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PRACTICAL APPROACHES TO QUALITY TESTING OF PIONEER MACHINES

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Abstract: *Pioneer machines, such as diggers, are particularly challenging to test, especially under real operating conditions. This paper presents a practical approach to quality testing of pioneer machines, using a digger as a representative case study, based on procedures applied at the Technical Test Center.*
The study in this manuscript focuses on the implementation of testing procedures required to verify compliance with specified technical characteristics and manufacturer requirements for a digger as a representative machine for the case study. Emphasis is placed on practical testing methods used at the Technical Test Center, including measurement techniques and testing conditions that ensure reliable and repeatable results in real operating environments. The results obtained were based on precise measurements within different testing frameworks and were evaluated against relevant standards and regulatory requirements.
Following the completion of all testing procedures, an overall assessment of the level of compliance with the required characteristics was conducted. In addition, the usability and future potential of the machine were evaluated from the perspective of its design and the analyzed performance characteristics.

Key words: *pioneer machine, testing, digger, exploitation.*

1. INTRODUCTION

The highest hierarchical principle of equipping and developing the Defence system is “creating maximum combat readiness”. That principle is realized with quality means at the level of competitiveness on the world market of armament and military equipment [1]. The degree of quality of an asset intended for the Defence system is evaluated by testing at the Technical Test Center (TTC).

The Technical Test Center is a scientific research institution established by the Serbian Ministry of Defence for testing different parts of armament and other equipment that is going to be part of the official armament of the Serbian Army. The Technical Test Center is testing various parts of regular classic armaments (classical infantry and artillery, missile, aviation, naval, etc.), ballistic protection equipment, different types of electronic equipment and systems, vehicles (combat, non-combat, special), pioneer machines, aircraft, etc. Tests are performed in laboratory, testing ground, and field conditions. All the measurements and tests performed and being conducted at the TTC are defined by both international and domestic standards. Likewise, the TTC is making some new standards and new test methods based on experience and modern achievements in measurement techniques and new measurement equipment. The measured values are being analyzed and compared both with the required characteristics specified in the standard and with the declared characteristics of the manufacturer, after which a decision is made on official use in the Serbian Army [2].

The pioneer machines are machines made for hard work in the construction industry, road construction, snow cleaning, and all other work that needs a lot of energy and force to be used in it [3]. One of the pioneer machines that is commonly used in the Serbian Army units for various heavy works is the digger. It is a self-propelled combined excavator-loader, which is being used for heavy land working and loading of material, material excavation, and heavy material moving with an integrated loader bucket as a working tool [4]. The machine has a lot of different additional equipment that gives us different possibilities: to break materials, dig holes in different ground types with a diameter depending on the used drilling tool, strip different layers of land, asphalt, and concrete, and meet

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various other demands as it is stated in [4] and [5].

Within the framework of pioneer machine testing at the TTC, a comprehensive evaluation is conducted with the aim of determining the level of compliance with all required technical characteristics and tactical/technical requirements defined by the customer (in this case, the Serbian Army). The testing includes an assessment of the machine`s usability under real exploitation conditions, taking into account specific operational requirements imposed by the user, as well as an evaluation of the modernity and future viability of the applied technical solutions, both at the level of individual subsystems and the system as a whole [4]. The majority of the tests are carried out with a focus on determining the exploitation and maneuvering capabilities of the machine.

The object of examination in this manuscript is a digger which is now in use in the Serbian Army, model JCB 4CX (Figure 1), with the following tools:
- loading bucket,
- digging spoon,
- soil drill,
- fork,
- hydraulic breaker.



Figure 1. Test object, digger JCB 4CX

2. PIONEER MACHINE TESTING

For this tested pioneer machine, first the Test Program is prepared in order to determine all parameters and characteristics that will be checked. The basis for the Testing Program is the declared characteristics of the manufacturer, the tactical/technical requirements of the institution that orders the testing (the Serbian Army in our case), as well as new standards and methods for testing. All tests will be performed according to the adopted Test Program.

The purpose of the test is to assess:
- Satisfaction of the tactical-technical requirements of users,
- Compliance of the declared characteristics with the tactical/technical requirements,
- Usability of the asset in real conditions,
- Modernity and perspective of the applied solutions,
- Ease of handling and maintenance.

Generally, mechanical testing of excavators consists of four stages, as shown in the block diagram in Figure 2.

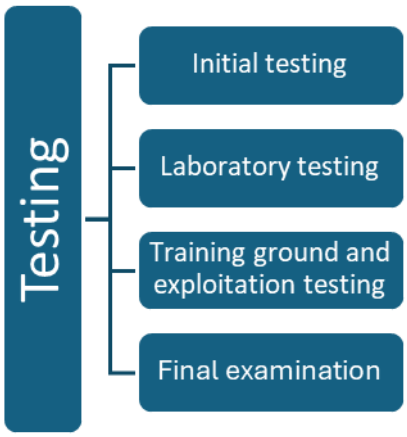


Figure 2. Test phases

2.1. Initial testing

Initial testing is carried out with the aim of determining whether there are basic prerequisites for conducting the test. First, the completeness of the construction documentation and identification data of the asset and basic subassemblies are determined, as well as a comparison of basic parameters with available documentation. The validity of attestations and certificates is checked. The general condition and proper functioning of the device are visually determined.

The intention of this part of testing the pioneer machine is as follows:
- recognition and identification of all constituting parts of the digger, machine sets and assemblies according to the technical documentation of the machine provided by the manufacturer,
- checking of the engine and engine systems, including the parts they are made of, specifically measurement of some engine and engine system parameters (air suction system, engine fuel supply system, system for engine lubrication, exhaust system, engine cooling system, checking the level of all working fluids in the engine, heating and ventilating system of a digger, etc.),
- transducer installation for some engine parameters (temperature of oil, cooling fluid etc.),
- checking the built-in parts of the digger transmission, tyres, measuring tyre pressure, all fluids and fluid levels in transmission sets, and checking the functionality of the digger transmission, etc,
- identification of the parts of the digger's braking, steering, and hydraulic systems (hoses, pumps and motors, small additional tools attachment set, etc.), fluid levels in all mentioned systems, etc.;
- Electromagnetic compatibility (EMC) characteristics (in documentation);
- basic checking of the functionality of all digger systems and simulation of work with machine tools.

Following the completion of all initial tests, it is necessary to conduct, at the end of the initial tests, a trial run of approximately 20 km on an asphalt road, in order to evaluate the performance and functional behavior of all components, assemblies, and the machine under

operational conditions [4].

2.2. Laboratory testing

Laboratory testing is customized for each individual machine and performed with respect to the specific characteristics of the test object. It generally consists of several stages and associated measurements, including:

- Geometric parameters of the machine [6],
- Digger mass characteristics – total mass of the machine, machine weight distribution by wheels and axles, machine center of gravity [7],
- Backward movement,
- Ergonomic noise characteristics – internal noise level in the cabin, external machine noise level, siren noise level [8],
- Ergonomic temperature characteristics in extreme environmental conditions – at temperature levels from -30ºC to +50ºC, checking the engine start at low (-12ºC) and high (+46ºC) ambient temperatures [9], [10],
- Determining Predicted Mean Vote (PMV – seven-point thermal scale that shows to what extent the comfort temperature is achieved in the real environment, namely: -3 (icy), -2 (cold), -1 (moderately cold), 0 (comfortable), 1 (moderately warm), 2 (warm), 3 (hot)) and Predicted Percentage of Dissatisfied (PPD - predicts the percentage of people dissatisfied with the thermal environment, that is, the percentage of people who will feel thermal discomfort in a certain real environment) index at low external temperature (-16ºC) and normal external temperature [11], [12],
- Characteristics of all electrical wiring systems and electrical equipment, voltage levels, current intensity, short circuit protection, insulation, alternator voltage level [13], [14],
- EMC characteristics [15],
- Corrosion protection [16],
- Safety features,
- Features related to environmental protection.

2.3. Training ground and exploitation testing

Training ground and exploitation tests include the examination of functional and other characteristics in real conditions of exploitation, which derive from the name of the means being tested, as well as the set requirements. The main goal of this test phase is to get as close as possible to the realistic working conditions of the machine. Polygon and exploitation tests involve some of the most intensive testing conditions we can put on a single machine. These tests include:

- Dynamic characteristics testing [17], [18], [19],
- Intensive driving testing of the machine in a few specific road conditions [20],
- Reliability, efficiency and durability of work tools,
- Accuracy, precision and life expectancy, etc.,
- Safety and resilience.

Testing the mechanical durability by driving on different types of roads is a mandatory part of this test phase, and when it comes to machines, it is also mandatory to test the work with all the tools that are mounted on it, also in different conditions.

The most important dynamic characteristics of the machine are:

- Stability and passability (overcoming longitudinal and lateral slope, clearance) [21],
- Handling performance (turning radius, steering sensitivity),
- Braking performance (stopping distance),
- Startability (acceleration and maximum speed).

Within the mentioned object of testing, dynamic characteristics according to [17] are being determined:

- Evaluation of the machine's capability to overcome longitudinal and lateral inclinations (gradients), including stability and mobility performance under such conditions,
- Wheel radius (static, dynamic);
- Evaluation of the machine's handling characteristics, including minimum turning radius and steering response sensitivity under defined operating conditions [22],
- Testing the braking system, braking distance measurement in driving testing [23],
- Highest and lowest velocity in manual and automatic mode in all gears,
- Acceleration in manual and automatic mode in all gears and acceleration from minimum to maximum velocity,
- Vehicle resistance using the coast method, etc.

Intensive driving testing of the machine in a few specific road conditions is a very important part. This is specific for a vehicle and/or machine by itself. For this object of testing - a digger, it includes driving of the machine for around 500 km, under a few different road conditions: about 250 km on plain and hill ground road and about 250 km under heavy off-road conditions.

While driving, some basic indicators are being monitored, where the most important are:

- Test road conditions, ground and meteorological conditions while driving for every day of testing,
- Total distance driven in kilometers per day and in total,
- Driving time, per day/total, time of standing (non-work time),
- Failures, fractures, and possible crushed parts of the machine construction that occur while testing is being done, with the number of kilometers at which the failure occurs being recorded,
- Regular maintenance, adjustment, and servicing while testing, with the number of kilometers being recorded,
- Durability of parts and sets in transport.

Reliability and efficiency of digger working tools are a special phase of testing. In this phase, work with the digging spoon is performed for a total of 25 engine working hours, while excavating, laying-off, and loading land, and working with the loading spoon is performed for a total of 25 engine working hours [4].

The objective of this testing is to verify and evaluate the following parameters:
- maximum excavation depth,
- ground reach of the excavator arm,
- kinematic and functional characteristics of the bucket, including digging speed, bucket width, and load-carrying capacity, as well as the operating speed of the loading shovel,
- functionality of the hydraulic control system, maximum working pressure within the hydraulic installation, condition of hydraulic hoses, and integrity of the system with respect to leakage and overall operational reliability.

Parallel with testing, the quality of oils is being checked, together with digger fuel consumption (in all different road and working conditions) and engine characteristics when working under maximum load, high external temperature levels, etc.

If auxiliary attachments are integrated into the machine (e.g., hydraulic hammer, concrete saw, drilling, etc.), additional testing procedures are required, including:
- verification of functional performance over a continuous operating period of 5 hours during the processing and fragmentation of various materials,
- assessment of drilling capability for boreholes with diameters up to 950 mm,
- evaluation of performance in the removal of asphalt and concrete layers with widths up to 400 mm and depths up to 120 mm,
- testing of cutting efficiency and the capability for demolition of concrete structures,
- evaluation of performance in auxiliary operations such as snow removal, etc.

2.4. Final examination

Final tests are carried out with the aim of determining whether there are any major failures or major deviations from the initial machine characteristics. Usually, all the parts of initial testing are performed again, but this time with the goal of determining major differences between the start and the end of the machine testing and deviations from the machine construction documentation.

3. ANALISE OF TEST RESULTS

3.1. Results of initial testing

At initial testing of a digger the conclusions were:
- All parts and sets are made according to the documentation of the machine provided by the machine manufacturer;
- All parts and sets are working correctly,
- All the fluids in assemblies are at proper levels that are set by the manufacturer. Also, the working fluids in the machine are filled according to technical documentation and maintenance manual, provided by manufacturer of the machine,
- Digger start-up is smooth and continuous, without abrupt or irregular dynamic responses,
- Transmission is working properly in manual and automatic mode and when moving forward and in reverse, in every gear, etc;
- The braking system is working, as well as the steering system,
- All digger sets are working without irregular responses,
- Additional tools are working properly,
- Digger is equipped with appropriate safety systems, including rollover and falling object protection, an adjustable steering mechanism, adequate ventilation, a safety belt, an audible warning device, and other relevant operator safety features, etc.

3.2. Conclusions of laboratory testing

The measured dimensions (including transport height, width, length, bucket width, etc.) comply with the required specifications, with negligible deviations of less than 5%, which are considered acceptable within the measurement tolerance limits, as stated in [4].

According to [4], the angles of the rear wheel turning are from 15° to 18°, which is acceptable. Also, the total mass and axle mass distribution are according to the documentation provided by the manufacturer.

The results of the digger cabin noise level measurements are given in Table 1.

Table 1. Digger cabin noise level

Noise level	Digger cabin	Directive 2003/10 [24]
Close windows	79,5 dB	Above 72 dB
Open windows	84 dB	Below 86 dB

The low and high temperature testing is performed according to [9] and [10], with all the required test preparations and conditions. The engine has successfully started both at high external temperature (+46ºC) and low external temperature (-12ºC) in the cooling and heating test chambers.

Together with high and low external temperature digger testing in cooling and heating chambers, the efficacy of the cabin heating system has been tested [11], [12], as shown in Table 2.

Table 2. Digger cabin heating system efficiency

Digger cabin	PMV	PPD
Measured	-0,5	10%
Criteria	-0,5≤PMV≥+0,5	≤10%

The electrical installation of the machine was characterized as follows:
- the conductors are adequately protected against mechanical influence,
- the alternator provides stable and reliable power supply, ensuring proper battery charging and maintenance,

- the minimum measured insulation resistance was 400 MΩ. Narrow-band interference at high frequencies slightly exceeded 400 MHz, with a maximum permissible deviation of 5 dB,
- prior to operation, the measured voltage drop ranged from ΔU = 0.30 V to ΔU = 1.25 V. After a 500 km test drive and 50 engine operating hours under working conditions (earth excavation), the voltage drop increased to a range of ΔU = 0.70 V to ΔU = 2.25 V, indicating a significant increase compared to the initial measurements. The system maintained a constant voltage of 14.4 V across an engine speed range from 500 rpm to 3000 rpm, with regulation provided by the alternator voltage controller.

3.3. Conclusions of training ground and exploitation testing

Dynamic characteristics of the machine were:

- Equal digger velocity at all gears, both in forward or reverse, except 4th gear, 38.9 km/h in reverse/ 40 km/h in forward motion (digger meets the demand for a maximum velocity of 40 km/h/or in the range of 40 km/h to 50 km/h),
- Satisfactory tire rolling radius according to the technical documentation provided by the manufacturer;
- The braking performance of the machine was assessed as satisfactory. Type "0" brakes with engage/disengage clutch demonstrated adequate efficiency, as the measured maximum stopping distance was below the permissible limit. The performance of Type "I" service brakes was also evaluated as satisfactory. The parking (hand) brake was capable of holding the machine stationary on the maximum tested gradient of 30%.

Testing of the machine in intensive driving conditions was performed similarly to [4] on plain-ground roads and under heavy off-road conditions. The average velocity of 14 km/h on plain roads and an average velocity of 15,5 km/h under heavy off-road conditions was rated as positive for this type of machine.

Functional performance and operational safety under working conditions were evaluated during excavation operations using both the backhoe bucket and the loader bucket over 50.6 engine operating hours, also similarly to [4]. The backhoe bucket was utilized for earthworks in soil of category II, while the loader bucket was also operated under category II soil conditions. During the test, the temperature of the engine fluids was monitored. The results obtained were within acceptable limits and were assessed as satisfactory.

Some characteristics of the digger, measured within exploitation tests, are given in Table 3:

Table 3. Some digger characteristics

Digger	Measured	Demand
Max. digging depth with spoon	5970 mm, fulfill	More than 5800 mm
Digging spoon velocity	0,24 m^3	-
Lifting Force of digging spoon, extracted telescope	1200 kg	
Lifting Force of digging spoon, sucked telescope	1550 kg	
Loading spoon velocity	1,22 m^3	
Lifting Force of forks integrated with spoon	1000 kg	
Total rate of flow	152 l/min	
Max. working presure	226 bar	

4. CONCLUSION

The combination of a backhoe and loader on the same engineering machine is the most optimal solution for the needs of the army. This model has a multi-purpose loading hydraulic opening bucket, according to the 6-in-1 system, with bucket blade protection and an additional fork. The machine has a power shift transmission and a high level of comfort. The construction of the digger ensures quick assembly of all additional tools (hydraulic hammer, spiral drill, fork, hydraulic breaker, concrete grinder, etc.), which is of particular importance for the purpose of the army pioneer units.

However, in terms of construction and workmanship, minor defects were observed. The measured turning angle of the wheels is less than required. The noise in the cabin is higher than allowed and a voltage drop was also found in some parts of the electrical installation, which directly affects the driving and working conditions in operational conditions.

Based on the comparison of the obtained results with other solutions of this type of pioneer machines, as well as based on the previous experience of researchers at the Technical Test Center, the summary view is that the digger meets the set requirements and is a promising product in terms of intended use.

This paper presents one approach of the TTC when testing a pioneer machine. With the results obtained by precise measurements, the customer can come to a conclusion as to whether a certain product meets the conditions for use and procurement or not. In this specific case - testing of the digger, the results are mostly positive, with minor defects, which do not significantly affect its operational use. We believe that this approach is expedient and recommended when purchasing this type of machine. Certainly, there is always the possibility of additional tests and checks, all in accordance with the needs of the client.

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