Parameters for the Characterization of Motor Vehicle Acceleration Ability

Juris Gunārs Pommers

Transport and Telecommunication Institute, Riga, Latvia

Abstract – **For the characterization of vehicle acceleration, in addition to such common parameters as change of speed and acceleration in time, there should be applied one more parameter: change of acceleration increase in time. Change of acceleration increase in time j_p progresses in four specific phases in each gear: I – beginning of run where j_p is growing rapidly to the maximum value of the gear; II – j_p reduction from the maximum value to the stabilized value; III – speeding up with stabilized value j_p and IV – shifting when j_p value is changing in a wide range to the maximum negative value and then to zero.**

Keywords – **Acceleration of vehicles, increase of acceleration, jars.**

I. INTRODUCTION

As it is known, acceleration ability is a parameter for the dynamism of vehicle run up: reaching high speed during a short period of time [1], [2].

The dynamism of vehicle speeding up and, accordingly, acceleration ability are commonly characterized by:

run up acceleration a;

run up maximum value a_{max};

speeding up time t_{ie};

distance s_{ie} for reaching certain speed v, for example, 100 km/h;

distance for covering a certain distance, for example, 400 m or 1000 m;

distance change s_{ie} in time t_{ie} [1], [3]–[11].

There is one more parameter used for dynamism – acceleration factor η_j. This is a ratio between power of inertia resistance overcoming N_j and power of potential traction supplied for driving N_k (1) [1]:

$$\eta_j = \frac{N_j}{N_k} \quad .\tag{1}$$

The definition and calculations of those parameters is a task of Theory of Ground Vehicles science sector [4], [12], [13] and particularly of its branches – Theory of Automobile [1]–[3], [5]–[7], [14], [15] and Theory of Motorcycle [9].

For instance, acceleration a of vehicles depending on powers applied to vehicles, namely traction power P_k and all i resistance powers P_i influencing vehicles in particular drive conditions, and reduced mass of vehicles m_{red}, can be defined as (2) [1]:

$$a = \frac{dv}{dt_{ie}} = \frac{P_k - \sum P_i}{m_{red}} \quad .\tag{2}$$

Analysis and calculations are easier if the dynamic factor of vehicles D, road-resistance ratio ψ and coefficient of vehicle gyrating masses δ are known (3) [1]:

$$a = \frac{g}{\delta}(D - \psi) \quad .\tag{3}$$

The maximum value of acceleration a_{max} can be found from the same formula (3) if dynamic factor D in it is replaced by its maximum value D_{max} for particular conditions of vehicle operation.

If the adhesion of vehicle movers with the ground surface is limited, acceleration values including the maximum one can be found from formula (3), replacing D with meshing dynamic factor D_{φ}.

When acceleration values are known, speeding up time t_{ie} and starting distance s_{ie} values can be determined, in particular for speed changes from v_1 to v_2 (4), (5) [1], [4], [7]:

$$t_{ie} = \int_{v_1}^{v_2} \frac{dv}{a} \tag{4}$$

and

$$s_{ie} = \int_{v_1}^{v_2} \frac{v}{a} dv \quad . \tag{5}$$

Usually, the above mentioned parameters are sufficient for conventional vehicles with normal dynamism. However, nowadays when acceleration of dynamic vehicles is already characterized by 4 to 5 seconds or even less for reaching a speed of 100 km/h (see Table I), these parameters become insufficient [16]–[19].

In such cases, one of the most important parameters alongside the developed acceleration is an increase of its speed da/dt, namely the parameter which characterizes how fast acceleration can be or has been increased. Therefore, it is now necessary to add to the traditional acceleration ability parameters one more parameter – speed of acceleration gain j_p, measured in m/s^3. Analogue parameter oscillation in theory is called *jar* or *jerk* by some mechanics. In this article, we will abstain from searching any other names and, therefore, use term *jars*.

II. SUPPLEMENT TO THE PARAMETERS OF ACCELERATION ABILITY

Analytical and graph-analytical methods will be used in this article for clearing up the acceleration ability.

TABLE I

PARAMETERS OF SOME OF THE MOST DYNAMIC AUTOMOBILES

Automobile	Engine power, hp	Engine torque, N·m	t_{ie}, s/(100 km/h)
Mercedes CL 500 Blue Efficiency	435	530	4.9
BMW7 ActiveHybrid	465	700	4.9
Lansarea CL600 with V12 turbo 5.5 l engine	517	830	4.6
AUDI SLS AMG E-CELL with V8 6.3 l engine	532	880	4.0
Porsche 977G72 Gemballa	600	840	3.5

If acceleration of vehicles a is (6):

$$a = \frac{dv}{dt_{ie}} = \frac{d^2 s_{ie}}{dt_{ie}^2} \quad , \tag{6}$$

jars are (7):

$$j_p = \frac{da}{dt_{ie}} = \frac{d^2 v}{dt_{ie}^2} = \frac{d^3 s_{ie}}{dt_{ie}^3} \quad . \tag{7}$$

They can also be expressed as follows (8):

$$j_p = \frac{da}{dt_{ie}} = \frac{da}{dv}\frac{dv}{dt_{ie}} = a\frac{da}{dv} \quad . \tag{8}$$

The analytical calculation of jars is made somewhat difficult by the fact that graphs of acceleration changes $a = f(t_{ie})$ and $a = f(v_{ie})$ are not usually described analytically. However, the theory of vehicles handles the graphic forms of these functions [1], [13]. Such pictures are obtained during experiments (see Fig. 1) or by using theoretical curves of dynamic factor [1]. If acceleration graph $a = f(v_{ie})$ is

known, by way of its graphical differentiation it is also possible to find jar graph coordinates da/dt_{ie} – v as function $j_p = da/dt_{ie} = f(v)$.
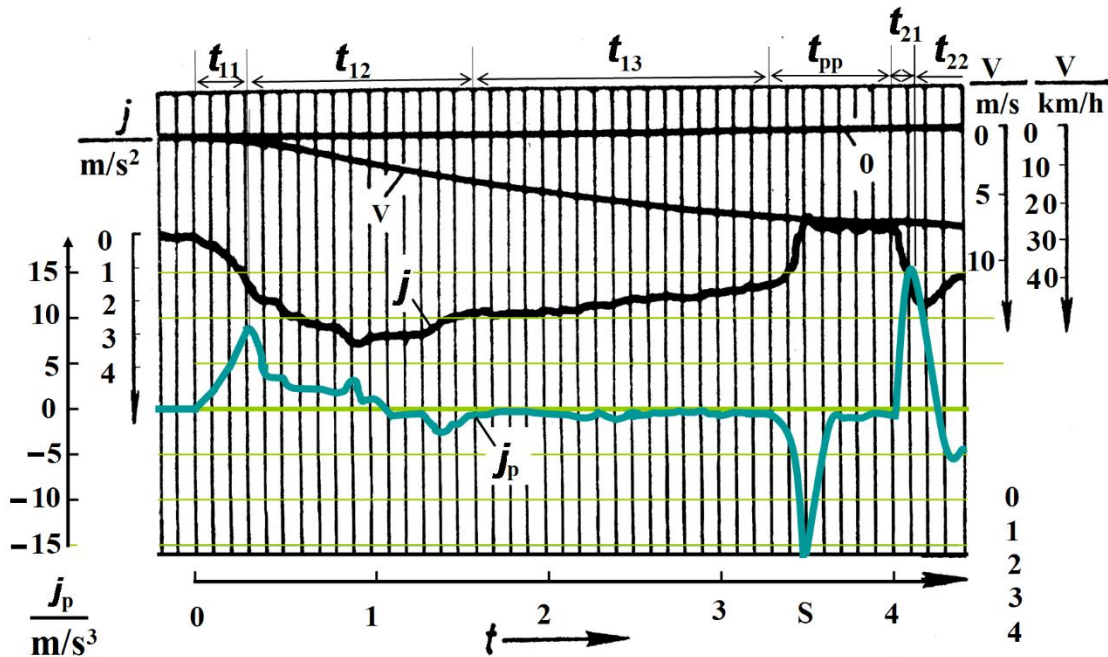

Fig. 1. Sample of oscillogram with a graph of j_p.

III. BEHAVIOUR OF JARS

Using a sample oscillogram with curve $a = f(t_{ie})$ [1] and graphical differentiation, we can draw a graph of jars in coordinates j_p – t (see Fig.1 in which $a = j$).

We can see from the graph that the maxima of curves a and j_p differ by time.

Maximum values a are reached at the initial phase of vehicle acceleration. For light vehicles (motorcycles, light motorcars), it is reached in the 1st gear during the development of maximum dynamic factor D_{max}. For heavy vehicles with multi-stage gear boxes, a_{max} can be reached only in the 2nd or 3rd gear.

The maximum values of jars for all vehicles are reached at the very beginning of run (first seconds).

During the acceleration of vehicles, a can reach negative values only during gear shift, but j_p could be obtained each time after reaching a_{max} in each gear.

The graph of jars for each gear used during acceleration can be divided into 4 phases characterising the mode, and in the graph their times are marked as t_1, t_2, t_3 and t_{pp}. For example, run up time in the 1st gear (including time used for switching gears to the 2nd gear) consists of a sum made by the times of the 4 mentioned phases (9):

$$t_{ie1} = t_{11} + t_{12} + t_{13} + t_{pp} \quad . \tag{9}$$

These phases can be characterised by the following indications:
1. Beginning of run (in each gear). During this time period t_{11} there is a fast increase of jars reaching the maximum value in the appropriate gear.
2. Decrease of jars from the maximum value to a stabilized value during time period t_{12}.
3. Speeding up with a stabilized value of jars. During this time period t_{13} the value of jars changes just a little (usually within the limit of error) and it is under zero.
4. Shifting of gears. During this time period t_{pp} the value of jars is changing in a wide range, at the beginning up to the maximum negative value and then to zero.

IV. ANALYSIS AND RESULTS

The desired curve of jar behaviour is influenced by two main factors displayed in Fig. 2.
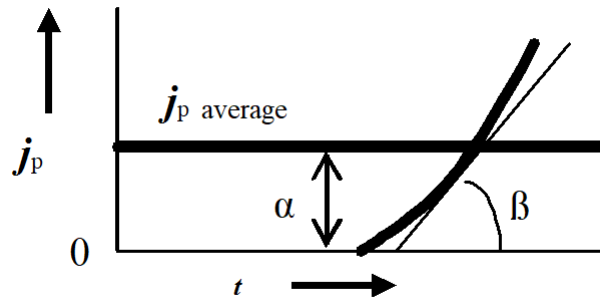

Fig. 2. Main factors for jar behaviour.

To manufacture vehicles with very good acceleration ability and short run up time for reaching high speed, it is necessary to influence the following two factors:
- inclination angle ß of the curve at the phase of jar increase j_p;
- height of jar average value α.

The angle of curve at the beginning of vehicle run up, namely in its 1st phase, should be as wide as possible because the speed of vehicle acceleration increase is characterized by the tangent of this angle, namely in the elementary range (10):

$$tg\beta = \frac{dj_p}{dt_{ie}} \ .$$
(10)

Higher speed can be achieved in shorter time when angle ß is wider.

Higher values of angle ß can be achieved by the first developing high usable traction force to movers P_k. and decreasing resistance powers $\sum P_i$. Theoretically, higher traction force can be developed by enlarging engine torque in the whole speed range by choosing rational total transmission ratios and reducing vehicle mass if we take no notice to factors with apparently lower influence such as the size of movers, radius of wheels, and transmission efficiency.

However, it should be emphasized that this is a matter of practically usable traction force (not a theoretical possibility). It can be quite different from theoretical, because it mainly depends on the adhesion between movers and ground surface characterized by adhesion factor φ. The largest values a and positive j_p can be reached only in case when a very good adhesion between the ground (road) and movers (for example, wheels) is provided at least temporarily, when the value of adhesion factor φ is approximately 1 or higher, namely φ > 1. Modern vehicles and roads can ensure the fulfilment of this provision.

Adhesion and consequently practical possibilities for using theoretically possible traction force can be enlarged by the appropriate design of movers (for instance, tread pattern), the material of movers maximally appropriated for establishing adhesion and other methods ensuring good adhesion, for example, an automatic device for preventing mover skidding.

Practically, during tests, inclination angle ß of curve j_p can be considerably influenced by driver's actions depending on his/her skills and experience and psychophysiological features and character.

The average value of jars can be calculated on the basis of vehicle run up time required for reaching a certain speed. We will calculate it for 3 characteristic cases when vehicles achieve speed $v = 100$ km/h $= 27.78$ m/s during:
1. 20 s (vehicles with quite poor acceleration capability);
2. 10 s (modern vehicles with quite good acceleration capability);
3. 5 s (some modern vehicles with very good acceleration capability).

Modern vehicles with very good acceleration ability are powerful motorcycles and some motorcars (mostly sport models), for example, *Lansarea CL600* with V12 turbo 5.5 l engine – 4.6 s, *Audi SLS AMG E-CELL* – 4 s, *Porsche 977GT2 Gemballa* – 3.5 s as apparent from Table I.

The results of calculations are given in Table II.

TABLE II

PARAMETERS OF ACCELERATION AND JARS

Parameters	Values of parameters for reaching a speed of 100 km/h in time		
	20 s	10 s	5 s
Average acceleration a, m/s^2	1.39	2.78	5.56
Average jars j_p, m/s^3	0.07	0.28	1.11

If the maximum values of acceleration are usually 1.5 to 2 times above the average, the maximum values of jars can be considerably (up to 200 times) higher than the average values. The difference between average and maximum j_p values is individual for each particular vehicle. Such a difference as well as good acceleration ability are mostly determined by:
  – 1st phase: ensured adhesion, engine power and torque, fast operation of clutch during switching;
  – 2nd phase: ensured adhesion, engine power and torque, total transmission ratio;
  – 3rd phase: engine power and torque, total transmission ratio;
  – 4th phase: in case of automatic transmission – automatic operation of gear switching, in case of non-automatic transmission – operation of gear switching mechanism and nature of operator activity during gear switching.

Additionally, jars are affected by the design and their technical condition of vehicles, streamlining form, weight and other less important factors, as well as the condition of ground.

The first and second phases are the most important for providing excellent acceleration capability.

V. CONCLUSION

In order to characterize the acceleration abilities of vehicles, in addition to common parameters, namely change of speed and acceleration in time, it is required to apply one more parameter: change of acceleration increase in time.

Change of acceleration increase in time $j_p = f(t)$ progresses in 4 specific phases:
  1. 1st phase – beginning of acceleration run where j_p is growing rapidly to the maximum value in the respective gear;
  2. 2nd phase – j_p decrease from the maximum value to the stabilized value;
  3. 3rd phase – speeding up with stabilized value j_p
  4. 4th phase – shifting when value j_p is changing in a wide range from the maximum negative value to zero.

Factors for providing maximum value j_p and good acceleration ability:
  – sufficient power and torque of engine and also good adhesion between the ground and movers (driving elements), $\varphi > 1$ (1st, 2nd, 3rd phase),
  – fast operation of clutches during switching (1st phase),
  – operation of gear switching mechanism during switching (1st, 4th phase);
  – appropriate total transmission ratio (2nd, 3rd phase);
  – automatic operation of gear switching in case of automatic transmission and nature of operator activity during gear switching in case of non-automatic transmission (4th phase).

The first and second phases are the most important for providing excellent acceleration ability.

The maximum of good acceleration ability can be reached in conditions when the greatest ascent (ß) of real curve $a = f(v)$ is obtained as a result of optimal combination of gain of torque, adhesion factor and total transmission ratio. Therefore, j_p can be increased by increasing the value of adhesion factor φ, ascend of engine torque M_e and value of M_e up to the maximum usable value from the point of view of adhesion, as well as by choosing the most appropriate transmission ratios, particularly in the first gears.

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Juris Gunārs Pommers graduated from the Latvian University of Agriculture in 1958. He has been a Professor of engineering since 1994, Professor Emeritus since 1996, Dr. habil. sc. ing. since 1993 and Dr. sc. ing since 1969.

Work experience: Since 2007 – Professor at Transport and Telecommunication Institute. From 2005 to 2000 – Professor, Head of Department and vice-rector at RIMPAK Livonia Institute. He taught the Theory of Automobiles in the Latvian University of Agriculture for 42 years (from 1958 to 2000).

Since 2003 he has been Sc. Emeritus. Since 1995 – President and Vice-President of the Latvian Association of Automobile Engineers. Since 1992 – Academician of the Latvian Academy of Agricultural and Forestry Sciences. Since 1965 – Member of Plenum of Terminology Committee and Head of Motor Vehicle Subcommittee of the Latvian Academy of Sciences. He has more than 230 publications including textboxes Theory of Automobiles (co-author G. Liberts), Motorbikes and Mopeds (co-authors J. Brass, Z. Jansons), Basics of Student Scientific Work. He has 2 patents.

Address: Transport and Telecommunication Institute, Lomonosova 1, Riga, LV-1019, Latvia.
Phone: +371 29512364
E-mail: jgp@inbox.lv