THE USE OF A NEODYMIUM FATIGUE TESTING MACHINE FOR FATIGUE STRENGTH EVALUATIONS

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Abstract

This article proposes a method and a laboratory setup for testing the fatigue strength of materials with the use of vibration signals and a neodymium fatigue-testing machine. The machine supports non-contact fatigue testing of construction materials, and analyses of bending and torsional behaviour of magnetic and non-magnetic materials at any excitation range. The discussed machine is a non-contact bending device, and when an appropriate adapter is used, it supports analyses of torsional behaviour in determinations of material wear. A neodymium fatigue-testing machine can also be used to evaluate sample deformation by registering amplitude, RMS deviation from equilibrium-calculated values, temperature of sample notch, deflections along the length of the sample, stress at the cross-section of the notch and load applied at the terminal section of the sample.

Simplified diagram of a rotating-bending fatigue testing machine, diagrams of biaxial rotating-bending fatigue testing machines, diagrams of a bending fatigue testing machine, displacement range of a material point in the sample induced by neodymium magnets on a double disc, displacement range of a material point in the sample at rotational frequency, displacement range of a material point in the sample at rotational frequency, changes in the sample's notch temperature and displacement amplitude are presented in the paper.

***Keywords**: fatigue tests, vibration signal, neodymium magnets*

1. Introduction

The fatigue wear of construction materials is evaluated with the involvement of methods and test stands characterized by various functional solutions [1, 2, 4, 6]. Rotating-bending fatigue testing machines are popularly used. The sample is positioned in self-centring clamps, which are pivotally mounted in bushings. The sample with bushings and spindles constitutes a model of a beam with two support points, which is subjected to two symmetrical transverse forces. The beam is subjected to a pure bending moment. Stress values are achieved by selecting an appropriate bending force, and the number of stress cycles applied until failure is calculated (Fig. 1).

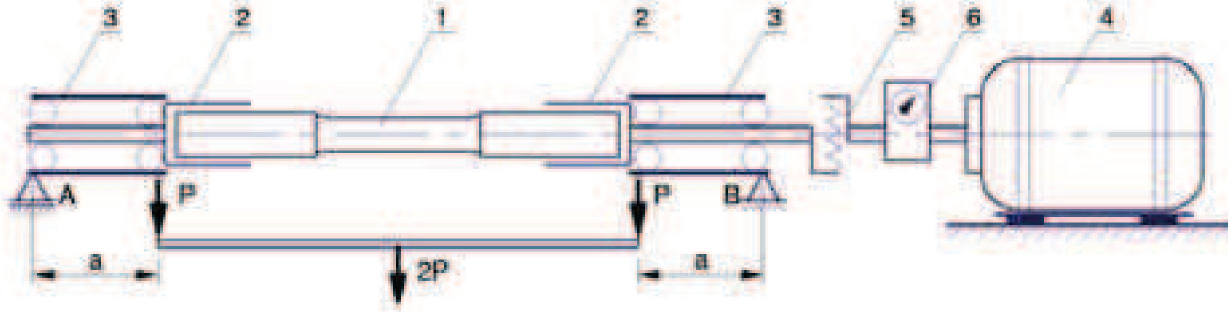

Fig. 1. Simplified diagram of a rotating-bending fatigue testing machine. 1 – sample; 2 – self-centring clamp; 3 – guide

bushings; 4 – electric motor; 5 – flexible coupling; 6 – cycle meter; P *– sample load; a – overall dimension*

Fatigue testing machines also feature other structural and functional solutions (Fig. 2-3). Depending on the type of produced stress, they can be classified into the following categories:

– bending machines,
– tensile-compression machines,
– rotating-bending machines,
– machines for testing samples subjected to complex stress.

Fatigue testing machines can also be divided into the following groups subject to the type of drive and load:

– load is produced by a cam and crank mechanism,
– load is produced by electromagnetic systems (electromagnetic pulsers),
– where hydraulic load is produced by a hydraulic pump (hydraulic pulsers),
– where dynamic load is produced (inertia and resonance pulsers).

The above fatigue testing machines come into mechanical contact with the analyzed sample. In this type of contact, the sample cannot be tested at high cycle frequency and low amplitude of material displacement.

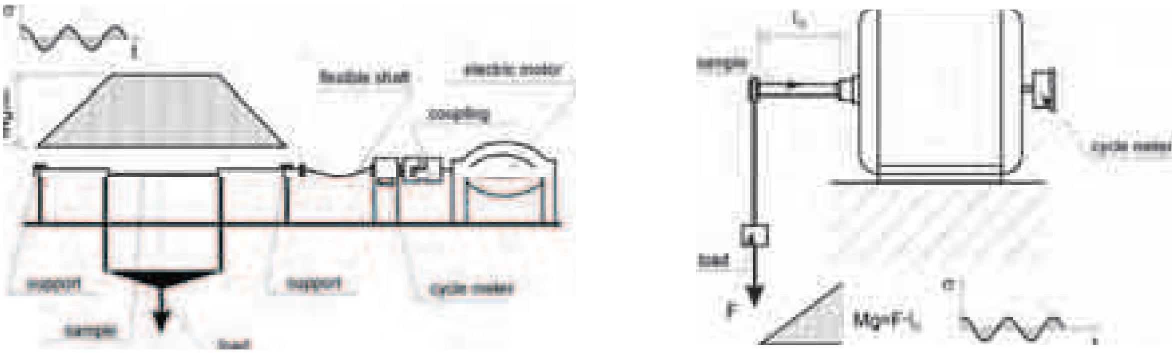

Fig. 2. Diagrams of biaxial rotating-bending fatigue testing machines

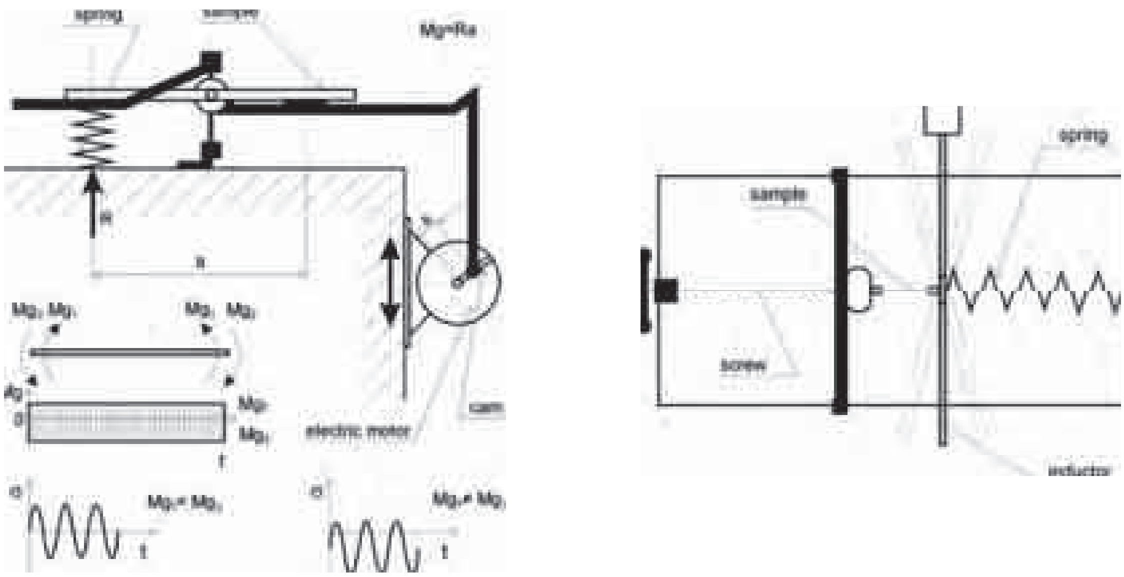

Fig. 3. Diagrams of a bending fatigue testing machine

This study proposes a method for evaluating the fatigue strength of materials with the use of vibration signals and a neodymium fatigue testing machine. The NMZ-1 neodymium machine has been designed for non-contact fatigue testing of construction materials. It supports non-contact fatigue testing of construction materials, and analyses of bending and torsional behaviour of magnetic and non-magnetic materials in any excitation range. The discussed machine is a non-

contact bending device, and when an appropriate adapter is used, it enables analyses of torsional behaviour in determinations of material wear. The applied machine also supports:
– determination of fatigue caused by pulsating stress (pulsating cycles) and fluctuating biaxial stress (symmetrical cycles),
– sample testing at high cycle frequency and low amplitude of material displacement,
– resonant frequency fatigue testing,
– fatigue testing at different values of displacement amplitude,
– registration of sample displacement (deformation) values,
– registration of temperature changes at any point in the sample,
– fully automated process of data measurement and results registration,
– automated measurement.

2. Materials and Methods

2.1. Structure and operation of fatigue testing machine

All mechanisms and assemblies of the NMZ-1 fatigue testing machine (Fig. 4) are mounted to a self-supporting frame.

a) b)

Fig. 4. NMZ-1 Neodymium Fatigue Testing Machine, a) – general view; b) view of clamp section and measurement sensors

NMZ-1 is equipped with three independent measurement sections, two of which have double heads, whereas the central section (No. 3) has a single head. In each section, samples are placed in grip jaws, which are attached to the frame with sliding brackets. The machine is controlled by a PLC unit in a panel cabinet. The sample is placed in a grip jaw between two discs on the motor shaft. Alternate neodymium magnets are symmetrically arranged on the discs. Neodymium magnets mounted on rotating discs act upon the sample and cause its displacement from the equilibrium position. The force acting upon the sample is a combination of the distance between the discs, the strength of neodymium magnets and the length of the analyzed sample. The frequency of changes in the amplitude of sample displacement is determined by the rotational frequency of the engine shaft, which is controlled by the PLC unit via an inverter. The values of fatigue process parameters, such as the number of fatigue cycles, sample displacement (amplitude) and the temperature of the sample's contraflexure region, are registered by the control unit.

Selected parameters of the fatigue testing process are identified as follows: the electric motor (2) is mounted to the base (frame) of the machine (1) (Fig. 5). The engine shaft is equipped with a single or double disc (3) with alternate neodymium magnets (4). The analyzed sample (6) is placed in the jaw grip (5) mounted to the frame. The sample is monitored by an eddy current sensor (7) and a temperature sensor (8). The number of engine shaft revolutions (cycles) is counted by a rotation sensor (9), and the engine's rotational speed is controlled by an inverter (10). Data are transmitted from the sensors to the PLC controller (11).

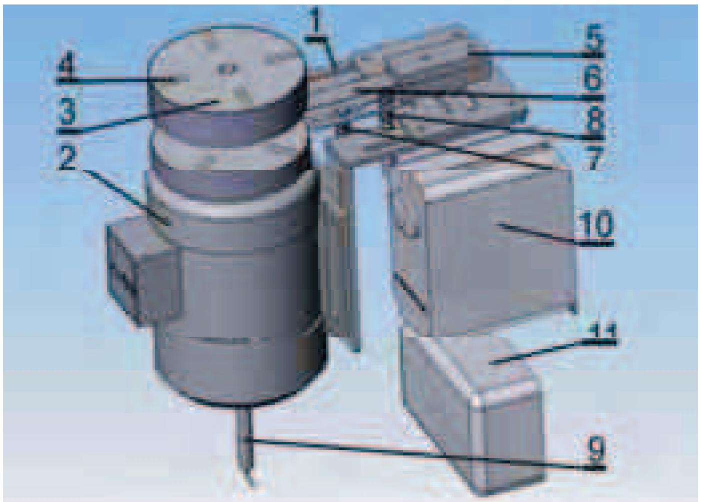

Fig. 5. View of the measurement section with a double head for the identification of selected parameters of the fatigue testing process, 1 – base; 2 – electric motor; 3 – double disc; 4 – neodymium magnets; 5 – sample grip; 6 - analyzed sample; 7 – displacement sensor; 8 – temperature sensor; 9 – cycle meter; 10 – inverter; 11 - PLC controller

The measuring and registering system of the NMZ-1 machine is controlled by the PLC unit with original process management software. Measurement sensors supply the PLC controller with data.

2.2. Sample characteristics

The analyzed samples were flat strips of corrugated sheet metal, which could be fitted into the applied grip jaws. The notch on the sample determined the place of deformation, and it supported the identification of measured and calculated values (Fig. 6). Preliminary tests were performed using samples of DC01 steel.

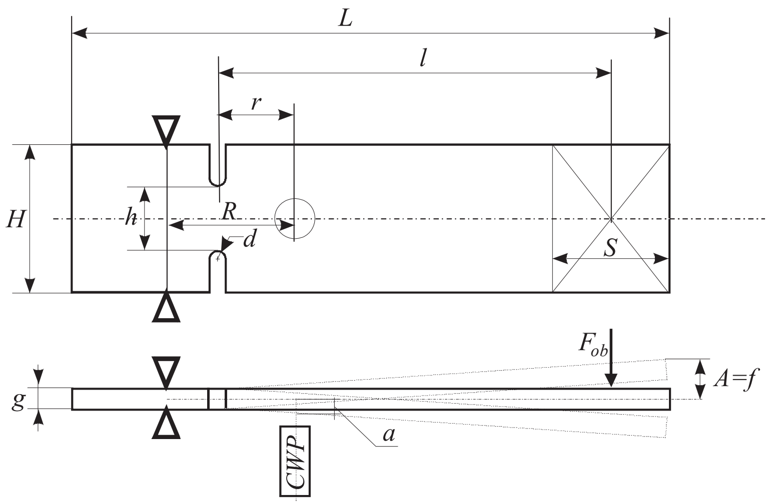

Fig. 6. Principal dimensions of the analyzed sample: L – sample length; l – active face of sample; H – sample width; h – width of sample notch; g – sample thickness; R – distance between the eddy current sensor (ECS) and grip jaws; r – distance between the ECS and sample notch; d – notch radius; S – length of magnetic field acting on the sample; Fob – computed (magnetic) force acting on sample; a – amplitude of the sample's deflection from a state of equilibrium caused by force Fob; A – displacement amplitude of the sample's terminal section; CWP

– *eddy current sensor (CW-10) for the determination of sample displacement*

Stress values at the cross-section of the notch in samples with a constant thickness are determined by the sample's active face (l), its width (H), notch width (h) and the length of magnetic field acting on the surface of the sample (S).

2.3. Measured parameters

The NMZ-1 machine registers and determines the parameters of the sample deformation process. Detailed data registered (measured) during the test and the computed values are presented in Tab. 1. Declared values in the memory of the controller unit in NMZ-1 are shown in Tab. 2.

Tab. 1. Values registered and computed during a fatigue test

No.	Parameter	Symbol	Determination
1.	Number of cycles	L_c [ ]	direct measurement
2.	Amplitude of $RMS_{PEAK\text{-}PEAK}$ deviation of sample	a [mm]	direct measurement
3.	Temperature of sample notch	T [ºC]	direct measurement
4.	Deflection of the sample's terminal section	f [mm]	calculated value
5.	Stress at the cross-section of the notch	δ [MPa]	calculated value
6.	Concentrated load applied to the sample's terminal section	F_{ob} [N]	calculated value

Tab. 2. Declared values in the memory of the controller unit in NMZ-1

No.	Parameter	Symbol	Determination
1.	Excitation frequency	H_z [Hz]	control – stepless adjustment
2.	Sample length	L [mm]	Declared
3.	Active face of sample	l [mm]	Declared
4.	Sample width	H [mm]	Declared
5.	Width of sample notch	h [mm]	Declared
6.	Sample thickness	g [mm]	Declared
7.	Distance between ECS and grip jaw	R [mm]	constant (structural) value R=20 [mm]
8.	Distance between ECS and sample notch	r [mm]	constant (structural) value r= 5[mm]
9.	Length of magnetic field acting on the sample	S [mm]	control – stepless adjustment
10.	Young's modulus	E [MPa]	value characteristic of the analyzed material

2.4. Load model

The computational values of the sample's declared overall and physical dimensions and the machine’s construction parameters (Tab. 2 and Fig. 2) are identified as follows (refer to the symbols in Fig. 6):

Modulus of cross-section bending strength at the notch:

$$W = \frac{h \cdot g^2}{6}\left[m^3\right], \tag{1}$$

The moment of inertia relative to the neutral axis was calculated using the following formula:

$$I = \frac{h \cdot g^3}{12}\left[m^4\right], \tag{2}$$

The displacement of a material point along the sample's active face caused by the neodymium magnet was determined with the below equation:

$$f = \frac{a \cdot l}{r}\left[m\right], \tag{3}$$

The load applied to the active face of the sample was calculated as follows:

$$F_{ob} = \frac{3 \cdot E \cdot I \cdot f}{l^3} [N], \tag{4}$$

Bending stress at the notch of the sample is defined by the below formula:

$$\delta = \frac{F_{ob} \cdot l}{W} [MPa], \tag{5}$$

3. Displacement of the sample's material point in a magnetic field

The deformation of a sample from a state of equilibrium is determined by the force exerted by neodymium magnets attached to the discs. Examples of sample deformation for double and single discs and for symmetrical and pulsating cycles are presented in Figures 7-12.

3.1. Displacement range in symmetrical cycles

Figure 7 presents the displacement range of a material point (mp) in the sample induced by a double disc with four neodymium magnets and rotational velocity of 2 Hz registered by ECS at a distance of r=5±0.1 mm from the notch.

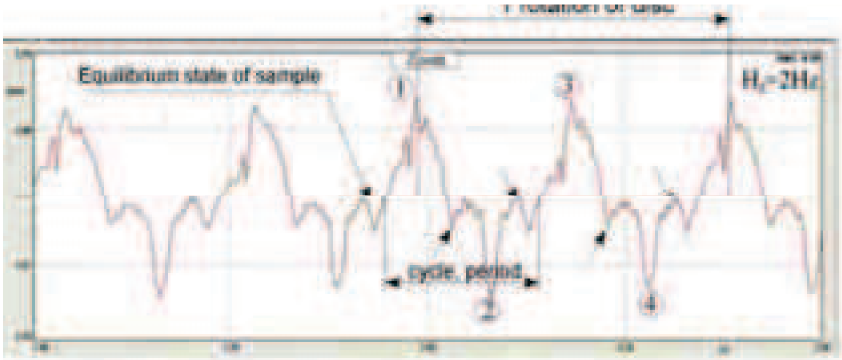

Fig. 7. Displacement range of a material point in the sample induced by neodymium magnets on a double disc, Hz=2Hz

Figure 7 shows the neodymium magnets acting on the sample and the sample's equilibrium state. Fragments of the displacement range clearly influenced by the sample's "elasticity" a moment after it was passed by the magnet are marked with arrows. The differences in time between sample positions 1 and 3, 2 and 4 (cycle asymmetry) resulted from the asymmetric positioning of the sample in jaw grips between the discs. Two stress cycles take place during a full rotation of the disc. The sample's displacement range (r=5 mm) at the observed resonance is presented in Fig. 8.

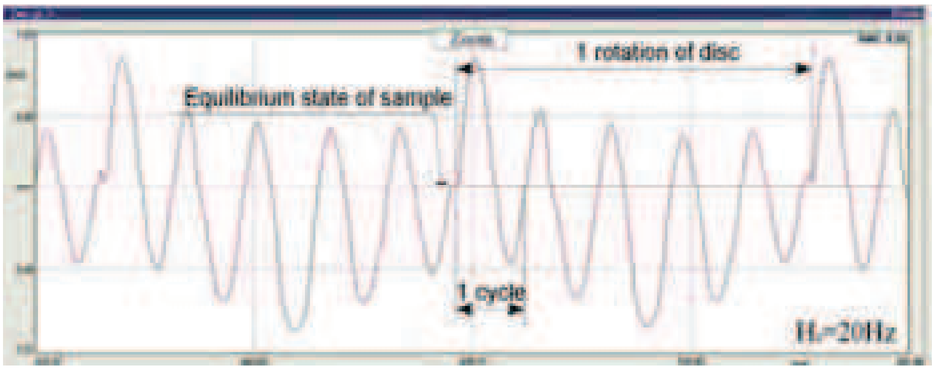

Fig. 8. Displacement range of a material point in the sample at rotational frequency of 20 Hz, excitation – double disc

As demonstrated above, there are five fatigue cycles with relatively high asymmetry per every full rotation of the disc. The above results from the structural and geometrical attributes of the analyzed sample. The displacement range for disc rotational frequency of 50 Hz is presented in Fig. 9. Two fatigue cycles take place during one full rotation of the disc. High cycle asymmetry can be attributed to the asymmetrical placement of the sample relative to excitation discs.

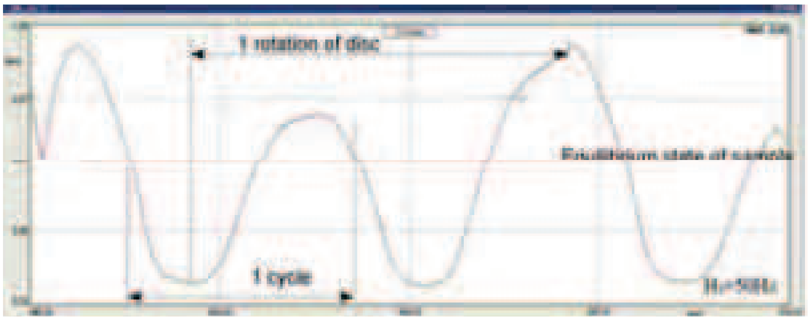

Fig. 9. Displacement range of a material point in the sample at rotational frequency of 50 Hz, excitation – double disc

The displacement range at disc rotational frequency of 100 Hz is shown in Figure 10. Every full rotation of the disc is accompanied by one fatigue cycle.

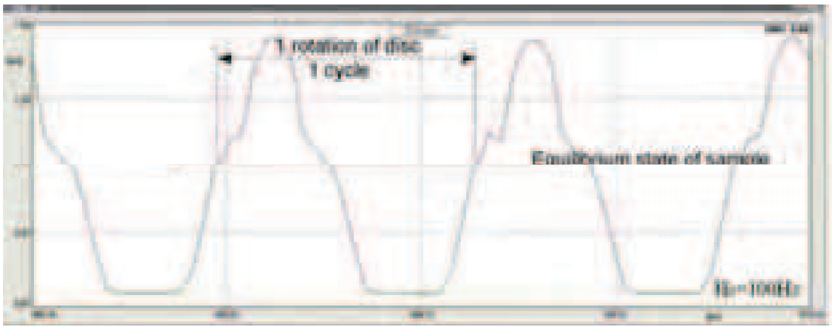

Fig. 10. Displacement range of a material point in the sample at rotational frequency of 100 Hz, excitation – double disc

3.2. Displacement range in pulsating cycles

The displacement range of a material point in an identical sample is presented in Fig. 11 and 12. The displacement was induced by a single disc with two neodymium magnets. When the sample was in a neutral position, the distance between the magnet and underside of the sample was 6±0.5 mm

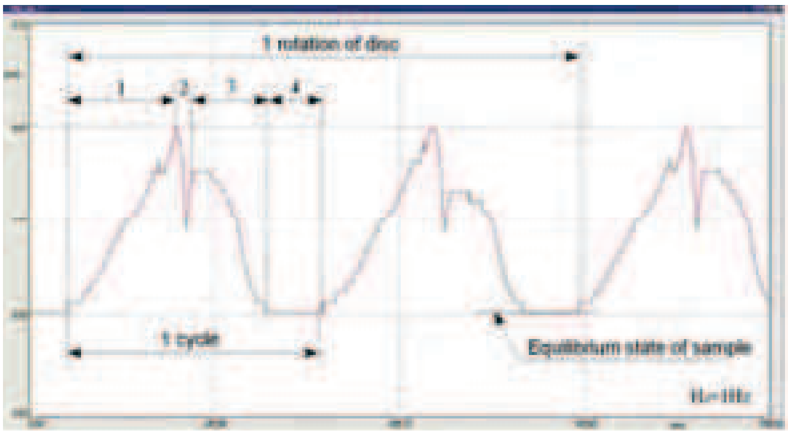

Fig. 11. Displacement range of a material point in the sample at rotational frequency of 1 Hz, excitation – single disc, 1 – deformation of sample; 2 – oscillation when the magnet passed the sample, 3 – return to a state of equilibrium; 4 – sample at a state of equilibrium

The displacement of a material point in the sample during a full rotation of the disc at rotational frequency of 100 Hz is shown in Fig. 12. One full rotation of the disc was accompanied by two fatigue cycles. An increase in the disc's rotational frequency (excitation frequency) resulted in a decrease in the sample's oscillation caused by its rigidity.

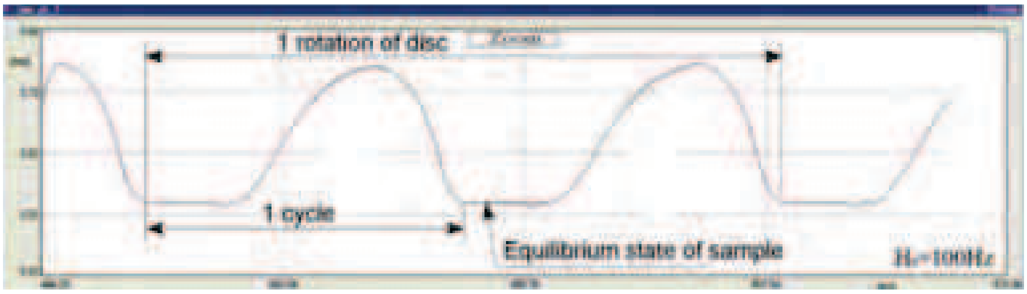

Fig. 12. Displacement range of a material point in the sample at rotational frequency of 100 Hz, excitation – single disc

The controller and the implemented software support observations of changes in the sample's notch temperature and amplitude of RMS deviation as a function of the number of fatigue cycles (Fig. 13 and Fig. 14).

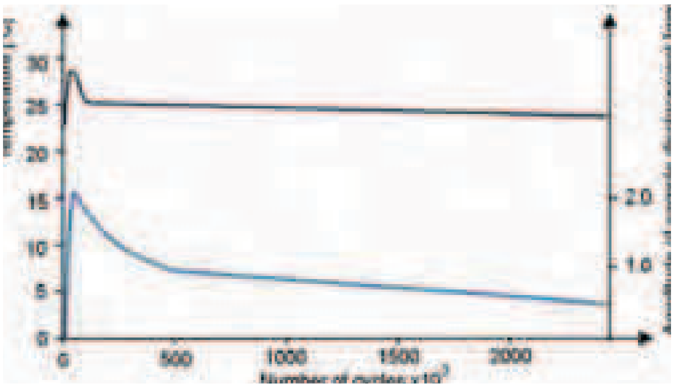

Fig. 13. Changes in the sample's notch temperature and displacement amplitude during test cycles – the sample was not damaged

Fig. 14. Changes in the amplitude of sample displacement during test cycles – the sample was damaged

4. Conclusions

A wide range of methods for analyzing material fatigue with the use of different signals has been discussed in literature [2, 5]. This study proposes an original method for analyzing the wear of construction materials using a neodymium fatigue testing machine. Sample vibrations are induced by neodymium magnets mounted on rotating discs. In the presented solution, the following parameters of the sample deformation process are registered: amplitude of RMS deviation from the sample's equilibrium state, temperature of sample notch, deflection of the sample's terminal section, stress at the cross-section of the notch and concentrated load applied to the terminal section of the sample. The presented machine will be used in follow-up research to determine the correlations between fatigue strength and vibration signals generated by samples.

A patent application has been submitted to the Patent Office for the discussed machine, described as "Device for non-contact fatigue testing of construction materials", application No. P393316 of 16 December 2010.

Acknowledgements

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