Estimation of adequacy of the simulation model of a water-jet propulsion drive of high-speed tracked amphibious vehicles.

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Abstract. There is a research study of the dynamic properties of water jet drives designed both for different high-speed tracked amphibious vehicles types and for various loads. It is within the framework of the problem solving of dynamic loading decrease of high-speed tracked amphibious vehicles water jet drives. To achieve this goal, a mathematical model was synthesized and a simulation model was developed. During experimental studies the validity check of simulation mathematical model of high-speed tracked amphibious vehicles water jet drive operation was carried out. In this regard, various operating modes in specific transients were taken into account.

1. Introduction.

The performance of high-speed tracked amphibious vehicles (HTAV) increases continuously – specificity, speed, propulsion qualities, agility, reliability, durability, and all they depend directly on quality and dynamic loadings of the components and units. In the HTAV the water jets rotation is provided through mechanical drive comprising spatially arranged cardan drives (driveshafts). Design of water jet drive (WJD) must have high reliability level because failure of one drive element eliminates HTAV movement possibility. Operating experience of HTAV and results of experimental study indicate the constraints of WJD elements durability. The functional failures (up to 85 %) occur due to excitement of oscillating processes.

Despite the lack of dedicated materials on the high-speed tracked amphibious vehicles many of topical issues are considered in publications that devoted to shipbuilding, for example, under editorship of Ya. Voytkunsky [1]. Enormous efforts in the field of studying of amphibious vehicles were carried out by A. Stepanov which wrote many separate works, handbooks, manuals, articles, where he has considered forces acting on amphibious vehicle afloat and described a choice of water propulsion unit depending on specific conditions [2]. Water propulsion units were considered by A. Rusetsky [3], A. Papir [4], S. Kulikov [5] in sufficient detail. In these works the jet theory of water propulsion units is in detail considered as well as the techniques for optimum elements determining for given conditions of engineering are offered. However, the issues of WJD dynamic loading are not considered in these works.

At the same time, the known techniques of drive design study, for example by V. Panteleev [6], provide structural strength and durability under load actions that are defined by dynamic factor.
without frequency characteristics of loading process and amplitudes during oscillating processes. It leads to life limitation of WJD elements. The analysis of known design calculation techniques testifies that an evaluation of WJD dynamic loading features does not receive required attention. In classical design calculation techniques the nominal sizes of drive parts are obtained from a guarantee condition of required hardness and durability indexes from the loads the dynamism of those is considered in calculation by the unique characteristic – dynamic factor.

In this regard, the problem of forecasting of WJD dynamic loading during the design phase and determination of its dynamic characteristics gets increasingly urgency.

There is a research study of the dynamic properties of WJDs designed both for different HTAV types and various loads. It is within the framework of the problem solving of dynamic loading decrease of HTAV’ WJDs. During experimental studies the validity check of simulation mathematical model of HTAV’ WJD operation was carried out. In this regard, various operating modes in specific transients were taken into account: acceleration of water jets afloat and ashore; water entry and exit to the shore; change of the reversing mechanism status; the steady-state modes of the vehicle movement with constant speed afloat.

Collecting the required volume of information for any HTAV’ WJD types that differ in design and operating environment is represented impracticable. In such task definition the scope and duration of field tests are very extensive for statistical data collection.

Capability to analyze model in operation distinguishes the simulation modeling from other methods, for example, use of Excel, Mathcad, or linear programming. Application of simulation modeling allows to study processes and to make changes to simulation model during operation that allows to analyze system operation better. When performing development works the application of simulation modeling allows to apply repeatedly simulation model in homogeneous numerical experiments, and after evaluation of results there is possibility of optimization of engineered article characteristics, as well as possibility of decreasing of time, working hours and materials for carrying out of large amount of natural experiments, tests and troubleshooting at the stage of article development [7, 8].

LMS Imagine.Lab AMESim is one of many program platforms for modeling of technical objects and multidisciplinary mechatronic systems. [9, 10, 11].

Figure 1. WJD’ simulation mathematical model developed using LMS Imagine.Lab Amesim. [12]
In the paper [12], for determination of HTAV’ JWD dynamic loading features a task of simulation mathematical model synthesis in LMS Imagine.Lab AMESim (Figure 1) was set that allows to define:

- dynamic torques and their frequency characteristics;
- power and kinematic parameters characterizing the dynamic torque dependence on speed of the engine shaft;
- stability of system: water entry and exit to the shore; straight-line movement afloat; and S-turn maneuvering;
- characteristics of dynamic loading of the WJDs elements used for evaluation of their durability and formation of loading spectra of the corresponding elements;
- processes of time-to-time variation of rotational speeds and accelerations of separate transmission links used for an evaluation of transient modes’ quality.

For checking of validity of the developed simulation mathematical model of HTAV’ WJD it is necessary to carry out comparison of calculated frequency characteristics of loading process and amplitudes during oscillating process, taking place in “engine - transmission – water jet drive – vehicle” dynamic system, with experimental data of dynamic loading of WJD elements when HTAV moves afloat in actual conditions.

2. Description of experimental study conditions.

In this work the simulation mathematical model is presented. For verification of simulation mathematical model the experimental study of BTR-MDM “Rakushka-M” (Figure 2) multipurpose armoured personal carrier’ WJD is carried out afloat. The vehicle equipped with the UTD-29V diesel engine and hydromechanical transmission, water jet drive, including driveshafts and angular gearbox. Water jet propulsion system ensure the vehicle movement afloat at a speed 10 km/h. Two water jets are installed on the vehicle, they placed on the bottom along the right and left hull sides.

![Figure 2. General view of experimental study object – BTR-MDM “Rakushka-M”](image)

| Parameter          | Value   |
|--------------------|---------|
| Weight, kg         | 13,500  |
| Engine power, kW   | 331     |
| Road speed, km/h   | 71      |
| Water speed, km/h  | 10      |

Vehicle water trials were performed on stagnant reservoir of the PAO Kurganmashzavod’s range. Volume of the executed works is 100 hours afloat. Trials were performed according to basic provisions of a PM-796118 “Tracked and wheeled amphibious vehicles” standard technique of tests afloat. Throughout this trials the water jet drive has operated in the following modes: acceleration of water jets on land at sudden change of the engine shaft speed; water jet drive operation at the fixed engine speed; vehicle’s water entering/leaving; vehicle turn to the left and to the right (“snake”
maneuvering) afloat; the reversing mechanism switching on/off afloat for determination of own frequencies of system and damping behavior of the drive; acceleration of water jets afloat at sudden change of the engine shaft speed.

In the course of the experimental study of water jets’ drive dynamic loading afloat the torque on the first driveshafts of both sides between angular gearbox and transmission as well as rotating speed of the engine shaft were measured.

Figure 3. Part of information-measuring recording equipment set: GETAC notebook, L-Card E 14-440, rotational speed-to-voltage converter.

Due to the tasks that are put in the study, the information-measuring recording equipment set, including IBM-compatible GETAC laptop, multichannel system of data recording, amplifier cells – normalizing converters of low level and the power supply stabilized for supplying of data recording system, – amplifiers, strain-measuring bridges and sensors, was used for measurements. The system of data recording is executed on the basis of 14-digit analog-digital (A/D) L-Card E 14-440 converter and allows to measure input voltage in eight channels in a range from ±10V with weight value of the low-order digit 20V/16384=1.22 mV. The E14-440 module is introduced in the State Register of Measurement Instrumentation. In this process the management of data recording system was made by using of the data of Power Graph Professional 3.3.9 software.

The utilized information-measuring recording equipment set allows not only to measure parameters of dynamic processes at stationary and transitional modes of HTAV’ JWD operation, but also to carry out statistical processing and the results’ spectral analysis with the use of up-to-date techniques. For determination of identity of coincidence of measurable parameters according to experimental data the calibration of measuring channels was carried out.

The information-measuring recording equipment set is certified according to the established procedure.

3. The results of statistical processing of results of the system dynamics simulation modeling and experimental data.

Figure 4 shows comparison of dependence of the dynamic torque in WJD on rotational speed of the engine shaft. Figure 5 shows comparison of the amplitude-frequency characteristic and the oscillogram of the WJD dynamic torque while in operation at the established modes. The amplitude-frequency characteristic and the oscillogram were received during theoretical and experimental study.

The calculations, which were received as a result of simulation modeling of process under study, show, the results are in borders of Pc=0.95 confidence interval and repeat reasonably accurately the rate of curves of the torque change in JWD received during experimental study. The simulating modeling error in the given case is no more than 9 %, and according to other characteristics of movement it is in 6-9 % range.

Knowing the study error, it is possible to establish the model validity, its correctness. This check was carried out using Fischer's criterion. This statistical estimation procedure was carried out for logged parameters at the established HTAV’ JWD modes.

Quantitative and qualitative comparison was carried out based on frequencies and amplitudes of HTAV’ JWD dynamic torque oscillation (Fig. 4-5). Observed divergence of the torque amplitude and
frequency is no more than 5…10 %, this depends on a deviation of simulation modeling initial conditions.

**Figure 4.** Comparison of dependence of the dynamic torque in WJD on rotational speed of the engine shaft. 1 – average torque of the left shaft; 2 – average torque of the right shaft; 3 – dynamic component; 4 – dynamic torque; 5 – dynamic torque collected during experiment.

**Figure 5.** Comparison of the amplitude-frequency characteristic and the oscillogram of the WJD dynamic torque while in operation at established modes. Solid line – experimental results; Dot-and-dash line – simulation modeling results.
4. Conclusions
Statistical processing of results of system dynamics simulation modeling and experimental data of WJD elements dynamic loading when HTAV moving afloat shows good repeatability of results and testifies to the developed simulation mathematical model validity.

Within the framework of the problem solving of HTAV’ WJD dynamic loading decrease there is urgent task to research of dynamic properties of WJDs designed for different types of HTAVs. By experimental study techniques the validity check of simulation mathematical model of HTAV’ WJD operation was carried out taking into account various operating modes.

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