The paper presents structure and operating parameters of a prototype hydraulic stand for fatigue tests of plane cruciform specimens under biaxial independent loadings. The stand includes a hydraulic supply system, system for generation of random signals, feedback control system, measuring system, system for data processing and cruciform specimen. Preliminary verification of a model worked out for fatigue life estimation of materials under multiaxial random loadings is also presented.

INTRODUCTION

Theoretical models for evaluation of fatigue life of materials under multiaxial random loadings, developed last years [1-4], should be verified in practice. In this order a special stand for tests of cruciform specimens under biaxial random stress state has been made. It is based on certain ideas applied in stands for fatigue tests of plane cruciform specimens under biaxial cyclic loadings [5,6] but the new stand is able to realize independent random loadings as well.

STRUCTURE OF THE TEST STAND

The stand for fatigue tests of cruciform specimens under plane random stress state (Fig.1.) consists of hydraulic supply system (1), loading system (2), system for random signal generation (3), control system (4), measuring system (5), system of data processing (6), specimen (7). On the stand loadings are independently forced in direc-

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tions of the specimen arms (7), according to histories of
the generated random signals (3). In the feedback con-
trol system (4) a given signal is compared with the sig-
nal from the cruciform specimen (force, strain or dis-
placement). The difference signal controls, by the servo-
valve, work of servo-motors in the loading system (2).
The generated loadings are independent owing to applica-
tion of two independent lines of generation, control and
loading. The loading system is supplied from the hydrau-
lic supply system (1). Signals from the specimen are
measured in the measuring system (5) and the obtained
histories are analysed in the system for data processing
Microcomputer Fatigue Damage Cumulator (MFDC) (6). The
stand is equipped with overload detectors connected with
the electronic system for automatic switching off the
stand when some limit values (for example minimum and
maximum temperatures of oil in the tank) are exceeded.
The applied servo-motors are characterized by low iner-
tia of the piston rod, low resistance to motion (oil
film) and prototype sealing rings made of teflon; leaka-
ges are carried away. Their main parameters are the fol-
lowing: maximum piston travel 100 mm, maximum pressure
16 MPa, maximum force 30 kN. For command signals genera-
tion (CSG) the generator of random signals is applied.
Owing to such generators it is possible to generate two
random signals with the required functions of probabili-
ty density and power spectral density. The generators
can be used for simulating service loadings on the test
stand and such simulation is based on statistical analy-
sis of loadings from real objects. The applied control
system is intended to proportional control of servo-
motors by servovalves. It transmits a signal from the
generator to the input of servovalve in such a way that
the quantity which is controlled in the specimen (force,
strain or displacement) is proportional to the command
signal. For data processing Microcomputer Fatigue Damage Cumulator (MFDC), described in [4], is used. MFDC calculates fatigue life from registered strain histories measured in the specimen. Software of MFDC allows also to calculate some statistical parameters of the observed histories, to register measuring data in external store of the computer and to present the data on the screen or the printer. Shape of the specimen for tests under plane stress state and long-life time was worked out on the basis of literature studies and our own investigations.

TESTS OF THE STAND

The tests were carried out in order to determine if all the systems of the stand act well. While the tests various command signals were used. Sinusoidal, rectangular, triangular and random (two versions − with feedback and in the open system) histories were applied. The obtained histories of forces, strains and displacements were compared with the command signal. For frequencies up to 35 Hz good representation of the command signal was obtained. From the analysis of the obtained statistical histories of forces, displacements and strains it appears that a type of probability distribution and forms of autocorrelation functions and power spectral density of command signals are correct.

MATHEMATICAL MODEL FOR FATIGUE LIFE ESTIMATION OF MATERIALS UNDER BIAXIAL RANDOM LOADINGS

Fatigue life calculating is divided into the following tasks [4]:
aquisition and preliminary processing of measuring data from two- or three-directional, rectangular strain gauge rosette,
determination of the expected fatigue fracture plane position with the method of: a) variance, b) weight fun-
ctions, or c) damage cumulation [1,2].
- determination of the equivalent stress or strain histories according to the chosen multiaxial fatigue criterion [3,4]:
a) stress based for long-life time \((\sigma_{1}, \sigma_{2}, \sigma_{3}, \eta_{1}, \eta_{2}, \eta_{3})\) or
b) strain based for long- and short-life time taking into account also plastic strains \((\varepsilon_{1}, \varepsilon_{2}, \varepsilon_{3}, \eta_{1}, \eta_{2}, \eta_{3})\)
schematization of the equivalent stress or strain histories according to one of the following cycle counting method: rain flow, range pair, hysteresis loop or full cycle,
- calculating damage degree and fatigue life according to Palmgren-Miner or Haibach hypothesis.

PRELIMINARY VERIFICATION OF THE MATHEMATICAL MODEL

Cruciform specimens of constructional steel 10HA with increased corrosion resistance were loaded by two independent histories having normal probability distributions, zero mean values and low-band frequency spectra \((< 40 \text{ Hz})\). 10HA has the following chemical constitution: 0.08% C, 0.39% Mn, 0.33% Si, 0.087% P, 0.024% S, 0.7% Cr, 0.35% Cu, 0.05% Mo and \(\sigma_{f}=442\text{ MPa}, \sigma_{y}=242\text{ MPa}, \sigma_{af}=203\text{ MPa}\).

Fatigue tests of cruciform specimens were carried out for long-life time (230 – 600 hours). It has been found that the obtained experimental fatigue lives can be effectively calculated with the variance method, criterion of maximum normal stress in the fracture plane, range pair method and Palmgren – Miner hypothesis. A little worse results are obtained by rain flow method and Haibach hypothesis.

CONCLUSIONS

From the tests of the fatigue stand of cruciform specimens under biaxial tension - compression and preliminary investigations of 10HA steel the following conclusions
can be drawn:

1. The used hydraulic and electronic systems allow to
correct realization of fatigue tests of specimens under
cyclic in- and out-of-phase as well as independent ran-
dom loadings for frequencies up to 35 Hz.

2. Experimental fatigue life under independent random
loadings can be effectively predicted with the algorithm
including:
- determining the expected fatigue fracture plane with
  the method of equivalent stress variance,
- reduction of the complex stress state to the equiva-
  lent uniaxial one according to the criterion of maximum
  normal stress in the fracture plane,
- cycle counting with the range pair method,
- damage cumulation according to Palmgren-Miner hypothe-
sis.

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Fig. 1. General scheme of the stand for tests of cruciform specimens under biaxial independent random loadings.

HS—hydraulic supply; SM—servomotor; SY—servovalve; F—frame; CS—cruciform specimen; U, V—displacements; \( R_x, R_y, R_z \)—electrical controlling signals; P—load; \( \varepsilon \)—strain; MS—measuring system; MFDC—system for data processing; GRS—generator of random signals; Cont.—feedback control system; \( T_R \)—fatigue life.