METHOD AND INSTALLATION FOR INVESTIGATING THE RESISTANCE OF STRUCTURAL MATERIALS TO CYCLIC LOADING UNDER NEUTRON IRRADIATION

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The building of thermonuclear reactors involves the solution of a number of problems of materials science, one of which is the selection of material for the first wall (FW). Together with problems due to surface and bulk radiation effects in the material (pulverization, blistering, swelling), securing sufficient mechanical strength of the FW under neutron irradiation is of considerable importance [1]. Since the reaction of thermonuclear synthesis is planned to be effected in impulse regime (duration of the work cycle is 10^2-10^3 sec with about 10^6 cycles during the entire operating time), the structural elements will be subjected to cyclic thermomechanical loads. Such loads limit the thickness of the FW substantially, but differently for different materials.

It is assumed that structural elements of thermonuclear reactors in the impulse regime of operation are deformed in the elastic range; however, at the stage of plasma burning, radiation-stimulated creep deformations develop in the material, and as a result the stresses relax. When the plasma attenuates and the temperature drops, the FW reverts to its initial state, and on its inner surface inverse (tensile) stresses are induced. In proportion to the accumulation of creep strain these stresses increase.

Thus the material of the FW is subjected to rigorous cyclic loading with one-sided delay under conditions of stress relaxation. Such a loading regime under conditions similar to operating conditions can be effected by the suggested method on an installation "Neitron-5M" designed and produced at the Institute of the Strength of Materials, Academy of Sciences of the UkrSSR in connection with the reactor VVR-M. This installation makes it possible to carry out imitation fatigue tests of specimens exposed to neutron irradiation.

The experimental investigation of the mechanical properties of structural materials under conditions of reactor irradiation has a number of methodological features [2]. Among them are the necessity of placing the specimen at the level of the center of the active zone, the small transverse dimensions of the research channels (30-50 mm diam.) with relatively great length (∿5-8 m), limited space under the reactor lid. In consequence of this, it is impossible to devise a very rigid testing machine. As a result of neutron irradiation of high intensity, the components of the testing machine that are near the active zone are heated by the radiation. The method of heating, controlling, and measuring the temperature of the specimen therefore has its specific peculiarities. The power drive and the measuring transducers have to be remote, at a radiationally safe distance from the active reactor zone, and loading has to be effected by remote control. The design of the loading device has to satisfy the requirements of safety from radiation, and it has to be convenient to operate, reliable, and ensure hermetic sealing when installed in the channel. In addition to that, the general methodological requirements concerning low-cycle fatigue tests under ordinary loading conditions have to be satisfied. For comparative analysis it is indispensable to carry out experiments outside the reactor on the same equipment.

As type of loading we chose cyclic torsion of a thin-walled cylindrical specimen. Such loading has a number of advantages over others: the stress–strain diagram and the endurance diagram in tests with delay are not sensitive to the direction of the initial loading, the specimen does not change its shape, any effect of thermal changes of the linear dimensions of the specimen and of the grips on the measured deformation is eliminated, and it is possible to ensure a uniform state of stress. Moreover, in the state of pure shear stress,

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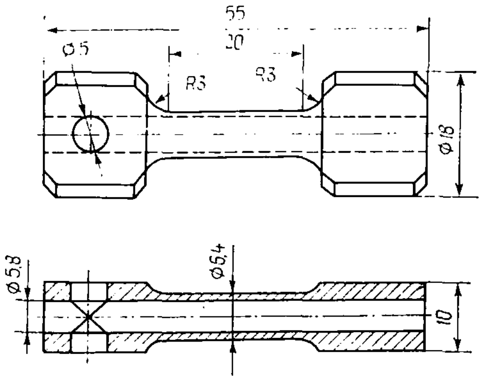

Fig. 1. Test specimen

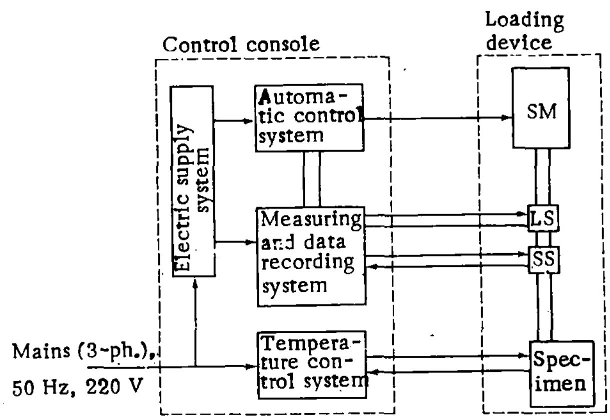

Fig. 2. Block diagram of the installation.

the ductile properties of the material manifest themselves most completely, and the kinds of fracture are most lucidly distinct from each other whether breakaway or shear is involved, since they occur along different surfaces in torsion.

Since there is height-dependent energy release in the experimental channel of the research reactor, the length of the specimen was chosen such that impermissible heating of its working part is prevented, on the one hand, and the effect of the heads of the specimen on the degree of uniformity of the state of stress is prevented, on the other hand. The geometric dimensions of the specimen, whose design is shown in Fig. 1, were chosen so as to ensure its stability in measurements of deformation. The wall thickness was taken such that the nonuniformity of the state of stress may be neglected. As a rule, the ratio of the wall thickness to the diameter is 0.05.

A block diagram of the newly devised installation is shown in Fig. 2, and its technical characteristic is given below:

Maximum torque, N·m	7
Maximum angle of rotation of the driven shaft, deg	±40
Angular velocity of the driven shaft, sec^{-1}	0-0.18
Range of delay, h	0-4
Accuracy of delay, %	±2
Error of strain measurement, %	±1.5
Error of load measurement, %	±2.1
Test temperature, °K	473-1073
Accuracy of maintaining temperature, deg	±5

The installation consists of the control console and of the loading device which is placed in the research channel of the reactor. The control console contains the electric supply system (ESS), the automatic control system (ACS), the measuring and data recording system (MDRS), and the temperature control system (TCS).

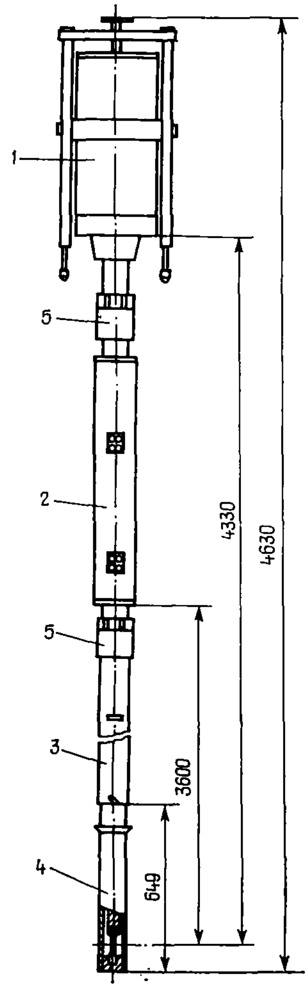

Fig. 3. Loading device.

The ESS, ensuring stabilized dc voltage supply to the component parts of the ACS and the MDRS, consists of ten dc sources and a supply control unit. The ACS contains a servo unit, the control desk, the programmed loading unit, time relay, and reversible program counter F5129. The system is intended for controlling the step motor (SM) of the loading device, and it makes it possible to effect tests by the specified regime, ensuring loading of the specimen in gentle and rigid regimes, and also with delay under conditions of creep or relaxation. In addition, it is envisaged that tests will be carried out according to a specified program with variations of the parameters during the experiment.

Both in gentle and rigid regimes, loading proceeds at a constant speed of rotation of the driven shaft which can be varied within the range 0-0.18 sec^{-1}. The time delay relay consists of two equal broad-range time relays each of which is a driven multivibrator. Envisaged are delays in the minute range: 0, 1, 2, 5, 10, 20, and 30 min, and in the hour range: 1, 2, 3, 4 h. It is also possible to set steplessly intermediate values of delays. Their separate setting in opposite load ranges makes it possible to obtain cycles with different time asymmetry including cycles with one-sided delay. After fracture of the specimen, the ACS ensures that the installation is automatically switched off.

The MDRS is intended for automatically recording the diagrams of cyclic strain in coordinates load—displacement, recording changes of the inspected parameters (torque or angle of torsion of the specimen) in time, digital recording of the number of the cycle and of the numerical values of the area of the loops of elastoplastic loading of the specimen. This system consists of the strain sensors (SS) and the load sensors (LS) situated in the measuring unit of the loading device, of the pedestal generator, the signal transducer unit, the device for selecting information, the digital printout EUM-23D with transcriber F5033, and graph recorder PDP4-002.

The TCS contains the temperature control and setting mechanism TUR 01-T4 which can operate in the range 273-1373°K, and a heater. In the control experiments, an electric-resistance furnace was used as the heater; in tests inside the reactor, the heater was a nichrome spiral wound directly onto the working part of the specimen. A consequence of the absorption of γ-quanta and neutrons by the irradiated material is radiational energy release. The temperature can be changed by changing the intensity of heat removal from the specimens and from parts of the ampoule adjacent to it by the coolant washing the research channel; this is attained by changing the pressure of the helium in the channel. The temperature is measured by three thermocouples which are spot-welded to the working surface of the specimen.

The loading device (Fig. 3), fitted into the reactor channel, provides reversed loading of the specimen which is situated at the level of the center of the active zone. The described device contains the drive 1, the measuring unit 2, the extender 3 and the ampoule with specimen 4 connected in sequence by collets 5 ensuring abutting without gaps.

Force-induced loading of the specimen is effected by a six-phase stepping motor type ShD-300/300 which transmits the torque to the tested specimen through a four-stage planetary reduction gear and the driven shaft. The gear ratio of the reduction gear is 625. Maximum torque on the output shaft of the drive is 7 N·m.

In the system measuring strains and loads, induction transducers of the angle of rotation type 45D-20-2 are used; they are situated in the measuring unit which is about 4 m from the center of the active zone; this makes it possible to avoid the effect of reactor irradiation on the characteristics of the transducers and the electrical insulation properties of the materials. The transducers have a linear characteristic in the range ±40° with an error in linearity not exceeding ±0.5%. Measurement of torque is based on determining the angle of torsion of the elastic element made in the shape of a tube and inserted in series into the chain of force of the loading device.

The ampoule is a replaceable part of the loading device which is used only once in experiments inside the reactor. It consists of an outer shell and the driven shaft inside it, with the fixed and moving grips at either end. Inside the shell the shaft is centered by a bearing and a ball separator. The upper head of the specimen is free to move axially in the moving grip to compensate for temperature fluctuations of the linear dimensions of the specimen and parts of the ampoule. The ampoule is connected to the extender with the aid of a bayonet grip which makes it possible to disconnect the ampoule remotely after the experiment.

When tests are carried out under conditions obtained inside the reactor, the loading device is placed in the research channel of the reactor which is evacuated and then filled with helium under the required pressure. The power and measuring cables from the loading device are led through the biological protection to the distribution panel through which the connection with the control console, situated outside the reactor hall, is effected. After the reactor has attained the operating power, the required temperature of the specimen is established. The testing begins after the specimen has been irradiated by a certain flux.

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