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ON APPLICATIONS OF OPTICAL FULL-FIELD STRAIN MEASUREMENTS IN VALIDATION AND EXAMINATION PROCEDURES

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Abstract

Full-field measurement methods are becoming commonly used in examination procedures. Features like: non-contact testing, rich data output, static and dynamic measurement make them reliable tools, especially in validation of numerical calculation in a design process of components and structures. This paper shows the potential of using full-field optical methods not only in validation process, but also in an inspection of a product in service. Moreover, other applications are mentioned like: damage detection and mixed numerical-experimental techniques. The potential of those methods makes them promising and valuable tools which are expanding in various areas of applications.
Keywords: full-field methods, optical strain measurement, validation.

1. INTRODUCTION

The document *Guide for Verification and Validation in Computational Solid Mechanics* developed by ASME (*American Society of Mechanical Engineers*) gives definitions of two basic expressions which are used in an evaluation of numerical models, verification and validation:

- *Verification:* the process of determining that a computational model accurately represents the underlying mathematical model and its solution,
- *Validation:* the process of determining the degree to which a model is an accurate representation of the real world from the perspective of the intended uses of the model.

Verification is a process focused on the correct use of mathematical model, numerical algorithm and errors of numerical calculation. Validation determinates how computational model is reliable in capturing physical phenomenon by comparing results with experiment. Verification is mainly an issue of software developer. Validation is a proper use of the software so that the results of calculations represent the outcome of real physical phenomenon.

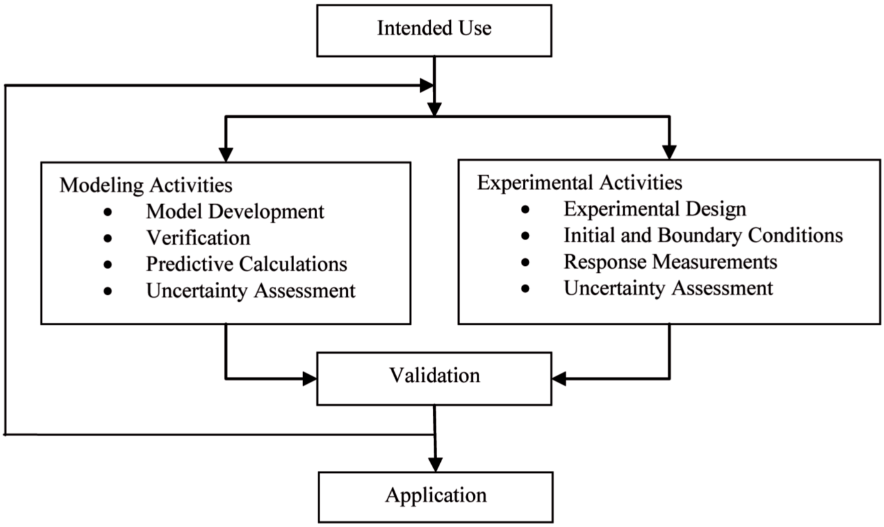

Fig. 1. Elements of verification and validation according to ASME

Optical full-field measurement techniques enable to measure strains on a surface which is in a field of view of an optical system. Resolution of measurement depends on dimensions of a surface, resolution of an image sensor, type of optical set up and type of measurement technique. Maps of strain can contain the order of 10^6 data points.

The main full-field measurement methods are:

- digital image correlation (DIC),
- grating interferometry,
- speckle interferometry,
- shearography,
- holography.

Those techniques differ in optical phenomena used for measurement, type of optical system, means of preparation of measured surface and resolution of measurement.

2. VALIDATION IN DESIGN PROCESS

Numerical models are most commonly validated by comparison with strain gauges measurement in some critical points (hot-spots). This approach is caused by a limited number of gauge sensors used in measurements. Strain gauges are located in stress concentrations points or points where strains or stresses can reach their limited values. However, there is no certainty that critical locations on the physical object are correlated with locations pointed by numerical analysis. As a result, it can create a source of errors in the validation procedure.

Optical full-field methods can provide very rich data from a measured object. The number of data points can be bigger than the number of points from numerical calculations, e.g. values in nodes of finite element mesh. Those methods seem to be a solution the verification problem. The whole surfaces of structures can be verified with full-field techniques instead of local measurements in a few locations. Those methods are used for verification of FEA of composite aviation structures reported by FAA (Federal Aviation Administration). With the use of fast cameras, full-field methods also can be used successfully for verifying non-linear dynamic simulations.

The presented method of verification of numerical calculations can be used in a wider perspective. Based on ASME procedure of validation and verification, Patterson et al. developed the use of full-field methods in design, optimization and service of an engineering component.

The process of validation can be expanded to an optimization of a structure. Commonly, mass optimization of a component is made by removing material in areas of the lowest stress. Again, there is no certainty that in the areas pointed by numerical analysis, stresses are the lowest at the physical structure. Also, the real values of theoretically low stresses are unknown. An application of full-field measurement should give some answers and make optimization process more reliable.

3. SERVICE CYCLE

The next stage is a control of the product in service. Data from full-field measurement can be used for creating a data base that can show changes in structure. The data can be collected during standard inspections. This "history" of a product can show the changes between inspections and also from the original design. In the future, this kind of database can be helpful in predicting the remaining service life of a product.

An examination of a loaded structure can additionally give instant information about failures e.g. delaminations. Moreover, data from a measurement contain information about changes in structure caused not by failures, e.g. plastic deformations.

This type of examination enables to go through four levels of information which non-destructive testing should give. Those levels were classified by Rytter:

- level 1: damage detection,
- level 2: level 1 + location identification,
- level 3: level 2 + extent definition,
- level 4: level 3 + remaining service life prediction.

The ability of damage detection and monitoring changes in a structure through its service time can make it possible to reach level four of classification.

Information from the above described examination techniques can be enriched by data gained from SHM (Structural Health Monitoring) systems. Nowadays SHM methods are limited to a strain measurement in some locations and ultrasonic methods of damage detection. Data from online monitoring of a structure can be an excellent addition to data from full-field inspection. Especially, where the remaining service life of a product is to be predicted.

There are some problems that need to be solved before data from different inspections can be compared, e.g. recurrent type of loading of a structure, recurrent measurement conditions for optical methods, methods of quantitative comparison between measurements data and analysis results. A solution to those problems will set the base for a standardization procedure for full-field examination.

4. VALIDATION OF FEM RESULTS

Important issue of validation of FEM models is a method of comparison between results from analysis and measurement data. Recently, research are carried out on developing methods for simple and effective data comparison. Image decomposition techniques allows to reduce 10^6 data points to 10^2 shape descriptors. Some of the decomposition methods are: Zernik moments, Zernik moments with Fourier transformation, Chebichef moments. Those advanced decomposition methods are information-preserving and invariant under rotation, scale and translation. Comparison of image. Comparison of values of image descriptors e.g. Chebichef moments, of measurement data and numerical model results gives information if the model is valid or not. In most simple cases the model is validated by comparing it with a full-field measurement data on certain points or on line.

5. IDENTIFICATION OF MATERIAL PARAMETERS

Mixed numerical-experimental techniques are recently developed for identification of material parameters. Those techniques utilize numerical methods to gain more information from rich data of full-field measurements. Identification of material parameters is made by solving an inverse problem. Two main methods are used for solving the problem: the iterative finite element method and the direct virtual fields method,. The examples of the inverse problem are identification of four parameters of orthotropic material based on one test, distribution identification of mechanical parameters of composite, identification of elasto-plastic material parameters.

6. DAMAGE DETECTION

Optical non-contact methods can be successfully used for damage detection. The basic non-destructive optical methods of damage detection are: visual inspection, radiology, thermography, shearography. Dantec Dynamics manual suggests that shearography inspection requires stressing or excitation of a component surface. Stressing techniques include, but are not limited to: mechanical, thermal, partial vacuum, mechanical-vibration and acoustic-vibration.

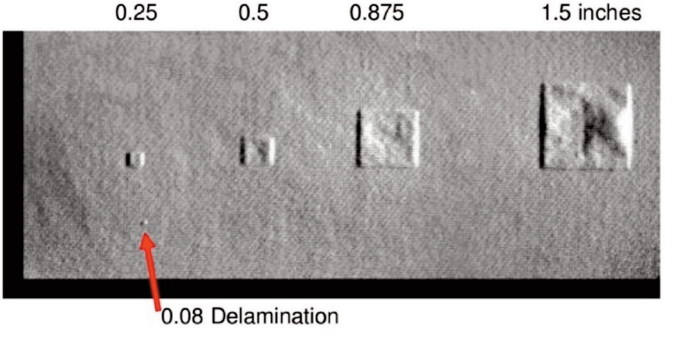

Fig. 2. Carbon fiber/Nomex shearograpny testing, teflon inserts and delamination. Nondestructive Testing at NASA WSTF (http://www.slideshare.net)

According to CMH17 Composite Materials Handbook shearography, which is classified as special detailed inspection, has the same reliability in detecting delaminations and disbonds as thermography or ultrasonics. Full-field methods can also be used for an inspection of repairs. Changes in strain distribution in component after repair can be examined.

7. DISPLACEMENT MEASUREMENT IN SUBMICRON SCALE

High resolution of measurement can be achieved by optical methods. Grating interferometry, which is based on deformation of diffraction grating, enables measurement of displacements with sensitivity lower than micrometer. It can be used for observing local phenomena like stress concentrations in notches or composite behaviour on level of yearns. Digital image correlation can also be used for measuring displacement lower than micrometer. There are examples of applying DIC to analysing the deformation mechanisms under transverse compression in a fibre-reinforced composite. Resolution of vertical displacement obtained using DIC in a micrograph at 2000x magnification was about 0,3 μm. Resolution of vertical displacement at 6000x magnification - 0,1 μm.

8. CONCLUSIONS

Full-field methods are recreantly used in many areas. Devices for optical non-contact measurement of strains and for damage detection are available on the market. An important issue is to develop methods for quantitative validation of numerical analysis of a design process.

Those methods have a potential to become 'disruptive technologies', which means they can change the market of measurement technologies. Nowadays, full-field methods are used commonly as an addition to other technologies, but are developed and improved constantly. At the moment, the most important issue is to develop standard procedures in the area of measurement and validation.

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ZASTOSOWANIE METOD POMIARU ODKSZTAŁCEŃ W PEŁNYM POLU W PROCEDURACH WALIDACJI ORAZ TESTOWANIA

Streszczenie

Metody pomiaru w pełnym są coraz częściej stosowanym narzędziem w procedurach badawczych. Cechy takie jak: pomiar bezkontaktowy, duża ilość danych pomiarowych, możliwość realizacji pomiarów zjawisk statycznych i dynamicznych sprawiają, że stają się one korzystnym narzędziem w procedurach walidacji obliczeń numerycznych stosowanych w procesie projektowania komponentów oraz struktur. W artykule przedstawiono możliwości użycia metod pomiaru w pełnym polu nie tylko w procesie walidacji, ale również w inspekcji produktu oddanego do eksploatacji. Dodatkowo opisano inne obszary wykorzystania metody takie jak wykrywanie uszkodzeń oraz metody eksperymentalno-numeryczne. Potencjał tych technologii sprawia, iż są obiecującymi oraz cennymi narzędziami, których cechy umożliwiają wykorzystanie ich w szerokim zakresie zastosowań.

Słowa kluczowe: metody pełnego pola, optyczne pomiary odkształceń, walidacja.