METHOD FOR MEASUREMENT OF DYNAMIC STRAINS IN EXPLOSION WELDING

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The method is suggested for measurement of dynamic strains by using resistance strain gauges. The working power is supplied by the generator of DC pulses with a voltage of 23 V and duration of 14 ms. The short-time supply of the power allows increasing the working current from 25–50 to 200–250 mA, this leading to almost an order of magnitude increase in sensitivity of the method. The measurement system comprises the DC pulse generator and the digital oscillograph connected to a computer. Calibration tests were carried out, and performance of the measurement system was investigated in a range of elastic and elasto-plastic strains. It is shown that the dynamic strains due to explosion loading of metal structures can be measured at a satisfactory accuracy within −0.6–0.6 % in a time interval of 0–14 ms. In addition, the system makes it possible to fix residual strains of metal of a structure after the dynamic impact. 6 Ref., 1 Table, 8 Figures.

Keywords: *dynamic load, strains, resistance strain gauge, measurement, bridge circuit, pulse generator, sensitivity of method*

Currently, the most widespread method for measurement of dynamic strains is the tensometric one by using resistance strain gauges (RSG), which are connected into the measurement system based on the bridge circuit. Advantages and drawbacks of its practical application are well known [1].

In case of using RSG to measure the stress-strain state of metal structures under explosion loading it is necessary to locate them in close proximity to a charge. The length of wires connecting the working and compensation RSG can be up to several dozens of metres, and their active resistance and reactance can no longer be neglected, as they introduce substantial errors in the measurements. Moreover, in this case the measurement system becomes more sensitive to interferences. In practical measurements, the amplitude of the useful signal differs from that of the interferences, and its identification becomes problematic [2]. Increase in value of the useful signal can be achieved due to increasing the working current powering the bridge. But one of the important factors affecting the measurement accuracy is heating of the RSG by the working current flowing through them. Proper operation of the commercial RSG with the measurement circuit that is permanently on is possible at a current value of 20–50 mA [3].

In structures subjected to explosion loading, as well as in metal during explosion welding the maximal strains last for several milliseconds [4]. Therefore, powering of the measurement circuit can be provided by supplying the pulse voltage for 10–15 ms. In this case it is necessary to synchronise initiation of an explosive charge, starting up of the oscillograph and feeding of the measurement voltage pulse. A short time of supplying the power to the RSG allows increasing the working current to 200–250 mA, this leading to almost an order of magnitude increase in the sensitivity of the measurement method.

The E.O. Paton Electric Welding Institute developed the method for measuring dynamic strains, with which the working voltage is supplied by the generator of DC pulses with a voltage of 23 V and duration of 14 ms [5]. The generator was made by specialists of the Volgograd Technical University. To assess the capabilities of the new method and its fitness for measurement of strains induced in metal structures under explosion loading, its performance was investigated in a range of elastic and elasto-plastic strains.

Calibration tests of the developed method in a range of elastic strains were carried out by using a specially made calibration device (Figure 1) according to the scheme of four-point bending of a prismatic steel beam measuring 400 × 40 × × 5 mm, as well as by using the tensile testing machine. Oscillograph Dataman allowing the measurement data to be displayed directly on the computer monitor was employed as recording equipment. The obtained calibration dependences are shown in Figure 2. The Figure also shows the dependence of mechanical stresses on the bridge unbalance voltage, which was derived by calculations from the following expression:

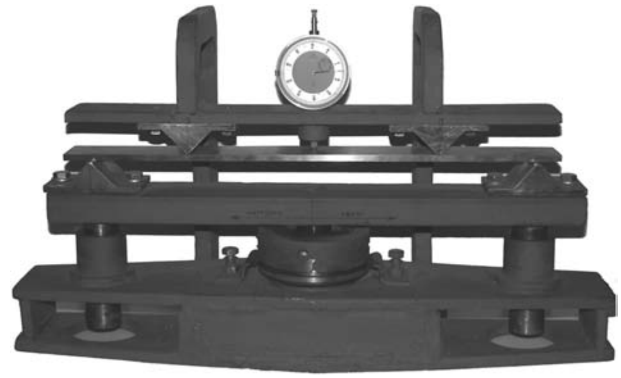

Figure 1. Appearance of the calibration device

$$\sigma = 4E\,\frac{\Delta U}{s(U - 2\Delta U)}, \qquad (1)$$

where σ is the stress; E is the elasticity modulus of the beam steel; ΔU is the measurement bridge unbalance voltage; U is the voltage supplied to

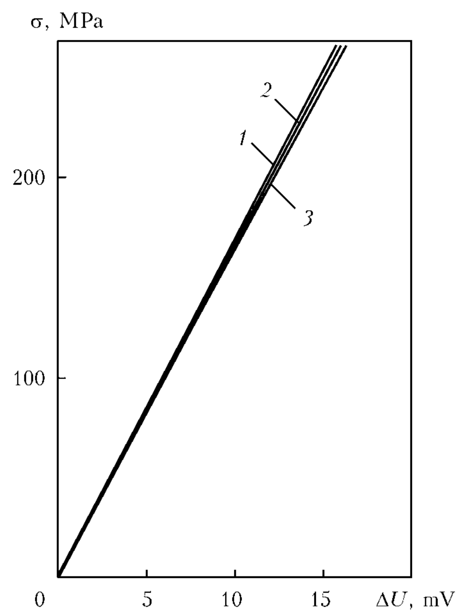

Figure 2. Calibration dependences derived experimentally by using the tensile testing machine (*1*), by calculations from the coefficient of tensosensitivity (*2*) and experimentally by using the special device (*3*)

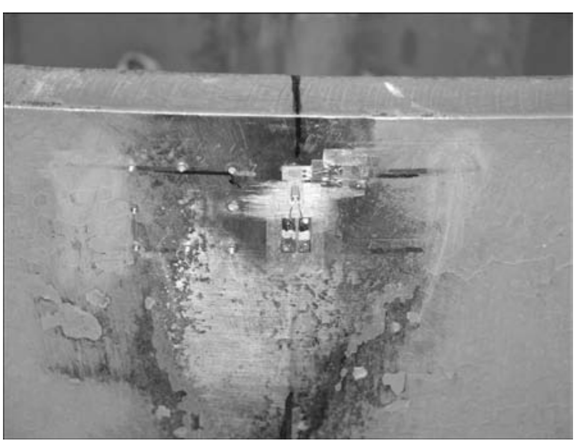

Figure 3. Measurement of strains in the explosion welding support (scale division value — 2 μm)

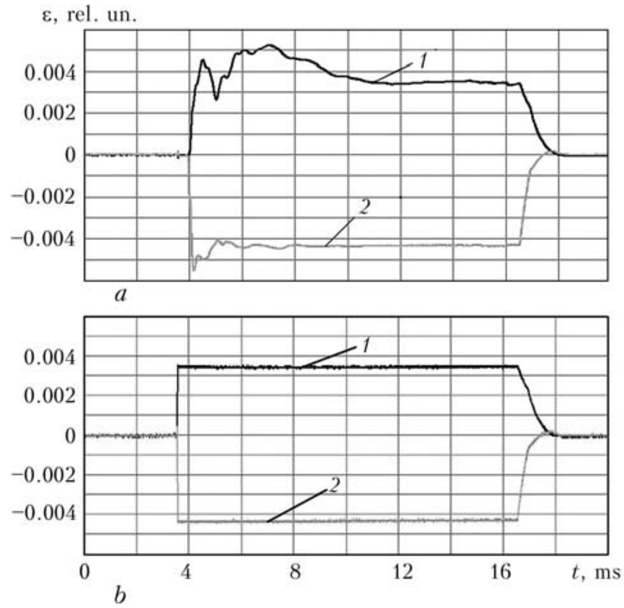

Figure 4. Strains in the supportwall at the moment of explosion of the 50 kg explosive charge (*a*) and after explosion (*b*): *1* — horizontal strains; *2* — vertical strains

the bridge; s is the coefficient of tensosensitivity of the resistance strain gauge specified by a manufacturer.

The obtained calibration dependences had a linear form. The calibration coefficient was equal to 17.7 MPa/mV ($56.5\cdot10^{-3}$ mV/MPa) in tests by using the tensile testing machine, 17.2 MPa/mV ($58\cdot10^{-3}$ mV/MPa) by using the calibration device, and 17.5 MPa/mV ($57.25\cdot10^{-3}$ mV/MPa) by calculating the stresses using expression (1).

The difference in the coefficients obtained in calibration tests by using the tensile testing machine and special device was related mainly to

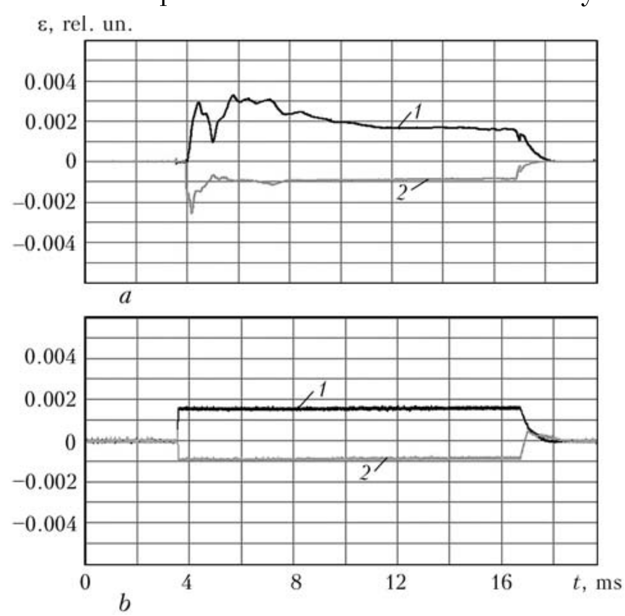

Figure 5. Strains in support wall at the moment of explosion (*a*) and after explosion of the 20 kg explosive charge (*b*) (here and in Figure 6 *1* and *2* are the same as in Figure 4)

the fact that the tests conducted by using the special device included a great number of geometric parameters, each being measured with some error, as well as to the unavoidable rounding of the calculated values.

Performance of the method in a range of elasto-plastic strains was checked by investigations of the strains taking place in a special support used for explosion welding. The support was a vertically placed steel cylinder 500 mm high and 2 m in diameter, having a bottom. The internal volume was filled up with steel shot. Billets for explosion welding were placed on the shot. Weight of the explosive charge was varied from 20 to 50 kg. Two measurement resistance strain gauges were attached to the support wall near the upper end: in circumferential and vertical directions. Gauge lengths were marked near the RSG to conduct measurements by using a mechanical deformometer with an indicator of the clock type (Figure 3). The deformometer fixed residual strains in the wall of the support after explosions. It should be noted that the method developed allows measuring residual strains in a structure of interest by re-switching on of the measurement circuit after explosion. Figure 4 shows examples of fixation of the strains developing with time at the moment of explosion of a charge and in a stationary state after explosion.

Figures 5 and 6 show similar oscillograms of the strains occurring in the support after explosion of charges 20 and 35 kg in weight.

The Table gives comparative results of measurements of the residual strains.

While evaluating the measurement results, it should be taken into account that the residual strains form due to the plastic strains in the support wall caused by explosion. The plastic strains differ from the elastic ones in a much higher non-uniformity of distribution. Measurements with the deformometer and RSG were conducted at different, although close points in the support wall. The spread of the accumulated strains (the last line of the Table) was smaller compared to the majority of individual measurements. Therefore, the spread of the indications obtained by two different methods can be considered acceptable. The results obtained are indicative of the fact that the developed method allows evaluating the strains that exceed the elastic ones.

Investigations on evaluation of reliability of the time intervals being fixed were carried out by fixing the loading wave generated in a straight cylindrical steel rod due to an impact by a free-falling steel striker. The RSG (gauge length of

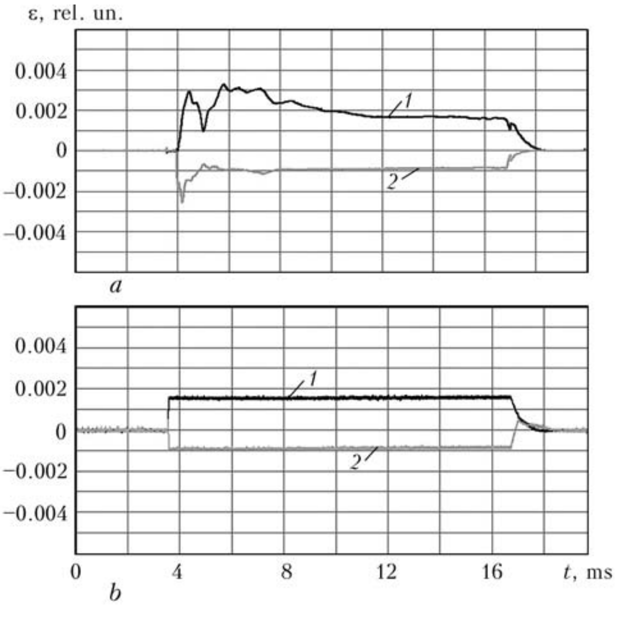

Figure 6. Strains in support wall at the moment of explosion (*a*) and after explosion of the 35 kg explosive charge (*b*)

3 mm, resistance of 100 Ohm) was attached to the rod 720 mm long and 18 mm in diameter at a distance of 30 mm from the end hit by the striker. The rod was secured vertically with a clamp through a rubber washer. The striker, which was a cylindrical rod 100 mm long and 10 mm in diameter, was thrown via a guide pipe onto the rod from a height of 1 m (Figure 7). Also, it performed the function of a starting sensor. An example of the loading wave being fixed is shown in Figure 8.

Plastic deformation of the striker and the rod occurs at a moment of their collision, this being evidenced by the resulting dents. Therefore, theo-

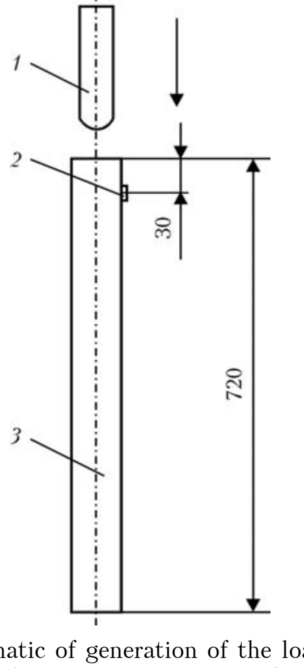

Figure 7. Schematic of generation of the loading wave in the rod: *1* — striker; *2* — RSG; *3* — rod

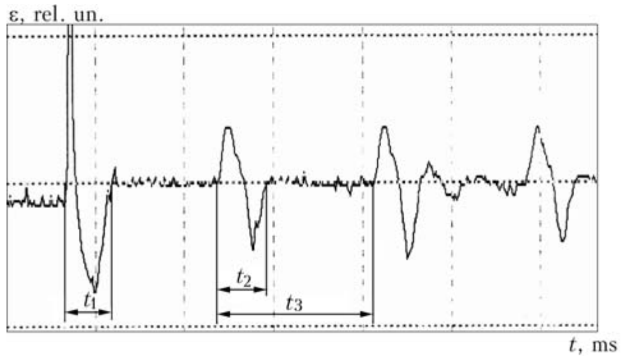

Figure 8. Loading wave in the rod (for designations see the text)

retical calculation of the length of the generated loading wave is problematic. This makes it impossible to compare time t_1 and t_2 with the calculated values (t_1 — time from the moment of collision of the striker with the rod to the moment of departure of the generated loading (compression) wave from the resistance strain gauge; t_2 — time from the moment of entering of the loading (tension) wave reflected from the remote end of the rod to the RSG to the moment of departure from it of the loading (compression) wave reflected from the collision end). The time of passage of the 1380 mm distance by the already elastic wave, which propagates at the sound velocity, characterises t_3 (time of propagation of the loading wave from the RSG to the remote end of the rod and back after reflection). Assuming the rod sound velocity in steel to be equal to 5100 m/s [6] yields that t_3 = 271 μs. Time t_3 averaged over measurements by 10 experiments and 3 periods in each experiment (totally 30 values) is 275 μs. Maximal measured time t_3 is 279 μs, and minimal t_3 is 272 μs. Good agreement between the calculated and experimental results, and small spread of the indications make it possible to consider the time measurement accuracy to be sufficient for the range of the problems being solved.

Conclusions

1. The new method developed for measurement of dynamic strains is fit for investigation of the stress-strain state of metal structures subjected to explosion loading.

2. The measurement system allows evaluating residual strains induced in structures by pulsed loading.

Comparative results of measurement of residual strains in the explosion welding support

Explosion No.	Strains, %			
	Horizontal		Vertical	
	Deformometer	Resistance strain gauge	Deformometer	Resistance strain gauge
1	–	0.12	–	−0.02
2	–	0.16	–	−0.09
3	–	0.35	–	−0.43
4	0.42	0.39	−0.27	−0.33
5	0.54	0.30	−0.17	−0.12
6	0.23	0.25	−0.29	−0.36
7	0.55	0.60	−0.55	−0.60
8	0.17	0.23	−0.25	−0.30
9	0	0	−0.27	−0.18
10	0	0	−0.56	−0.42
11	0	0	−0.56	−0.33
Total of lines 4-11	1.91	1.77	−2.92	−2.64

1. Nedoseka, A.Ya. (2001) *Principles of calculation and diagnostics of welded structures*. Kiev: INDPROM.
2. Kolodyazhny, A.V., Sevryukov, V.I. (1986) *Impact and pulse actions on structures and materials*. Kiev: Naukova Dumka.
3. *TU3.06 Ukraine 7710-0001–93*: Resistance strain gauges. Purpose and field of application.
4. Vorobiov, Yu.S., Kolodyazhny, A.V., Sevryukov, V.I. et al. (1989) *Rapid deformation of structural elements*. Kiev: Naukova Dumka.
5. Dobrushin, L.D., Bryzgalin, A.G., Pekar, E.D. et al. (2012) On the possibility of application of pulse current generator for measurement of dynamic strains in metal structures. *Izvestiya Volgograd. Gos. Tekhn. Un-ta. Series Explosion welding and properties of welded joints*. 5(**14**), 78–82.
6. Kuchling, H. (1985) *Reference book on physics*. 2nd ed. Moscow: Mir.

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