TRACTION PROPERTIES OF THE TRACKED COMBAT VEHICLE AT LOWERED POWER OF THE DRIVING ENGINE

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Abstract

Contemporary and future battlefield may be characterized by a great dynamism of action in both defensive and offensive operations. It is possible, that armoured and mechanized troops, acting at first attack, will suffer from shortages of supplies of materials and other equipment, especially propellants. It concerns particularly a fuel to engines of driving vehicles. Therefore in many cases for engine powering (as multi-propellant engines or adapted to work on substitute fuels) may be used substitute fuel. The fuel parameters sometimes may be much different from parameters of diesel. So it is substantially important to estimate their dynamics during the planning stage of combat missions. Paper includes attempt to estimate dynamic features of the combat vehicles using substitute propellants. Applying substitute propellants leads to reducing the power of the engine up to 10 % comparing to diesel. It has essential impact on lowering the dynamic ratio at similar level. That leads to lower maximum drive speed at given resistance of motion and reducing the ability to climb slopes. There also appears deterioration of spurt, extending the time of reaching speeds at about 17%. Paper shows results of traction calculations of combat vehicles and the influence of powering them with renewable fuel on their effectiveness.

Keywords*: combat vehicle, tank, renewable fuel, drive characteristic, mobility*

1. Introduction

Experiences of bygone and current armed conflicts, in spite of different opinions, confirm the thesis, that tracked armoured combat vehicles (tanks and infantry fighting vehicles) are still an essential means of the fight of the army, assigned to perform offensive as well as defensive objectives in different field, climatic and meteorological conditions. Its three basic properties are characteristic of an effectiveness of the armoured combat vehicle:

- fire power,
- armour,
- mobility.

Two first combat features (the fire power and the armour) are conditioned above all with structural assumptions of the armoured combat vehicle and during the operation are not changed in principle (omitting changes resulting from the arming technical state, the system of supervising the fire, arrangements of protecting systems and the like).

Under the term mobility, we understand the complex of features describing the ability of manoeuvring of the armoured combat vehicle on the battlefield in different field conditions, describing traction properties of the vehicles. As most essential of these features should be mentioned: parameters of a linear motion, the manoeuvrability and the ability to overcome the hostile area.

The high mobility of the armoured combat vehicle determines the pace of carrying out combat missions. It is also inseparably connected with remaining battle features (with the fire power and the armour). The greater mobility has armoured combat vehicle, the more difficult target constitutes for the opponent fire means, more quickly crosses dangerous stretches as well as has greater abilities of using the natural field protections - Fig. 1.

Fig. 1. Tank on off-road (photo. M. Dabrowski)

Achieving the high mobility of the armoured combat vehicle depends on many factors starting from the construction of the engine onwards, the driving and suspension systems, through command systems to conditions to the work and abilities of the driver-mechanic. Most important however are technical and structural parameters of driving and suspension systems, which mean:

- the rate of power, average ground pressure, the grip of tracks to ground;
- features of the driving system enabling optimal use the engine power, which provides gaining of the required span of the driving forces and the speeds of drive;
- properties of turn mechanisms providing the great manoeuvrability of the vehicle, the high angular speed of completion of the turn, fluid entering the turn and the transition to the linear motion;
- structural parameters of the track suspension system describing the ability to move in rough field conditions, in the scope of full use of the grip of tracks;
- quality of the vehicle steering mechanisms.

About the fact that there is constant strive for increasing parameters characterizing mobility of tracked armoured combat vehicles, prove the tendencies of development observed in the course of years, in individual generations of post-war tanks, according to the following division:

1. generation covering years of the II World War till 1960,
2. generation covering years 1960-1980, including the transitory period in 1970-1980 years,
3. generation covering years 1980-2000,
4. the nowadays generation covering years above 2000.

Some of the parameters are presented on the Fig. 2 to 5.

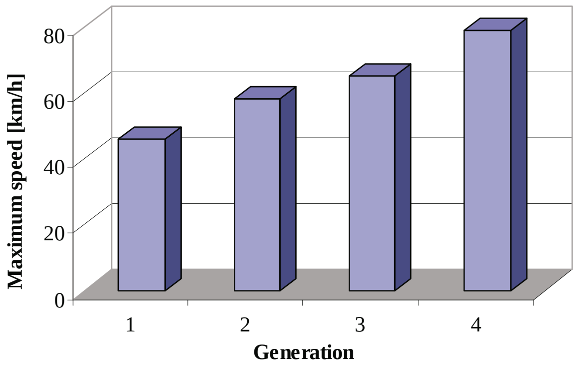

Fig. 2. Maximum drive speed of the tanks

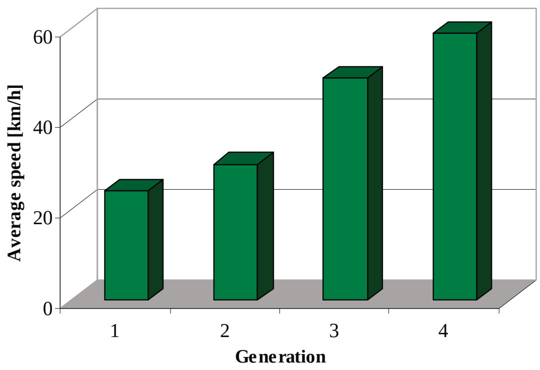

Fig. 3. Average drive speed in ground

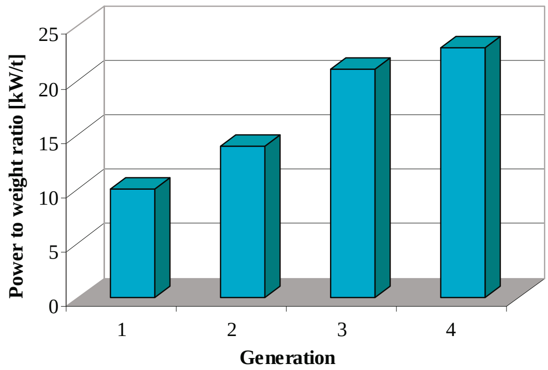

Fig. 4. Power to weight ratio of the tanks

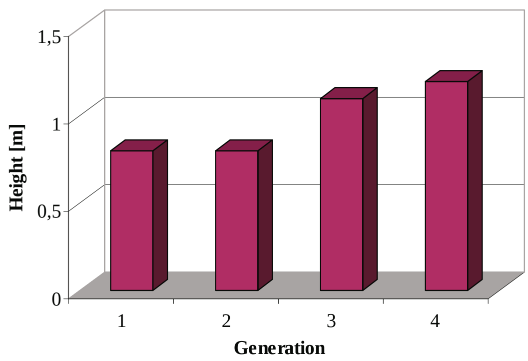

Fig. 5. Height of cleared vertical wall

Mentioned above construction features for the given type of the armoured combat vehicle are established through technical conditions at the stage of design or modernization. In the process of the operation (omitting the technical state of the power drive system) only the unit power of the engine may be changed in the result of powering it with different fuels. Issues of feeding of internal-combustion engines with alternative fuel are being elaborated for many years. The literature review on the subject shows that oriented examinations are mainly to analysis of working processes of the engine and ecological problems. Economic and public aspects of applying alternative fuels are also being brought up, particularly on the basis of the rape oil. Published results of examinations show that applying renewable fuels leads, in general, to reducing the power of the engine. The influence of this fact on traction properties of the vehicle does not find too wide reflection in examinations. Aspiration to fill up this gap became the purpose of the presented work. The object of analysis is a main battle tank PT-91 Tough, which silhouette is presented at Fig. 6.

Paper presents the numerical research results of the influence of the change of power characteristics of the engine (as a result of fuelling with alternative fuel) to basic traction properties of the tank, using the basis of the theory of motion of tracked vehicles.


Fig. 6. Main battle tank PT-91 Tough

2. Basic equations of theory of motion of tracked vehicle

2.1. Rectilinear motion

On the tracked vehicle being in motion has an effect forces (Fig. 7), which balance equation in the rectilinear motion has the form for:

$$F_N – F_T – F_W – F_P – F_B – F_U=0. \tag{1}$$

Forces in the above equation (1) are defined as:

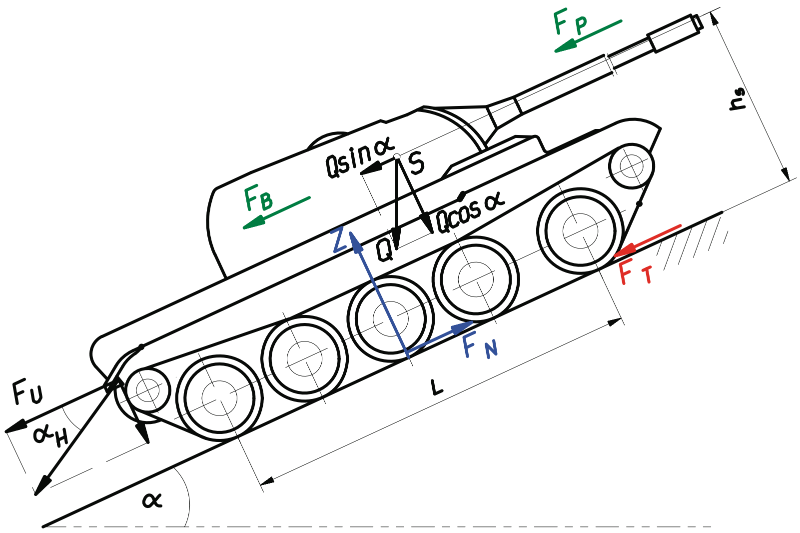

Fig. 7. Schematic diagram of the forces affecting on tracked combat vehicle

- driving force

$$F_W = \frac{M_s i_c \eta_m \eta_g}{r_k} , \tag{2}$$

- resisting force of rolling (on the assumption that force at a tow hook is parallel to the ground surface)

$$F_T = N f = Q f \cos\alpha , \tag{3}$$

- resisting force of surface sloping

$$F_W = Q \sin\alpha \,, \tag{4}$$

- force of aerodynamic resistance

$$F_P = 0.5\, C_x \,\rho\, A\, V_w^2 \,, \tag{5}$$

- force of inertia

$$F_B = \delta \frac{Q}{g} \frac{dV}{dt} \,, \tag{6}$$

- pull force (towing power) F_U results from the mass and motion resistance of the towed trailer.

Individual variables in expressions (2) to (6) have the following meaning:

M_s – output torque of the engine,
i_c – total transmission ratio of the power transmission system,
η_m – efficiency of the power transmission system,
η_g – efficiency of the track mechanism,
r_k – radius of the driving wheel,
Q – force of gravity of the battle vehicle,
f – drag coefficient of rolling,
α – angle of climbing of the ground surface (surface slope up),
ρ – density of air,
A – surface of a cross section of the vehicle,
V_w – relative speed of the vehicle and airs,
V – speed of the vehicle,
δ – factor of reduced masses, taking into consideration resistance of the inertia of whirling masses of the power transmission system and track mechanism.

Considering the definitions of the forces, the balance equation of rectilinear motion of the vehicle will take the form

$$\delta \frac{Q}{g}\frac{dV}{dt} + 0.5 C_x \rho A V_w^2 = \frac{M_s i_c \eta_m \eta_g}{r_k} - Qf\cos\alpha - Q\sin\alpha - F_u \,. \tag{7}$$

In order to determine or to compare traction properties of various kinds of vehicles are being made out dynamic characterization defined as

$$D = D(V) = \frac{F_N - F_P}{Q} = \frac{1}{Q}\left(\frac{M_s i_c \eta_m \eta_g}{r_k} - 0.5 C_x \rho A V_w^2\right), \tag{8}$$

where D is called the dynamic rate. For tracked vehicles reaching small speeds of the drive (up to 70 km/h) the force of aerodynamic resistance is negligible small. It means that the dynamic rate is approximately equal of the unit driving force. Taking into consideration (8) equation (7) may be presented in the form

$$D = f\cos\alpha + \sin\alpha + \frac{\delta}{g}\frac{dV}{dt} + \frac{F_u}{Q} \,. \tag{9}$$

From the expression (9) it appears that knowledge of the dynamic characterization enables in the convenient way to determine or compare the basic properties of traction vehicles that is:

- speeds for given power drive transmission ratio and road conditions,
- abilities to climb hills,
- abilities of the vehicle to tow the trailer (or other e.g. damaged vehicle),
- value of accelerations for given gear and road conditions,
- the time and the route of the run-up, from the initial speed V_0 to the given speed V.

The first four quantities are being described directly on the basis of the equation (9), whereas the time and the route of the run-up from the expression

$$t = \int_{V_o}^{V} \frac{g}{\delta} \frac{dV}{D(V) - f}, \tag{10}$$

$$S = \int_{t_o}^{t} V dt \ , \tag{11}$$

taking assumption that $\alpha = 0$ and $F_U = 0$.

While determining traction properties one should consider the fact of limiting the driving force as well as the D factor by the value of grip force.

2.2. The curvilinear motion

In order to determine or compare the manoeuvrability of the tracked vehicle, there are made characteristics of the turn. That characteristic is a graphical presentation of unit driving force at overtaking track, needed to take the turn with given radius. Input data for making characteristics are unit driving forces at tracks defined as

$$f_2 = 0.5 f + \frac{\mu L}{4B}, \tag{12}$$

$$f_1 = -0.5 f + \frac{\mu L}{4B}, \tag{13}$$

$$\mu = \frac{\mu_m}{a + (1 - a)\frac{R}{B}}, \tag{14}$$

where: f_1, f_2 – unit driving forces on the running and staying tracks, μ – coefficient of the turn resistance, μ_m – coefficient of the turn resistance for the given vehicle at the turn with radius R=B, R – the turning radius, L – length of the track contact with the ground, B – gauge (track) of tracks, a – factor dependent on the kind and the state of ground a=(0.8-0.87), f – drag coefficient of rolling.

The method of estimation the unit driving force f_p needed to take the turn, depends on the type of the turn mechanism. Issues in detail are described in literature [1, 2].

3. Influence of fuelling the engine with renewable fuels on traction properties of the tracked combat vehicle

Calculations were made for the PT-91 tank powered with the S-12U engine. Basing on literature data [3, 4, 5], was assumed that maximum power (maximum torque) of the engine is 8 to

9 % less than at fuelling it with diesel. Essential data for making traction characteristics out was compared in the Table 1.

Tab. 1. Initial data for calculations

Item	Parameter	Value
1	Combat weight [t]	45.3
2	Maximum power / engine speed [kW]/[RPM]	625/2200
3	Maximum torque / engine speed [Nm]/[RPM]	3150/1350
4	Primary gear transmission ratio	0.706
5	Gearbox transmission ratio on gear: 1 7	i_1 .... i_7
6	Side gear transmission ratio	5.454
7	Number of track sprocket teeth	14
8	Track pitch [m]	0.137
9	Power transmission system efficiency	0.85 – 0.9
10	Track mechanism efficiency	η_g

where: $$\eta_g = 0.95 - \frac{1}{f_k}(0.025 + 0.000003V^2).$$

Dynamic, the turn and the run-up characteristics were determined using programs CHARDYN, CHSK and RUNUP, worked out at the Institute of Mechanical Vehicles and Transportation. Obtained results of calculations are presented on the Fig. 8 to 10.

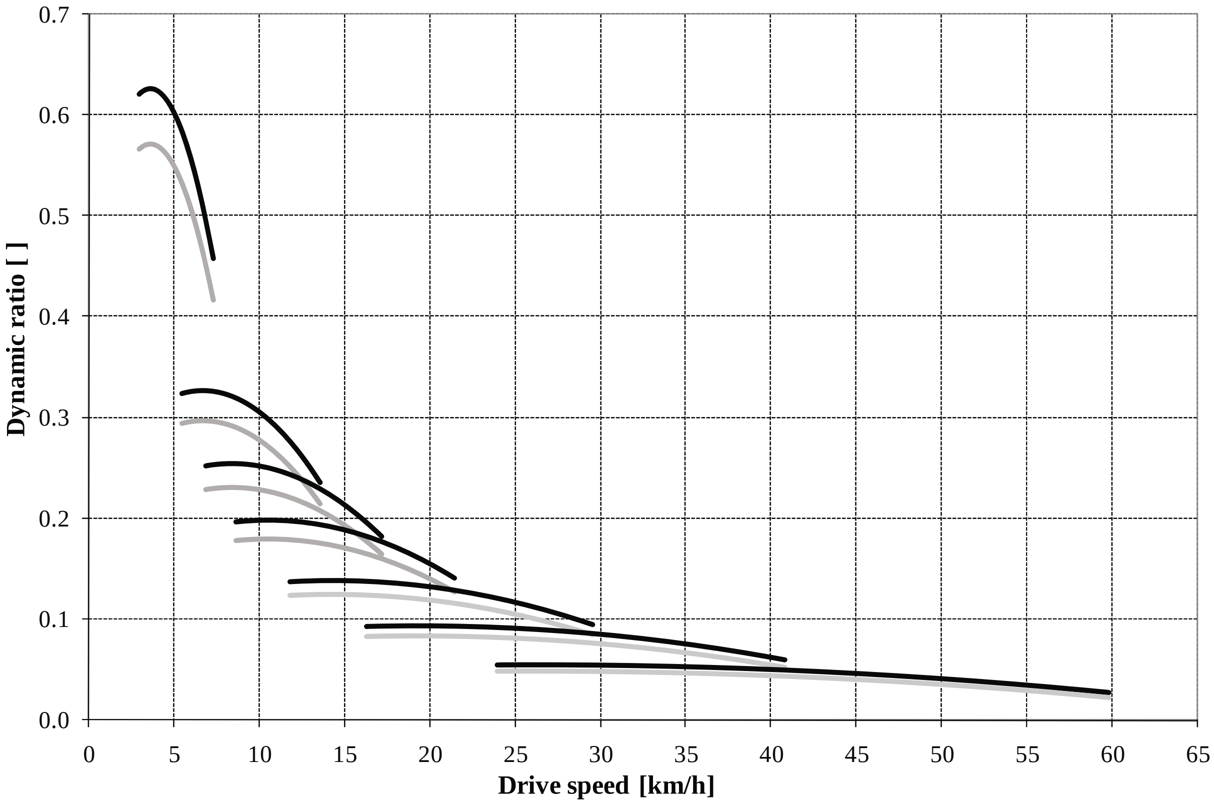

Fig. 8. Dynamic characteristics of the vehicle fuelled with: diesel – D_{ON} (black line), renewable fuel – D_{PO} (grey line)

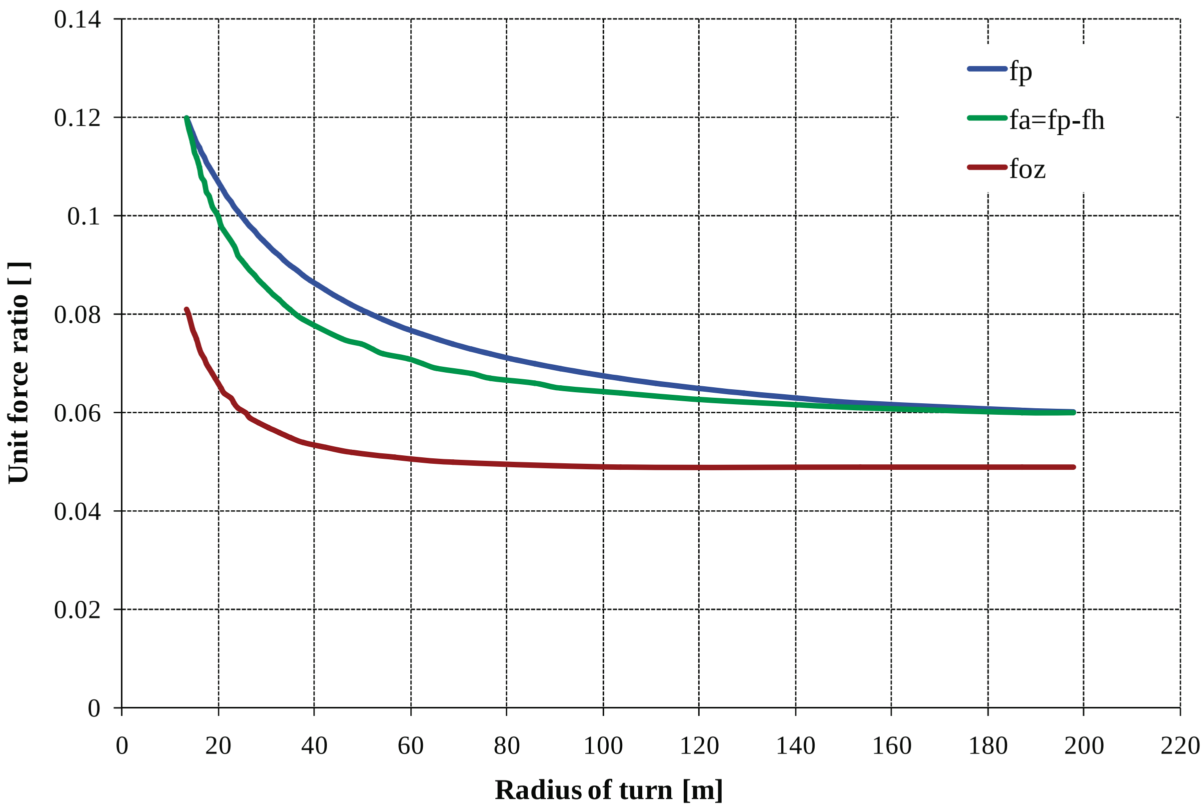

Fig. 9. Turn characteristic of the tracked vehicle

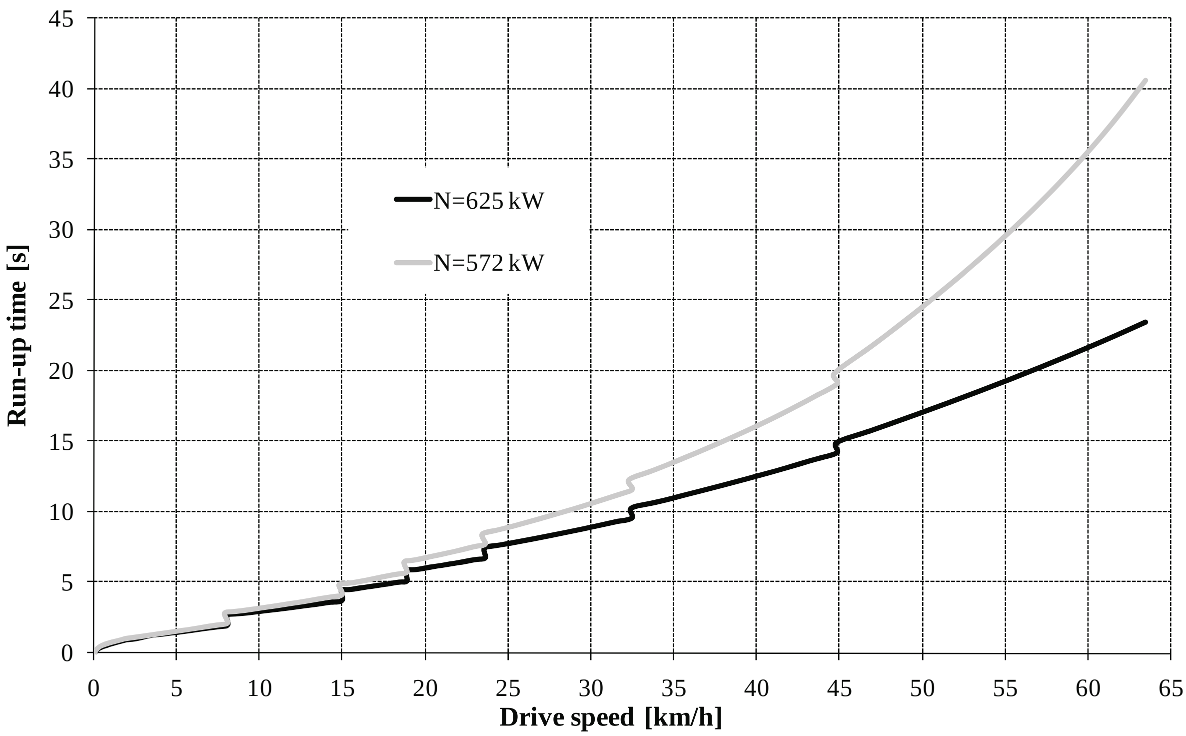

Fig. 10. Run-up characteristic of the tracked vehicle fuelled with: diesel (N=625kW – black line), renewable fuel (N=572 kW – grey line)

Parameters determined on the basis of these characteristics describing traction properties were put together in the Table 2.

Tab. 2. Characteristic parameters of traction properties of the vehicle

Item	**Parameter**		**Value for the fuelling with**		**Change [%]**
			diesel	**renewable fuel**	
1	Maximum dynamic ratio D	I gear	0.626	0.571	~ 9
2		II gear	0.327	0.297	~ 9
3		III gear	0.254	0.231	~ 9
4		IV gear	0.199	0.180	~ 10
5	Maximum drive speed for the motion resistance factor f=D_{PO} V[km/h]	I gear	5.74	3.84	31
6		II gear	10.8	7.34	32
7		III gear	13.4	8.92	~ 34
8		IV gear	16.7	11.3	~32
9	Maximum drive speed for the motion resistance factor f=0.003 V_{kmax} [km/h]		58.3	54.4	~ 7
10	Maximum slope slide with M_{smax}		34º30'	30º45'	12
11	Maximum slope slide with N_{smax}		23º25'	20º55'	12
12	Run-up time [s] from V=0 to V=32 km/h		9.4	11.3	~17

4. Conclusion

Obtained results of calculations show that fuelling the engine with renewable fuel can have the essential influence on the mobility of the armoured combat vehicle, the quality of performed tasks on and ability to survive. Accepted average value of fall in the engine power for 8.5% causes:

- lowering the dynamic ratio on average about 9%,
- fall in the maximum drive speed on every gear at given resistance of motion on average about 32%,
- about 7% reducing the maximum drive speed on asphalt,
- reducing the ability to climb hills by the 12%, at required for the examined class of vehicles 35º,
- deterioration of spurt, extending the time of reaching speeds of 32 km/h from the stop about 17% (essential influence on avoiding hostile hitting),
- there is no evident influence on the turn on the horizontal surface since parameters of the turn depend on weight of the vehicle, its dimensions, mechanical properties of the ground.

Conditions and dynamics of the turn are significantly deteriorated on slopes.

Average times of reaching speed 32 km/h from the stopped take-off of contemporary tanks were presented Fig.11.

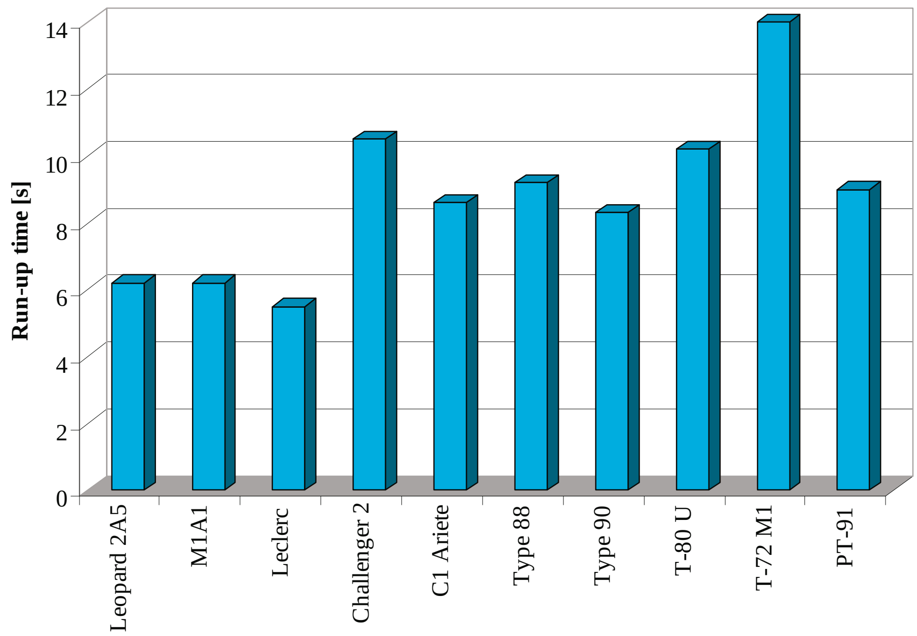

Fig. 11. Run-up times from 0 to 32 km/h of contemporary tanks

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