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FATIGUE TESTING MACHINES AND APPARATUS

Abstract: This paper presents selected examples of construction and applications of fatigue test stands. The authors made a review of universal fatigue machines and test stands, made specifically for own and individual programs to research fatigue material properties. The publication contains the developed procedures to determine the fatigue life of materials. The authors also describe how to implement these procedures to control and measurement systems in research stands. The article briefly reviews the history of the development of fatigue testing methods, with respect to industrial needs. Moreover, it presents selected examples of solutions and applications systems for fatigue testing, available in scientific

Słowa kluczowe: fatigue machine, test stand, stress, strain, fatigue test design

1. INTRODUCTION

Aiming for safety and quality engineers make versatile tests of materials and constructions. Considering material tests, the investigations are performed on precisely defined specimens taking into account the adequate standards and the expected or evaluated type of loading in service conditions. The tests could be destructive and/or non-destructive. In case of non-destructive tests different physical phenomena are utilized for performance an inspection of a specimen e.g. eddy currents, penetrating liquids, ultra-red cameras, ultrasonic images, neuron radiography etc. They could be used during production, checking the final product or as a method incorporating in the Structural Health Monitoring (SHM) systems. These systems together with the IoT allow for on line monitoring of such structures as planes, bridges, production installations as well as improvement of maintainability of monitored objects.

However, in case of new production method, new surface treatments, new materials or new expected load and service conditions the destructive tests are

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2019
Nr 1(10)
s. 80-108

unavoidable for engineers to recognize new properties of these innovative or modernized materials or parts.

The aim of the presented paper is to review the range of possible fatigue tests and testing equipment, procedures and ideas taking into account history and modern design solutions. The paper also includes some review of additional equipment as well as modern proposals known from references as well as proposals of chosen paper authors.

Some of the stands were designed by one of the authors being a part of achievements listed due to receiving the PhD diploma.

The proposed review could be a valuable help for engineers in a choice of tests and a purchase of test machines.

Fatigue testing consists in an application of loading acting on a fixed item until it is damaged. The test condition are assumed, the duration of test as well as several other indicators are registered. The meaning of damage could be defined in different way i.e. full breakage or its symptoms. The damaged item is then inspected analysing type of damage, surface shapes, type of cracking and many others. The registered indicators can be also analysed checking some statistical relationships among them. The non-destructive monitoring could accompany the destructive-type fatigue testing. There are also hybrid tests routines e.g. specimen subjected to the test via testing machines is monitored via a system of image registration and image analysis measuring e.g. the crack propagation process.

Tests are accelerated and simplified in comparison to the service conditions. Nevertheless, based on standards and engineering experience they are reliable methods for an assessment of the analysed items. An acceleration means that loading is in some manner greater (e.g. considering an amplitude) than the current one, a simplification means also that instead of random loading the so called pseudo-random, programmed or just sinusoidal loadings are utilized. Additionally, sometimes the one-axis tests are used instead of multi-axial solutions. The variability of loadings is essentially important. The laboratory frequencies could be different than the service ones.

Fatigue testing machines usually apply cyclic loads to test specimens. Therefore, fatigue testing is a dynamic testing mode, which can be used to simulate the behaviour of a material under real life loading conditions. They can incorporate tensile, compressive, bending or torsion loading. Some fatigue machines allow to generate a combination of these loading types.

Construction and efficiency of fatigue machines are closely related to the development of technology in different areas. These include: the development of mechanical structures, methods for measurement and calculation of fatigue life as well as the development of drives and control systems.

Continuous development of measurement methods, drive and control systems and computer technology is especially visible on the example of fatigue testing because it is a crosscutting theme. Methods of testing materials are endeavouring not only extensive characterization of their mechanical properties defined or prescribed in the Fatigue standards, developed and published, among others, by ASTM – "Fatigue Standards and Fracture Standards"5, but also to accurately depict real operational loads occurring in constructional elements and machine parts. Hence, there is a need to build specialized machines for fatigue testing of materials using multiaxial loads of different waveforms in time, and to verify and improve formulated calculation models to predict the fatigue life of machine parts and structures. A fatigue machine can be classified [1,2], by purpose of the test, type of load, means of producing the load, operational characteristics, etc.

The requirements placed on the drives for working machinery, in particular fatigue machines drives [3] are dependent on the technological needs of a given machine. In fatigue machines, the type of loading for a specimen is most often generated by:

- servohydraulic [4],
- servopneumatic [5],
- electrodynamic [6],
- electromagnetic actuators and vibrators [7],
- centrifugal and inertial vibrators [8],
- dead weight or constant spring [9].

The fatigue test of a material is mostly carried out by controlling the stress, strain, or another parameter that is a combination of the two figures. The choice of controlled parameter is often caused by the scope of research. For HCF (High Cycle Fatigue) and VHCF (Very High Cycle Fatigue) regime, the load is relatively low so the feedback loop can be controlled by force, according to ASTM [10], and ISO [11] standards. For LCF (Low Cycle Fatigue) and ELCF (extremely low cycle fatigue), which is a higher load, exceeding the scope of the linear Hooke's law, control

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[5]ASTM's fatigue and fracture standards provide the appropriate procedures for carrying out fatigue, fracture, and other related tests on specified materials. These tests are conducted to examine and evaluate the behavior, susceptibility, and extent of resistance of certain materials to sharp-notch tension, tear, axial fatigue, strain-controlled fatigue, surface crack tension, creep crack, and residual strain. In addition to fracture toughness and strain gradient, these standards also present the procedures for determining K-R curves, stress-life and strain-life fatigue data, threshold stress intensity factors, and reference temperatures. These fatigue and fracture standards are useful to manufacturers and other users concerned with such materials in understanding their failure and stability mechanisms.
Selected standards will be cited in further part of the work.

2019
Nr 1(10)
s. 80-108

parameter is usually strain, according to ASTM [12], and ISO [1]3] standards, or another parameter [14] which takes into account the total or plastic deformation.

2. GENERAL PURPOSE FATIGUE TESTING MACHINE

In this section, a description of historical equipment dating back to the 1960's was based on third chapter of the Weibull book [1].

2.1. Axial Loading

The simplest way to refer the load with a constant amplitude is mounting the spring on one side of the specimen and set in motion by sliding the other part by means of the crank drive. This type of testing machine was used by Woehler in his basic research. Later on, this method was modified many times by different researchers.

If the plane motion is applied directly to the end of the specimen, without a spring, it must be maintained very high machine rigidity in relation to the specimen. Machines of this type use a crank lever system and cause large forces of inertia which introduces limitations to the frequency ranges and masses. Often oppositely distributed masses are used in order to reduce the inertia forces.

The loads are also generated by the fixed weight or a spring constant. The forces caused by the spring are not always reliable, and errors caused by inertia deepen the overload.

Methods of generating loads by centrifugal forces have found extensive useage in fatigue tests. Machines of this type were initiated by Smith, early twentieth century, and developed by many researchers [1]. One unbalanced weight rotates at a constant speed. The centrifugal force can be changed in steps after stopping the machine by changing the load.

Another possible impact on the specimen in the fatigue machine is the use of electromagnetic forces. At first, their main advantage was an ability to work at high frequencies loads. The first machine of this type, designed independently by Kapp and Hopkinson, also early twentieth century, reached 7000 cycles/min. Haigh's machine, developed in 1912, was a frame positioned between two magnets. One end of the specimen was fixed to the base whilst the other end remained connected to the frame with a double spring bracket. The resonant frequency of the vibration system was adjusted by changing the length of the bracket. Another machine of this type, developed by (among others) Russenberg in 1945 with two weights connected with the specimen and the dynamometer, vibrated with the natural frequency. By changing the mass, it may be tuned to a frequency of 3000 to 18000 cycles/min. with a load of

10 kN and 50 kN. Specimen loads in the fatigue machines excited by hydraulic generators can be very large. Another feature of the hydraulic machines is that they can achieve a relatively low frequency. The first machines consisted of pulsators connected to a standard frame. Along with the evolution of this type of machine construction, there were developed different ways to load changes during operation. In one of that solutions, pump comprises two identical rotating cylinders. Obtained by changing the angle between the volume is brought to another cylinder which allows to adjust the load on the specimen. Fatigue machines based on pneumatic actuators are used less frequently than e.g. hydraulic machines. The machine proposed by Lehr in 1931, allowed to obtain a load of about 1 MN, stroke 5 mm and a frequency of 1200 cycles/min. The load was regulated by the change in volume between the pump, which operated at a constant stroke. At present, pneumatic equipment for fatigue strength verification is mainly used for testing small forces. Their advantage is, among others, that it is easier to prepare the machine for testing.

An exemplary, servohydraulic axial fatigue machine is presented in Fig. 1. Presented testing machine for dynamic tests have the testing actuator mounted on the upper crosshead for maximum versatility. Optional tests also can be performed in addition to standard fatigue tests. Dynamic testing machines are available in various versions for test loads, in this case, from 25 to 2500 kN.

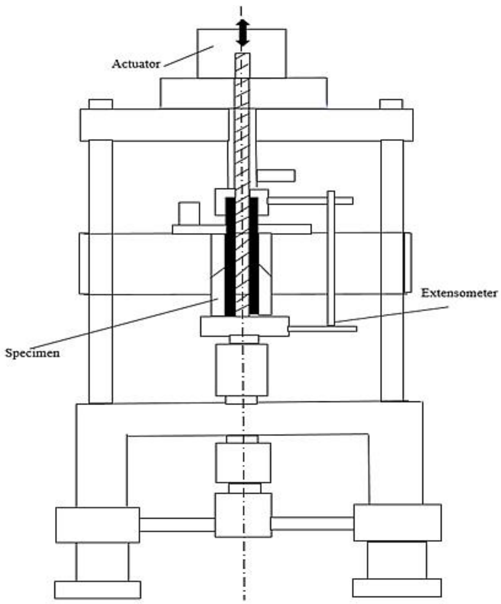

Fig. 1. General simplified view of a specimen with side grooves

Source: [1]

2.2. Bending

Machine, which was used to test the mechanical flexing of the specimen generally used adjustable lever, which deforms the attached specimen. The first device of this type was described by Lewis in 1912. The use of inertia forces resulting in generation of bending load applied, for example, by fixed weights on the eccentrically rotating discs. The use of electromagnetic forces to bending fatigue specimen were carried out in a similar way as in the case of testing the axial tensile-compression. The pneumatic fatigue loads used in bending allow to testing at a very high frequency. The first machine of this type, designed by Jenkin and Lehman in 1929, introduced a small specimen to resonate through the air stream. By a pneumatic oscillator, also e.g. turbine blades were tested.

The disc bending fatigue test technique was shown in [15]. In this test stand, presented in Fig. 2, a uniform thickness disc specimen was subjected to a bending load by applying air pressure on the specimen surface.

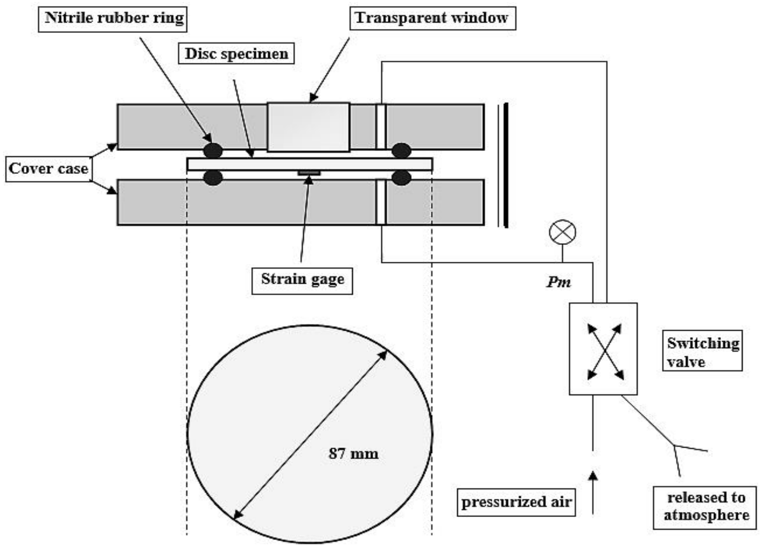

Fig. 2. Schematic drawing of the Disc bending fatigue testing system

Source: rewrite based on [15]

2.3. Torsion

Loads caused by mechanical deflection or inertial force [1] applied by Woehler in 1871, Foppel in 1909, and Rowett in 1913. They used a crank drive, acting directly on the specimen with the coil springs or rods. Loads induced by inertia in the fatigue test are used for the torsion of specimen in a similar manner as previously described for other types of loads, using an inverted torsional vibrations. With the use of this method were tested crankshafts for diesel motors by Reuf and Lehr in 1943 and used in ships and full-sized shafts with a diameter of 25 cm by Dorey in 1943 with a planetary gear. The first attempts to use pneumatic excitation for torsion involved modifications of systems for testing specimens to bending.

The electromagnetic forces are used in many fatigue torsion applications. Initially, flywheels combined with actuators for loading specimens. In some cases also in the double flywheels in order to eliminate the vibration of the bending specimens. The ultrasonic fatigue testing machine operating in pure torsion is shown in some works [16]. The specimen is excited in resonance by an ultrasonic vibration at one of its natural Eigen modes. The proposed ultrasonic torsion-fatigue testing system uses a single horn. It is directly connected to a piezoelectric converter as shown in Fig. 3.

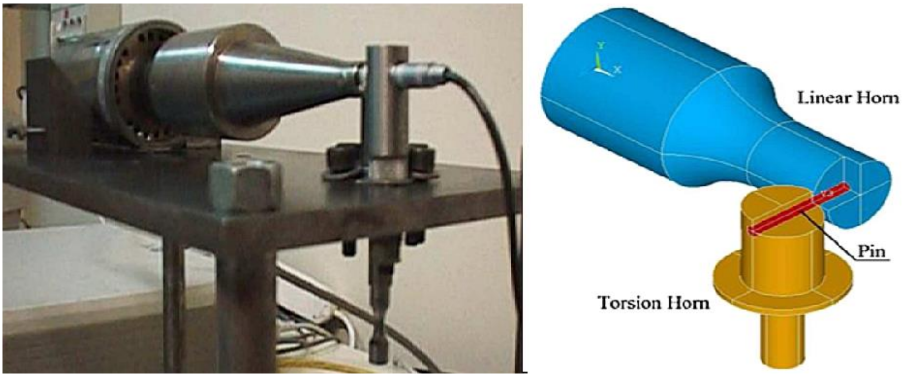

Fig. 3. Torsion testing machine with an axial piezoelectric converter and scheme of the connection between the two perpendicular horns showing the pin

Source: [16]

2.4. The combination of bending and torsion

The loads caused by bending the mechanical or inertial force of the combination of bending and torsion were generated initially by the use of special holders for conventional machines. Devices of this type which were used by Bruder in 1943 and by Nishinara and Kavamoto in 1943, have been described by Weibull [1]. The impact of bending and torsion on a specimen is also possible with the use of centrifugal force. The machine described by a Lehr and Prager in 1933 based on a mechanical oscillator with four unbalanced masses, which caused the axial force. By the use of the lever effect obtained bending and torsion. The concept is similar to the existing fatigue machines type MZGS for testing under bending and torsion [17].

Initially, most of the load combinations of fatigue tests on the specimens were generated with circular cross-section for the combination of bending and torsion. A wider range of load capacity also allowed for increasing the type of specimens and loads used. Other authors [18] present the fatigue resistance of a pipe-to-plate welded joint, which was investigated under combined in-phase and out-of-phase bending and torsion. The pipe and plate were made of S355 steel and the joint was not subjected to any after welding relieve treatment.

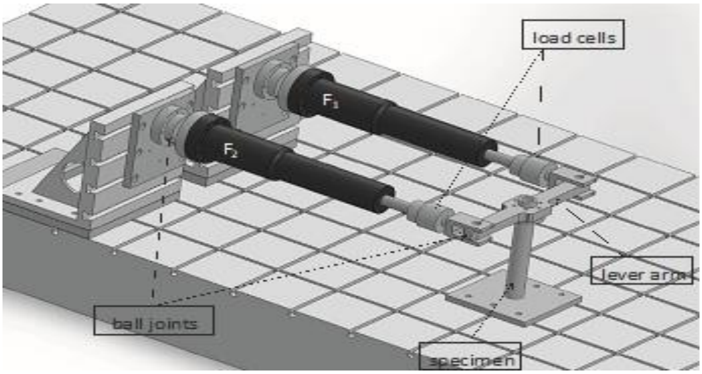

Fig. 4. Layout of the test bench. The specimen is fixed to the lower basement and is loaded by two hydraulic actuators, which are independently controlled

Source: [18]

2.5. Axial –Torsional

Authors [19] presented a test stand MZRS-1, designed to test materials under tension and torsion, cyclic or random. Hydraulic machine type MZRS-1 allows you to generate load range of axial force equal to ± 50 kN, and a torsion moment range of values ± 600 N.m.

Authors [20] show the developed inner pressure on multiaxial fatigue testing machine. A schematic view of Testing machine of push-pull and reversed torsion with inner and outer pressure is presented in Fig. 5.

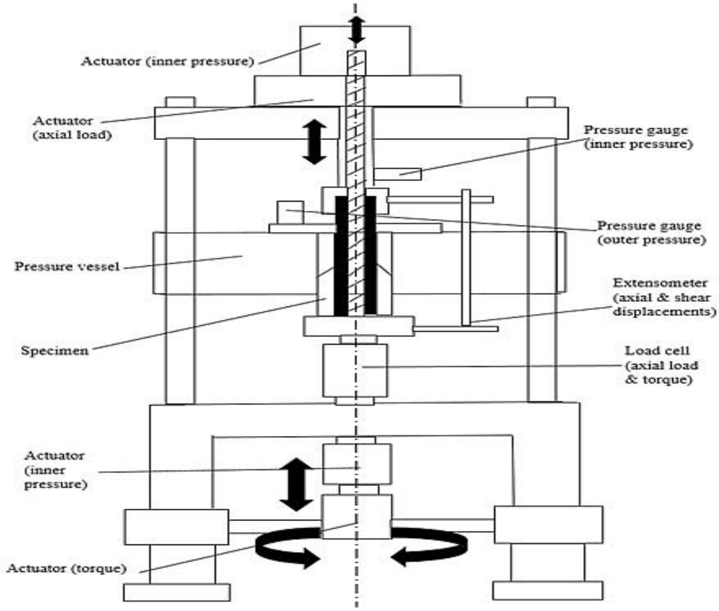

Fig. 5. Testing machine for push-pull and reversed torsion with inner and outer pressure

Source: rewrite based on [20]

As presented in [21], the tension–compression and torsion fatigue tests were conducted on the Instron 8874 multiaxial fatigue-testing machine under constant displacement and torsion angle control, respectively, with a strain ratio of R= −1 at room temperature. The cyclic stress response and dislocation patterns of coarse-grained copper under the two fatigue tests are compared. Fatigue crack initiation, propagation and fracture surfaces of the specimens were found relying on the loading mode.

2.6. In-plane biaxial

The hydraulic test stand MZPK-300L is originally designed and made by staff from Opole University of Technology, fatigue test cruciform specimens, the biaxial load condition (tension-compression). The specimen is subjected to independent axial loads in two directions (plane stress state) with freely shaped waveform histories at the time (including random). Figure 6 shows a schematic of the test stand MZPK-300L.

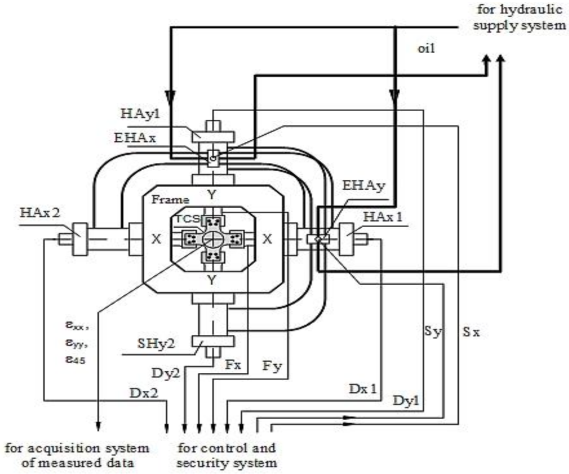

Fig. 6. A diagram of forced loads system on MZPK-300L test stand
HA – hydraulic actuator, EHA – electro-hydraulic amplifier, TCS – tested cruciform specimen, F- signal of measured force, D – signal of piston rod displacement, S – signal of tracking control/sequential control system

Source: rewrite based on [19]

To the machine frame are mounted four hydraulic actuators, with axes perpendicular to each other. The ends of the actuators are fitted with gips for fixed specimen. Actuators mounted strain gauge force sensors, while in the outer parts of the bearing are displacement sensors, which generate signals in the control and security system. In the control system current signal is supplied to the electrohydraulic amplifiers, which regulate the flow of pressurized hydraulic oil, supplied to the respective actuators, thereby causing the load in the desired direction by the appropriate value. Controlled by one servo valve actuators provides synchronization, moving in one direction.

2.7. Planar tri-axial

The authors of the article [22] present the testing machine that can reproduce arbitrary in-plane stress states by applying three independent loads to the test specimen using actuators which apply loads in the 0, 45, and 90 degree directions. The reproduction was tested with complex stress data obtained from the actual operation of transport machinery. Figure 7 shows the fatigue machine structure. Two frames, each of which has an actuator and a reaction wall, are installed on the fixed frame through linear motion guides. An electro-hydraulic control system is installed in the testing machine. This testing machine was manufactured by Shimadzu Corporation.

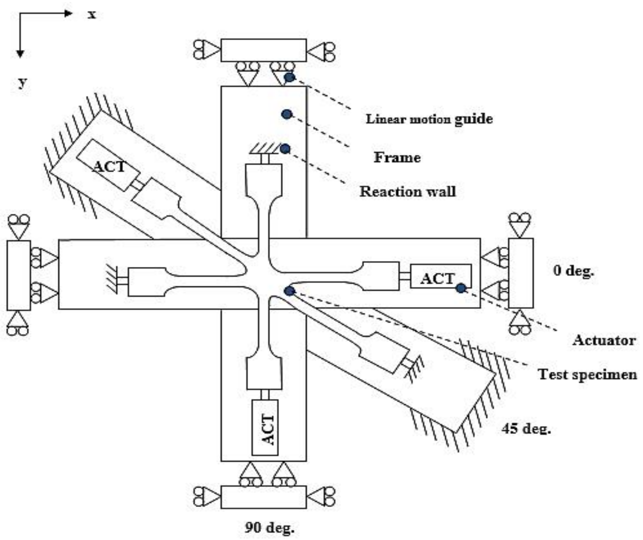

Fig. 7. Planar tri-axial fatigue testing machine

Source: rewrite based on [22]

3. Special purpose fatigue testing machine

3.1. Ultrasonic fatigue testing machines

For HCF, and even more VHCF regime, there is a need to shorten the duration of the tests [23]. For example, for a traditional fatigue machine with operating frequency of 50 Hz, duration of the test on the 109 number of cycles, it amounted to about 7 months. When planning tests of high-frequency, the impact effect of high frequency and temperature must be taken into account. Ultrasonic fatigue testing device under biaxial bending is shown in [24]. Specimens were tested under biaxial loading at 20 kHz. A flat smooth specimen with a disc geometry is placed on a torus frame and cyclically loaded at the center of its upper face. Disc bending generates a biaxial proportional stress state at the center of the lower face.

Next to used fatigue tests of the traditional way of forcing, the loads for testing at high frequency are also applied electrodynamic vibration systems based on shakers.

Researchers [7] presented the fatigue test stand, based on the electrodynamic vibration systems and the control system software in LabVIEW. The operating range of the inductor type TIRAvib TV 51 144 allows the realization of research 2-6500 Hz, which for the test, the fatigue is limited because of the weight and the characteristics of the test. Figure 8 presents a diagram of the test system based on the electromagnetic shaker.

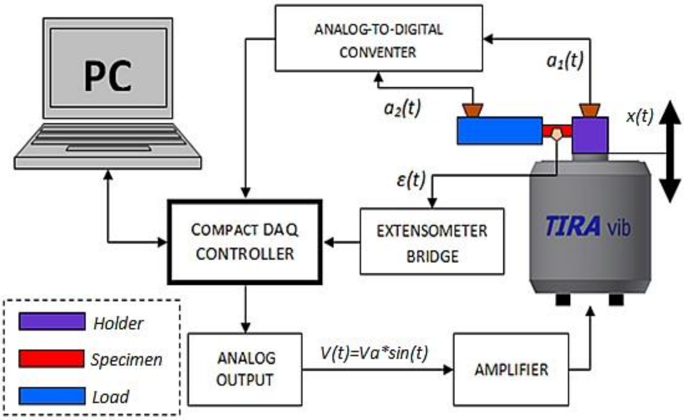

Fig. 8. Fatigue test stand, based on the electrodynamic vibration system

Source: [7]

3.2. Generating the loads with the mean value

In the works of authors [25,26] they presented the results of tests porformed on the machine type MZGS-100. The loads may contain non-zero values of static force moments. The average values of loads are caused by the spring-loaded actuator (15), shown in Fig. 9.

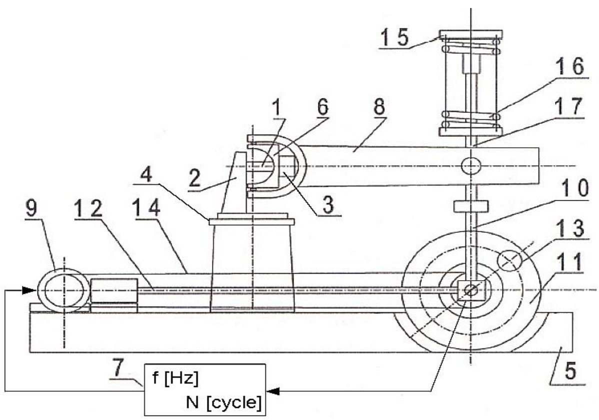

Fig. 9. A diagram of fatigue test stand MZGS-100, generating the loads with the mean value: 1 - specimen, 2 – clamp, 3 – rotary head, 4 – head base, 5 – machine base, 6 – grip, 7 – control system, 8 – lever, 9 – motor, 10 – lower rod, 11 – vibrating disk, 12 – flat springs, 13 –weights, 14 – belt, 15 – spring-loaded actuator, 16 – spring, 17 – upper rod

Source: rewrite based on [25]

3.3. Study of the temperature effect on the fatigue life of material

Temperature has a strong impact on the fatigue life of materials. There are many stands to test the fatigue life under the influence of temperature, mostly high, but also reduced.

Authors [27] present an original experimental stand, consisting of a biaxial servo-hydraulic MTS 858 MiniBionix material testing system, Maytec resistance furnace, high-temperature MTS extensometer and hydraulic grips of original design, was used in tests. Tubular specimens were subjected to multiaxial fatigue loading, proportional and non-proportional (with phase shift), under isothermal conditions of the air atmosphere. Multiaxial tests were performed under combined axial-torsional loading. The test stand used for fatigue life tests at temperatures up to 300°C. For this purpose an induction heating furnace system, as shown in Fig. 10.

Fig. 10. Main elements of induction heating furnace system

Source: rewrite based on [27]

In the article [28] authors present fatigue tests which were performed on notched aluminum-alloys 2524-T3 and 7050-T7451 subjected to constant amplitude and random spectra loading at 25°C room and −70°C cryogenic temperatures, and the load-environment interaction. Fatigue tests were conducted on MTS-880-100kN servo-hydraulic machine under longitudinal cyclic loadings, sinusoidal waveform at a loading frequency of 10 Hz at about 25°C room temperature and air moisture. During cryogenic fatigue tests, the SDGDYD−180/+350 environmental chamber with an electromechanically operated solenoid valve was employed to maintain the testing temperature of −70°C through controlling the gas flow of gasified nitrogen from the YDZ-50 cryogenic liquid nitrogen cylinder (shown in Fig. 11).

2019
Nr 1(10)
s. 80-108

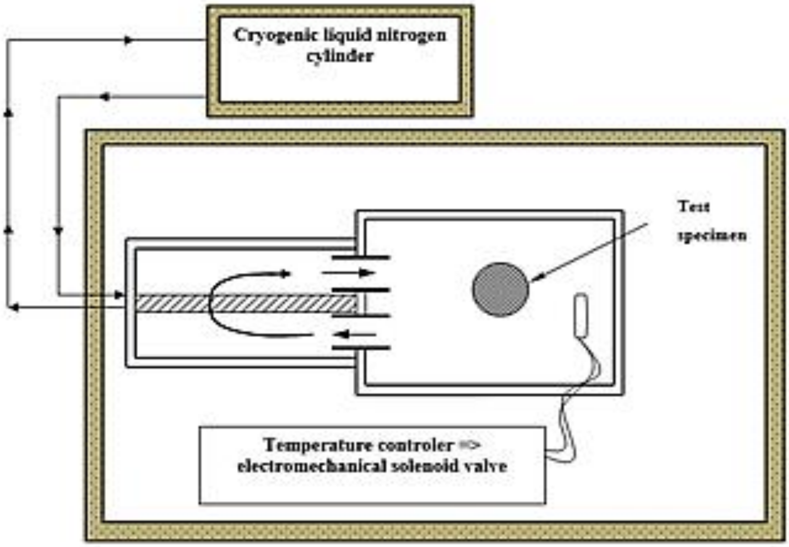

Fig. 11. Fatigue test setting in cryogenic temperature

Source: rewrite based on [28]

3.4. Fatigue machines to study the effect of corrosive environment

The study of fatigue life often tends to test materials under conditions as nearly as possible the actual operating conditions of the constructional element.

Fatigue machines for special purpose are also test stands taking into account the effects of corrosive environment. Very often, for this purpose, a standard fatigue machine uses only special equipment. In the paper [29] researchers presented a methodology for fatigue testing prostheses made of alloy Ti6Al4V and Ti6Al7Nb in corrosive environments. The tests were carried out on the machine LFV series 10-63 kN, produced by Walter & Bai AG from Switzerland, and they were conducted in accordance with ASTM standard (F 1440) concerning Fatigue Testing of Metallic Stemmed Hip Arthroplasty Femoral Components. An examplary, chamber for corrosive environmental fatigue tests, is presented in Fig. 12.

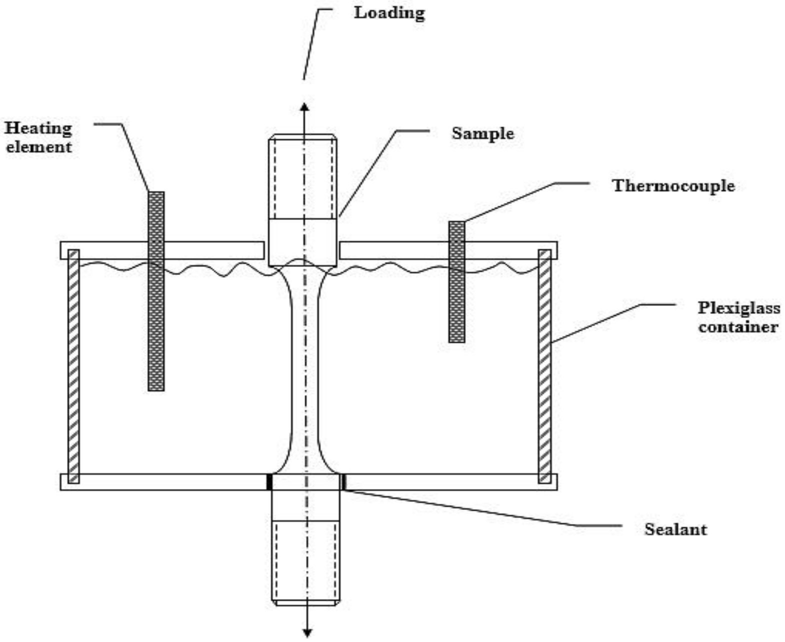

Fig. 12. Chamber for corrosive environmental fatigue tests

Source: rewrite based on [30]

4. THE EQUIPMENT FOR TESTING OF PARTS AND COMPONENTS AS WELL AS MACHINERY

The influence of the geometry of the test material is negligible and acceptable for model research on specimens of materials. In practical examples assessment of the fatigue life of machine elements and structures, this approach has some limitations. The main difficulty is the evaluation of the actual state of stress and strain in the selected element design, and transfer the conditions of laboratory tests on specimens. Therefore, in some cases, the solution is to test the actual structure element.

In the work of other authors [31] presented fatigue tests procedure on diamond bird-beak square hollow section (SHS) T-joints. Figure 13 shows the test setup of fatigue tests. Both ends of the chord member were pin-supported. A constant amplitude of cyclic loading was applied through a hydraulic pulsation fatigue testing machine, which can provide a maximum load of 500 kN, at a rate of 200 cycles per minute. As the fatigue testing machine can only apply compressive load directly, the specimens were placed upside down, so that tensile load could be applied on the brace by using a rigid loading frame.

2019
Nr 1(10)
s. 80-108

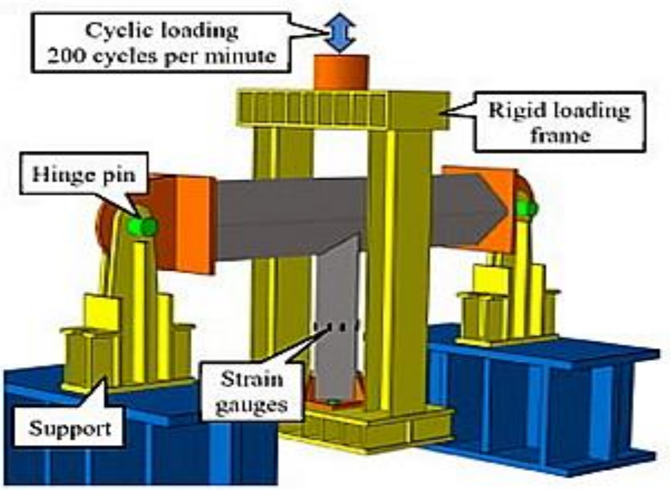

Fig. 13. Fatigue test setting for diamond bird-beak square hollow section (SHS) T-joints

Source: [31]

An exemplary advanced road simulation by MTS company is shown in catalog [32]. The catalog contains testing equipment for components, subsystems and full vehicles.

Fig. 14. Model of MTS 329 6DOF system, road simulation

Source: [32]

5. COMPONENTS OF FATIGUE TEST SYSTEMS

Machines for fatigue tests include the following elements:

- system for generation of loads (subchapter 5.1),
- control and protection system (subchapter 5.2),
- measuring instruments, including the cycle counter (subchapter 5.3),
- the fatigue machine frame,
- clamping of specimens – grips (subchapter 5.4),
- element for transmitting the load that acts on the specimen.

5.1. Generating of loading histories

The most extended system (in terms of actuator) is equipped in a servo-hydraulic system. Components for a servo-hydraulic fatigue stand are: servo-hydraulic testing actuators, pumps, oil collection pans, distribution units, servo valves, pipelines. These selected items were derived from the Zwick / Roell catalog, shown in Fig. 15.

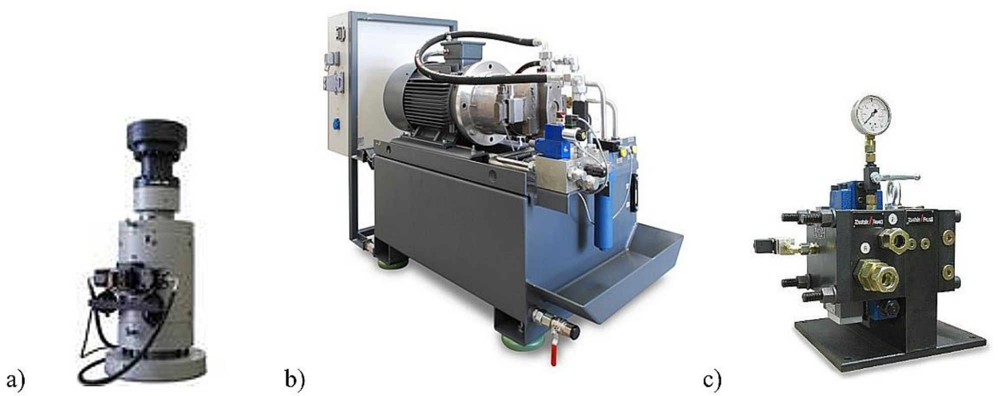

Fig. 15. Servohydraulic components: (a) Servo-hydraulic testing actuators (b) Hydraulic power pack (c) Hydraulic distribution unit,

Source: [33]

5.2. Control and protection system

In most described in literature test stands are more or less advanced measurement and control systems. One of the fundamental decisions in the design phase of each fatigue machine is the selection of the control system. Whether based on programmable logic controllers (PLC) or, for example, on PC based systems, control systems offer opportunities to implement control drives functions, implementing the functions of continuous processes (e.g. PID), protection, communication and data logging.When selecting a control system, the designer takes into account such factors as the costs of implementation, application development time, working conditions, ability to modify hardware and software.

The theory of regulation is the science of control systems with feedback, in which we include the description method of dynamic properties, identify objects control, stability systems, the design and the analysis and correction of control systems. Significant progress in the possibilities of regulating AC motors, occurred in the late 80s of the twentieth century, when the prediction of frequency converters began. Currently manufactured frequency converters allow easy adjustment and secure drives with three-phase AC motors. The use of semiconductor power regulators, known as frequency converters, that is, the speed control by varying the supply voltage frequency, the three-phase asynchronous motors, also allows achieving energy savings up to 50%.

The mechatronic control system, shown in Fig. 16, described in [19], in which one of the most important elements is a programmable frequency converter ATV28 that converts the voltage single phase to three-phase of 230 V. With function adjust the frequency, you can make a potentiometer connected to the analog input of the ATV28, or remotely via an original control system. The frequency converter ATV28 is also equipped with relay signaling errors and, in case of a short circuit or overload on the motor, it will shut down the entire system.

ASTM standard [34] explains how to understand and minimize errors associated with data acquisition in fatigue and fracture mechanics testing equipment. In Figure 17, Sources of Error in Data Acquisition Systems are shown.

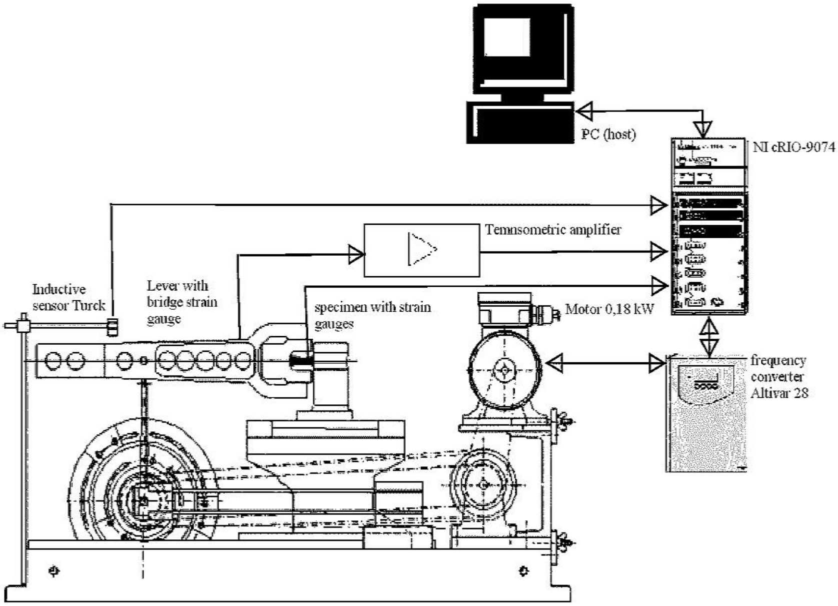

Fig. 16. Control system for the fatigue test stand MZGS-100 PL

Source: [19]

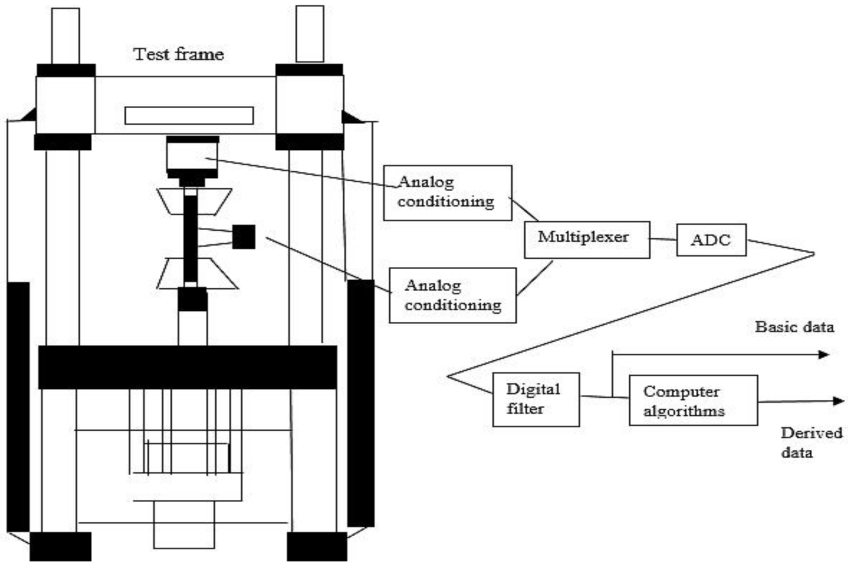

Fig. 17. Sources of Error in Data Acquisition Systems

Source rewrite based on [34]

2019
Nr 1(10)
s. 80-108

5.3. Measuring instruments, including the cycle counters

5.3.1. Strain measuring

Methods for measuring displacement, in general, are shown in the standards ASTM [12] and ISO [13].

Used in the measurement of displacements and strains solutions can be divided into contact and non-contact. In the first case, the most popular way is to use a resistive strain gauge. In the case of non-contact measuring strains and displacements, the electrical and optical phenomenon are used.

Among the sensors, enabling measurement of strain, the most widely used are resistance strain-gauge sensors. The reason for this has been insignificant inertia sensors, their small size and ease to read measurements. Resistance strain gauge sensor is glued to the deformable element. Direction bands of resistance of the sensor must be consistent with the direction of the tested strain. The resistive material sensor is identical deforming to that element on which the sensor is affixed. As a result of strain, the band resistance changes its length and the sensor has a resistance change proportional to the strain. Characteristic of a resistance strain gauge sensor is a sensitivity factor k, expressed as the ratio of the relative change in resistance of the sensor R/R to the strain unit l/l. In Figure, 18 an exemplary diagram of a system for measuring the strain of the specimen under bending is presented.

Resistance values of the produced strain gauges are standardized, and most are 120 Ω, 300 Ω, 600 Ω, and 1000 Ω, whilst measurement databases of available metal electro-resistant strain gauges mostly cover the ranges from 0.2 to 150 mm. In terms of the type of an element sensitive to strains, besides the most common metal strain gauges, are also used electrical resistant, semi-conductor strain gauges.

On the market there are a number of solutions for extensometers, for example, the one that attaches an extensometer to the specimen with clips or elastic bands and uses edges to accurately track deformation in a specimen during testing.

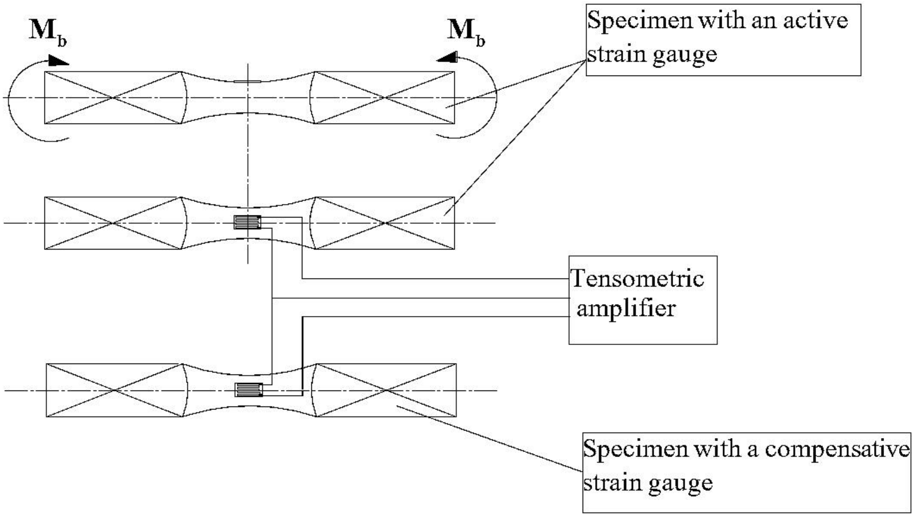

Fig. 18. Specimen with strain gauges for bending testing

Source rewrite based on [19]

Fig. 19. Dynamic Extensometer 12.5mm GL ±2.5mm Travel,

Source: [35]

There have also been many attempts to use non-contact optical phenomena to measure strains in order to test various materials. The following optical methods, among others, are distinguished: classic double-beam interferometry, grating interferometry, digital speckle interferometry, holographic interferometry and

2019
Nr 1(10)
s. 80-108

electronic speckle interferometry (ESPI), and the method of structured light, including projection grid and Moire fringes.

Companies specializing in the production of fatigue test equipment, developed video extensometers in the early 90's. This was achieved by following two contrasting marks placed on the specimen prior to the start of the test and had the benefit that no physical contact was made with the specimen. Authors [36] presented a video extensometer (Fig. 20), in which a single-lens 3D imaging system with a prism and two mirrors was constructed to acquire stereo images of the test specimen surface, so the problems of synchronization and out-of-plane displacement were solved.

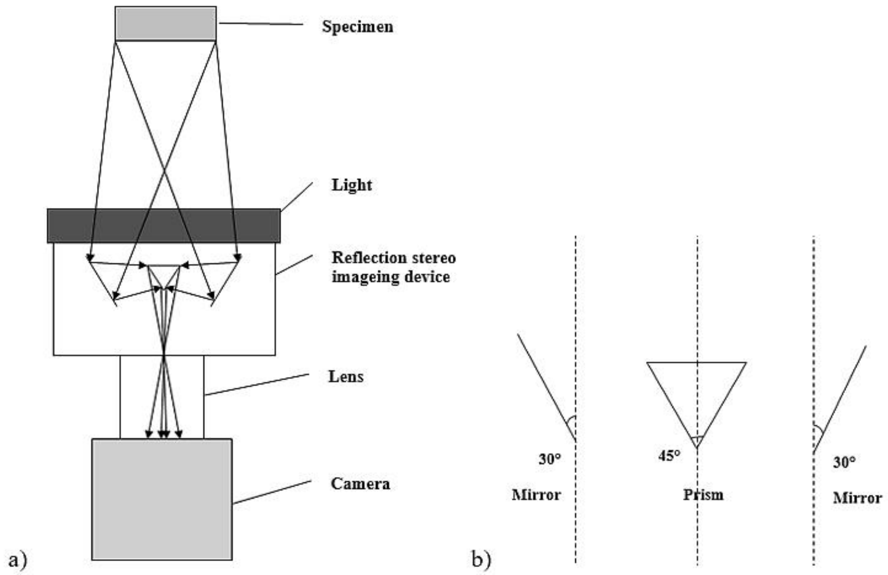

Fig. 20. (a) Schematic diagram of the single-lens 3D video extensometer and (b) optical arrangement of the reflection stereo imaging device

Source: rewrite based on [36]

5.3.2. Force Measurement

In the ASTM [10], and ISO [11] we find a brief mention of Forces measure Equipment Characteristics.

Sensors for Dynamic Forces measure are, first of all, Load Cells. During tests carried out on servohydraulic machines, elements of the system are subjected to acceleration. As a result, in addition to the force applied to the specimen, the load cell also reads forces resulting from its own movement and the mass of the grips and fixtures attached to it.

In addition to the force sensors available commercially, there are a lot of solutions designed by the researchers, based mainly on strain gauge technology.

5.4. Clamping of specimens - grips

Mechanical grips, gripping force being applied via movement of the grip body relative to the wedge shaped jaw faces. While Hydraulic grips maintain a constant gripping force on the specimen regardless of the test forces acting upon it, as long as there is hydraulic pressure to the grips.

Authors [27] showed the grip used to eliminate the ‘‘sticking” phenomenon of the threaded parts of moving grips in the furnace chamber, the specimen clamping mechanism 5 in Fig. 2 was moved outside of the high temperature heat zone. This was achieved through the mechanism effecting reciprocating motion of the rod acting on the element clamping the grip’s inserts (Fig. 21).

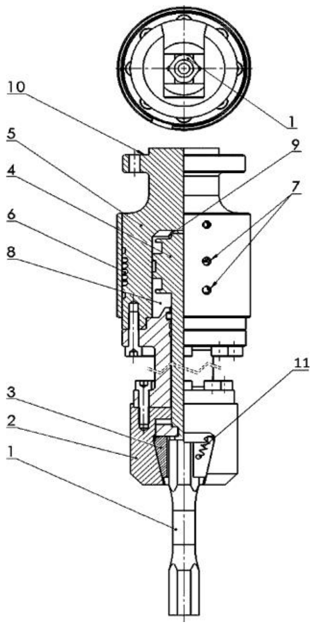

Fig. 21. Diagram of the grip for fastening test specimens at elevated temperature hydraulic clamp (1-specimen; 2-grip head; 3-replaceable insert; 4-piston of hydraulic cylinder; 5-hydraulic cylinder; 6-cooling water channels; 7-supply channels to cooling circulation; 8-grip opening chamber; 9-grip closing chamber; 10-fastening adapter; 11-tension spring),

Source: [27]

2019
Nr 1(10)
s. 80-108

6. FATIGUE TEST SPECIMENS

A typical fatigue test specimen consists of the test section and the two grip ends. The grip ends are designed to transfer load from the test machine grips to the test section. The transition from the grip ends to the test area are designed smoothly to eliminate any stress concentrations. Fatigue test specimens usually have finely polished surfaces to minimize surface roughness effects. The design and type of specimen used depend on the fatigue testing machine.

Common fatigue test specimens, usually used for axial or bending tests, are shown in Fig. 22a,b,c. Stress concentration influence can be studied with most of these specimens by machining in notches, holes, or grooves, such as shown in Fig. 22d.

In Fig. 22e is presented a thin - walled tube specimen designed for torsion and combined axial/torsion. The thin-walled tube allows for essentially uniform normal and shear stresses in the cross-sectional area. Fixed-Cantilever Flat Sheet Specimen for bending is shown in Fig. 22f.

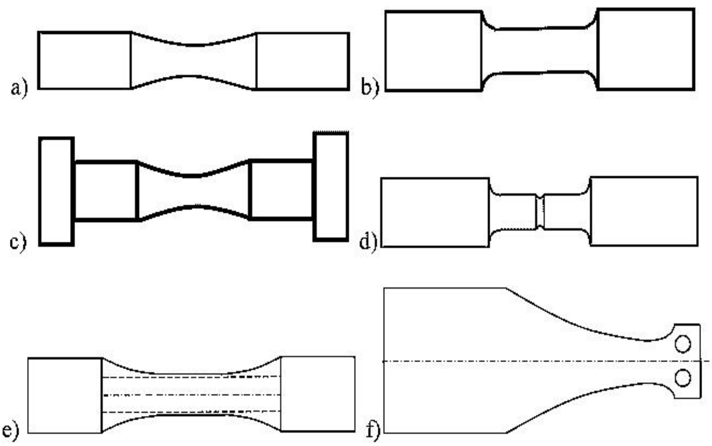

Fig. 22. Specimens: (a) Rotating bending, (b) Axial uniform, (c) Axial hourglass, (d) Axial or bending with circumferential groove, (e) thin - walled tube specimen, (f) Cantilever flat sheet for bending.

Source: rewrite based on [12]

Examplary specimens, recommended for Low-Cycle Fatigue, is shown in Fig. 23. The drawing below was taken from ASTM standard ASTM [12].

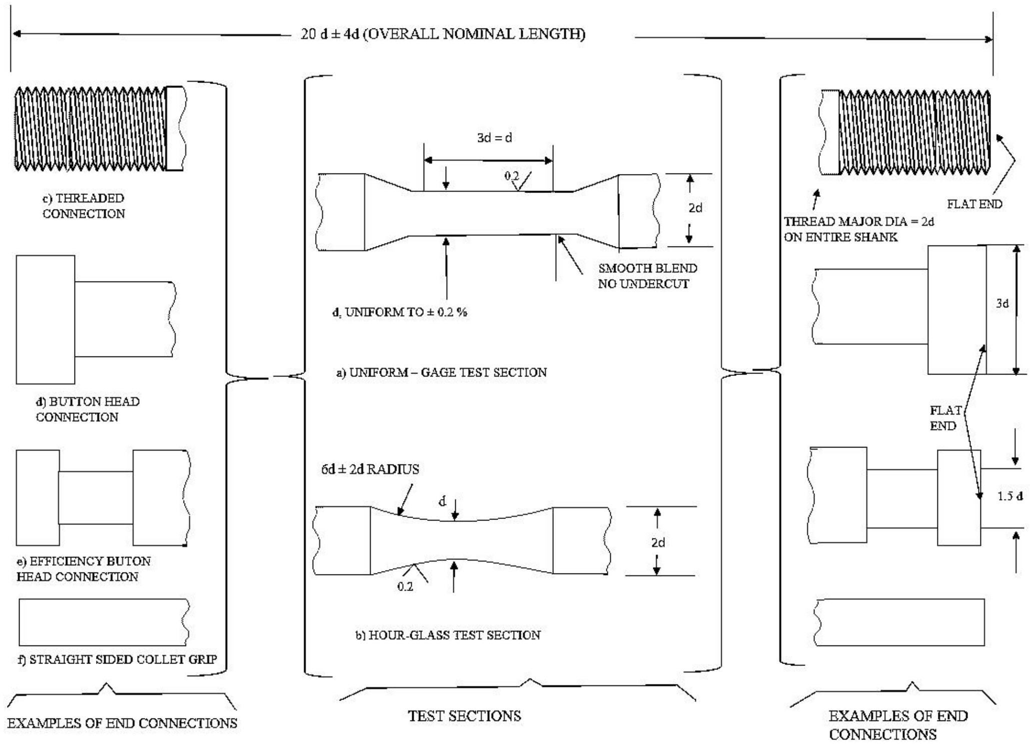

Fig. 23. Low-Cycle Fatigue Specimens, Recommended by ASTM

Source: rewrite based on [12]

There is also a group of specimens used for obtaining fatigue crack growth data. In all cases a thin slit, notch, or groove with a very small root radius is machined into the specimen.

7. CALIBRATION AND CHECKING THE ACCURACY OF MACHINES AND EQUIPMENT FOR FATIGUE TESTING OF MATERIALS

The ASTM [37] and ISO [38] recognized the general principle of verification of the accuracy of fatigue tests of materials. The overall accuracy is a combination of control precision and measurements accuracy.

Elements of a fatigue testing machine that affect the dynamic performance are frame stiffness, specimen stiffness, moving mass, deflection of moving mass, machine resonance, actuator friction.

Because of the many factors that influence the dynamic accuracy test of strength, it is recommended a verification for each new combination of potential factors causing the errors. In the ASTM standard [37] are described the main factors such as the test specimens, the configuration of the machine, the test frequency or the load range. Calibrating or verifying the performance specific to one testing criteria may not necessarily provide evidence that the system is capable of performing under different conditions. Of course, performing a full verification for each configuration is often impractical. To solve this problem, dynamic checking should be done in two ways: full control, at least once a year, and simplified verification, in the case of configuration changes. Standard ISO [38] describes a process for verifying the settings in test devices using strain gauges. It applies to fatigue uniaxial tension-compression, torsion and combination of tension with torsion during fatigue tests.

7. CONCLUSIONS

Apart from the known offers of companies producing fatigue machines, there also exist "own" solutions for fatigue testing systems, which are often dedicated to a particular type of research. This results from the cost of acquisition of such a system from commercial sources as well as from the possibility of using any configuration of such machine, for example, created for a specific type of research. Fatigue machines made for this purpose also have to meet some of the standards, for instance, developed and published by ASTM or ISO, so that the results of tests performed on them will be considered reliable and useful to other researchers and engineers.

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MASZYNY I APARATURA DO BADAŃ ZMĘCZENIOWYCH

Streszczenie: W artykule przedstawiono wybrane przykłady budowy i zastosowań stanowisk do badań zmęczeniowych tworzyw konstrukcyjnych. Autorzy dokonali przeglądu uniwersalnych maszyn zmęczeniowych i stanowisk testowych, jak również urządzeń stworzonych specjalnie dla indywidualnych programów badania własności zmęczeniowych materiałów. Autorzy opisują również, jak wdrożyć te procedury do układów sterowania i pomiarów w stanowiskach badawczych.. W artykule przedstawiono historię rozwoju metod badań zmęczeniowych w odniesieniu do potrzeb przemysłu. Ponadto zaprezentowano wybrane przykłady rozwiązań i ich aplikacji do badań zmęczeniowych, dostępnych w nauce.

Słowa kluczowe: maszyny zmęczeniowe, stanowiska badawcze, neprężenie, odkształcenie, planowanie badań zmęczeniowych

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