The given calculations show that the registering of the adiabatic curve indications is necessary for more accurate determination of the thermodynamic parameters for the compressor and turbine performance. The calculation of the kinematic parameters of the flow in the system and the design of the flow sector and turbine or compressor blades should also be carried out taking into account the variability of the adiabatic curve indicator.

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COMPUTERIZED TEST STAND FOR INVESTIGATION OF STRAIN WAVES IN COMPOSITE CONSTRUCTIONS

The paper presents a test stand for investigation of ramp loading of composite constructions such as beams and plates. This ramp loading was performed using a striker with a piezoelectric force transducer. The velocity of the striker is up to 40 mps. The registration of the measurements results is carried out using a computerized measurement system. The experimental results of contact shock force acquisition are stated with appropriate calculations of non-stationary bending and shearing strain waves in glass-fiber-reinforced plastic beams and plates.

Keywords: composite constructions, shock loading, strain waves, computer measuring system.

The percentage of composite materials content in modern military and civil aircrafts does not exceed 20. Increasing composites percentage up to 50 and more, like in Boeing-787 (introduced in 2007) revealed a number of drawbacks because of the insufficient shock strength of composite materials being used. The matter doesn't concern the damage caused by some extreme situations inside an aircraft but it concerns normal shock loads for constructions made of traditional materials. Thus, at present time it is necessary to create crash-proof construction elements made of fibrous-layered composite materials like glass-fiber and coal-plastic. The application of these materials is not possible without reliable expert evaluations obtained by numerical simulation combined with experiments.

Carrying out shock tests gives more empirical data than carrying out static tests. Moreover, the experiments on shock loading and non-stationary deformation even for simple constructions like beams are complicated by the lack of complete standards for test stands, sensors, instruments and test techniques. So, experimental data are required to be accurate and reliable.

The present paper proposes an automated shock loading test stand with the computerized measuring system based on the LabVIEW virtual instrumentation from the National Instruments Corporation. The developed impact force and dynamical strain acquisition procedure provide sufficiently accurate experimental data to design crash-proof composite constructions.

Automated shock loading test stand. The scheme of the automated test stand for studying beams and plates non-stationary deformation processes under lateral shock loading is shown in fig. 1. It consists of loading device, impact rate acquisition system, and strain gauging system, dynamic force measurement system and computerized measuring system.

The loading device is a light gas ballistic installation for ramp loading of objects with the strikers having mass from 5 to 100 g providing shock loading rate up to 40 mps [1]. The striker rate was measured with drag-type sensors during its flying between magnets N1 and N2 with the inductance coils L1 and L2. Beams and plates non-stationary surface deformations were measured by foil strain gauges KF-4P1-5-100-B-12.

The novelty of the dynamic force measuring system is in using the striker sensor [1] to measure impact contact force including its magnitude, duration and form change in the contact zone between the striker and an object. This sensor is made of piezoelectric tablets that have the diameter 8 mm and are 2.8 mm thick.

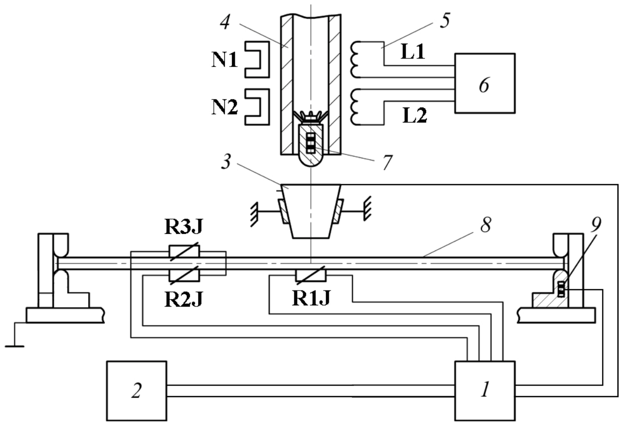


Fig. 1. The scheme of the automated test stand to study beams and plates non-stationary deformation processes under lateral shock loading:
1 – signal conditioning module; *2* – personal computer with built-in data acquisition device; *3* – conic contact surface; *4* – pilot borehole of light gas ballistic installation; *5* – striker rate drag-type sensor; *6* – electronic frequency meter to measure striker rate; *7* – piezoelectric striker-sensor; *8* – specimen under test (beam, plate); 9 – universal support with piezoelectric force sensor

The registration of signals from strain gauges R1J, R2J, R3J and a piezoceramic striker-sensor was acquired by the computerized measurement system shown in fig. 2. The measuring system consists of strain measurement system, force measurement system, hardware and software [2].

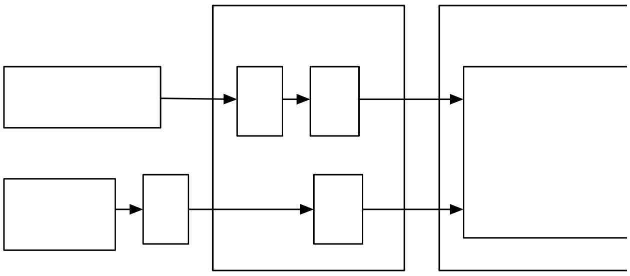


Fig. 2. Computerized measuring system block diagram

Hardware includes the following blocks:

− signal conditioning module SC1 NI SCXI-1520;
− terminal block TB1 NI SCXI-1314;
− signal conditioning module SC2 NI SCXI-1120;
− terminal block TB2 NI TBX-1316;
− chassis NI SCXI-1000;
− data acquisition (DAQ) device NI PCI-6221M.

Software includes the following components:

− graphical application development environment NI LabVIEW;
− drivers NI DAQmx.

SC1 is an 8-channel signal conditioning module converting strain gauge resistance change into electrical voltage. Gauges are connected to SC1 by means of the connector block TB1. Each channel has half-bridge completion resistors. RJ1 is connected by 1/4 bridge circuit and RJ2, RJ3 are connected by 1/2 bridge circuit.

SC2 is an 8-channel high-voltage signal conditioning module. The piezoelectric sensor is connected to SC2 by means of the terminal block TB2 which can accept voltage up to 1000 V. Each channel has an isolated amplifier and 10 kHz low-pass filter to protect the DAQ device and the computer from damage.

SC1, SC2 and TB1 are placed inside the shielded chassis SCXI1000 having power supply and 4 slots for signal conditioning modules and terminal blocks.

Output voltages from SC1 and SC2 are connected to the DAQ device 8-channel analog input subsystem. Two analog input channels are for the strain gauges and one channel is for the piezoelectric sensor. DAQ device also contains a double-channel subsystem of the analog output, an eight-channel subsystem of the digital input/output and two timer/counters.

DAQ device is plugged into a PCI slot inside the computer.

The computer controls DAQ device and signal conditioning modules, analyses data acquired and displays measurement results in digital and graphical formats by means of the graphical application development environment LabVIEW [2]. Interaction between LabVIEW and DAQ device and signal conditioning modules is controlled by DAQmx drivers.

Computerized measuring system error includes DAQ device analog input error and signal conditioning modules errors. Maximal error of analog input for the 16 bit analog-to-digital converter is 0.02 %. Maximal error of SC1 is 0.2 % and maximal error of SC2 is 0.8 %. (Error values are taken from the National Instruments specifications). Application of electronic scopes in old test stands [1] gave the strain measurement error 5.4% and the force measurement error 6.1 %. The computerized measuring system allows reducing the error to 2 % replacing electronic scopes by NI virtual instruments.

Impact force pulse shape identification. Fig. 3 shows the contact force $P(t)$ oscillogram for transverse central impact by the striker-sensor on a hinged beam made of symmetrically arranged glass-fiber $\left[0_8^0/\pm45_8^0/90_8^0\right]$. The dimensions of the beam are (100.0 × 10.0 × 10.2) mm. The impact rate is 5 mps and the striker mass is 51 g. A glass fiber monolayer has the following characteristics: $\rho = 1800$ kg/m^3, $h = 0.3$ mm, $E_{11} = 270\cdot10^8$ N/m^2, $E_{22} = 70\cdot10^8$ N/m^2, $G_{12} = 46\cdot10^8$ N/m^2, $\nu_{12} = 0.26$. The inclusion volume fraction of the bonding polymer in the composite package is 35 %.

It is known that a single impact takes place if the beam-to-striker mass ratio *m/M* is less than one [3]. If this ratio is more than one, impacts are repeated (fig. 3). In the context of the elementary theory of impacts we can explain this phenomenon in the following way: when the striker hits, the beam rate exceeds the rate of the striker, the beam advances the striker, the contact density decreases and at the moment $t \approx 3$ μs the first relative maximum appears. Then beam rate decreases and it behaves as a compressed spring and the striker does not change rate, the contact density increases and at the moment $t \approx 19$ μs the second maximum appears. After all the striker moves backward and at the time moment $t \approx 86$ μs rebound takes place.

The function $P(t)$ should be approximated to perform numeric calculations. If plates shock loading rate is less than 5 mps, contact force can be approximated rather accurately by a sine half wave with the maximal amplitude P_{max} and duration t_{max} [4, p. 8–46]. The presented experimental results show that if the impact rate is from 5 to 40 mps, other approximations are required.

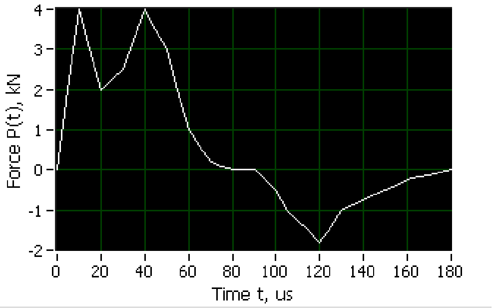


Fig. 3. Contact force time function $P(t)$ at transverse central impact on the glass fiber hinged beam

Fig. 4, *a* shows the contact force time function measured at transverse central impact on firmly fixed glass fiber plate with fiber placing angles $\left[0_8^0/\pm45_8^0/90_8^0\right]$ and geometrical dimensions (100.0 × 100.0 × 7.2) mm. The impact rate is 18 mps and the striker mass is 51 g.

The repeated impacts pulses envelope has a triangular form with rising and falling parts (fig. 4, *b*). The number of repeated impacts increases with the growth of shock loading rate. Such an envelope shape corresponds to impact rates from 5 to 40 mps. The initial part 2, where the load is increasing, is significantly less than the part 1 where the load is decreasing. Moreover, the higher the impact rate is, the less the initial part is.

Non-stationary deformations numeric simulation. Non-stationary deformations under impacts described by the function $P(t)$ have been calculated for composite beams by means of the finite elements method. The displacement equation has the form:

$$[M]\{\ddot{\delta}\}+[C]\{\dot{\delta}\}+[K]\{\delta\}=P(t)\{\delta_j\}, \qquad (1)$$

where $[M]$, $[C]$, $[K]$ are the mass, viscosity and rigidity matrices; $\{\delta\}$ is the generalized displacement vector; $P(t)$ is the contact impact force function; $\{\delta_j\}$ is the Kronecker symbol. This equation is integrated by the Runge–Kutta method.

The finite elements consider transversal shift with respect to the Timoshenko theory [5]. The 3rd order finite element with two nodes and four generalized displacements in a node is selected for a fiber multi-layered beam.

Mechanical behavior of composite materials is described by the linear differential equation named Foight model [6]:

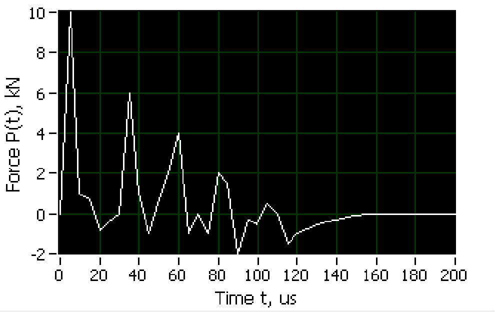
$$\{\sigma\}=[D]\{\varepsilon\}+[W]\{\dot{\varepsilon}\},$$

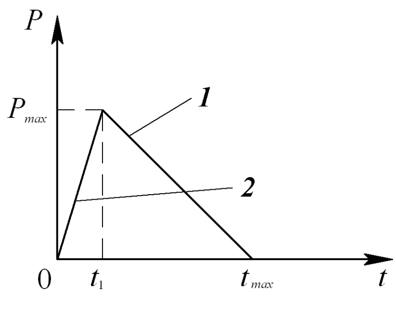
where σ is stress; ε is strain, $[D]$, $[W]$ are rigidity and viscosity reduced matrices.

Fig. 5 states calculated maximal bay bending strains ε_b and shear strains ε_s of the hinged beam with fiber arranging angles $\left[0_8^0/\pm45_8^0/90_8^0\right]$ and geometrical dimensions (250 × 10 × 10) mm. The beam was loaded by the transversal central sine pulse with maximal impact level $P_{max} = 2\cdot10^3$ N and duration $t_{max} = 0.2$ ms caused by the striker having 51 g mass and 5 mps rate. The points correspond to maximal experimental values of bending strains. The difference between calculated and experimental values is not more than 10 %.

Non-stationary bending and shear strains in beams made of fiber-layered materials such as glass fibers and coal plastics having low shear rigidity are featured to be of the same order. As it follows from the calculations (fig. 5), the maximal non-stationary bending strain often taking place in the beam center is $\varepsilon_b = 0.565$ % and maximal shear strain is $\varepsilon_s = 0.432$ %.

Therefore, if the shock loading rate is less than 5 mps and the height to length ratio h/L is from 0.04 to 0.10, shear and bending strains are of the same order ($\varepsilon_s/\varepsilon_b \approx 0.8$–0.9). If the beam is short and the ratio h/L is more than 0.1 shear strains can cause damage as they are more than bending ones ($\varepsilon_s/\varepsilon_b \approx 1.06$). If the shock load rate is more than 5 mps, the impact force function $P(t)$ in (1) should be approximated by a triangle pulse (fig. 4). As it follows from the calculations, if the contact impact force pulse duration decreases, shear strains can damage longer beams with the ratio $h/L < 0.04$.





a *b*

Fig. 4. The contact force time function $P(t)$ (*a*) and pulse envelope (*b*) at transversal central impact on the firmly fixed glass fiber plate: *1* – $P = P_{max}(1 - t/t_{max})$; *2* – $P = P_{max}\, t/t_1$

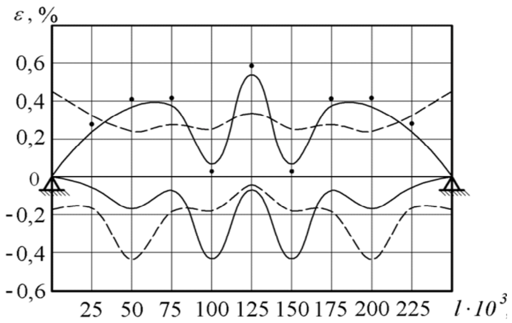


Fig. 5. Maximal bay bending ε_b (solid) and shear ε_s (dashed) strains of the hinged beam loaded by the transversal central sine pulse: lines stand for calculation data; points stand for experimental data

The application of the computerized measuring system in the automated test stand for performing impact tests allows decreasing experimental data acquisition error two and more times. It is possible essentially by means of graphical application development environment LabVIEW supporting virtual instrumentation.

Transversal impact force pulse shapes are established to depend on the impact rate to be approximated by certain functions:

– if the impact rate is less than 5 mps, the pulse shape is close to sine with maximal amplitude $P_{\max}$ and duration $t_{\max}$;

– if the impact rate is from 5 to 40 mps, the pulse shape can be approximated by a triangle pulse. The rising part corresponds to the increasing load and the falling part corresponds to the decreasing load;

– if the impact rate is more than 40 mps, the pulse shape should be approximated by a sawtooth pulse corresponding only to the decreasing load.

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