Selecting a Rational Operation Mode of Mobile Power Unit Using Measuring and Control Complex

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Abstract. *Research goals and objectives*: to increase efficiency and safety of Mobile Power Unit operation mode using Information and Communication Technology and Measuring and Control Complex.
Results of the research: The proposed algorithm made it possible to remove the worst mode, namely the overload mode, almost at the initial stage of analysis, and the nominal one dominates 1.5 times over the under load mode, both in volume and in terms of the ellipsoid nucleus specific weight. This suggests that the application of this algorithm is not inferior to the precision of the classical analysis method. The methodology for selecting a rational operation mode has been experimentally confirmed and can be used to rationally control the Mobile Power Unit in the operation region.

Keywords: operation mode, mobile power unit, measuring and control complex.

1 Introduction

The term mobile power unit (MPU) is adopted in connection with the use in the transport industry of a large number of technical means for special purposes. For MPU, it is typical to perform several operations, thereby changing the concept of their classification as compared to vehicles. During MPU operation, there arise dynamic loads, which destabilize the motion mode and cause oscillation of accelerations in a three-dimensional space. Such fluctuations lead to higher energy consumption, reduce the quality of the work performed and produce a detrimental effect on the operator.

Recently, in the area of mobile power unit (MPU) operation control, a clear trend in using information systems used to track stochastic changes in dynamic parameters is evidenced. One of the most promising ways is the use of systems that enable to track the changes in the acceleration of the MPU during routine operation and give recommendations as for the operation mode. In order to accurately determine the dynamic parameters it is not sufficient to use in-built onboard systems, since the appropriate algorithms were not embedded into their design parameters. Therefore, in order to solve the problem in question, it is possible to additionally install the required components of monitoring systems with embedded software, or to develop new software for the on-board systems in use.

The purpose of the paper is to increase efficiency and safety of Mobile Power Unit operation mode using ICT and Measuring and Control Complex.

The paper is organized as follows: part 2 describes related works on MPU; part 3 demonstrates parametric ellipsoid of the MPU operation; part 4 considers the system algorithm; part 5 describes the Measuring and Control Complex development; part 6 describes the on-road experiment; the last part concludes.

2 Related Work

In work [1] it is proposed to present a vector of complete MPU acceleration in the inertial coordinate system, using a hodograph (fig. 1).

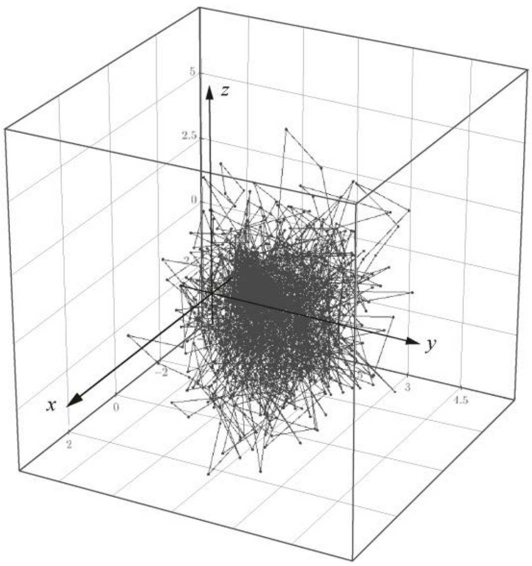


Fig. 1. Partial fragment of steady MPU motion, characterized by a hodograph.

The hodograph of the vector of full acceleration shows the sequence of changes in the value and position of vectors. When analyzing the fragment of stable running it can be argued that the constructed vectors determine the region of MPU operation, where an increase in the volume of the latter characterizes the growth in energy costs. Analysis of the methods of the operation region approximation has revealed that it is most accurately described by the surface of the second order (ellipsoid).

In work [2] an energy approach to estimating the dynamics and fuel economy of cars that makes it possible to determine the interrelation between the consumption of energy and the kinetic energy of the car is developed. Based on the obtained coefficients, it is possible to rank energy losses, as well as identify the ways to reduce them. In work [3] the laws of change in the vehicle acceleration time at the existing step transmission, when implementing the total traction force, boundary for the drive wheels adhesion to the road, and during implementation of the proposed rational law for acceleration control are established.

The vehicle detection process plays the key role in determining the success of intelligent transport management system solutions [4]. The risk of this forecast, predicted by the neural network, is "very low", we can definitely trust the forecast, and the risk is calculated by the equation of the neuroregression "low", which indicates that we can trust the forecast, but with caution and further monitoring [5].

In work [6] it is analyzed the four-wheel independent steering vehicle dynamic characteristics and the influence of linear quadratic regulator control parameters on control performance, a linear quadratic regulator control parameter adjustment strategy based on vehicle steering state is proposed to achieve the adaptive adjustment of linear quadratic regulator control parameters. In work [7] it is declared the essential novelty that distinguishes a new MPU from the standard tractors through the usage of complex multipurpose operations. The implementation of automatic weighing systems [8] will affect both the improvement of road safety and indirectly limit the number of road users moving by overloaded vehicles.

3 Parametric Ellipsoid of the MPU Operation

To calculate the resulting volume, we'll specify the ellipsoid (fig. 2) equation [1]:

$$\frac{(x-M_x)^2}{(a_{x\max}-M_x)^2}+\frac{(y-M_y)^2}{(a_{y\max}-M_y)^2}+\frac{(z-M_z)^2}{(a_{z\max}-M_z)^2}=1, \tag{1}$$

where $a_{i\max}$ is the maximum value of projections of the vector of full acceleration on the axis of the applicator, in terms of the mean square deviation of the sample $a_{i\max}=3\cdot\sigma_i$, M_i is the mathematical expectation for the corresponding axis.

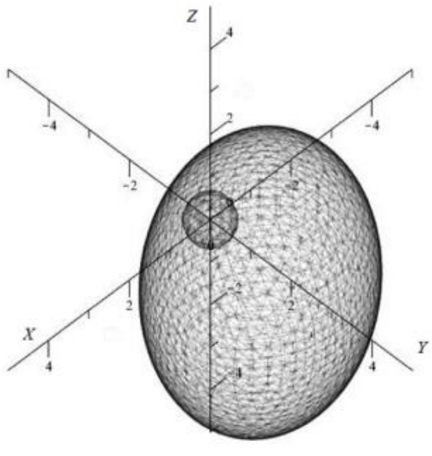


Fig. 2. Parametric ellipsoid of the MPU operation

By studying the properties of the finite character structures, such as the deterministic signal obtained experimentally, as well as the infinite structures of technological operation, which involve the discontinuity of processes in them or the separation of constituent elements, it is opportune to apply the elements of the theory of sets.

The range of operation, approximated by the ellipsoid, is given by the set of ends of the radius of the vector of full acceleration established from the center of mass of the MPU $\Phi_{\bar{a}} = \{\bar{a}_1, \bar{a}_2, \bar{a}_3 ... \bar{a}_n\}$.

The potency of this set is limited by the time of the experiment conducted t and the frequency of the measuring complex survey Δt, $|\mathrm{M}| = N = t/\Delta t$.

The scope of minimum deviations of acceleration is a subset of the set $\Phi_{\bar{a}}$ – $T_{opt} \subset \Phi_{\bar{a}}$:

$$T_{opt} = \{\forall \bar{a}_n \in \Phi_{\bar{a}} | \bar{a}_n \leq \operatorname{sgn} 0{,}5\}, \tag{2}$$

The set T_{opt} is the nucleus of the ellipsoid, and its specific gravity is the criterion for assessing the operation mode. It is possible to determine it on the basis of statistical processing:

$$p_t = \frac{n_t}{N}, \tag{3}$$

where n_t is the number of acceleration values belonging to the set $\bar{a}_n \in T_{opt}$.

Since the spherical form of the nucleus with a center at the origin of coordinates is regarded as an ideal case being approached, the nucleus can change its position in the middle of the ellipsoid during statistical processing. Analysis of the nucleus position will make it possible to determine which direction the maximum energy losses are due to, as well as identify the methods for reducing them.

One should determine the areas where the displacement of the nucleus can be admitted. The value of projections on the axis of ordinates is determined by the nature of technological operation: the forces causing the deviation in direction; the frequency of the path of motion adjustment; application of variable-mass machines, etc. In the absence of the possibility to eliminate the displacement of the nucleus, this is allowed for a particular technological operation and the given MPU in comparative studies.

The greatest impact on the value of the acceleration projection on the axis of the applicate has the relief of the agricultural background, both macro and micro inequalities have a stochastic character due to the given displacement of the nucleus for this axis is allowed, however, the magnitude is not greater than M_z .

Any displacement of the nucleus relative to the origin of coordinates along the abscissa will give a constant increase or decrease in velocity, which will characterize the mode of motion as a transient one, so the displacement along the axis of abscissa is not allowed.

4 Algorithm

Based on the presented method of analysis, it is possible to find a rational mode of the MPU operation, which with other factors being equal will be characterized by less energy losses and improved quality of the technological operation implementation.

The initial question to be answered is the allowable range of changes in the parameters responsible for the efficiency of the technological operation (hereinafter the initial conditions).

It is possible to implement the required speed of the MPU by engaging several transmission gears given the possibility of using partial speed modes of engine operation. The selection of a rational mode according to the classical methods in this case is reduced to the definition of the minimum fuel consumption and the maximum engine load. Based on the proposed method of analysis of the MPU functioning it is possible to determine a rational mode, avoiding the loss of quality over a shorter period of time.

To implement the method in question, one must follow the analysis algorithm (fig. 3). Let's assume that the operation of the MPU is allowed in different k modes according to the initial conditions. First, the valid displacement area of the real nucleus is selected for all modes, providing the minimum distance from the normal one $T'_{opt} \to T_{opt}$.

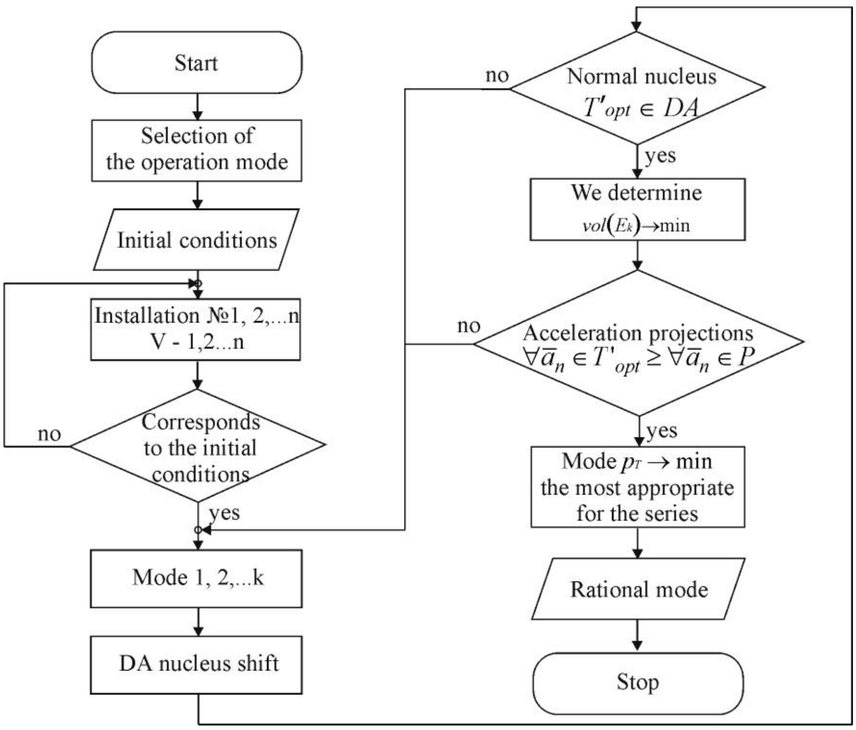


Fig. 3. Algorithm for selecting the operation mode, based on the analysis of the area of MPU operation

To speed up the analysis, the ones that do not match this area for the rest are then eliminated. We build an ellipsoid of functioning and select the modes with the lowest volume $vol(E_k) \rightarrow \min$. After obtaining the modes with the lowest volumes, it is necessary to determine those in which the distribution $\overline{a}_n \in \Phi_{\overline{a}}$ is subject to the following condition:

$$\forall \overline{a}_n \in T'_{opt} \geq \forall \overline{a}_n \in P\,, \tag{4}$$

The mode with the highest specific gravity p_r is the most appropriate for the analyzed series. It should be noted that if several modes have been identified, the share of the latter equals to $p_{r1} \approx p_{r2} \approx p_{rn}$. The mode with a minimal shift of the actual nucleus is given the selection priority.

The proposed algorithm will enable to significantly accelerate the analysis of experimental data and select the mode most closely related to the rational one, taking into account both the elements of the classical traction method and the dynamic characteristics of the MPU. Taking into account the additional energy losses and ways for their reduction, new perspectives for improving the efficiency of MPU application in carrying out transport operations are created.

5 Measuring and Control Complex Development

Implementation of the given algorithm requires the development of measuring and control complex. To achieve the goal set, one needs to accomplish the following tasks:

- the elements of the complex should provide comprehensive information for the study of functional stability generalized parameters;
- the measurement and control complex is supposed to provide reliable information for further analysis, which requires systems duplication;
- the number of elements of the complex must be substantiated and tend to the minimum necessary;
- the software for monitoring, filtering and analyzing the experimental data obtained is to consume the minimum of allocated resources (a constituent element required for applying a complex with low computing power systems);
- the installation and calibration of the measuring elements of the complex in question should not take up more than 30 minutes;
- when selecting a warehouse for storing the measuring equipment it is necessary to use such equipment, which application for scientific purposes leaves no doubt in the world experience;
- synchronization of the experimental data flow obtained through various elements of the complex.

The proposed complex (fig. 4) should ensure the implementation of the control algorithm through the use of high-sensitive sensors and related software. One of the most daunting problems to be solved is the synthesis of measuring sensors, which work relies on the application of fundamentally dissimilar physical effects (induction, electromagnetic oscillations, and radio waves).

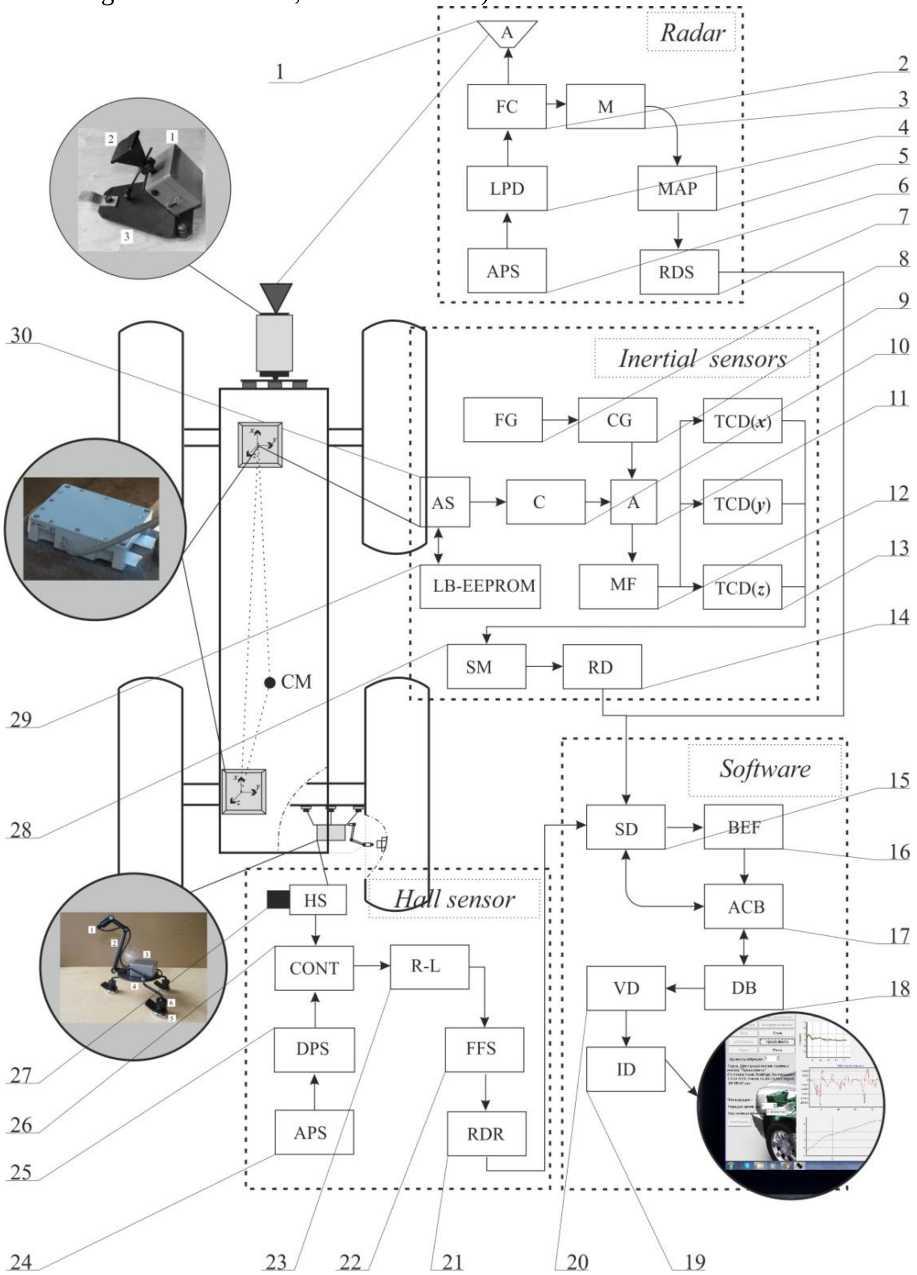


Fig. 4. Diagnostic complex of monitoring the dynamic parameters of mobile energy resources

An individual noise spectrum is inherent for each of these sensors, so when applying the software, it is required to use filtration algorithms that enable to eliminate this shortcoming.

The world experience proves that one of the best options for solving this problem is the use of duplicate monitoring systems. When choosing duplication systems, one should remember that the use of a large number of measuring equipment will complicate the conduct of experiments and reduce the effectiveness of the latter; therefore, it is required to apply the necessary minimum of devices. When selecting the devices, one needs to be guided by the following rule: at least two duplicate systems should be applied while determining the generalized parameters (acceleration, speed, hitching)of functional stability. For instance, to determine the acceleration, in addition to the accelerometer, one should apply either a radar or a lidar.

Application of such a principle of kitting the measuring and control complex will make it possible, subject to the appropriate filtering of the data received, to adjust the operating modes of the MPU, based on the control algorithm.

The task set is solved due to the fact that the diagnostic complex used for monitoring the dynamic parameters of traction vehicles includes measuring sensors, a data collection and synchronization system, software for filtering and analysis of experimental studies, which differs in that the measurement of the actual speed of motion occurs with the use of a coherent radar performed through the agency of a homodyne circuit, which design provides for the possibility of changing the angle of inclination of the transmitting antenna, and for measuring the propulsion sensor rotation they use a sensor based on the Hall effect that is simply mounted on any type of MPU due to a unified mounting system based on neodymium magnets, in addition to the filters mounted in the sensors proper, there is added a filtering system, programmed to the appropriate sensitivity, according to the consumer's requirements and advanced software, enabling detailed comparison of the selected operating modes by the criterion of energy saving in real time.

Establishing the actual speed of motion is performed using a specific range radar. The corresponding frequencies are emitted by the use of the generator based on the LPD 4 and the ferrite circulator 2 (FC), and the signal reflected from the resistive surface is received by antenna 1 (A), then the Doppler frequency 5 (MAP) is amplified with the use of the mixer 3 (M), the processed signal falls into the registration device of speed 7 (RDS). The radar has an autonomous power supply 6 (APS) sufficient in capacity for conducting long-term experiments.

To investigate the power dynamic parameters, they use inertial acceleration sensors 30 (AS) that are located at arbitrary points of the MPU frame elements, provided that at least two sensors are installed on each element. The obtained data are converted to 10 (C) and amplified by 11 (A) using the frequency generator 8 (FG) and the clock generator 9 (CG). The amplified signal then goes to the low-pass filter 12 (MF) mounted in the board and adjusted using the temperature compensator device 13 (TCD) for each of the main coordinate axes. The sensor exhibits the property of selecting the sensitivity mode 28 (SM) and the recording device 14 (RD). The system of self-testing and correction of sensor position 29 (LB-EEPROM) is provided for.

The wheel rotation is determined using the Hall sensor 27 (HS), fed by the power from the autonomous source 24 (APS) through a double-current source 25 (DPS). Controller 26 (CONT) controls the operation of the sensor, the received signal enters the receiver-limiter 23 (R-L), then it is filtered from the available fluctuation errors 22 FFS and recoded in the recording device 21 (RDR) of the wheel rotation.

Further, processing and synchronization of experimental data is performed by special software. Experimental data supplied by registration devices is synchronized at a constant time and checked for compliance with 15 (SD). Next, in the block of external filtration 16 (BEF), where filter kits are provided for each of the received signals, the amplitude-frequency spectra necessary for further study are isolated. The processed signals fall into the analytical-calculation block 17 (ACB) where the mathematical apparatus carries out the statistical and spectral estimation and detects the inconsistencies of signals, in the presence of such ARB re-accesses the SD and conducts filtering along with other settings. The analyzed experiment is stored in data bank 18 (DB) on the hard disk. The visual representation of the parameters that the diagnostic complex captures is carried out using the «Vehicle Dynamics v. 3.9.2 » program 20 (VD) on the information display 19 (ID) of the laptop or tablet. The software of the complex has the property of analyzing the obtained data, both directly during the research in real time, and to reproduce the experiment in laboratory conditions, based on the data supplied by registration devices.

The general view of the Vehicle Dynamics v. 3.9.2 software interface is shown in Fig. 5.

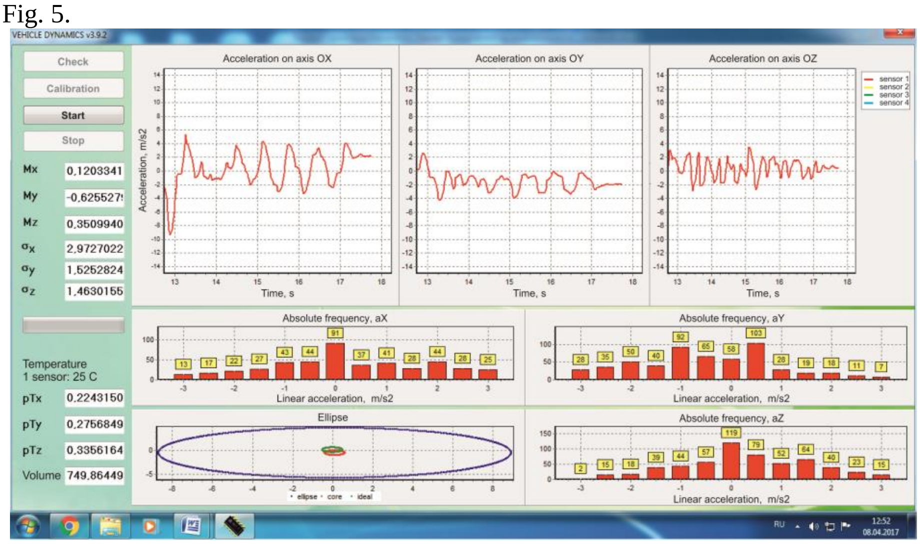


Fig. 5. The software interface of the recording and control complex

The application of the functional parameter monitoring program allows to visually analyze the selected modes and, if necessary, to adjust the initial data, or to make conclusions regarding the aggregation of the MPU. The results of each experiment are recorded into the data bank and stored for the purpose of obtaining a statistical data sample, which will enable to provide recommendations for the MPU series.

Thus, the offered diagnostic complex of monitoring the dynamic parameters of traction vehicles makes it possible to investigate the changes of the MPU operation parameters with high precision, in real time, as well as select the rational functioning modes.

6 Experiment

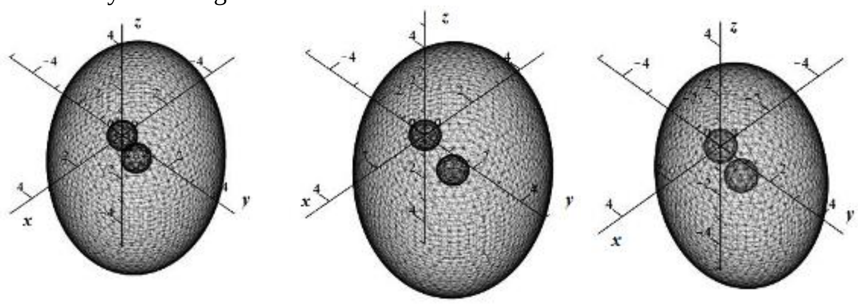
The experiment was carried out on a mobile power special purpose unit, namely KrAZ 5233. The experiment methodology and the requirements for the installation of measuring equipment are described in detail in work [1].

To provide the experimental confirmation of the relationship between the scale of fluctuations of full acceleration of the MPU as well as the mode of engine operation of the latter, it is required to simulate the load in field conditions.

The load of the engine is specified at 55 – 60%, 85 – 95% and 105 – 115% of the nominal value (the required towed load is selected using the classical traction characteristics, and fixed with a strain gauge link). With stabilization of speed (achievement of the steady state of motion) by making use of the registration complex the following parameters are fixed: the components of the full acceleration vector, the actual speed of motion, the engine rpm speed (to obtain the theoretical speed), fuel consumption, traction load, the temperature of both the sensors and the environment, as well as the pressure.

Upon completion of basic research, analysis of the experimental data is obtained using the operating mode control algorithm. It is theoretically substantiated that the rational mode of the MPU operation must correspond to the minimal dynamic losses of the unit. That is, the control algorithm is to select the second series of experiments as the best one from the energy saving position since the engine is loaded close to the nominal value.

On the basis of statistical processing we construct an operation ellipsoid for the modes analyzed in Fig. 6.



a) engine load *b) engine overload* *c) nominal mode*

Fig. 6. Ellipsoid of operation

The sequence proposed in the algorithm requires setting the permissible shift region of the actual nucleus, the worst possible mode is the engine overload, the actual nucleus of the latter is outside the permissible range. Next, we determine the *vol* (E_k)

volume of each of the ellipsoids: the mode of under loading *vol* (E_k) = 147,2 (Fig. 6, a), the overload mode *vol* (E_k) = 183,5 (Fig. 6 b), the nominal mode *vol*(E_k) = 97,76 (Fig. 6 c). That is, the control algorithm chose the nominal mode as being the most appropriate one according to the two evaluation criteria: the volume of operation ellipsoid for the nominal mode is 1.5 and 1.8 times smaller than the corresponding ellipsoids of the under load and overload modes; the value of the specific weight of the nucleus also confirms the nominal mode to be the best one of the series.

7 Conclusions and Outlook

The methodology for selecting a rational operation mode has been experimentally confirmed and can be used to rationally control the MPU in the operation region.

The proposed algorithm made it possible to remove the worst mode, namely the overload mode, almost at the initial stage of analysis, and the nominal one dominates 1.5 times over the under load mode, both in volume and in terms of the ellipsoid nucleus specific weight. This suggests that the application of this algorithm is not inferior to the precision of the classical analysis method.

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