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Experimental Stress Analysis

Impact force identification on sandwich beam

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Abstract: This work investigates the applicability of impact force identification method on sandwich beam which is excited by linear combination of sinus signal. The beam consists of composite skins and foam core and is instrumented with piezoelectric sensors. The response of beam on impact loading in given position is characterized by the transfer matrix which is determined experimentally from sensor measurements. The transfer matrices in reference positions are then used in inverse process to investigate unknown impact force and impact location. Furthermore, the operational conditions are simulated by piezoelectric actuator and the applicability of the identification method on oscillating structure is discussed.

Keywords: Impact force identification, Sandwich beam, Oscillating structure

1. Introduction

Identification of impact force on composite structure is becoming important task. Composites are growingly popular and permanently more important parts from classical materials are replaced by composites. This happens because of their excellent stiffness and strength to weight ratios and other unique properties. On the other hand composites have more complicated behaviour and are susceptible to failure caused by impact. Moreover, failure of material induced by such type of loading can be hidden inside material to the classical visual inspections and more complicated and expensive techniques like ultrasonic inspections have to be utilized. Alternatively, the impact force can be identified and localized permanently by appropriate identification method within so-called structural health monitoring system. Such system should evaluate the recorded events in real time and force inspections of construction only in situations, when they are actually needed.

Impact force identification problems were studied in recent years intensively and several methods were proposed. Most of the used methods are based on deconvolution of measured response in time or frequency domain. Martin and Doyle in [3] worked in frequency domain and identified impact force on beam structure. Hu *et al.* in [1] used nonlinear programming method to solve deconvolution in time domain and Sekine and Atobe in [4] used the method in time domain with little modification to identify multiple forces on isogrid-stiffened panel. There are some other methods which can be adopted such as neutral network. The proposed methods were studied in laboratory conditions, with different instrumentations and on variety of geometries and boundary conditions. Influence of measured signal distortion or other parameters on the accuracy of methods was mentioned marginally or not at all.

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The identification of impact force and its location on sandwich beam is discussed in the paper. The mechanical properties of the beam are not known and whole identification process is based on experimental measurements and deconvolution of measured signals in time domain. The beam is also excited by piezoelectric (PZT) actuator and its influence on the identification method is discussed.

2. Identification method

The identification method used in the paper is based on the deconvolution of signals from sensors placed over the structure. The assumptions are validity of principle of superposition, impact loading limited to one place and measurement in K discrete time steps. Then the response of sensor s can be considered in form

$$\mathbf{u}^s = \mathbf{G}^s \cdot \mathbf{f}\,, \tag{1}$$

where $\mathbf{u}^s = \left[u_1, u_{2,} \ldots, u_K\right]^T$ is vector of response, $\mathbf{f} = \left[f_1, f_{2,} \ldots, f_K\right]^T$ is vector of applied forces and $\mathbf{G}^s$ is transfer matrix between impacted point and sensor s.

The transfer matrix must be determined before the identification process from

$$\mathbf{F} \cdot \mathbf{g} = \mathbf{u}\,, \tag{2}$$

where $\mathbf{F}$ is matrix composed from vectors of impact forces, $\mathbf{u}$ is vector composed of coresponding responses and $\mathbf{g}$ is unknown first vector of transfer matrix $\mathbf{G}^s$. This equation was solved in the paper by the least square method. The transfer matrices can be determined only in the limited number of descrete points (reference positions). Linear extrapolation from these rference positions is used to determine transfer matrix for the latter positions on the beam. The determination of transfer matrices is described in detail in [2].

The impact force history is set as a solution of Eq. (1). For the measurement using S sensors the equation can be rewritten in form

$$\begin{bmatrix} \mathbf{G}^1 \\ \mathbf{G}^2 \\ \vdots \\ \mathbf{G}^S \end{bmatrix} \cdot \hat{\mathbf{f}} = \begin{bmatrix} \mathbf{u}^1 \\ \mathbf{u}^2 \\ \vdots \\ \mathbf{u}^S \end{bmatrix}, \tag{3}$$

which is solved with the consideration of positive contact forces ($\hat{f}_n \geq 0$). The deconvolution was solved in the paper by the least square method.

The unknown impact force vector $\hat{\mathbf{f}}$ is determined for the impact location specified by the used transfer matrices. If the impact location is unknown, than its estimate is determined by minimization of residuum

$$r_1(x) = \left\| \mathbf{u} - \mathbf{G}(x) \cdot \hat{\mathbf{f}} \right\|^2, \tag{4}$$

which was done by adapted half-interval search algorithm with evaluation of nine equidistant points in each iteration.

3. Experiment

The impacted construction was represented by sandwich beam. The beam was composed of skins made from glass/epoxy textile composite and foam core. The beam was clamped on both ends and was instrumented with four PZT transducers. Three of them (PI P-876/SP1) were used as a sensors and one (PI P-876/A12) as an actuator. The signal from sensors is proportional to the deformation of the bottom skin in the plane of sensor. The geometry of the beam is in Fig. 1 and important dimensions in Table 1.

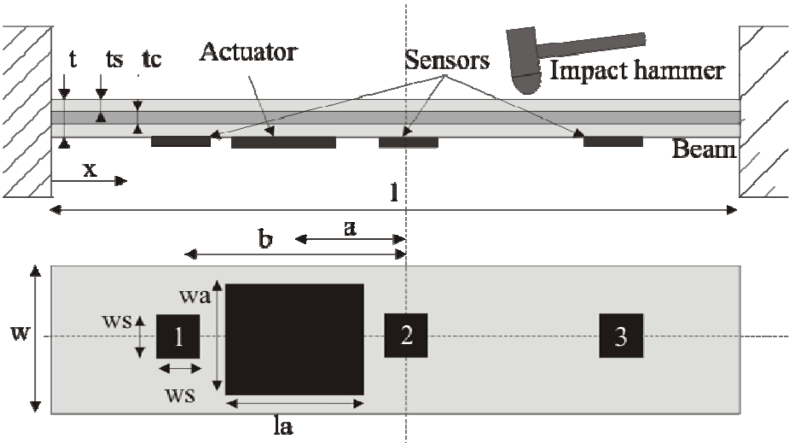

Fig. 1. Sandwich beam

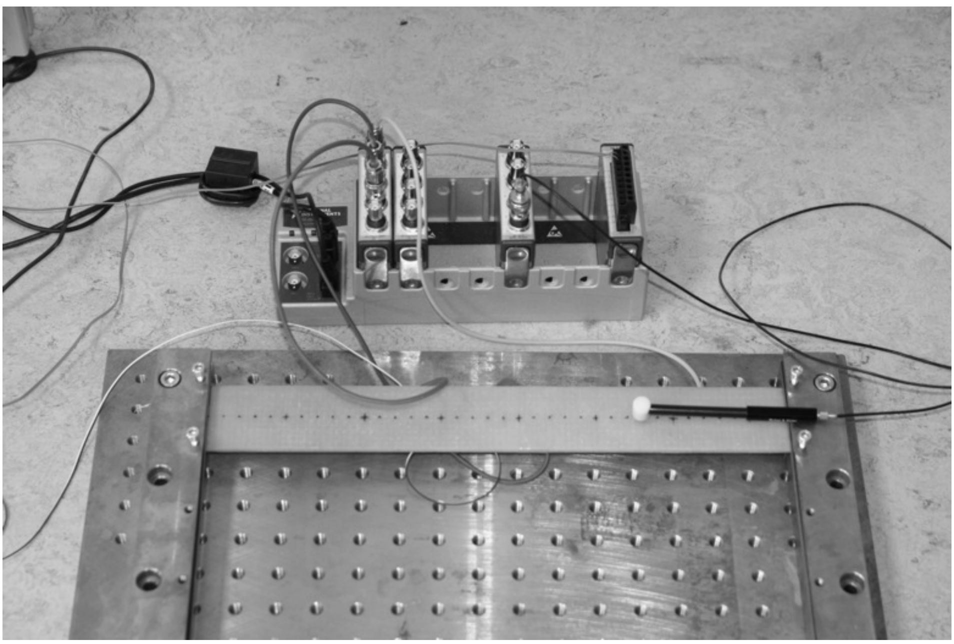

Fig. 2. Arrangement of the experiment

Table 1. Dimensions

Dimensions	l	w	T	ts	tc	a	b	ws	wa	la
[mm]	375.0	50.0	4.5	1.5	1.5	25.0	90.1	10.0	30.0	50.0

Two types of loading were applied on the beam. Firstly, the beam was loaded only by impacts caused by impact hammer (B&K 8204). The beam was stepwise impacted along the beam axis with spacing of 1 cm and totally six measurements were recorded for each reference position. The signals from piezoelectric sensors and from impact hammer were wired to measurement system (NI CompactDAQ) for simultaneous data acquisition with sampling frequency 51.2 kHz. The overall experiment arrangement is in Fig. 2 and an example of measured data is shown in Fig. 3.

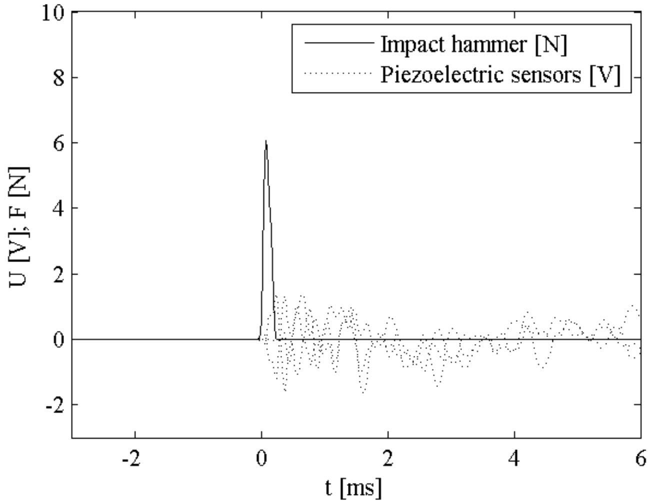

Fig. 3. Measured signals for loading by only impact hammer in location x = 14 cm

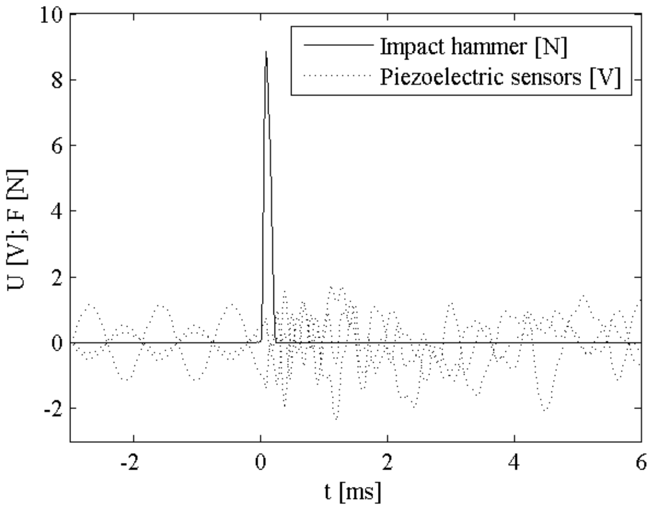

Fig. 4. Measured signals for loading by actuator and impact hammer in location x = 14 cm

The second type of loading was continuous excitation by PZT and simultaneous impacts from impact hammer. Three types of signals were used for the excitation of the beam. The equations used for signal generation are in Table 2. One set of measurements with spacing of 1 cm and six measurements for each reference position was recorded for each excitation function. Example of measured data is shown in Fig. 4.

Table 2. Function used for actuator excitation

Set number	Excitation function
Reference	0
1	f_1=100·sin(2·π·250·t)
2	f_2=100·sin(2·π·900·t)
3	f_3= f_1+f_2

4. Identification of impact force history and impact location

The process of identification was verified on the sandwich beam for measurements without excitation. The transfer matrices were determined in each point of measurement from the first three measurements. The impact force history $\hat{\mathbf{f}}$ and impact force location $\hat{x}$ were identified for the rest three measurements. Resulting values were compared with measured values ($\mathbf{f}$, x). The error was evaluated as

$$e_{\mathbf{f}}\left(x\right)=\left\|\left(\mathbf{f}-\hat{\mathbf{f}}\right)/\max\left(\mathbf{f}\right)\right\|^{2}, \tag{5}$$

$$e_x=\left|x-\hat{x}\right|. \tag{6}$$

Example of search of impact location within the identification process and resulting impact force history is shown in Fig. 5 and the resulting errors along the beam axis are shown in Fig. 6.

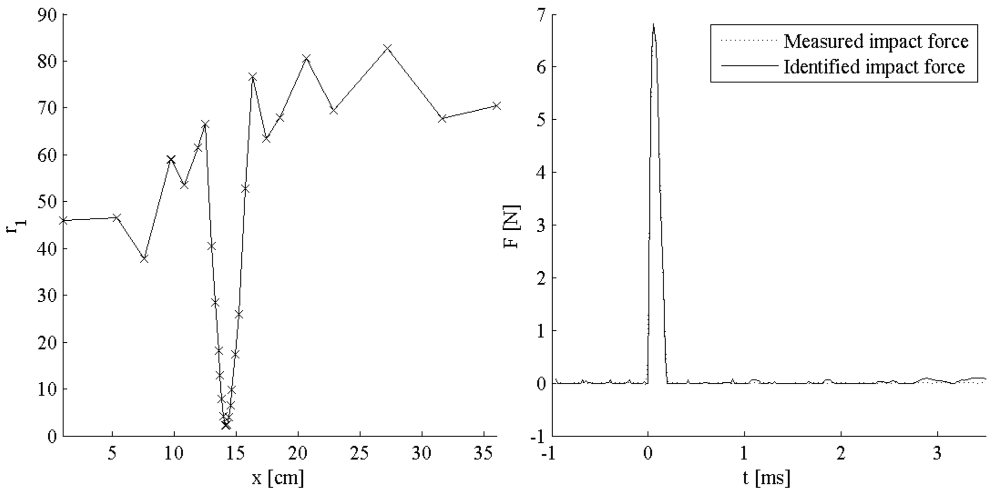

Fig. 5. Process of impact location identification (left) and identified impact force history (right) for loading by impact hammer in location x = 14 cm

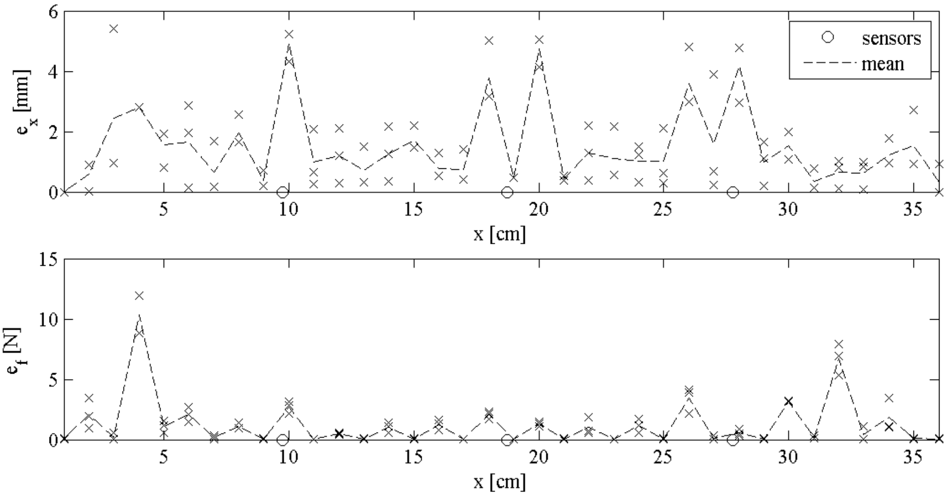

Fig. 6. Identification errors along the beam axis for the loading by impact hammer

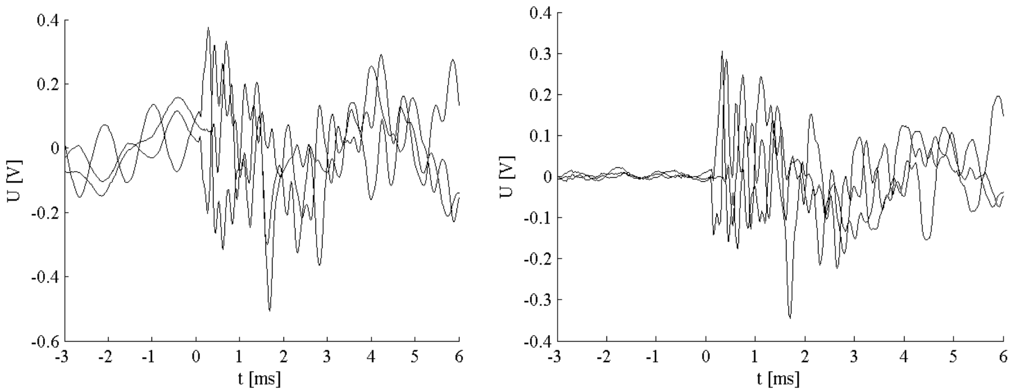

Fig. 7. Measured (left) and pre-processed (right) signals for the excitation by function f_3 a and location of impact x = 14 cm

5. Identification of impact force on vibrating beam

The identification of vibrating structure was verified on the beam loaded by PZT actuator and impacted by impact hammer. Although the measured signals before impact event was considered to be periodical the direct identification on measured data is not possible because the impact event can occur for different phase shift. Measured data were therefore pre-processed before identification to suppress the component of signal which corresponds to excitation. This component was considered in form:

$$\mathbf{n}^s = \sum_{1}^{I} a_i^s \cdot \sin\left(2 \cdot \pi \cdot f_i^s \cdot \mathbf{t} + \varphi_i^s\right), \tag{7}$$

where $\mathbf{t}$ is time vector with time steps before impact event. Parameters a_i^s, f_i^s and φ_i^s were searched in minimization:

$$r_2^s(x) = \left\| \mathbf{u}^s(\mathbf{t}) - \mathbf{n}^s \right\|^2 . \tag{8}$$

Number of components I searched in the signal corresponded to number of components in excitation functions. The example of measured signal and its pre-processed equivalent for the excitation function f_3 are shown in Fig. 7.

The identification method on pre-processed signal of excited beam was applied similarly to the reference set. The identified transfer matrices for reference set were used and the errors for all available measurements in each set were determined. Example of search of impact location within the identification process and resulting impact force history is shown in Fig. 8 and mean values of errors for each point of measurement and for measured sets are shown in Fig. 9.

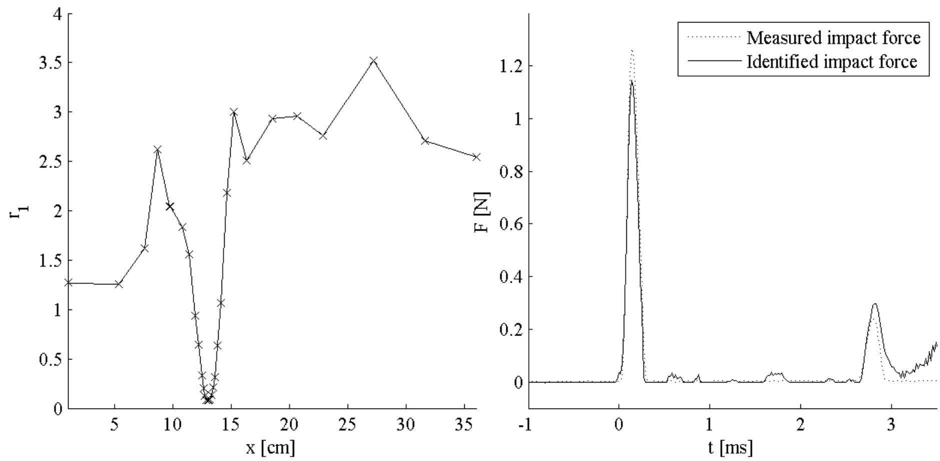

Fig. 8. Process of impact location identification (left) and identified impact force history (right) for loading by impact hammer in location x = 14 cm on beam exited by function f_3.

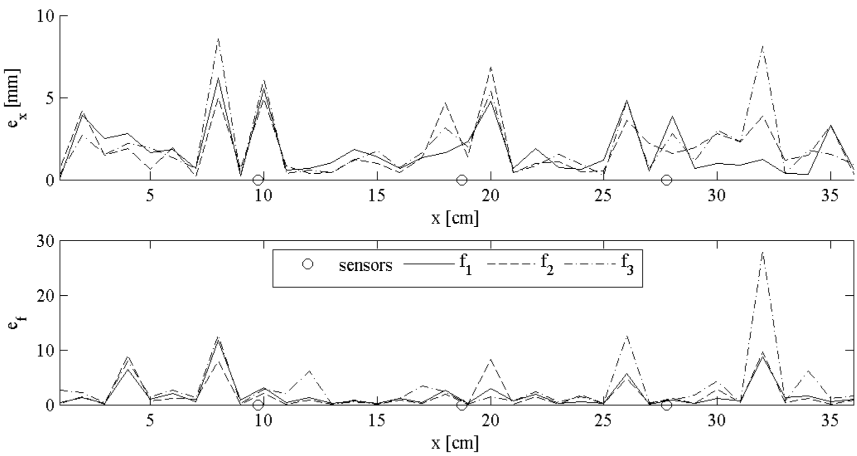

Fig. 9. Mean values of identification errors along the beam axis for different excitation functions

6. Results and conclusion

Results shows that used impact identification method can be applied on sandwich beams. The identified impact locations and identified impact force histories correspond well to the actual one for the beam without excitation. Small differences are in locations of sensors and between outside sensors and points of fixation. The identification was verified on excited beam with various secondary excitation functions. The component of signals which corresponded to secondary excitation was suppressed. Identification of such type data shows sufficient results. The inaccuracies of identified impact positions and impact force histories are probably caused by local nonlinearities of the beam caused by mounted sensors and supplement wiring, inaccuracies during measurements and remaining noise from excitation and another sources like electromagnetic interference.

The prospect for future work is excitation of the beam with more complicated functions such as white noise, where it would not be possible to decompose signal in time domain to its individual components.

Acknowledgements

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