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DYNAMIC CHARACTERISTICS OF A TRANSLATIONAL MOBILE AGGREGATE

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***Abstract*—** This paper defines dimensional and dimensionless dynamic characteristics for a mobile aggregate in translation. Its optimization is ensuring: the drive power available in excess; driving force available, downward equilateral hyperbolic with speed (ideal traction characteristic); acceleration of the variable movement, decreasing with speed.

The numerical application refers to a vehicle driven by an internal combustion engine equipped with a three-speed gearbox.

The analysis undertaken reveals the main influencing factors and limits of the process, addressing researchers that deals with optimization of startup through transmission of continuous power, hydraulically monitored.

***Keywords*—** force, power, speed, torque

I. INTRODUCTION

TRANSLATIONAL mobile aggregates are conveyors, vehicles per bands, with large inertia and weights. Higher total weights of these mobile units *G* determines the mechanical power losses through friction in brackets, bearings and guides, expressed through coefficients of resistance to transport ψ, f and/or through dimensionless indicator energy called mechanical efficiency η_m.

During the variable and transient movements, of starting or braking, occur temporal variations of the transport speed dv/dt, positive (acceleration-start) or negative (deceleration-braking). Large masses *m* of these mobile units determines the dynamic forces of inertia provenance, opposite to the movement.

II. THEORETICAL CONSIDERATIONS

It defines the available driving force, in excess, F_e, that is used to overcome the resistance of the translational movement due to mechanical friction movement $F_{fr.mec.}$, the dynamics of inertia variable motion $F_{dyn.}$, and resistances of work, F_R.

$$F_e = F_{fr.mec.} + F_{dyn.} + F_R \tag{1}$$

Force F_e characterizes the dynamics of translation mobile unit, but cannot be used as an indicator for comparative assessing of performance for different aggregate with varied dimensions, weights, destinations and operating conditions [1].

Appreciation and define the dynamic quality of translation mobile aggregates can be done using a dynamic factor *D*, which is a specific excess power, unitary, relative and dimensionless. This factor can be defined as the ratio of excess driving force F_e and total weight (weight plus own parts, materials, goods, passengers, etc.).

$$D = \frac{F_e}{G} = \frac{F_e}{m \cdot g}, \tag{2}$$

with F_e and *G* expressed in Newton.

Dynamic factor can be expressed as the ratio of mechanical powers:

$$D = \frac{v_0}{v} \cdot \frac{N_e}{N_0}, \tag{3}$$

where $N_e = F_e \cdot v$; $N_0 = G \cdot v_0$ and *v* is the current speed of translation; v_0 is rated speed in uniform motion.

It is proposed analytic relationship for the dimensionless dynamic factor:

$$D = \psi + \frac{\delta}{g} \cdot \frac{dv}{dt} + \frac{F_R}{G} \tag{4}$$

This factor defines the characteristic/variable transitional capability of mobile aggregate. This factor defines the characteristic/capability transitional cell aggregate variable [2]. Specific resistance, dimensionless and translational is given by:

$$\psi = k \cdot f \tag{5}$$

The coefficient *f* is the friction coefficient in roller bearings for conveyors and rolling resistance coefficient for wheeled vehicles, being increased in direct proportion to the speed.

The coefficient *k* is a coefficient of increase, higher than one, particular (Example: *k*=1.3 for a road slope of

30%, for vehicles) [3].

It is obvious that $\psi(v)$ depends on the constructive solutions, the operational conditions of functioning and the quality and degree of wear of the track, on a case by case basis.

The coefficient δ is a coefficient greater than one that takes into account the assemblies, bodies, parts and attached auxiliary machinery, in translational moving, integral with the mobile unit (via couplings, gears, etc.).

If nominal operation and functioning of the motion is uniform $v=v_0$=const., $dv/dt=0$, under load and F_R is different from zero, the dimensionless dynamic factor is:

$$D = \psi + \frac{F_R}{G} \tag{6}$$

Given the current conventional expression of relative mechanical power losses through the mechanical efficiency, is proposed the original expression:

$$D = (2 \quad \eta_m) \quad \frac{\delta}{g} \quad \frac{dv}{dt} \quad \frac{F_R}{G} \tag{7}$$

This expression eliminates the ψ coefficient from the relation, being difficult to determine or express for conveyors. For vehicles we recommend the use the coefficient ψ [4].

Equation (7) contains explicit η_m coefficient, the influence coefficient ψ as default. Knowledge, determination and estimate the values of ψ and η_m are difficult and require a careful examination of each case. Approximation correctly, leads to preliminary calculations, estimates and comparative with an acceptable accuracy.

The relationship between ψ and η_m it is obtained equaling expressions (6) and (7). It is obtained:

$$\frac{\psi}{1 \quad \eta_m} = \frac{\delta}{g} \quad \frac{dv}{dt} + \frac{F_R}{G} \tag{8}$$

Proposed expressions combined factors: constructive G, operational (v, dv/dt, F_R) and quality η_m.

The indicator D can be used as a criterion of comparison between different units, constructive solutions, and represents the dynamic characteristic of starting and braking [5]. A high dynamic characteristic can be obtained by requiring large accelerations, which determines, among other things, lower values for starting or braking time (as reflected on the times and rhythms of technology, productivity, carrying capacity, etc.).

Mobile unit is driven by an engine from which it follows some typical specifications. The gear ratio is:

$$i = \frac{n}{n_m} = \frac{30}{\pi} \quad \frac{\omega}{n_m} = \frac{30}{\pi \quad n_m} \quad \frac{v}{r_0}, \tag{9}$$

where n_m is speed of the drive motor, usually of maximum power; ω, n, r_0 is the angular velocity, speed and radius of gear final drive unit (in the case of vehicles driven wheels); v is velocity of transport/current translation.

In case of using variable speed in steps (gearbox), the link between dynamic factors and the reports of transmission is given by the equation:

$$D_k = \frac{i_{k \quad 1}}{i_k} \quad D_{k \quad 1} \tag{10}$$

Torque of the drive unit is multiplied from the driving motor and rotation speed decreases corresponding to the ratio value in each gear [6].

III. NUMERICAL APPLICATION

We consider an automobile with: $m = 1200kg = 11.8kN$; $v_0 = 30\, m/s = 108\, km/h$; $\psi = 1.3 \cdot f$. It also adopts F_R = F_{air}, aerodynamic resistance force.

$$F_{air} = c_x \quad A \quad \frac{\rho \quad v^2}{2} = k \quad A \quad v^2 \tag{11}$$

In the considered case are used the following values:

1) *the front surface* $A = 1.2 \cdot m^2$;
2) *aerodynamic resistance coefficient* $c_x = 0.45$;
3) *specific weight of the air under conventional conditions* $\rho = 1.293\, kg/m^3$;
4) *dimensional coefficient of proportionality* $k = \rho/2 \cdot c_x$.
5) *There are used the values:* $n_m = 2200\, rot/min$; $i_0 = 1/2.3$; $n_0 = 955\, rot/min$; $N_0 = 354kW$.

The curves of variation of the dynamic factor in relation to the vehicle speed for a gearbox with three gears represents the dynamic characteristic of the vehicle.

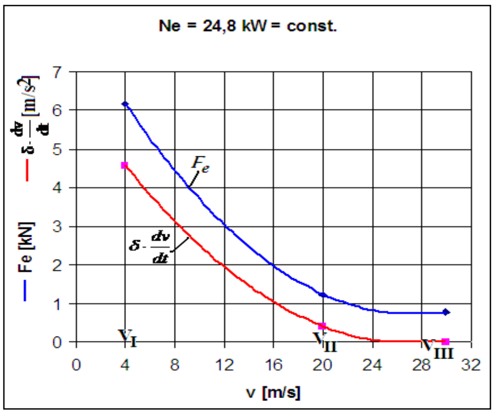

Fig. 1. Optimized dimensional characteristic for the vehicle

In Fig. 1 is showed the dimensional characteristic, in Fig. 2 is the dimensionless characteristic, systematized and optimized based on the calculations shown in TABLE 1.

TABLE I
VALUES OF ALL PARAMETERS IN FUNCTION OF GEAR

Gear	Speed	Relative speed	Friction coef.	Specific resistance	Form coef.
	v [m/s]	v_r [-]	f [-]	ψ [-]	δ [-]
I	4	0.133	0.045	0.0585	1.3
II	20	0.666	0.040	0.0520	1.5
III	30	1	0.035	0.0455	1.7
Gear	**Dynamic factor D**	**Gear ratio i**	**Power N_e**	**Acceleration $\delta \cdot \frac{dv}{dt}$**	**Driving force F_e**
	[-]	[-]	[kW/hp]	[m/s²]	[kN]
I	0.525	1/17.25	24.72/33.6	4.58	6.18
II	0.105	1/3.45	—	0.413	1.24
III	0.0702	1/2.3	—	0	0.83

Dimensional dynamic characteristic was built:

1) *with driving force available, in excess, F_e, downward hyperbolic with the speed (ideal characteristic of traction);*
2) *with acceleration of variable motion, transient and positive, $\delta \cdot \frac{dv}{dt} > 0$, but on decreasing absolute value with velocity v;*
3) *with available driving power in excess, N_e = 24.8 kW = const.*

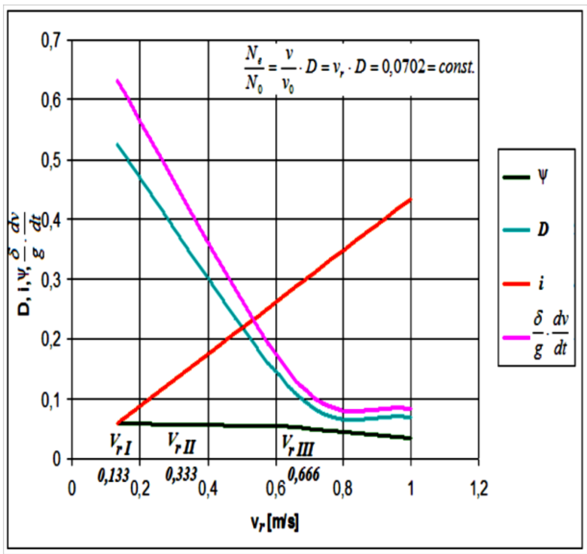

Fig. 2. Optimized dimensionless characteristic for the vehicle

With relative values, specific and dimensionless, optimizing conditions from above leads to a dynamic characteristic dimensionless generalized with:

1) *the dynamic factor, which is a specific force, unitary/relative, dimensionless, decreasing with relative speed,* $v_r = v/v_0 \in [0,1]$, *$D(v_r)$ following a hyperbolic law;*
2) *specific dynamic force, unitary, dimensionless, relative acceleration to the inertial origin, decreasing with the v_r;*
3) *specific dynamic force, unitary, dimensionless, relative acceleration, of inertial origin, $\frac{\delta}{g} \cdot \frac{dv}{dt}$, decreasing with the relative speed v_r;*
4) *specific driving power available, relative, dimensionless,*

$$\frac{N_e}{N_0} = \frac{v}{v_0} \cdot D = v_r \cdot D = 0{,}0702 = const.$$

In this cases were considered dimensionless coefficients:

- gear ratio *i(v)* increasing with the speed;
- coefficient of running resistance (running and slope), slightly downward with the speed.

IV. PROVISION OF THE AGGREGATE DRIVING MOTOR WITH THE DYNAMIC CHARACTERISTIC

The operation and ideal entrainment is made by a continuous operation without breakage of power flow, which can be achieved using an engine:

1) *electrical of continues current;*
2) *electrical three-phase, alternating with constant speed (Example: Ward-Leonard group);*
3) *using a hydraulic drive adjustment with elements (primary or secondary).*

It is considered an internal combustion engine equipped with a speed variator. It will analyze its behavior for the considered application.

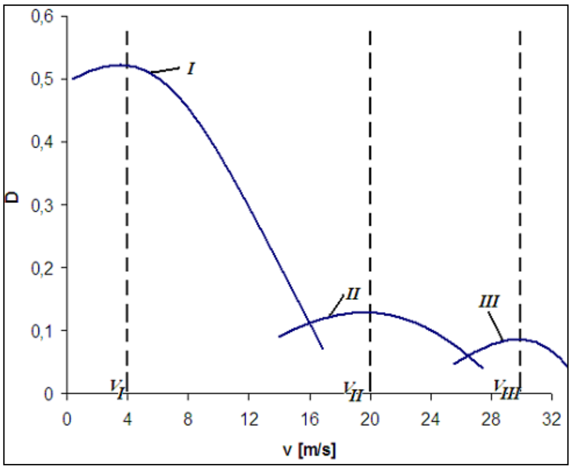

Fig. 3. Vehicle dynamic characteristic of vehicle with three gears

In Fig. 3 it is presented the vehicle dynamic characteristic of vehicle with three gears. Fig. 4 shows the external characteristic of the internal combustion engine speed, raised on the test bench, between 1800 and 2000 rpm.

Maximum revolution speed is specific revolution speed of engine maximum power, $n_{m,max} = 2200 rpm$, $N_{m,max} = 35 CP$.

TABLE II
VALUES REVOLUTION SPEED, POWER AND TORQUE

Revolution speed	Power	Torque
n_m	N_m	M_m
[rpm]	[hP]	[Nm]
1800	4.48	17.4
1850	13	49
1900	22.4	82.7
2000	30	105
2100	34.2	114
2200	35	112

Figure 5 shows the diagram of engine power during startup using three gears. On the vehicle starting in first gear, the rotation speed of the crankshaft is changed from the minimum to the maximum value [7].

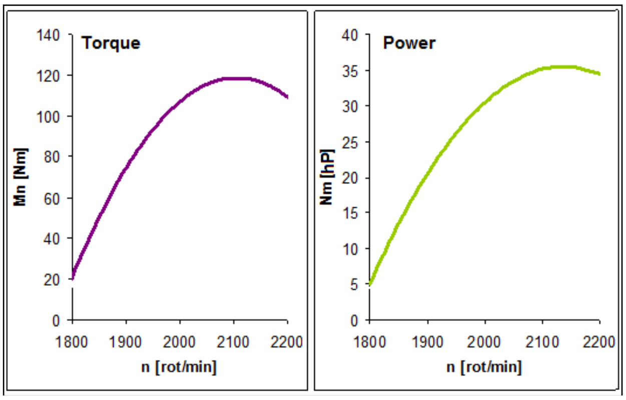

Fig. 4. Power and torque in relation with revolution speed

If on a vertical axis corresponding to the right part of engine external characteristic represents speed of the vehicle, then its variation during the startup of the first gear can be calculated and represented by the line *ab*.

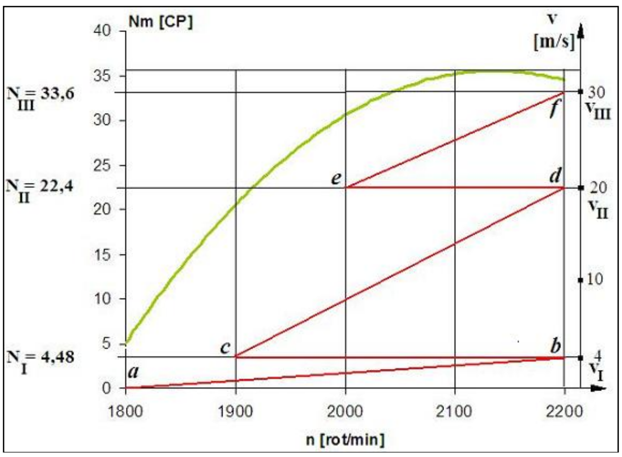

Fig. 5. The diagram of engine power usage during startup

Once the vehicle reaches maximum speed v_{Imax} when driving with first gear, is transferred to second gear and crankshaft revolution speed drops to n_{II}. The size of this reduction is determined from the ratio of the gear transmission reports of the first and second gear. Considering that the transition from one gear to another occurs instantaneously and vehicle speed remains unchanged at this time, this process can be represented by the line *bc*.

On starting in second gear, the speed changes to v_{IImax}, and crankshaft speed again reaches the maximum value (right *cd*). The transition from second to third gear is the right *de* and startup in the third gear is right *ef*.

At the first gear engine power has changed from N_I to N_{max}, the second gear of the N_{II} to N_{max} and third from the N_{III} to N_{max}.

V. CONCLUSION

Using a multistage transmission, or continuous, average power used is noticeably higher, and starting can be performed faster.

Analysis undertaken, containing all influencing factors and limits of analyzed process is addressing to researchers concerned with optimizing startup continuous power transmission, hydraulic controlled and monitored.

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