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Ways to increase the traction efficiency of modular draft device

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Abstract. The versatility of tractors can be increased by using them as a part of a modular draft device (MDD). MDD consists of energetic (EM) and technological (TM) modules. EM is a high-energy tractor with a 2WD or 4WD wheel arrangement and a traction force of 14-16 kN. TM is an additional axle with an active drive of its wheels. By connecting TM to the rear hitch linkage (RHL) of EM, the tractive effort of the entire MDD, which has a 4WD or 6WD wheel arrangement, increases to 32-36 kN. MDD can function as a road-rail vehicle. Depending on the traction resistance, MDD can be used both as part of an EM+TM or as a single EM. According to the research results, it was found that the maximum traction efficiency (TE) of MDD with a 6WD wheel arrangement is about 10% higher than that of MDD with a 4WD wheel arrangement. The TE value of MDD increases with an increase in the inclination of EM rear hitch linkage top link. The increase in MDD's tractive efficiency is facilitated by an increase in the coefficient of kinematic discrepancy in the drive of the EM and TM wheels from 1.00 to 1.05.

1. Introduction

One of the most effective ways to solve the problem associated with the nomenclature of the tractor power industry is the introduction of modular draft devices (MDD). Its high production versatility and technological adaptability are ensured by the variability of the nominal tractive effort [1]. In total, it displays the range of traction forces for tractors of 2-3 traction classes. This new property of draft devices is caused not by the use of their mechanical ballasting but by the division functions into energetic and technological within one design of the tractor.

This fundamentally new direction in the development of tractors is relevant today for almost all countries of the world. First of all, because many manufacturers, instead of the old traction concept, have begun producing tractors of a new - traction and energy concept.

The essence of the first concept consists of the approximate constancy of the energy saturation level of the tractor E_t . The latter concept represents the ratio of the tractor engine power (N_e , kW) to its operating weight (M_t , t) and is expressed in kW t⁻¹. That is, $E_t = N_e \cdot M_t^{-1} = \text{const}$.

Following the traction and energy concept, the tractor engine power is increased, while its operating weight remains practically unchanged. In this case, we have: $E_t = N_e \cdot M_t^{-1} = \text{var}$.

Our research has established that the limiting value of the parameter E_t , at which the total power of the tractor engine can be converted into the tractive effort, is approximately 15 kW t⁻¹ [2]. A larger value of this parameter raises the problem of using the engine power reserve.



One of the most effective ways to solve this problem is to create energetic devices with a split flow of power from its engine. Its main part is realized by a tractor, which we propose to call the energetic module (EM). The remaining ("extra") part of the engine power is used by an additional axle with an active drive of its wheels, called a technological module (TM). The result is a modular draft device (MDD).

The MDD energetic module is essentially a tractor of a specific traction class, designed to work with a corresponding variety of machines and implements. The MDD technological module attaches to the rear hitch linkage of the energetic module. The technological module wheels are driven from a synchronous power take-off shaft of the EM, and TM is also equipped with its rear hitch linkage, a semitrailer, a brake system, etc.

When TM is attached to EM, the traction forces developed by them are summed up. As a result, the MDD, having a greater tractive effort, can be aggregated with wider and more productive agricultural machines. Due to summing the traction forces of the energetic and technological modules, MDD is a vehicle of variable traction class.

We have developed and tested in production conditions industrial models of modular draft devices of traction classes 1.4-3 (Figure 1) and 3-5 (Figure 2).



Figure 1. MDD of traction class 1.4-3



Figure 2. MDD of traction class 3-5

The study of the operation of machine and tractor units based on modular draft device is a very relevant direction in solving problems associated with an increase in the annual load of existing tractors, a reduction in the range of necessary traction equipment at enterprises, and an expansion of the MDD applicability range in various industries.

2. Analysis of recent studies and publications

The technical feasibility and economic suitability of these modular draft devices with variable traction class have been confirmed by long-term research and production tests. Particular attention was paid to the study of the engine power balance of such device. As a result, dependencies that allow determining the values of N_e , M_t , and E_t for MDD were obtained [3]. Perspectives for possible ballasting of MDD modules are considered considering the restrictions put forward by this process [4]. Problems of movement stability of machine-tractor units based on this device were investigated using a new stability criterion [5]. The issues of kinematic discrepancy influence in the drive of the MDD modules wheels on its traction indicators are detailed [6].

The analysis of the technological properties of MDD shows that it can be successfully applied not only in the agricultural sector. After a simple re-equipment, MDD is potentially suitable for rail transport, first of all, as rail vehicles of category N3 [7, 8] or category T [9, 10]. The latter is represented by the MMT-3 series motor locomotives [11-13], which are almost entirely similar to MDD [14-16]. The forecast of these studies shows that modular draft devices can be successfully used in modern bimodal transportation by rail [17, 18].

The analysis of theoretical studies shows that the design parameters [19-21] of modular draft devices almost wholly meet the criteria for the movement stability of railroad motor locomotives [22-24]. The methods for assessing the ways to reduce the rolling resistance of rail vehicles, motor locomotives, and modular draft devices are almost identical [25].

Using MDD as a motor locomotive will be more efficient, if its traction properties are higher. The universal evaluation parameter of the latter is the power delivery efficiency (PDE). The nature of its change under the influence of new requirements for the maximum permissible level of slipping of wheeled draft devices is disclosed in the study [26].

The performed studies' analysis shows that the issue of PDE components changes nature in the modular draft device has been studied very poorly, especially considering the influence of its design parameters. Therefore, this work is devoted to exploring the impact of MDD design parameters changing on its traction efficiency.

3. Statement of the objective and tasks of the study

Firstly, it is necessary to determine the design parameters that have the most significant impact on the change in traction efficiency of MDD. As shown by the preliminary analysis, such parameters include 1) wheel arrangement of the energetic module; 2) the angles of inclination of EM rear hitch top and lower links; 3) the coefficients of kinematic discrepancy in the wheel drives of MDD energetic and technological modules.

Thus, this article aims to increase the operating efficiency of the MDD by bringing it to the operating mode with the traction efficiency tending to the maximum. And also, to ensure this mode due to the optimal parameters of MDD structural elements, which affect the increase in traction efficiency. We will achieve this goal by solving the following tasks:

- study the influence of energetic module wheel arrangement on MDD traction efficiency change dynamics;
- assess of the impact of EM rear hitch links angles of inclination changes on the nature of MDD traction efficiency;
- study the influence of changing the kinematic discrepancy coefficients in the wheel drives of MDD energetic and technological modules on MDD traction efficiency.

4. The basic part of the study

We will consider the optimal interaction of the modular device traction axes, at which the maximum value of its PDE is achieved (η_o). For MDD, this parameter can be determined from the equation:

$$\eta_o = \frac{N_a(\varphi_a - f_a) + N_b(\varphi_b - f_b) + N_c(\varphi_c - f_c)}{\frac{N_a\varphi_a}{\eta_{ta}(1 - \delta_a)} + \frac{N_b\varphi_b}{\eta_{tb}(1 - \delta_b)} + \frac{N_c\varphi_c}{\eta_{tc}(1 - \delta_c)}}, \quad (1)$$

where N_a, N_b, N_c – vertical loads on MDD axles (starting now, indices a and b refer to the front and rear axles of the energetic module and the index c - to the axle of the technological module); $\varphi_a, \varphi_b, \varphi_c$ – coefficients of adhesion of MDD wheels to the soil; f_a, f_b, f_c – wheels rolling resistance coefficients of the appropriate MDD axles; $\delta_a, \delta_b, \delta_c$ – wheels slip coefficients of the appropriate MDD axles; $\eta_{ta}, \eta_{tb}, \eta_{tc}$ – drive transmissions efficiency of the appropriate MDD axles.

For determining the vertical loads acting on MDD axles, a design scheme was drawn up (Figure 3).

The influence of the unit technological part on MDD is presented in the form of the main torque (M) and horizontal (P_g) and vertical (R_v) components of the main vector of forces applied to the technological module in the longitudinal-vertical plane.

In addition to these forces and torques, in the general case, the MDD is affected by (Figure 3): tangential traction forces P_{ka}, P_{kb}, P_{kc} ; forces P_{fa}, P_{fb}, P_{fc} and torques M_a, M_b, M_c ; rolling resistances; weight force of energetic (G_e) and technological (G_t) modules.

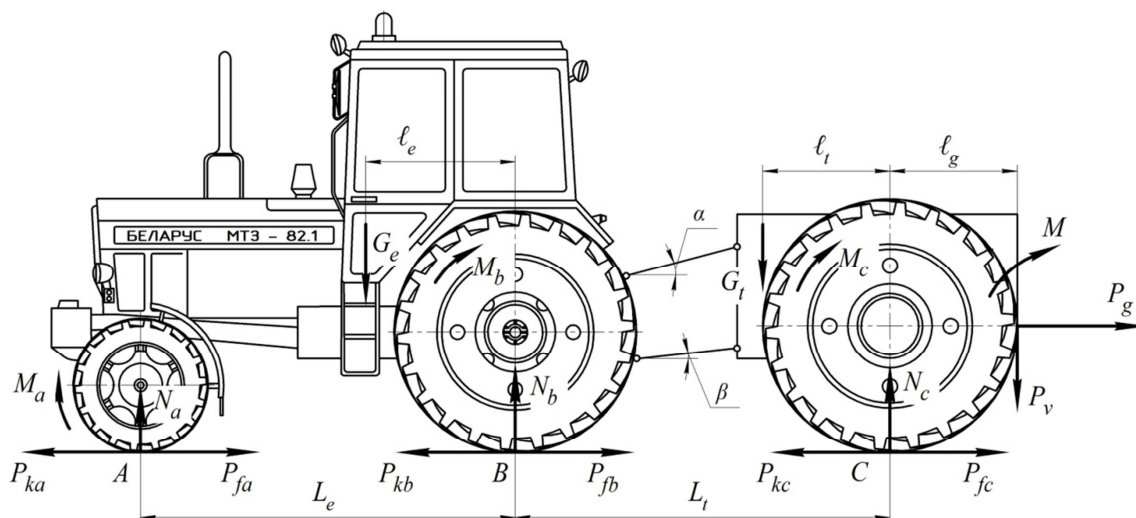


Figure 3. Diagram of forces and torques acting to MDD in longitudinal-vertical plane

Equation (1) determines the PDE value for MDD with the 6WD wheel arrangement. When using the EM with rear-wheel drive only, the MDD wheel arrangement is referred to as 4WD. The equation for determining the PDE (η_1) of such MDD is as follows:

$$\eta_1 = \frac{N_b(\varphi_b - f_b) + N_c(\varphi_c - f_c) - N_a f_a}{\frac{N_b \varphi_b}{\eta_{tb}(1 - \delta_b)} + \frac{N_c \varphi_c}{\eta_{tc}(1 - \delta_c)}} \quad (2)$$

The parameters of equations (1) and (2) are described by a system of 20 additional algebraic equations, which are not given in this article but described in detail in [27, 28].

An analysis of the calculation data for equations (1) and (2) showed that the maximum PDE value for an all-wheel-drive MDD (6WD) is greater than that of a non-all-wheel drive (4WD) (Figure 4).

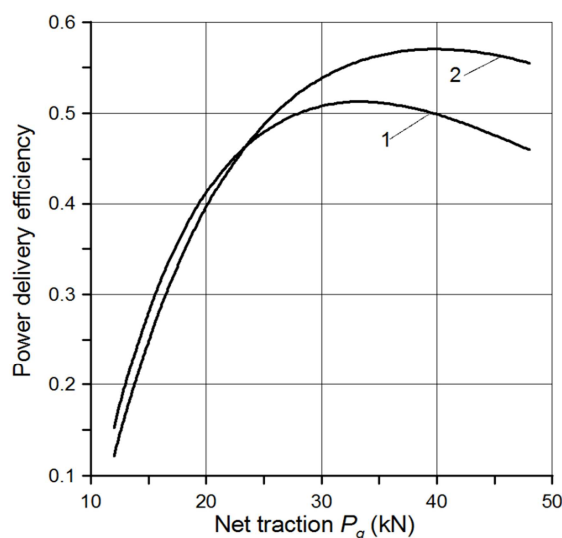


Figure 4. Dependence of MDD power delivery efficiency on its net traction: 1 – 4WD MDD; 2 – 6WD MDD

If, for the first design variant of MDD (6WD), this parameter is equal to 0.570, then for the variant of the modular draft device with the 4WD arrangement, the maximum PDE value is only 0.512 (i.e., 10% less).

Moreover, if the PDE of non-all-wheel drive MDD reaches its maximum at pulling force of 34 kN (curve 1, Figure 4), then for an all-wheel-drive device, the maximum PDE value shifts to the zone of high pulling forces. In this case, it is almost 40 kN (curve 2, figure 4).

Noteworthy is the fact that in the 12-22 kN traction range, the PDE of the non-all-wheel drive MDD is greater than that of the all-wheel-drive (curve 1, Figure 4). At high values of the MDD tractive effort, the nature of change in PDE becomes the opposite. Moreover, the greater tractive effort P_g , the greater difference between PDEs in favor of the all-wheel-drive version of the MDD.

Let us analyze what causes such a result. To do this, we should disclose the nature of those components that are included in the equation that allows us to calculate the efficiency.

According to the theory of the tractor, the traction efficiency should be determined by the equation:

$$\eta_3 = \eta_{tr} \cdot \eta_r \cdot \eta_s, \quad (3)$$

where η_{tr} – transmission efficiency; η_r – rolling efficiency; η_s – MDD wheel slip efficiency.

To clarify the reasons for the higher and shifted to the zone of large tractive forces traction efficiency of MDD with the 6WD arrangement, it is necessary to investigate the nature of the last two components.

For studying the nature of rolling efficiency and mover slipping efficiency of MDD, graphs of their dependence on tractive effort were built (Figure 5).

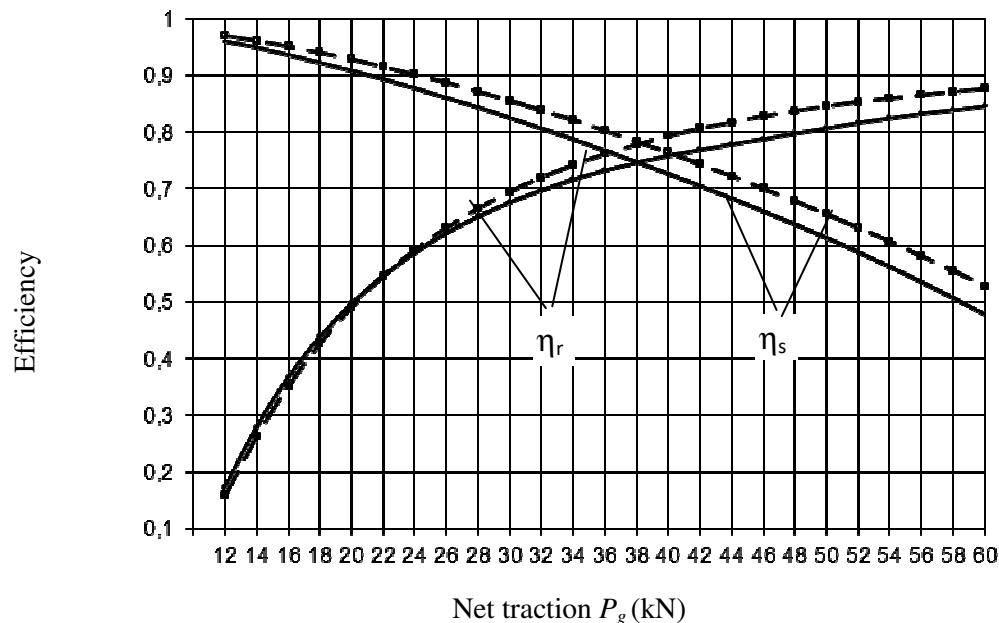


Figure 5. Rolling (η_r) and slipping (η_s) efficiency: - - - - 6WD MDD; — — — 4WD MDD

The rolling efficiency was determined by the following equations [27-29]:

for MDD with 6WD arrangement

$$\eta_r = \frac{N_a \cdot (\varphi_a - f_a) + N_b \cdot (\varphi_b - f_b) + N_c \cdot (\varphi_c - f_c)}{N_a \cdot \varphi_a + N_b \cdot \varphi_b + N_c \cdot \varphi_c}. \quad (4)$$

for MDD with the 4WD arrangement

$$\eta_r = \frac{N_b \cdot (\varphi_b - f_b) + N_c \cdot (\varphi_c - f_c) - N_a \cdot f_a}{N_b \cdot \varphi_b + N_c \cdot \varphi_c} \quad (5)$$

The slipping efficiency was determined from the following dependence:

$$\eta_s = 1 - \delta_s, \quad (6)$$

where δ_s is the tractor rear axle slipping.

$$\delta_s = A \cdot \frac{P_g - (\varphi_c - f_c) \cdot N_c}{N_a + N_b} + B \cdot \left[\frac{P_g - (\varphi_c - f_c) \cdot N_c}{N_a + N_b} \right]^2, \quad (7)$$

where A, B are slip curve approximation coefficients of the MDD.

Analyzing the nature of the slip efficiency curves (η_s), it can be seen (Figure 5) that the tractive effort of the MDD (6WD) is growing. However, it continually remains higher than the MDD (4WD) slip efficiency (Figure 5). The difference between them gradually increases; that is, the reduction intensity η_s of the second is greater than that of the first. The latter can be explained by the more advanced MDD (6WD) chassis than the MDD (4WD).

The nature of the efficiency flow (η_r), for both MDDs, in the zone of low tractive forces, is almost the same (area up to 22 kN). However, for MDD (6WD), the rolling efficiency increases more rapidly, starting from a tractive effort of 22 kN (Figure 5). Also, the difference between the values η_r is growing continuously. It is not surprising, since the MDD (6WD) slip is less in this area. This fact leads to the shift of maximum traction efficiency of MDD (6WD) into the area of high tractive forces.

Next, let us analyze how the inclination angles of the top (α) and lower (β) links of the EM rear hitch linkage (Figure 3) affect the changing nature in the power delivery efficiency of MDD.

Calculations revealed two patterns. The first of them is that an increase in the parameter α from 1 to 20° causes an increase in the PDE of the modular draft device (Figure 6). For example, with MDD pulling force 22 kN, its PDE increases from 0.420 (when $\alpha = 1^\circ$) to 0.436 (when $\alpha = 20^\circ$), i.e. by 3.8%.

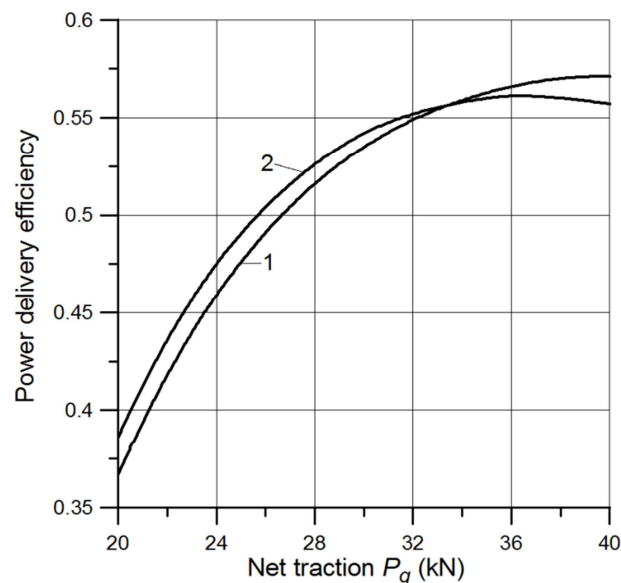


Figure 6. Dependence of MDD power delivery efficiency on its net traction: 1 – $\alpha = 1^\circ$; 2 – $\alpha = 20^\circ$

The reason for this result is the following. Research [1] established the influence of installing the MDD EM rear hitch linkage top link on the nature of vertical loads on MDD axles. Simultaneously, it has been proven that an increase in the value of the angle α leads to an increase in the vertical load on the EM rear wheels. The result is less MDD wheel slip while PDE increases.

The second regularity of the results, the graphic interpretation of which is shown in Figure 6, describes that as the tractive effort P_g increases, the influence of the inclination angle of EM rear hitch linkage top link on the change in PDE is neutralized.

In the same study [1], it is noted that the intensity of additional vertical loading growth of EM rear wheels and TM wheels gradually decreases with an increase in the value of the angle α . As a result, this determines the nature of the PDE dynamics of the modular draft device, shown in Figure 6 for P_g values over 34.5 kN.

Another design parameter that theoretically can influence the dynamics of the MDD PDE is the angle of inclination of the EM rear hitch linkage lower links β (see Figure 3).

The theoretical calculations analysis showed that changing this parameter value from 0 to 10° has little effect on the nature of the change in MDD PDE. Moreover, both for small and large values of the angle α . The reason for this result is that a change in the values of the angle β within the specified limits ($0-10^\circ$) causes a slight redistribution of vertical loads on the axles of the modular draft device [1].

An increase in the kinematic discrepancy coefficient (K_{ve}) in the wheel drive of the MDD energetic module (in this case, from 1.00 to 1.05) causes its rear wheels to create a so-called "pushing" effect. As a result, this contributes to slipping reduction and, therefore, to PDE increase of the modular draft device (Figure 7).

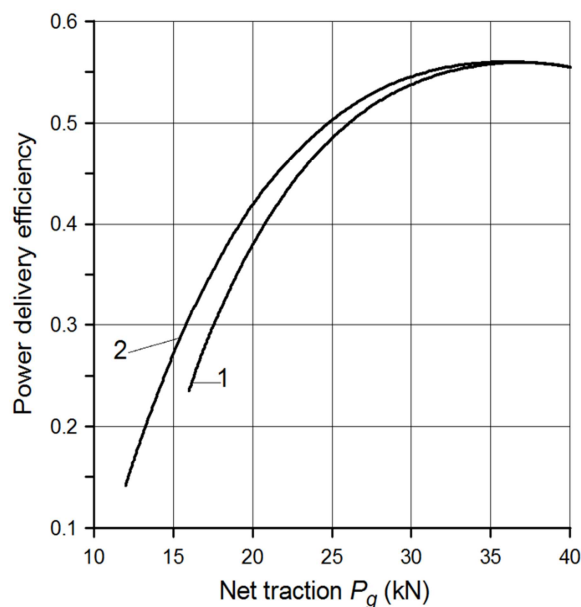


Figure 7. Dependence of MDD power delivery efficiency on its net traction: 1 – $K_{ve} = 1.00$; 2 – $K_{ve} = 1.05$

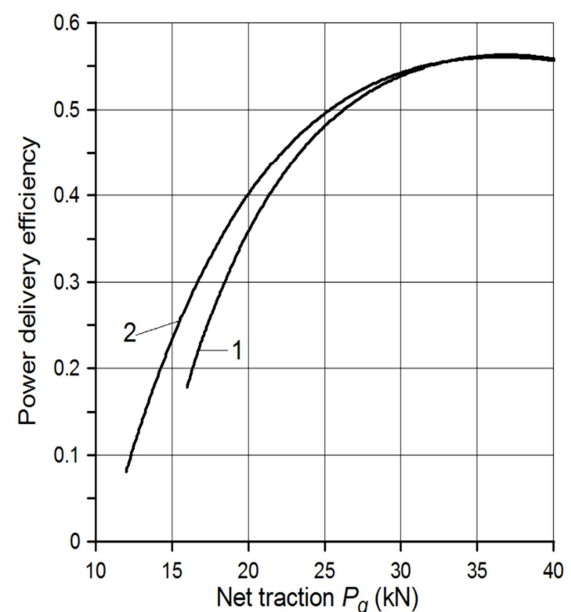


Figure 8. Dependence of MDD power delivery efficiency on its net traction: 1 – $K_{vt} = 1.00$; 2 – $K_{vt} = 1.05$

At the same time, as the P_g force increases, the MDD slip also increases. Because of this, its wheels form a deeper track. As a result, MDD's rolling resistance increases. In turn, it causes a decrease in the intensity of growth of its PDE with an increase in the value of the parameter K_{ve} .

This explains the fact that with an increase in the kinematic discrepancy coefficient in the wheel drive of the MDD energetic module, the intensity of its PDE growth, as the force P_g increases decreases. When the MDD tractive effort is more than 32 kN, the rolling resistance of its wheels

increases so much that it practically neutralizes the influence of an increase in the K_{ve} coefficient on the process of changing PDE of MDD.

A similar quality result is obtained in changing the kinematic discrepancy coefficient (K_{vt}) in the wheel drive of the MDD technological module (Figure 8). The difference is only in quantitative indicators, which is entirely logical and understandable. For example, the influence of an increase in the parameter K_{vt} from 1.00 to 1.05 on MDD PDE dynamics neutralized at a slightly lower value of the tractive effort it develops. In this case, it is approximately 29 kN (see Figure 8).

5. Conclusions

Calculations have shown that the maximum power delivery efficiency of the 6WD modular draft device is approximately 10% higher than that of the 4WD one.

In the 12-22 kN traction range, the power delivery efficiency of the 4WD modular draft device is higher than the 6WD one. At high MDD tractive effort values, the nature of change in the PDE values becomes the opposite. Moreover, the greater the tractive effort of the modular draft device, the greater difference between the PDE values in favor of the 6WD arrangement version.

When choosing the installation angle of the top link of the MDD energy module's rear hitch linkage, it is desirable to give preference to large values of parameter α , since in this case, its PDE increases. Simultaneously, installing the lower rear hitch linkage links at an angle to a horizon of 0-10° does not significantly affect this indicator.

With MDD traction forces up to 29-32 kN, an increase in kinematic discrepancy coefficient in the wheel drive of MDD energetic (K_{ve}) and technological (K_{vt}) modules from 1.00 to 1.05 contributes an increase in PDE. At large MDD tractive effort values, this parameter change dynamics is practically invariant concerning the increase in coefficients K_{ve} and K_{vt} .

References

- [1] Nadykto V T 2003 *Fundamentals of modular draft devices application* (Melitopol: KP "MMD")
- [2] Bulgakov V, Kyurchev V, Nadykto V and Olt J 2015 Structure Development and Results of Testing a Novel Modular Power Unit *Agriculture and Agricultural Science Procedia* **7** 40-44
- [3] Adamchuk V, Bulgakov V, Nadykto V, Ihnatiev Y and Olt J 2016 Theoretical research into the power and energy performance of agricultural tractors *Agronomy Research* **14(5)** 1511-18
- [4] Bulgakov V, Nadykto V, Kyurchev S, Nesvidomin V, Ivanovs S and Olt J 2019 Theoretical background for increasing grip properties of wheeled tractors based on their rational ballasting *Agraarteadus* **30(2)** 78-84
- [5] Bulgakov V, Adamchuk V, Nadykto V, Kyurchev V and Nozdrovicky L 2017 Theoretical consideration of the controllability indicator of machine-tractor unit movement *Acta Technological Agriculturae* **1** 11-18
- [6] Bulgakov V, Pascuzzi S, Ivanovs S, Nadykto V and Nowak J 2020 Kinematic discrepancy between driving wheels evaluated for a modular traction device *Biosystem Engineering* **196** 88-96
- [7] Platonov A A 2014 Classification Features Constructive-Technical Parameters of Road Rail Vehicles *Modern Problems of Science and Education* **2** 161-168
- [8] Platonov A A 2016 On the prospects of application of tractors for couse combined to implement shunting operations of the wagons *Modern technics and technologies* **3(55)** 78-86
- [9] Popov A T and Diakonova N S 2012 Locomobile as an Alternative to Diesel Switchers *World of Transport and Transportation* **03** 66-69
- [10] Tarasov D E 2017 The Development of Hybrid Road-roll Rolling Stock in Russia Switchers *World of Transport and Transportation* **15(2)** 74-80
- [11] Jennings B 2009 Investigating private railroad operations and the locomotive issue *Journal of Transportation Management* **20(1)** 48-58
- [12] Konarzewski M and Niezgodna T 2013 Hybrid locomotives overview of construction solutions *Journal of KONES Powertrain and Transport* **20(1)** 127-134

- [13] Kozachenko D, Dovbnia M, Ochkasov O, Serdiuk V, Shepotenko A and Keršys A 2018 Rationale for Choosing the Type of Traction Rolling Stock for the Enterprise of Industrial Transport *Proceedings of 22nd International Scientific Conference. Transport Means* 991-5
- [14] Kozachenko D M, Ochkasov O B, Shepotenko A P and Sannytsky N M 2017 Prospects of the private locomotives usage for goods traffic in the direction of sea ports *Science and Transport Progress, Bulletin of Dnipropetrovsk National University of Railway Transport* **6(72)** 7-19
- [15] Jennings B 2009 Investigating private railroad operations and the locomotive issue *Journal of Transportation Management* **20(1)** 48-58
- [16] Konarzewski M and Niezgoda T 2013 Hybrid locomotives overview of construction solutions *Journal of KONES Powertrain and Transport* **20(1)** 127-134
- [17] Myamlin S, Kozachenko D and Grevtsov S 2014 Improving the competitiveness of railways through the use of bimodal technologies transportation *Ukrainian railways* **12(8)** 20-23 (in Ukrainian)
- [18] Ruger B 2003 Kombiniertes Verkehr als Rettung des Schienengüterverkehrs *Technische Universität Wien (Institut für Eisenbahnwesen, Verkehrswirtschaft und Seilbahnen)* **5** 1-27
- [19] Sebesan I and Ene M-O 2015 Method of static determination of the safety against overturning of the road-rail machines *University POLITEHNICA of Bucharest Science Bulletin Ser. D* **77(1)** 51-60
- [20] Iwnicki E 2006 *Handbook of Railway Vehicle Dynamics* (CRC press Boca Raton S.U.A.)
- [21] Wickens A H 2003 *Fundamentals of Rail Vehicle Dynamics: Guidance and Stability* (Lisse: Swets & Zeitlinger BV)
- [22] Daniyan I A, Mpofu K, Daniyan O L and Adeodu A O 2019 Dynamic modelling and simulation of rail car suspension systems using classic controls *Cogent Engineering* **6(1)** 1602927
- [23] Khromova G, Mukhamedova Z and Yutkina I 2017 Mathematical mode of oscillations of bearing body frame of emergency and repair railcars *Transport problems* **12(1)** 93-102
- [24] Drożdźiel J and Sowiński B 2008 Simulation of railway track deterioration influenced by ballast stiffness and dry friction *WIT Transactions on The Built Environment* **103** 693-702
- [25] Shubin A A, Vitchuk P V and Smolovik A E 2019 Development of a backup drive in locomobile construction *IOP Conference Series: Materials Science and Engineering* **560** 1-7
- [26] Nadykto V, Arak M and Olt J 2015 Theoretical research into the frictional slipping of wheel-type undercarriage taking into account the limitation of their impact on the soil *Agronomy Research* **13(1)** 148-157
- [27] Chaplinskiy A 2007 Analysis of the influence of changes in the design parameters of MED of traction class 1,4-3 on its traction efficiency *Visnik Kharkiv Petro Vasylenko National Technical University of Agriculture* **67(1)** 193-201
- [28] Chaplinskiy A 2012 The traction efficiency definition of the module power units of the variable drawbar category 1,4-3 *Scientific Bulletin of the Tavriya State Agrotechnological University* **3(2)** 88-94 (in Ukrainian)