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DEVELOPMENT OF DEVICES FOR TESTING DYNAMIC DURABILITY OF MATERIALS

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RESEARCH ARTICLE

ABSTRACT: Many automotive parts are exposed to complex dynamic stresses during their exploitation. For the design of such elements as shafts, axles, etc., it is necessary to perform fatigue testing in order to obtain permanent dynamic strength of the part. For the purposes of such tests, a device has been developed that provides the possibility of dynamic testing of parts loaded only by torsion, only on bending or parts that are loaded with combined bending and torsional stress. The device provides the possibility of testing cylindrical workpieces. The obtained experimental data show that the maximum error of measuring the dynamic strength of materials at complex stresses is 5%.

KEY WORDS: *body structures, fatigue strength, devices for testing material, dynamic durability, combined stress*

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RAZVOJ UREĐAJA ZA ISPITIVANJE DINAMIČKE IZDRŽLJIVOSTI MATERIJALA

REZIME: Mnogi automobilski delovi su tokom eksploatacije izloženi složenim dinamičkim naprezanjima. Za projektovanje elemenata kao što su vratila, osovine itd., potrebno je izvršiti ispitivanje na zamor kako bi se dobila trajna dinamička čvrstoća dela. Za potrebe ovakvih ispitivanja razvijen je uređaj koji pruža mogućnost dinamičkog ispitivanja delova opterećenih samo torzijom, samo na savijanje ili delova koji su opterećeni kombinovanim savijanjem i torzionim naprezanjem. Uređaj pruža mogućnost ispitivanja cilindričnih delova. Dobijeni eksperimentalni podaci pokazuju da maksimalna greška merenja dinamičke čvrstoće materijala pri složenim naponima iznosi 5%

KLJUČNE REČI: *strukture karoserije, čvrstoća na zamor, uređaji za ispitivanje materijala, dinamička izdržljivost, kombinovani naponi*

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INTRODUCTION

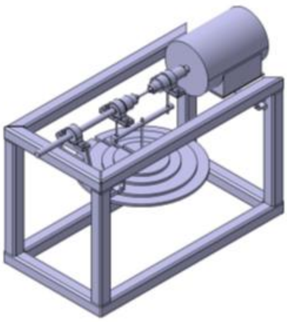
Metal parts that are exposed for a long time to the dynamic effect of a force of variable intensity and direction break even though the intensity of the stress that causes the break is smaller than the force at the yield point of the tested material under static stress. Due to the long-term effect of periodically changing loads, gradual destruction of the material may occur. This phenomenon is called fatigue, and the fracture caused by it is a fracture due to fatigue. Fractures due to material fatigue are very dangerous in practice because they are not preceded by plastic deformation even in tough materials. Initial cracks caused by fatigue are the sharpest natural cracks, which in complex dynamic systems can hardly be detected before the fracture occurs. One of such systems is the car, where not only axles, shafts, crankshafts, transmission levers, screws, etc., but also toothed and chain transmissions, rolling bearings, roller and spherical parts exposed to abrasion are exposed to dynamic, variable loads. Product durability is related to three main factors: structure, load and material. The endurance performance of an automotive product depends not only on the structure configuration, but also on the dynamic load characteristics and fatigue properties of the materials [1]. Due to the fact that automotive vehicle loads are dynamic in nature, one of the main technical challenges for product durability design is how to quantify the fatigue damage sensitivity. Su [1] uses a finite element model and a developed mathematical model to simulate the dynamic stresses of the structural system of car axles, which would simultaneously act on the car on the road. The obtained results show the level of influence on the durability of components under dynamic loading in relation to different design variables.

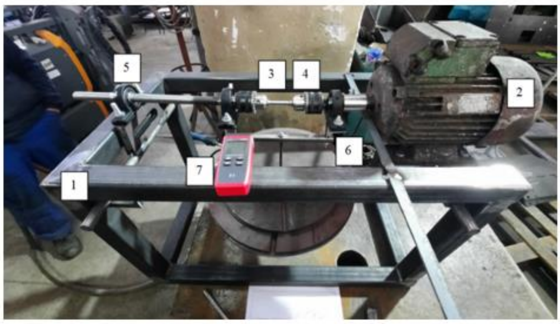
In the 1950s, fatigue testing devices were introduced, which enabled tests with real loads of samples, components and entire mechanical systems. From then until today, there are numerous literature references on the design of devices for dynamic stress testing of materials, all with the aim of assigning complex and variable loads that occur in real conditions. The life of an automatic weapon is a leading requirement in the field of automatic weapon design. This problem is discussed by Lingl et al. [2] in their work, developing a device for fatigue testing of mechanisms of automatic weapons due to impact loads, thus reducing component manufacturing costs and improving component design reliability. Ghielmetti et al. [3] in their work describe the development of an electromechanical fatigue test machine with force control, as well as the corresponding software, for flat specimen testing. The advantage of this device, taking into account the appropriate accuracy of the obtained results, is its simplicity and low cost. The work of Bhatkar et al. [4] describes the design and production of a dual fatigue testing machine. Currently available devices for fatigue testing of materials have a very high price, and the authors designed an economical, compact and efficient device, which uses two types of mechanisms for fatigue testing of samples of mild steel material (bending with constant or shock loads). In their work, Rajesh and Saravanan [5] develop an economical device for fatigue testing of materials with 95% efficiency. The authors emphasize the simplicity of its modeling of the device and ease of understanding [6-8]. More than one sample can be tested simultaneously on the material fatigue tester. The design of a device for testing two samples of different materials simultaneously was presented by Shreyas et al. [9]. The developed device uses less energy during the test and it is environmentally friendly because it has one motor, shortens the test time, and a comparative analysis of the obtained results for both samples can be done at the same time.

This paper presents the development of a simple and economical device for material fatigue testing, which can be used for educational and research purposes, as well as applied in industry.

1. METHODS AND MATERIAL

The developed device provides the possibility of determining the permanent dynamic endurance during rotational bending of the part. The bending force is realized by weights in the direction normal to the axis of the sample, creating compressive stresses above and tensile stresses below the axis of the sample. As the tested sample rotates around its own axis all the time, compressive and tensile stresses will alternate cyclically in all the fibres of the tested sample. The period of oscillation will solely depend on the set rotation speed of the sample.
Figure 1a) shows the 3D model of the device designed in the Catia program.


a) 3D model



b) developed device

Figure 1 Material fatigue testing device

The developed device shown in Figure 1b) is composed of standard and specially made parts. The entire measuring system is placed on a stable frame (1), made of steel box profiles. An electric motor (2) with a power of 0.75 kW, with 1450 rpm is attached to the frame via the bogie. Bogie of the electric motor enables elastic deformation of the sample under the action of normal force, which causes torque transmitting shaft rests on three MSC UCP 204 bearings. The bearing (5) is also mounted on the bogie to apply a given normal force to the specimen deformation. The system for setting a normal load consists of a weight carrier (6), on which different weights of 8 kg, 12 kg, 24 kg, 32 kg and 40 kg are placed. As one cycle of stress is completed for one revolution, by measuring the number of revolutions of the specimen until breaking, the number of stress cycles of the specimen is also measured. A UNI-T UT373 digital counter (7) was used to measure the number of revolutions of the sample until it broke. The specimen is placed in the testing device, the load (bending moment) is applied until it breaks, and the number of revolutions that the specimen endured until it breaks is read on the digital counter. Performing a series of tests on identical specimens with different stresses enables the creation of an S-N curve (Weller curve) [10].
The main difference between the axial fatigue test method and the rotational bending method is that the axial fatigue test applies a uniform stress over the entire cross-section of

the specimen being tested, while the rotational bending fatigue test is performed under the action of a stress that increases linearly from 0 at the neutral axis to maximum stress on the surface of the specimen.
The specimen used to test the dynamic durability of C10 steel material is shown in Figure 2. Five samples of C10 material were tested, for each given load.

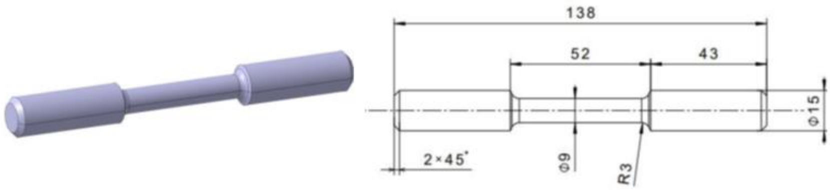


Figure 2 Test specimen made of material C10

The investigation was conducted on the specimen made of unalloyed steel C10 whose chemical composition is: ≤ 0.12 % C, ≤ 0.35 % Si, ≤ 0.5 % Mn, ≤ 0.045 % P, ≤ 0.045 % S. The mechanical and physical characteristics of unalloyed steel C10 are: elastic modulus = 210 GPa, hardness = 610-680 HB, tensile strength = 420-520 MPa, yield strength = 250 MPa, Poisson ratio=0.3 and density=7.8 g/cm3, fatigue strength = 180-240 MPa. In carburized and quenched condition it is used for light-duty structural parts with soft core and hard case, for sample pins, shafts, axles, hubs.

2. RESULTS

Table 1 presents the input data during fatigue testing of materials, for given loads with weights of mass m of 8, 12, 24, 32 and 40 kg, based on which the weight W, i.e. the force acting on the tested samples, can be determined. Based on the shaft length L=346.5 mm on which the load acts and the diameter of the test tube D=15 mm, the moment M and the bending stress σ are calculated.

***Table 1** Input data of testing material C10*

Load m, kg	W=m·g, N	M=L·W, Nmm	$\sigma=32\cdot M/(\pi\cdot D^3)$, MPa
8	78.48	27193.32	82.112
12	117.72	40789.98	123.169
24	235.44	81579.96	246.337
32	313.92	108773.28	328.450
40	392.40	135966.60	410.562

After the test, the results are obtained and shown in table 2. The results are the mean values of measurements of five specimens for each applied load.

***Table 2** Test results of material C10*

Load m, kg	No. of cycles to failure N	Time taken, s
8	80378	3326
12	66700	2760
24	17376	719

32	6960	288
40	3891	161

Figure 3 shows the Weller curve with the obtained results. On the diagram, the red, dotted line shows the exponential trend of the data, because the material testing device has losses that reduce the accuracy of the results obtained.

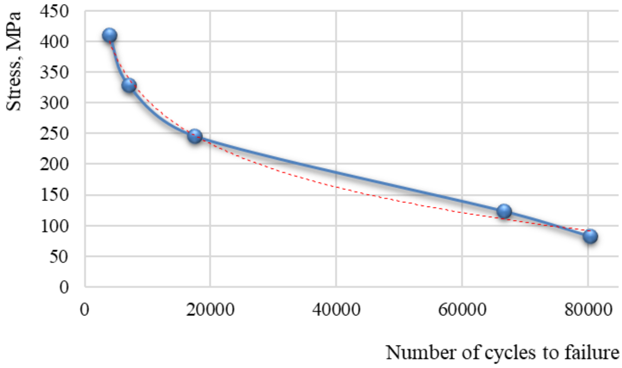


Figure 3 Weller's curve stress-number of cycles S-N

Figure 4 shows the fracture appearance of the specimen after testing with different loads.

a) minimal load b) maximal load

Figure 4 Fracture of the specimen under different loads

The developed device provides the possibility of testing the permanent fatigue strength by applying different types of stress, with minor modifications. In the event that the specimen with a cylindrical cross-section is clamped in both universal clamping heads, then in addition to the bending moment, tensioning stresses in the axial direction also act on the test tube, which occur as a result of bending the specimen. If the chuck (4) is released, the axial component of the force will disappear. In the event that, in addition to the described stresses, the twisting moment of the specimen needs to be varied, it is possible to install some type of brake behind the bearing (5) on the shaft that passes through it, which will achieve the desired resistant torque. In addition to the mentioned methods, it is possible to improve the device in terms of vibration reduction by installing flexible connections between the drive and measuring system as well as between the bogie and the frame.

3. CONCLUSION

Literary sources and the results of conducted experimental research confirm the possibility of applying the developed device for testing the dynamic durability of material samples or finished cylindrical products loaded during exploitation with different types of combined stresses: bending and pressing; tensioning, bending and pressing; twisting, bending and pressing; twisting, tightening, bending and pressing. The specified combinations of stresses during the dynamic durability test enable the testing of a large number of parts used in the automotive industry.

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