysis modules are available.
- Various export formats to support post processing for simulation validation or country and company specific procedures are provided (e.g. HDF5).
- End user customizable procedures for complex calculations are supported and can be initiated with a single keystroke.

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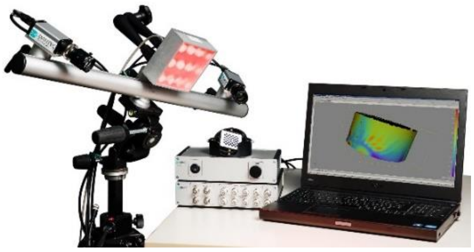

Figure 14 - DIC System with two cameras and illumination option

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