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SYSTEM OF STRAIN AND LOAD MEASUREMENT IN DYNAMIC TESTING OF MATERIALS

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A multichannel system of high-speed recording of strains and loads during fracture toughness tests of materials has been developed. A four-channel analog-to-digital converter was used to record signals. Tests were carried out using a rotary and a vertical impact testing machines at various loading rates and temperatures. Some results are presented for impact testing of Charpy specimens with recording of load variation at supports during tests.

Keywords: impact fracture energy, Charpy specimen, load, temperature, multichannel recording system.

Introduction. Analysis of the known experimental data has shown that even with a common brittle character of fracture of the material, considerable plastic strains that reach tens and even hundreds of percents are present at the stress raiser (a notch, a crack) apex, the strain localization and shear strips as well as the stretching of crack surfaces and their ductile extension increment are observed. Up to now, there has been no common point of view on the criteria of ductile-to-brittle transition, especially under dynamic loading. The available test results permit no full explanation of this phenomenon, there remain many open questions, in particular a combined effect of the strain rate, temperature and stressed state rigidity on the process of dynamic deformation and fracture of materials.

To study the peculiar features of deformation and fracture of materials at both static and dynamic loads, extensive experimental data are required. Standard impact tests of Charpy specimens are widely used in determining the mechanical properties of structural materials, in particular in assessing the embrittlement of the base material and weld metal of NPP reactor pressure vessels, from the shift of the critical temperature of brittleness due to the radiation and thermal effects during operation. However, such tests usually provide rather limited data on the analysis of the effect of various factors on the material behavior. The energy spent for fracture of specimens [1–5] is determined from the test results, whereas the fraction of the ductile component in the fracture or the value of the lateral expansion of the specimen in the fracture zone is determined from the appearance of their fracture surfaces [6].

The use of instrumented impact testing machines with the recording of load versus time diagrams makes it possible to determine not only the fracture energy but also a number of such critical parameters as the load corresponding to the general yielding, the maximum load, the levels of loading at the moments of the brittle fracture start and arrest. With the use of load versus time diagrams it is possible to divide the energy spent for the specimen deformation and fracture into the components related to the crack nucleation and propagation.

It is possible to increase the amount of information obtained during such tests for its subsequent analysis by way of equipping conventional testing equipment with up-to-date data recording instruments [1–3, 5, 6].

Development of the System for Data Recording in Impact Testing. For this purpose, a multichannel system for high-speed recording of strains and temperatures during Charpy impact tests of materials mounted on a vertical and a rotary impact testing machine was developed at the Pisarenko Institute of Problems of Strength of the National Academy of Sciences of Ukraine. The scheme of data recording during testing with the use of this system is illustrated by Fig. 1. To record loads, the strain gauges are cemented to the tup and supports of this system. The information about loads at the tup and supports and also about temperature at the notch apex arrives, via the

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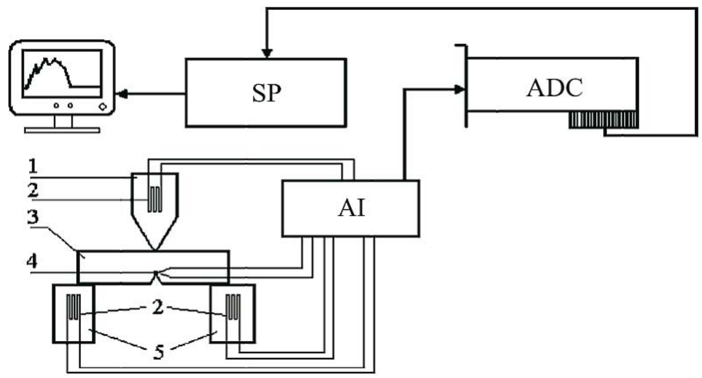

Fig. 1. Scheme for recording the data on the specimen loading during the impact three-point-bend testing: (*1*) tup of the impact testing machine; (*2*) strain gauges; (*3*) specimen; (*4*) thermocouple; (*5*) supports of the impact testing machine.

amplification unit (AI) and the printed circuit board of the analog-to-digital converter (ADC), at a personal computer where, after having been processed using the proper software program (SP), it is stored in a tabular and/or graphical form convenient for a subsequent analysis. Moreover, in order to increase the sensitivity and amplification of the recorded signal, support structures on a rotary and a vertical impact testing machine were debugged.

A signal amplification unit is one of the key components of the arrangement for data recording under consideration.

To amplify signals of strain gauges and thermocouples up to the level of about 1 V, which is required for proper operation of the NuDAQ PCI 9812/10 ADC made by the ADLink Technology Inc., a high-speed amplifier was used (the respective block diagram is shown in Fig. 2) The amplifier contains two channels of amplification of the strain gauge signals and two channels of amplification of the type K (chromel-alumel) thermocouple signals.

For the purpose of common-mode rejection, each of the channels of strain gauge signal amplification contains an input and output amplifiers assembled using precision low-noise operational amplifiers. The possibility exists of varying the amplification factor of the channels in a stepwise fashion from $k = 121$ up to 484.

To calibrate the amplifiers against the amplitude, we used both the internal crystal-controlled oscillator of rectangular calibration pulses and the calibration block with a set of calibration resistors of various nominal values connected to the input of the amplifiers.

The unit of external synchronization makes it possible to trigger the recording device by a signal from the external contact pick up that operates in the closing/opening mode, as well as to provide the time delay of the trigger pulse.

Each of four channels of amplification signals of the thermocouple is an AD595 Analog Devices instrumentation amplifier with the compensation of voltage at the cold end. The microcircuit of that kind is a calibrated amplifier that permits the output voltage of a high level (10 mV/°C) to be produced directly at the thermocouple output. The AD595 amplifier includes a thermocouple fault detector, which makes it possible to check the connection of the thermocouple ends to the microcircuit. In addition, the connection of the two-pole power supply permits measurement of subzero temperatures.

Each of the amplification channels makes it possible to produce a signal of the order of 1 V at the output, which is sufficient for proper operation of the NuDAQ PCI 9812/10 ACD, to digitize a signal, to input it into the computer, to perform its subsequent processing and analysis using a variety of software. Some characteristics of the ADC are given below:

Number of channels (input/output)	4
Maximum sampling frequency	20 MHz
Bit capacity	12 bits
Analog input range	±5 or ±1 V
Trigger circuit	analog/digital

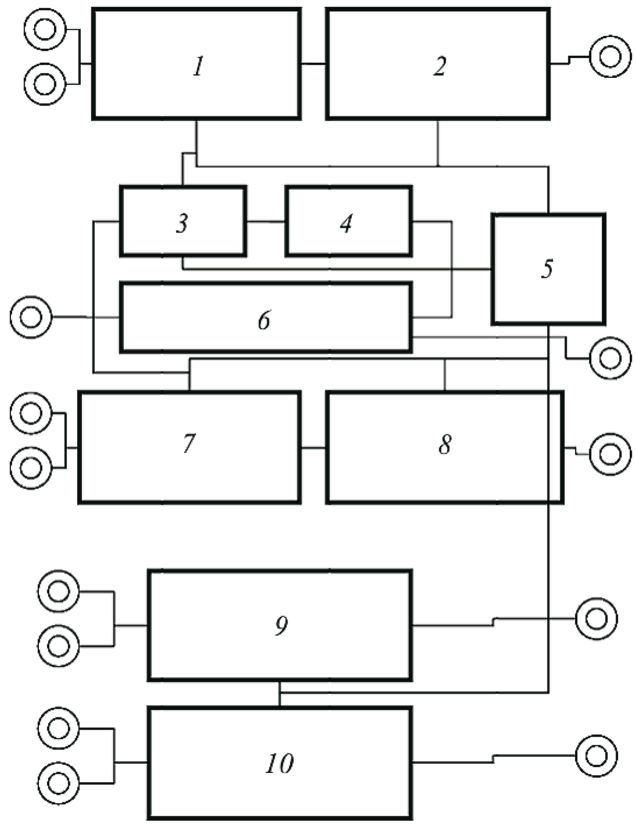

Fig. 2. Block diagram of the amplifier of strain gauge and thermocouple signals for operation with the ADC: (*1*, *7*) input differential amplifier; (*2*, *8*) output amplifier; (*3*) calibration unit; (*4*) crystal-controlled oscillator; (*5*) power supply; (*6*) external synchronization unit; (*9*) thermocouple signal amplifier AD595, Analog Devices, channel 1; (*10*) thermocouple signal amplifier AD595, Analog Devices, channel 2.

By way of multiple debugging, it has become possible to achieve a considerable reduction in the noise level. The required calibrations and calibration checks, including those using the Tiratest mechanical testing machine, were carried out. During impact Charpy testing of specimens, owing to several recording channels available, it is possible to record signals from the tup and supports of the impact testing machine simultaneously.

Results of Check-Out Testing of the Recording System. A series of experiments was performed on the vertical impact testing machine. 45 grade steel was used as a model material.

Taking into account the high-speed characteristics of the system and the possibility to store a large amount of data, it is possible to selectively consider the received signal of several milliseconds in length within very narrow time intervals (of the order of unities or tens of microseconds) of interest to us, which permits assessing the crack propagation rate.

Typical load variation diagrams in ductile and brittle fracture, including the portions of the sharp drop in the load during the crack jump in brittle fracture of the specimen, are shown in Fig. 3. The average rate of the brittle crack propagation was 450 m/s.

The peculiarities of the material deformation and fracture with consideration for the strain rate and temperature effect can be studied from the results of the load variation recording at supports during testing. In particular, it is seen from the experimental diagrams shown (Fig. 4) that the ductile crack growth occurs at temperatures of 60 and 100°C, whereas the crack jump inherent to brittle fracture is especially pronounced at room temperature. This has been verified by the analysis of the fracture surfaces of the specimens tested.

Thus, the use of the system developed for high-speed recording of the specimen loading parameters makes it possible to obtain additional information on the material deformation and fracture processes under impact loading.

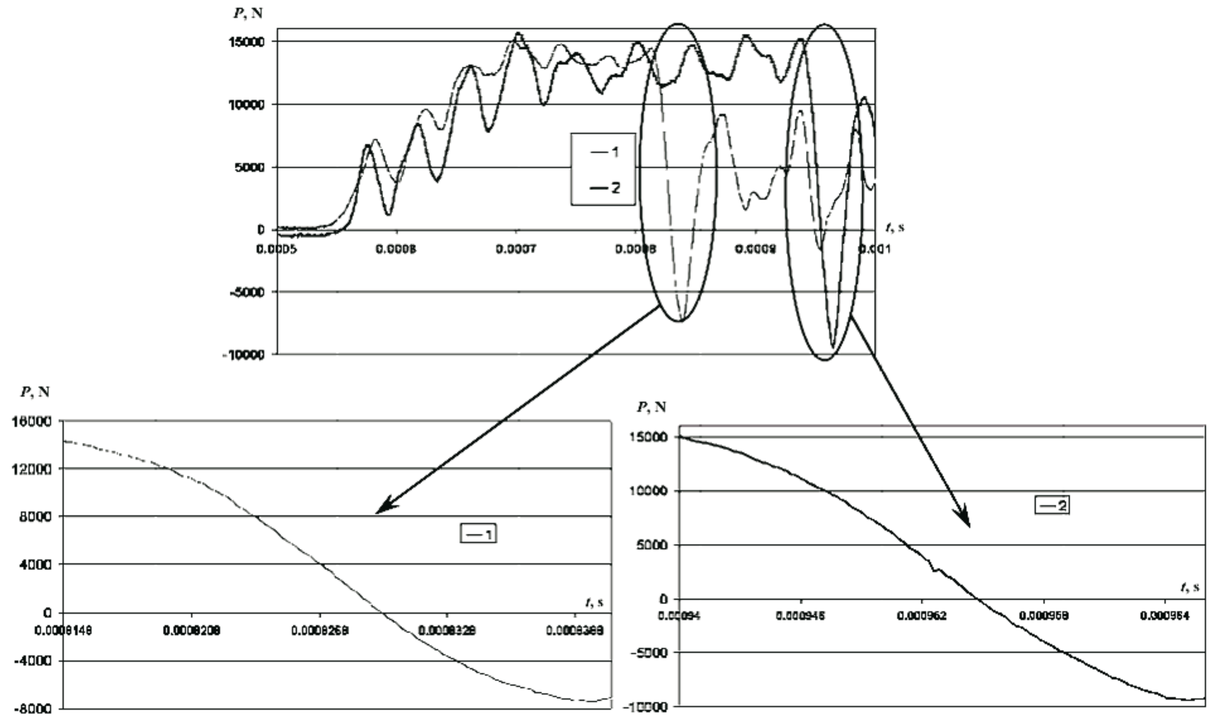

Fig. 3. Data recordings for the loads at supports of the impact testing machine in Charpy impact testing of specimens made of 45 steel, as well as the increased in time portions of the signal which correspond to the crack jump. [Here and in Fig. 4: (*1*), (*2*) specimens under study].

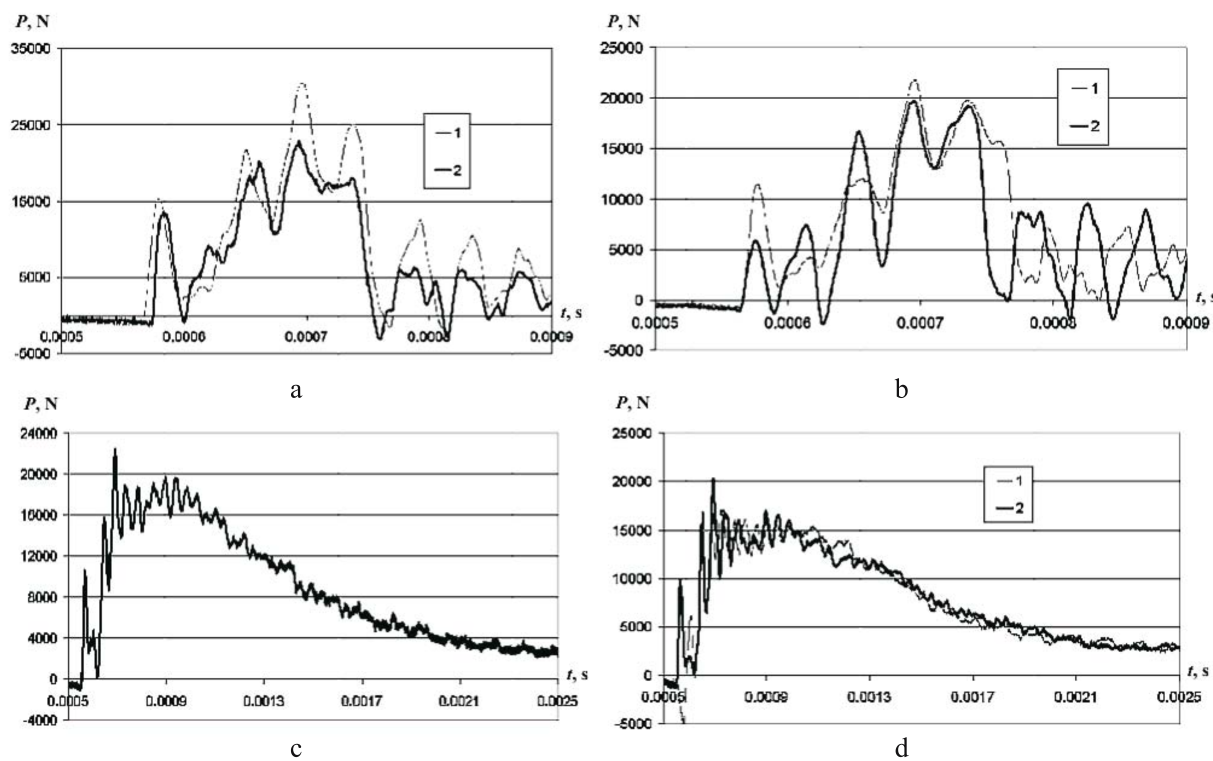

Fig. 4. Data recordings for the loads at supports of the impact testing machine in Charpy impact testing of specimens made from 45 steel at various temperatures and strain rates: (a) $T = 200°C$, $V = 4.5$ m/s; (b) $T = 20°C$, $V = 33$ m/s; (c) $T = 60°C$, $V = 3$ m/s; (d) $T = 100°C$, $V = 3$ m/s (V is the striker rate).

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