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# IMPROVEMENT OF TRACTION INDICATORS OF A TRACK-CHAIN TRACTOR

*The aim of this research was to conduct the comparative traction tests for T-170M1.03-55 tractor with a flat and elliptical rim. Structurally rational geometry of the crawler's support surface for tractors with semi-rigid suspension is realized by placing the support rollers at different heights relative to the cart. The results of traction tests showed that elliptical track rim has increased the maximum traction power by 10.4%, conditional traction propulsive efficiency coefficient to 7.43% and the specific traction effort by 8%. The increase in indicators is provided by a lower rolling resistance of a tractor with an elliptical rim. Reduction of the resistance power to rolling of the tractor with an ellipse track rim occurs due to alignment of support rollers vertical load and reduction of resistance to rollers movement on internal contours of tracks and in hinges of track chain links. The results of the research indicate a significant improvement in traction performance of T-170M1.03.55 tractors with elliptical track-chain rim.*

**Keywords:** track-chain tractor, traction, power balance, drawbar tests; rolling coefficient

## 1 Introduction

When performing technological operations in agriculture, a track-chain tractor is an effective pulling device [1]. Track-chain tractors in comparison to wheeled tractors have better traction, better off-road capabilities, low soil compaction indicators, 8-20% lower fuel consumption per unit of work performed [2-4]. Along with the advantages, a chain-track tractor has a number of disadvantages that worsen its performance [5].

At present, much attention is paid to improving the technical level of tractors and track assembly traction indicators, as well as to the reduction of metal content and soil compaction [4-6]. Based on results of the in-depth analysis of the mover's impact on soil, new methods for determining the maximum pressure of wheeled and track-chain movers on soil were developed, as well as calculation methods for defining the indicators of wheel and metal track-chain movers, which guarantee permissible machinery impact on soil, and stress-strain state of soils [2].

One of the ways to increase traction and reduce soil compaction is the tractor movers' improvement [7]. In tractor construction, more than twelve mover designs are used. Most of these movers have semi-rigid suspension [1, 4-5]. The use of rubber-reinforced tracks is a promising direction for improving the track-chain travel system. Rubber-reinforced tracks have both, advantages and disadvantages compared to metal track-chain movers [8-11].

Models of interaction between wheels and deformable gravel developed for wheeled vehicles are often used [12]. Influence of air pressure in the front and rear wheels on

the rolling coefficient of the wheeled tractor and fuel consumption have been determined [13]. An improved model of tire-ground interaction has been proposed based on FEA-SPH modeling. [14]. A method for estimating a three-dimensional (3D) footprint of pneumatic agricultural tires has been developed based on the tire footprint molding with liquid plaster. Using a 3D scanner, the molds were then converted to three-dimensional models [15]. A model based on particle filtration was proposed to estimate thermomechanical parameters of wheel-ground interaction [16].

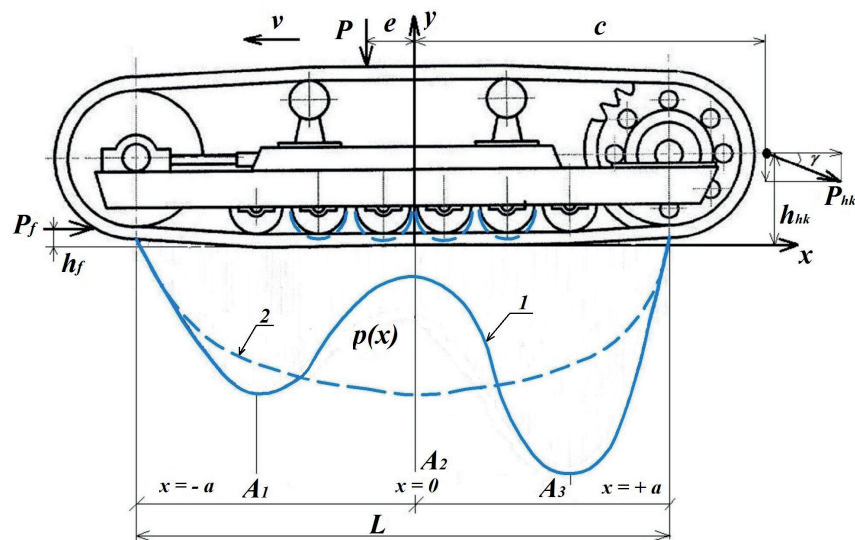
The models of wheel interaction with the ground [12, 15-16], which were proposed, can be used to model the interaction of rubber-reinforced tracks with soil [12-16]. The issue of improving traction properties is of a great importance for all types of track-type vehicles. An empirical model of traction characteristics of rubber tracks on agricultural soils has been developed [7]. A method for calculating crawler track traction on soft ground has been presented [17]. A simple general method has been proposed for calculating soil deformations by the track of track-type vehicles [18]. The traction characteristics of seafloor-tracked vehicles were evaluated based on the mechanical laboratory tests [19].

Interaction of steel and rubber crawler movers with the soil, the uneven distribution of soil reactions on the support surface of the mover, traction characteristics and calculations are considered in different studies [7, 17-19]. The impact of the mover on the soil increases together with the rise in uneven load distribution along the support part, which results in crop yields reduction [20-29]. Uneven distribution of loads between the lower support rollers of a track-chain tractor is accompanied by uneven wear

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**Figure 1** Scheme of a track-chain mover and the stress distribution diagram in the longitudinal section of the support part of T-170.M1.03-55 tractor (1 - flat track rim; 2 - ellipse track rim):  $P$  [N] - load on a single mover;  $P_{hk}$  [N] - traction effort on the tractor hook;  $e$ -eccentricity [m];  $L$  [m] - length of the support part;  $\pm a$  [m] - half-length of the support part;  $h_f$  [m] - shift of the longitudinal component of the rolling power  $P_f$  from relative to soil reaction;  $c$  [m] - distance from the contact center to the vertical component  $P_{hk}$ ;  $h_{hk}$  [m] - the height of the trailer relative to the support surface

of support rollers, tracks and a decrease in the mover durability [30].

During the experimental studies of the impact of T-170M1.03-55 tractor movers on soil it was found that the maximum values of its pressures reached 0.166 MPa [3]. At the same time, the pressure profile along the length of the support surface has two local extrema in the zone of the first and the sixth support rollers (Figure 1), which causes a decrease in the traction performance and increased soil compaction. It is more preferable to reduce the uneven load distribution along the support part, the maximum pressure and multiplicity of influences, than its uniform distribution on the site of contact of the basic surface. The pressure profile can be significantly decreased by changing the geometry of the tractor support part [31-33]. The purpose of this research was to evaluate influence of the geometry of the support part of a track-chain mover on the traction characteristics of the T-170M1.03-55 tractor.

## 2 Methods

Traction characteristics of a tractor are the basis in correct choosing of parameters of a machine-tractor aggregate. Using the traction characteristics, a theoretical analysis was carried out and potential energy and technical and economic performance of the machine-tractor aggregate were estimated [34]. In accordance with the requirements of the State All-Union Standard (SAUS) 23734, 25836, 7057, comparative traction tests of T-170M1.03-55 tractor with flat and elliptical track-chain rim were carried out, taking into account scientific works [34-36]. This type of tractor is widely used in the post-Soviet countries [37-38].

## 3 Equation of the support part geometry of a track-chain tractor

As theoretical studies have shown, a significant reduction in the maximum pressure ensures its uniform distribution over the contact area of the tractor support surface with the soil. Based on the contact problem of the theory of elasticity, an equation of the geometry of the support surface of a track-chain tractor with a semi-rigid suspension, providing a uniform distribution of pressure along the support surface, was obtained [25, 38]:

$$f(x) = 0.5p_{av}\pi\beta\{x \arcsin(x/a) + A - (B[xA/a^2 + \arcsin(x/a)]\} + C, \quad (1)$$

where:

$p_{av}$  [Pa] is the average pressure of the tractor on soil;

$p_{av} = G_e/(2bL)$ ;

$G_e$  [N] is the operating tractor weight;

$L$  [m] is the length of the tractor support surface;

$b$  [m] is the track width;

$\beta = v_1 + v_2$ ;

$v_1 = (2(1 - \mu_1^2)/\pi E_1)$ ;

$v_2 = (2(1 - \mu_2^2)/\pi E_2)$ ;

$E_1$  [Pa] is the soil elasticity modulus;

$\mu_1$  is the soil Poisson's ratio;

$E_2$  [Pa] is the steel elasticity modulus of a track link;

$\mu_2$  is the Poisson's ratio of the track link steel;

$A$  [m] =  $\sqrt{a^2 - x^2}$ ;

$a = L/2$  is the contact half-width;

$x$  [m] - the horizontal coordinate of the support surface point;

$B$  [kN] =  $P[e + \varphi_{hk}(h_{hk} \cos \gamma + c \sin \gamma) + fh_f]$ ;

$P = G_e + P_{hk} \cos \gamma$  - the load to a single mover;

$P_{hk}$  [N] - the power on the hook;

**Table 1** The soil and atmospheric conditions during the traction tests

Indicators	Track-chain mover	Transmission gear						
		1	2	3	4	5	6	7
Intake air temperature inside the air cleaner [°C]	elliptical	28	26	30	26	29	27	27
	flat	36	36	40	39	29	27	34
Diesel fuel temperature [°C]	elliptical				33			
	flat				42			
Atmospheric pressure [kPa]	elliptical				98			
	flat				97			
Soil density number of strokes	elliptical				7 ... 10			
	flat				7 ... 10			
Soil moisture [%]	elliptical				at a depth of 8 cm - 10%,			
	flat				at a depth of 12 cm - 15%			
Track slope (in the movement direction/ against movement direction) [%]	elliptical				0.4/2.5			
	flat							

$\gamma$  [°] is the angle between the power on the hook and the horizontal plane;

$\varphi_{hk} = P_{hk}/P$  - the coefficient of the hitch weight use;

$e$  [m] is the longitudinal coordinate of the gravitational center of the tractor relative to the middle of the track length on ground;

$h_{hk}$  [m] - the height of the trailer relative to the support surface;

$f$  - the resistance factor to the tractor movement,  $f = 0.07-0.15$ ;

$h_f$  [m] - the shift of the longitudinal component of the rolling power relative to the soil reaction,  $h_f = 0.015-0.029$ ;

$C$  [m] is the coefficient equal to the initial soil deformation determined empirically,  $C = -0.027 \pm 0.003$ .

The established dependence  $f(x)$  shows how far the points of the tractor support part are separated from the OX horizontal axis. Structurally elliptical geometry of the support part is implemented by lowering the axis of the less loaded lower support rollers, that is, by setting plates of appropriate thickness under the axis of lower support rollers. Thickness of the plates is determined by Equation (1).

The elliptical geometry of the support part depends on the following parameters: tractor weight, support surface length, location of the center of mass, tractive power and its loading point, tracks material properties and the soil type. Therefore, the T-170M1. 03. 55 tractor parameters were determined and its typical working conditions were: traction power is 40-80 kN, the length of

the support surface is 2.88 m, the trailer height is 0.4 m; eccentricity  $e = -0.165$  m; track material, which is carbon steel (steel 20, steel 45, etc.); loamy soil; soil moisture is 16-20%.

All the parameters have been structurally applied for the T-170M1.03.55 tractor in the following way: when position of the 1st and 6th lower support rollers remain unchanged, the 2nd and 5th support rollers are lowered by use of spacers for 5 mm, the 3rd and 4th for 10 mm relative to the support surface of the cart frame. The same tractor was used during the traction tests, but the geometry of the mover support part was changed.

#### 4 Ground and atmospheric conditions during the traction tests

The traction tests were carried out at the test base of Chelyabinsk tractor factory. The length of the traction track was measured to be 600 m, and the width was 25 m. Density and moisture of the soil of the track were measured on testing day at least 12 times. The density was measured with DorNII ram tester. Control of slopes and deviations from the track flatness was carried out by theodolite 2T30, special racks and a metal ruler. Atmospheric conditions were checked daily at the beginning and end of the tests, as well as during the experiments for determining the maximum traction power and maximum traction effort. The soil and atmospheric conditions during the traction tests are presented in Table 1.



**Figure 2** T-170M1.03-55 tractor with a mobile dynamic laboratory SDL-30



**Figure 5** Registration of track driving wheel speed rate



**Figure 3** Tractive power registration



**Figure 6** Path measurement device



**Figure 4** Engine speed registration



**Figure 7** Brake tests of D-160 diesel engine

## 5 Pilot unit and measuring

In accordance with the instruction manual, the undertaken maintenance and the run-in process lasted for 150 Moto-hours. At the beginning of testing, the tractor was weighed on a weighing complex with limits of 5-100 tons.

Resistance temperature devices were installed to measure the air temperature at the inlet to the air filter and the temperature of the fuel entering the fuel filter. The tractor was equipped by sensors and devices, which were a part of the measuring systems for a movable dynamic laboratory SDL-30 (Figures 2-6).

Parameters to be registered, measuring instruments, and measurement errors are presented in Table 2.

Calibration of a traction link was performed before and after the tests. Adjustment of the measuring instruments, which are a part of the measuring system of laboratory SDL-30, was done.

Characteristics of the D-160 engine were determined on a hydraulic brake stand using the breaking method in accordance with the State All-Union standard 25836-83, 23734-79 and 18509-88. At the front of the tractor, the engine crankshaft was attached to the E-1500 brake stand as follows. The rotor shaft of the balancing machine was connected to the main shaft through a pin bush coupling. The other end of the main shaft was connected to the engine through the driveshaft and the mid-shaft, which was mounted on a bearing support on the tractor bumper and connected to the engine crankshaft grooved sleeve (Figure 7).

All experiments were carried out in the steady traction load mode with straight-line movement of the tractor on the track, created by the SDL-30 laboratory through the trailer E-900 with a straight-gage element. After the mode stabilization, loading was carried out in stages with fixed values of  $P_{hk}$  for at least 7.5 seconds. The traction characteristics was measured on forward movement gears

**Table 2** List of parameters to be registered and measuring instruments

Measured parameter	Measurement instrument	Measurement range	Measurement error
Traction power [kN]	Strain-gauge-type segment E-1810-2 Electro-magnetic transducer EMT-P	1...150	not more than 0.66 %
Crankshaft speed [min <sup>-1</sup> ]	E-753-1SB sensor Electro-magnetic transducer EMT-P	0...1500	not more than 0.5 %
Driven wheel speed [min <sup>-1</sup> ]	contact sensor E-1344 Electro-magnetic transducer EMT-P	0...60	not more than 0.5 %
Tractor trip mileage [m]	contact sensor E-985-14 Electro-magnetic transducer EMT-P	0...200	not more than 0.5 %
Experiment time [s]	Electro-magnetic transducer EMT-P timer	0...7.5	0.2 s
Fuel temperature, ambient air temperature, intake air temperature inside the air cleaner, [°C]	Multipoint electro-thermometer 234.00.000 consisting of: - resistance copper thermometer; - measuring unit. Thermometer TL-2	-50...+40	±1°C
Fuel density [t·m <sup>-3</sup> ]	Density hydrometer ANT-1	0.77...0.83	±0.0005 t/m <sup>3</sup>
Atmospheric pressure [kPa]	Meteorological aneroid barometer BAMB-1	80...106	±0.2 kPa
Soil density, the number of strikes	DorNII ram tester	-	± 1 strike
Track slope [°]	Theodolite 2T30	+60...-55	±30"

in the form of a series of experiments covering the entire range of traction effort  $s$  in each gear.

Based on the measured and decoded values, the following indicators were calculated for each gear:

$V_T$  [m·s<sup>-1</sup>] - theoretical speed;  $V_a$  [m·s<sup>-1</sup>] - actual speed;  $\delta$  [%] - sliding.

The theoretical speed of the tractor on the  $j$ -gear is determined by the formulas:

$$V_T [m \cdot s^{-1}] = 0.0167 \frac{n_d \cdot t \cdot z}{i_j}, \quad (2)$$

where:

$n_d$  [min<sup>-1</sup>] is the rotational speed of a diesel engine crankshaft;

$t$  [m] - track pitch;

$i_j$  - tractor gear ratio;

$z$  - number of chain track links tractor number of links moving during one driven wheel turn,  $z=13.5$  cm.

The actual speed of the tractor per hour (when using a master gear, a circle perimeter of which is  $C = 2.515$  m);

$$V_A = 0.027944 \frac{Q_{mg}}{\tau} [m \cdot s^{-1}], \quad (3)$$

where:

$Q_{mg}$  is the total number of rotation impulses of a master gear during the experiment;

$\tau$  - time of the experiment [s].

$$\delta = \left( 1 - \frac{m_{mg}}{m_{dw}} \cdot \frac{Q_{mg}}{Q_{dw}} \right) \cdot 100, \quad (4)$$

where:

$m_{dw}$  [m/imp] is impulse scale of sensors measuring the number of driven wheels rotations;

$m_{mg}$  [m/imp] - impulse scale of a sensor, which measures the number of a master gear rotations;

$Q_{mg}$  is the total number of impulses of the rotation sensor of a master gear during the experiment;

$Q_{dw}$  - the total number of impulses of a driven wheel rotation sensor during the experiment.

Based on the calculation results, the graph of dependence of the tractor sliding coefficient on the tractor traction  $\delta = f(P_{hk})$  was obtained. All the measurements made on all the gears, were used to create the graph of sliding

The traction power  $N_{hk}$  at a given point was calculated by formula:

**Table 3** Main traction indicators of the T-170M1.03-55 tractor at maximum power  $N_{hkmax}$  and at maximum traction effort

Gear	Indicators													
	Test mode													
	Nhkmax							Phkmax						
$N_{hk}$ [kW]	$P_{hk}$ [kN]	$V_a$ [km/h]	$\delta$ [%]	$G_T$ [kg/h]	$g_{hk}$ [g/ kW/h]	$\eta_{cond}$	$n_{eng}$ [min-1]	$\eta_{hk}$ [kN]	$V_a$ [km/h]	$N_{hk}$ [kW]	$\delta$ [%]	$\varphi_{hkmax}$ [°]	neng [min-1]	
flat track-chain rim														
I	84.49	113.47	2.68	2.8	30.06	356	0.684	1096	129.50	1.69	70.37	5.3	0.820	824
II	82.79	92.67	3.22	2.6	30.27	366	0.67	1112	109.68	2.43	73.90	4.0	0.694	848
III	78.09	68.32	4.12	2.6	30.32	388	0.638	1120	84.14	2.83	66.40	4.5	0.533	784
IV	75.96	51.52	5.31	2.5	30.84	406	0.619	1208	67.23	3.57	66.62	2.5	0.426	800
V	70.44	40.25	6.3	1.9	30.74	436	0.560	1232	53.90	3.93	58.82	1.5	0.341	768
VI	70.22	37.19	6.8	2.4	29.65	422	0.546	1120	44.35	5.07	62.43	3.2	0.281	848
VII	59.04	31.03	6.85	3.4	29.33	497	0.475	1016	34.66	5.65	54.34	2.2	0.219	840
elliptical track-chain rim														
I	89.5	117.3	2.75	1.7	30.17	337	0.700	1128	140.1	1.88	73.0	8.6	0.887	824
II	89.2	97.0	3.31	2.8	30.17	338	0.695	1152	116.5	2.29	74.2	5.4	0.738	824
III	85.7	72.1	4.28	0.8	30.02	350	0.673	1136	86.7	2.91	70.1	4.1	0.549	800
IV	82.1	57.6	5.14	0.2	30.07	366	0.640	1144	72.1	3.41	68.2	2.2	0.457	784
V	79.8	51.5	5.58	1.1	29.76	373	0.626	1104	61.8	3.98	68.3	3.7	0.391	792
VI	74.7	39.3	6.84	2.2	30.02	402	0.584	1136	47.7	4.52	59.9	4.5	0.302	768
VII	71.9	35.6	7.28	3.1	29.46	410	0.562	1072	42.0	5.35	62.4	4.3	0.266	800

$$N_{hk} = P_{hk} \cdot V_a, kW. \quad (5)$$

Conditional traction propulsive efficiency coefficient of a tractor by gear:  $\eta_{cond}$  is:

$$\eta_{cond} = N_{hkmax} / N_{op} \cdot C_{PRI}, \quad (6)$$

where:

$N_{op}$  is the engine operating power, according to the State All-Union Standard 18509;

$C_{PRI}$  - the engine power coefficient according to the State All-Union Standard 18509, corresponding to atmospheric conditions and fuel parameters during traction tests on a specific (i-th) gear.

The specific fuel consumption  $g_{hk}$ , at a given point, is calculated by formula:

$$g_{hk} [kg/h] = \frac{G_t}{N_{hk}}, \quad (7)$$

where:

$G_t$  [kg/h] - fuel consumption per hour.

## 6 Results and discussions

The main indicators of the traction tests of the T-170M1.03-55 tractor, with flat and elliptical track-chain rims, are given in Table 3. A graphical analysis of the data is presented in Figures 8 and 9.

To evaluate influence of the mover support part geometry on traction characteristics of the T-170M1.03-55 tractor, several indicators of traction characteristics were used. Those indicators are: the maximum traction power,  $N_{hkmax}$  [kW]; conditional traction efficiency coefficient [ $\eta_{cond}$ ]; traction effort corresponding to the maximum traction power,  $P_{hk}$  [kN], engine speed at maximum traction power,  $n_e$  [min<sup>-1</sup>]; the specific fuel consumption at maximum traction power,  $g_{hk}$  [kg.kW<sup>-1</sup>.h<sup>-1</sup>]; operating speeds,  $V_a$  [km/h]; coefficient of resistance to the movement,  $f$ ; sliding coefficient [ $\delta$ ].

After testing, calculations were made on the comparable indicators of the traction characteristics of the T-170M1.03-55 tractor with a flat and elliptical chain-track rim (Table 4).

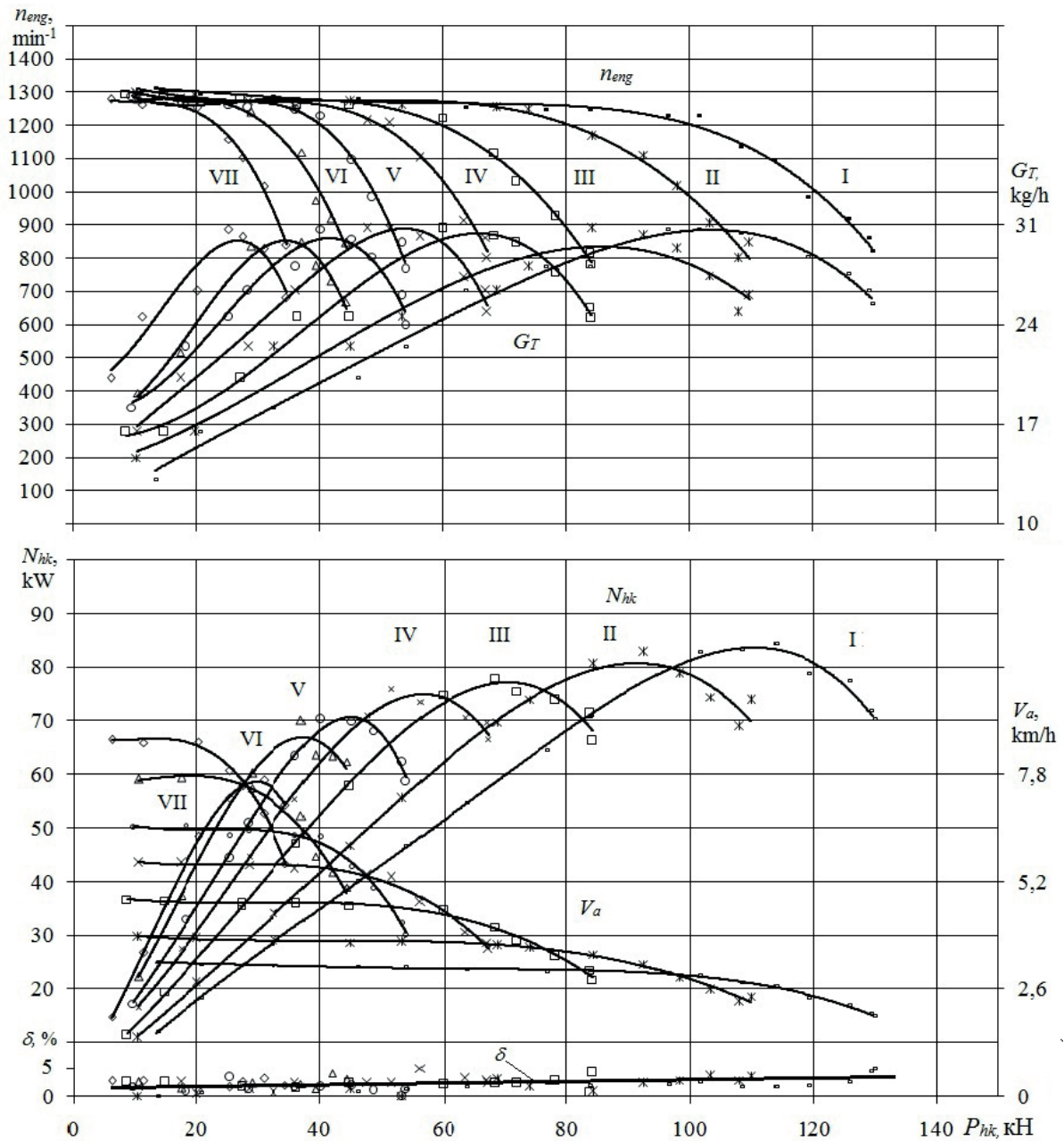


Figure 8 The traction characteristics of the T-170M1.03-55 tractor with a flat track-chain rim

The maximum traction power of the T-170M1.03-55 tractor with an elliptical track-chain rim is almost the same when driving in the first and second gears: when driving in the first gear the tractor's maximum traction power is 89.5 kW at 117.3 kN of thrust, speed of 2.75 km/h and the sliding of 1.7 %. In the second gear the tractor's maximum traction power is 89.2 kW at 97.0 kN of thrust, speed of 3.31 km/h and sliding of 2.88 %, which corresponds to a conditional maximum traction thrust coefficient of 0.7 (Figure 10).

Tractor T-170M1.03-55 with a flat track-chain rim does not have alignment of the maximum traction power in different gears. The maximum traction power is 5.9% lower and amounts to 84.49 kW in first gear with a traction effort of 113.5 kN, speed of 2.68 km/h, sliding of 2.8%. The maximum conditional traction efficiency coefficient is 0.684.

With increase in speed, the maximum traction power of the T-170M1.03-55 tractor, with an elliptical track-chain rim, increases from 5.9% in the first to 21.8% in the seventh gear compared to the corresponding indicators with a flat track-chain rim. The maximum traction power in all the gears increased on average by 7.39 kW, 10.4%. Due to increase of the maximum traction power, the potential capabilities of the T-170M1.03-55 tractor also increase.

The rolling resistance of the tractor with a flat track was between 16.48 kN to 22.8 kN with an average value of 19.64 kN. With an elliptical track, the rolling resistance was between 13.79 kN and 14.94 kN, with an average value of 14.36 kN. The rolling resistance of the tractor was determined at a speed of 2.15 to 4.25 km/h. The average difference in rolling resistance power values was 5.27 kN (Figure 11).

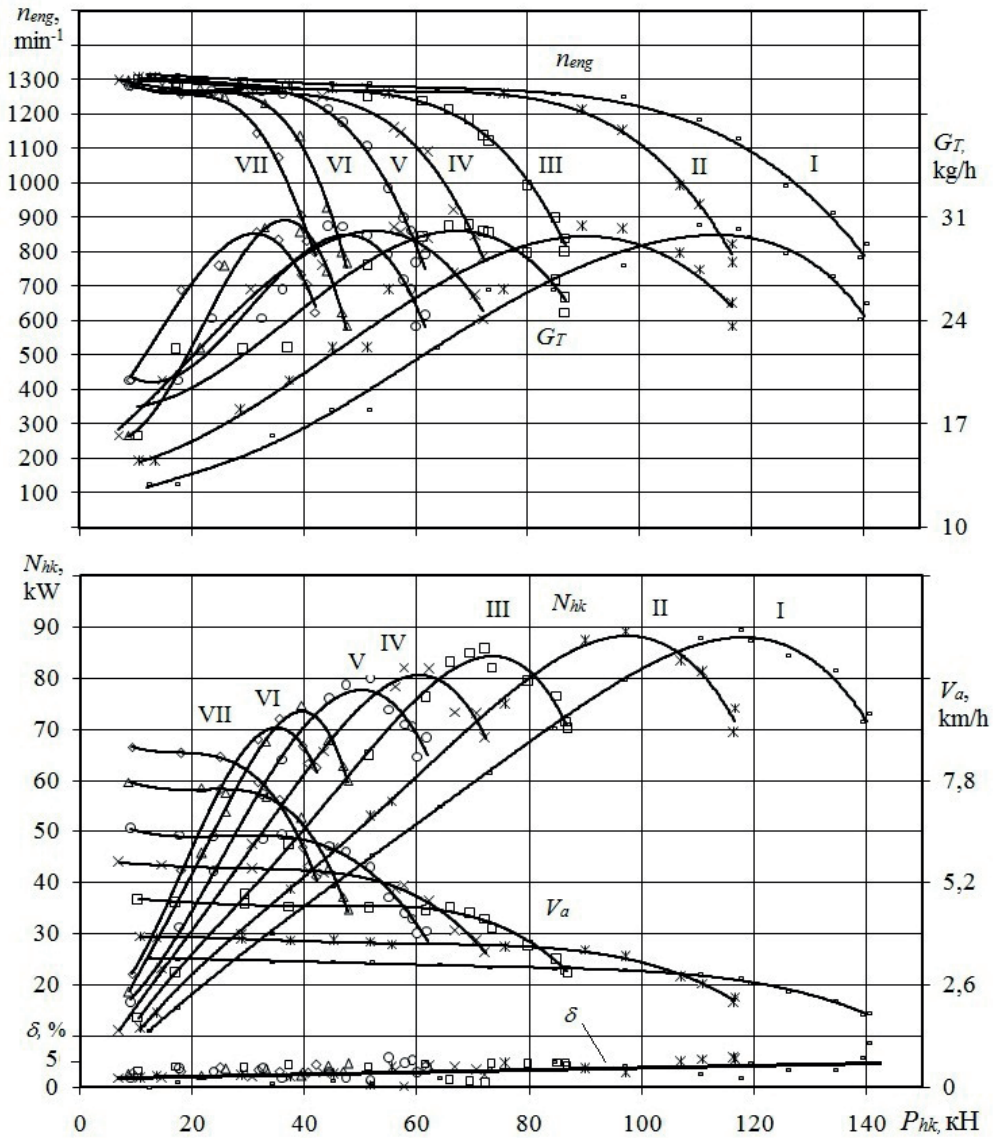


Figure 9 The traction characteristic of the T-170M1.03-55 tractor with an elliptic track-chain rim

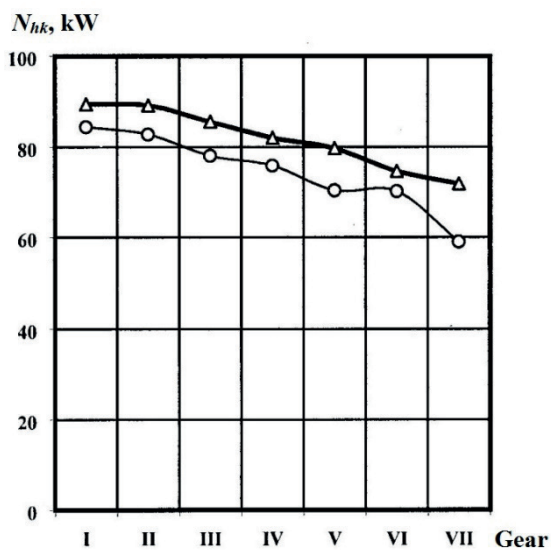


Figure 10 The maximum traction power of the T-170M1.03-55 by gear:  $\circ$  - flat track-chain rim;  $\Delta$  - elliptical track-chain rim

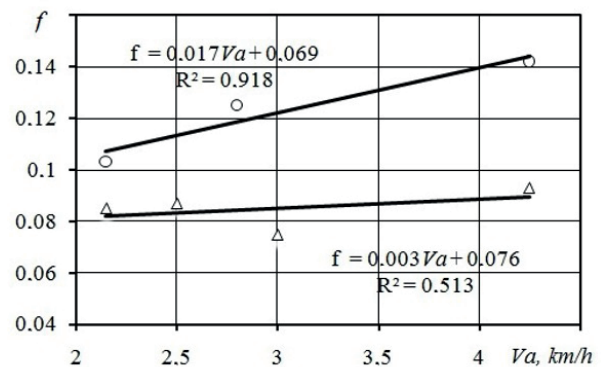
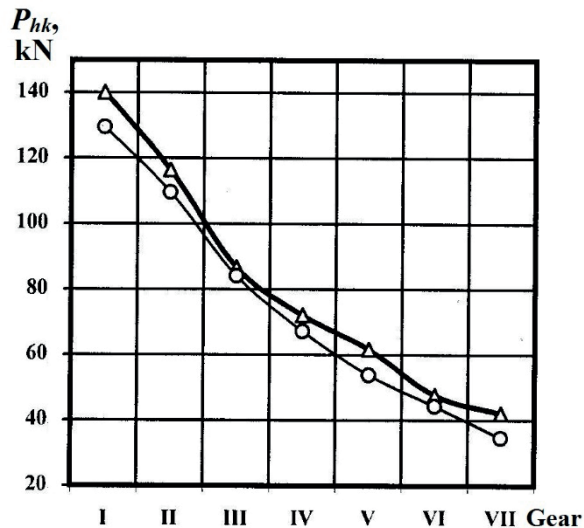


Figure 11 Dependence of the rolling power coefficient of T-170M1.03-55 tractor on speed:  $\circ$  - flat track-chain rim;  $\Delta$  - elliptical track-chain rim

**Table 4** Comparable indicators of the T-170M1.03-55 tractor's traction characteristics with different geometry of the mover support part

Test mode	Mover	Gear ratios							Average values	
		1	2	3	4	5	6	7		
$N_{hkmax}$ [kW]	elliptical	89.5	89.2	85.7	82.1	79.8	74.7	71.9		
	flat	84.49	82.79	78.09	75.96	70.44	70.22	59.04		
	$\Delta N_{hkmax}$ [kW]	5.0	6.4	7.57	6.1	9.34	4.49	12.87	7.39	
	$\Delta N_{hkmax}$ [%]	5.9	7.7	9.7	8.0	13.3	6.4	21.8	10.40	
$P_{hk}$ [kN]	elliptical	117.3	97.0	72.1	57.6	51.5	39.3	35.6		
	flat	113.5	92.67	68.32	51.52	40.25	37.19	31.03		
	$\Delta P_{hk}$ [kN]	3.8	4.3	3.8	6.0	11.3	2.2	4.5	5.14	
	$\Delta P_{hk}$ [%]	3.3	4.7	5.6	11.7	28.0	5.8	14.6	10.54	
$N_{hkmax}$ [kW]	$\Delta f$	0.024	0.027	0.024	0.037	0.070	0.013	0.028	0.032	
	$V_a$ [km/h]	elliptical	2.75	3.31	4.28	5.14	5.58	6.84	7.28	
	flat	2.68	3.22	4.12	5.31	6.3	6.8	6.85		
	$\Delta V_a$ [km/h]	0.07	0.09	0.16	-0.17	-0.72	0.04	0.43	-0.01	
$\delta$ , %	$\Delta V_a$ [%]	2.6	2.8	3.9	-3.2	-11.4	0.6	6.3	0.22	
	elliptical	1.7	2.8	0.8	0.2	1.1	2.2	3.1		
	flat	2.8	2.6	2.6	2.5	1.9	2.4	3.4		
$g_{hk}$ [g/kW·h]	$\Delta \delta$ [%]	-1.1	0.2	-1.8	-2.3	-0.8	-0.2	-0.3	-0.9	
	elliptical	337	338	350	366	373	402	410		
	flat	356	366	388	406	436	422	497		
$\eta_{cond}$	$\Delta ghk$ [g/kW·h]	-18.65	-27.34	-37.83	-39.58	-63.36	-20.40	-87.08	-42.04	
	$\Delta ghk$ [%]	-5.2	-7.5	-9.7	-9.7	-14.5	-4.8	-17.5	-9.87	
	elliptical	0.700	0.695	0.673	0.640	0.626	0.584	0.562		
$P_{hkmax}$ [kN]	flat	0.684	0.670	0.638	0.619	0.560	0.546	0.475		
	$\Delta \eta_{cond}$ -	0.016	0.025	0.035	0.021	0.066	0.038	0.087	0.04	
	$\Delta \eta_{cond}$ [%]	2.34	3.73	5.49	3.39	11.79	6.96	18.32	7.43	
$P_{hkmax}$ [kN]	elliptical	140.1	116.5	86.68	72.14	61.75	47.73	42.04		
	flat	129.5	109.7	84.14	67.23	53.90	44.35	34.66		
	$\Delta P_{hk}$ [kN]	10.6	6.86	2.54	4.91	7.86	3.37	7.38	6.22	
	$\Delta P_{hk}$ [%]	8.19	6.25	3.02	7.31	14.58	7.61	21.29	9.75	
$V_a$ [km/h]	$\Delta f$	0.066	0.043	0.016	0.031	0.049	0.021	0.046	0.039	
	elliptical	1.88	2.29	2.91	3.41	3.98	4.52	5.35		
	flat	1.69	2.43	2.83	3.57	3.93	5.07	5.65		
	$\Delta V_a$ [km/h]	0.19	-0.14	0.08	-0.16	0.05	-0.55	-0.30	-0.12	
$N_{hk}$ [kW]	$\Delta V_a$ [%]	11.24	-5.76	2.83	-4.48	1.27	-10.8	-5.31	-1.58	
	elliptical	73.0	74.2	70.1	68.2	68.3	59.9	62.4		
	flat	70.37	73.90	66.40	66.62	58.82	62.43	54.34		
	$\Delta N_{hkmax}$ [kW]	2.65	0.29	3.68	1.62	9.49	-2.57	8.09	3.32	
$\Delta$ [%]	$\Delta N_{hkmax}$ [%]	3.76	0.40	5.54	2.43	16.13	-4.12	14.88	5.57	
	elliptical	8.6	5.4	4.1	2.2	3.7	4.5	4.3		
	flat	5.3	4	4.5	2.5	1.5	3.2	2.2		
$\Delta \delta$ [%]	3.3	1.4	-0.4	-0.3	2.2	1.3	2.1	1.37		



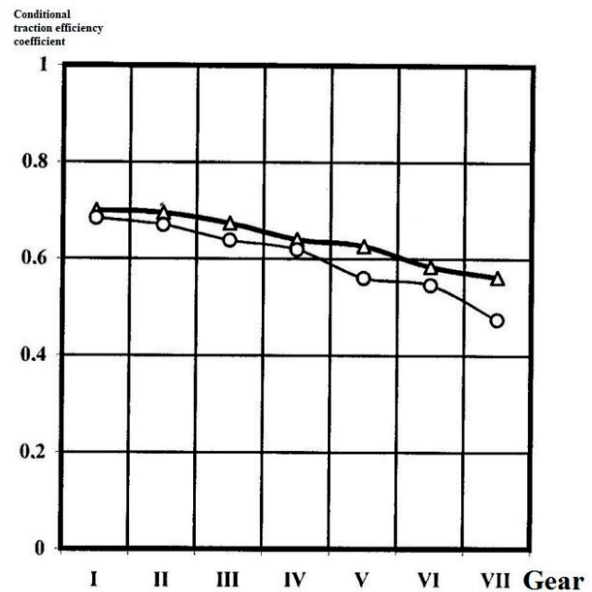
**Figure 12** The maximum traction effort of the T-170M1.03-55 tractor in gears: - flat track-chain rim;  $\Delta$  - elliptical track-chain rim

At the maximum traction power, the tractor develops traction effort: from 117.3 kN to 3.5 kN for a tractor with an elliptical track-chain rim and from 113.5 kN to 3.10 kN for a tractor with a flat track-chain rim (Table 4). A amount of increase in the traction effort ranges from 3.8 kN to 11.3 kN with an average value of 5.14 kN, absolute value of which is almost equal (5.27 kN) to the traction resistance to the rolling of the tractor. The increase in traction effort is observed in all the gears, while there is no certain pattern of their changes.

When analyzing the parameters at the maximum values of the traction effort, a similar pattern is observed. The maximum traction effort of the T-170M1.03-55 tractor is limited by the maximum torque of the engine, and is equal to 140.1 kN when sliding for elliptical track-chain rim is 8.6 %. When sliding for a flat track-chain rim is 5.3 %, the maximum traction effort is 129.5 kN. The maximum traction effort values of a tractor with elliptical rim do not depend on the speed and exceed the maximum traction effort values of a tractor with flat rim on average by 6.22 kN or 9.75% (Figure 12). The increase in the traction power in the maximum traction effort mode was approximately 3.32 kW or 5.57%.

The actual speed of a tractor with an elliptical rim exceeds that of a tractor with a flat rim on average by 3.24 % in all the gears. However, the speed of a tractor with an elliptical rim reduces by 7.3% in fourth and fifth gears. Such a speed difference can be explained by the fact that the maximum power given for the analysis, was obtained at different traction efforts and corresponding engine shaft speeds.

The value of sliding in the maximum traction power modes (in the entire range of the corresponding traction powers) is low for both variants ( $\delta = 0.2...3.1\%$  - for an



**Figure 13** The conditional traction efficiency coefficient (efficiency factor) of T-170M1.03-55 tractor according to gears:  $\circ$  - flat track-chain rim;  $\Delta$  - elliptical track-chain rim

elliptical rim and  $\delta = 1.9...3.4\%$  - for a flat rim). Sliding of a tractor with an elliptical rim is on average 0.9 % lower than that of a tractor with a flat track-chain rim (Table 4).

The conditional traction efficiency coefficient (efficiency factor) in gears of a tractor with an elliptical rim ( $\eta_{cond} = 0.7...0.562$  - for an elliptical rim;  $\eta_{cond} = 0.684...0.475$  - for a flat rim) is higher by 0.016...0.087, or by 2.3...18.3% than that of a flat rim. Same as for the maximum traction power, there is an increase in  $\eta_{cond}$  in all the gears of the tractor with an elliptical rim (Figure 13).

Increase in the traction power and in traction indicators of the T-170M1.03-55 tractor with an elliptical track-chain rim is accompanied by an increase in the tractor fuel efficiency. The specific fuel consumption per unit of the power output of a tractor with an elliptical track-chain rim is reduced from 5.2% in the first gear to 17.5% in the seventh gear (Figure 14). The specific fuel consumption is reduced by an average of 9.87 %.

There is an increase in the maximum traction power and conditional traction efficiency coefficient of a tractor with an elliptical rim in all the gears by an amount independent of gear with almost equal speed values in appropriate gears.

Analysis of results of the traction tests showed that the change in the geometry of the support part of a track-chain mover improves traction of the T-170M1.03.55 tractors and has a positive effect on the engine dynamics. The elliptical geometry of the support part of a track-chain tractor with semi-rigid suspension is realized in a simple way, i.e. installation of track rollers at different heights with the help of plates. Plates thickness is determined using Equation (1).

Reducing the rolling resistance leads to increase in the traction indicators of the T-170M1.03-55 tractor with elliptical rim when under the steady load.

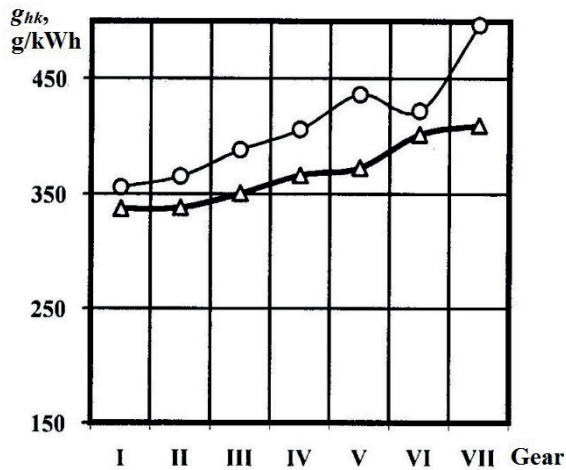


Figure 14 The specific fuel consumption of the T-170M1.03-55 tractor in the maximum traction mode according to gears: - flat track-chain rim; Δ - elliptical track-chain rim

The tractor power balance equation can be written as:

$$N_{hk} = N_w - N_\delta - N_f = N_w - N_\delta - P_f V_a, \quad (8)$$

where:

- $N_{hk}$  [kW] is the traction power;
- $N_w$  [kW] - power on the driving wheel;
- $N_\delta$  [kW] - power loss for sliding ;
- $N_f$  [kW] - power loss for movement;
- $P_f$  [kN] - movement resistance power;
- $V_a$  [km/h] - actual speed of the tractor.

It can be noted that an increase in the maximum traction power of a tractor with an elliptical track-chain rim in gears is determined by a decrease by an approximately constant amount in the movement resistance coefficient:

$$N_{hkmax}^{ell} = N_{hkmax}^{fl} + \Delta P_f V_i, \quad (9)$$

where:

- $N_{hkmax}^{ell}$ ,  $N_{hkmax}^{fl}$  is the maximum traction power in the  $i$ -th gear of the tractor with an elliptical and flat rim respectively;
- $\Delta P_f \sim \text{const} = 5.27$  kN is a reduction of a drag power to rolling of the tractor with elliptical rim compared to flat track rim that is equal to increase in traction;
- $V_i$  - tractor speed with maximum power in the  $i$ -th gear.

Having analyzed the works of various authors, it can be noted that, generally, resistance to tractors' rolling depends on speed, traction power, soil conditions and a mover type [1, 4, 6, 8, 34, 39-45].

According to most studies, the increase in speed results in an increase in the rolling coefficient  $f$ , which leads to the power loss necessary for rolling. Such an intensive increase in power loss for rolling is explained by an increase in loss for friction and strikes in tracks, as well as vertical compaction of soil. In the traction balance, the tractor power losses per a share of these losses, account for about 80%, of which 40-60% are losses for friction. Generally, the

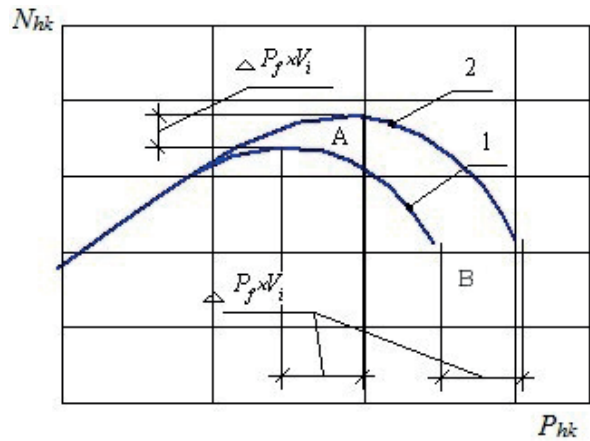


Figure 15 Diagram of the traction power increase in gears for a tractor with an elliptical track rim: 1 - flat track-chain rim; 2-elliptical track-chain rim

growth of movement resistance powers and accordingly the growth of losses for movement with increasing speed is explained by the fact that there is an increase in power loss for friction in the bearings of track rollers, in idler wheels and track pins power loss for friction when track links slip on track rollers and driven wheels. Other factors have the same effect, like losses caused by the tractor weight when track rollers move and the power of tracks pre-tension when they roll; power loss for friction caused by the increasing irregularity of the pressure distribution along the length of the supporting part of the tracks; the power loss for friction caused by the uneven movement of the track.

Reduction in the rolling resistance of a tractor with an elliptical track rim by 27 % should be considered as a decrease in uneven distribution of normal loads between the track rollers, especially the first and the sixth support roller and a decrease in the maximum pressures under these rollers. The elliptical track rim can be represented as circle segment with a large radius. During the tractor movement the tracks elements move more smoothly relative to each other, which leads to a reduction in rolling resistance of track rollers on the inner track rims and in the track links joints. By reducing the maximum pressure and the number of impacts on soil to one, the loss for soil deformation also decreases.

Based on the data analysis of these studies, the linear dependence of the rolling resistance coefficient on speed can be determined by the following equations:

$$f = 0.017 \cdot V_a - \text{for a flat track rim}; \quad (10)$$

$$f = 0.003 \cdot V_a + 0.076 - \text{for an elliptical track rim}, \quad (11)$$

where  $V_a$  is tractor's actual speed, km/h.

Most authors have similar positions in Equations (10) and (11). They consider the dependence of the coefficient

of resistance to rolling on the speed to be linear or close to linear [1, 4, 33, 39-40].

The higher operation efficiency of a tractor with an elliptical rim, which is a part of a machine-tractor aggregate, compared to that one with a flat rim, is achieved by the presence of additional A zone of high traction powers and B zone, associated with an increase in the maximum traction effort in each gear (Figure 15). In this case, the speed of the aggregate, with an elliptical rim tractor, increases provided that the traction resistance is within the mentioned zones.

In further studies of a tractor with an elliptical track rim as a part of a plowing unit, the comparative operational field tests should be conducted in the unsteady load mode.

## 7 Conclusions

Based on the research results, the influence of the geometry of the support part of a track-chain mover on the

traction characteristics of the T-170M1.03-55 tractor has been revealed. The results of traction tests showed that elliptical track rim has increased the maximum traction power by 10.4 %, conditional traction efficiency coefficient to 7.43% and specific traction effort by 8%. At the same time, the specific fuel consumption was reduced on average by 9.87%. The increase in indicators is provided by a lower rolling resistance of a tractor with an elliptical rim. Reduction of resistance power to rolling of a tractor with an elliptical track rim by 27% occurs due to alignment of support rollers vertical load and resistance reduction to rollers movement on the internal track rims and in the joints of track chain links.

The increase in the maximum traction powers and conditional traction efficiency coefficient of a tractor with an elliptical rim is observed in all the gears. The maximum values of the conditional traction efficiency coefficient are in the range of large traction efforts, where the power losses during the rolling are significantly reduced.

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