AUTOMOTIVE ENGINEERING
POLITECNICO DI TORINO
MOTOR VEHICLE DESIGN
(02LNLLI)

PROJECT 1_2

A. Y. 2017-2018

Contents

1 Maximum power that can be transferred by the tires to the ground

The power needed for motion increases with speed and slope. This power is supplied by the power unit installed on the vehicle. Apart from the power unit performance, some limitations related to the maximum power that can be transferred by the tires to the road can occur. The maximum power exploited at the tire - ground contact point is given by the following expression:

$$P_{\max} = V \sum_{\forall i} F_{zi}\mu_{ip}, \tag{1}$$

where the summation is extended to all the driving wheels while F_{zi} represents the vertical load acting on the wheel hub of each driving wheel. Considering the longitudinal dynamics only, it is realistic to assume that there is symmetry plane and that all the forces act in that plane. The equations of equilibrium in that plane (in x and z direction and the rotation about the point O) ([1], pp.157-160) lead to obtain the expressions of the vertical forces F_{zi} acting on the front and rear axle (we are assuming a 2 axles vehicle). Such expressions, considering $V = const.$ and neglecting the aerodynamic lift are

$$\begin{cases} F_{z1} = mg\dfrac{(b - \Delta x_2)\cos(\alpha) - h_G \sin(\alpha) - K_1 V^2}{l + \Delta x_1 - \Delta x_2} \\ F_{z2} = mg\dfrac{(a + \Delta x_1)\cos(\alpha) + h_G \sin(\alpha) - K_2 V^2}{l + \Delta x_1 - \Delta x_2} \end{cases} \tag{2}$$

where

$$K_1 = \frac{\rho S}{2mg} C_x h_G, \qquad K_2 = -K_1, \qquad \Delta x_i = R_{li}(f_0 + KV^2), \tag{3}$$

while the undefined terms adopted in 2 and in 3 are explained in Figure 2. The term R_l is referred to the loaded radius of each wheel that for the radial tires is $R_l = 0.92R$. R is referred to the undeformed radius that can be computed according to the normed designation. Remember that a tire designation for examples as 155 / 65 SR 13 is referred to a tire having a total width (W) of 155 mm and an aspect ratio H/W=65% of W. The first letter (S) indicates the maximum speed that can be reached by the tire (ex.: S$\Rightarrow$ $V_{\max} = 180\ km/h$) while the second one is referred to the tire plies (R=radial). The last number indicates the rim diameter in inches.

It follows that for a tire designed as 155 / 65 SR 13 the loaded radius is:

$$R_l = 0.92\left(\frac{13 \cdot 25.4 \cdot 10^{-3}}{2} + 155 \cdot 10^{-3} \cdot 0.65\right) = 0.245\ m.$$

The longitudinal force coefficient μ_{ip} varies with the longitudinal speed V according to the law

$$\mu_{ip} = c_1 - c_2 V,$$

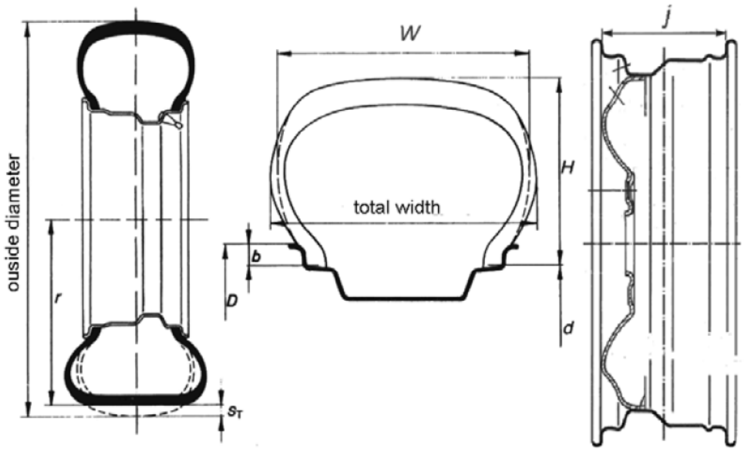

Figure 1: Tire characteristic

where the coefficients c_1 and c_2 are realistically:

	c_1 $[-]$	c_2 $[s/m]$
dry road	1.1	$6 \cdot 10^{-3}$
wet road	0.8	$8 \cdot 10^{-3}$

According to above mentioned considerations it is asked to:

1. compute and plot the maximum power that can be transmitted at the wheel ground contact point as function of speed V. This analysis should be computed considering the longitudinal slope null and the dry and wet road. This means that are required two plots, one for dry road and another for wet road.

2. Plot on the same diagrams the power needed for motion P_n considering that with a front/rear driving wheels the vertical load F_{z2}/F_{z1} should be considered instead of $mg\cos a$.

3. Compute the maximum speed V related to the maximum power that can be transmitted by the wheels. This is given by the intersection of the curves $P_{\max}$ and P_n.

2 Acceleration performance

Acceleration performance

The difference between the available power P_a and the needed power P_n $(P_a - P_n)$ is available to accelerate the vehicle. This surplus of power is equal to the variation of the kinetic energy:

$$P_a - P_n = \frac{d\mathcal{T}}{dt}, \tag{4}$$

where $\mathcal{T}$, represents the kinetic energy of all vehicle moving parts:

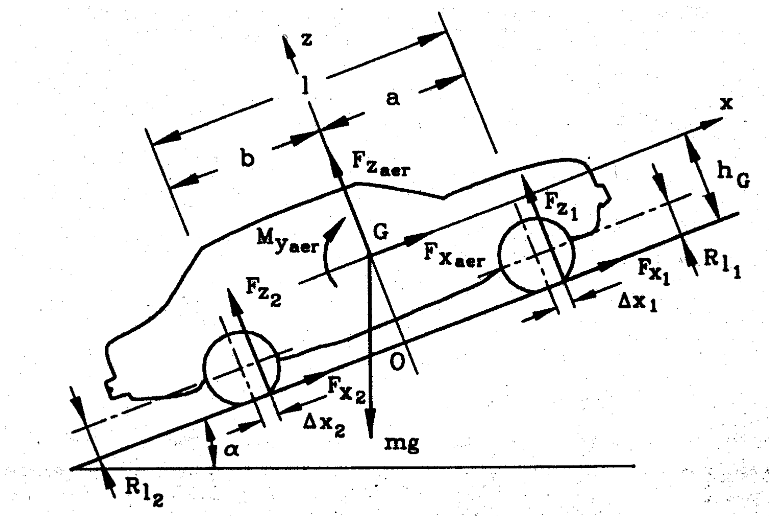

Figure 2: Forces acting on the vehicle.

$$\mathcal{T} = \frac{1}{2} m_e V^2. \tag{5}$$

The term m_e represents the equivalent mass and is given by the following expression:

$$m_e = m + \frac{J_w}{R_e^2} + \frac{J_t}{R_e^2 \tau_f^2} + \frac{J_e}{R_e^2 \tau_f^2 \tau_g^2}, \tag{6}$$

where J_w, J_t, J_e are the moment of inertia of the wheels, the moment of inertial of the power train and of the engine.

The equivalent mass represents the mass of the vehicle that moving at a certain speed V is storing the same energy of the actual system. It is worth to note that m_e depends on the gear ratio τ_g. Substituting eq. 5 into eq. 4 and derivating the speed V with respect to the time, the maximum acceleration of the vehicle at maximum throttle is given by the following expression:

$$a_{\max} = \left(\frac{dV}{dt}\right)_{\max} = \frac{P_a - P_n}{m_e V}. \tag{7}$$

In Fig. 3 is reported an example of the maximum acceleration curve as function of the speed at the different gear ratios.

Separating the variables and integrating the equation 7 with respect to V, the minimum time ($T_{V_1 \to V_2}$) needed to pass from speed V_1 to speed V_2 is obtained:

$$T_{V_1 \to V_2} = \int_{V_1}^{V_2} \frac{m_e}{P_a - P_n} V dV = \int_{V_1}^{V_2} \left(\frac{1}{a_{\max}}\right) dV. \tag{8}$$

The expression 8 must be computed in the speed range in which the equivalent mass is constant. The integral can be solved numerically. To this end, the time t_s for shifting from one gear to

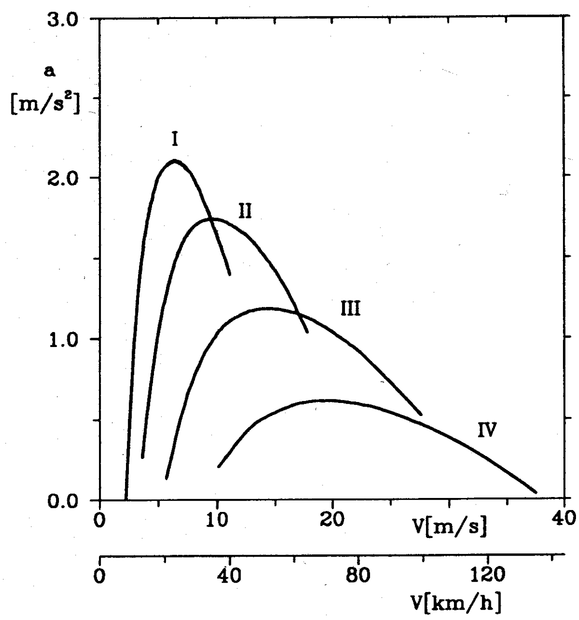

Figure 3: Maximum acceleration as function of the speed at the different gear ratios.

another must be taken into account. In this time interval it is realistic to assume that the speed is constant.

To this end, it is required to

1. compute the equivalent mass for each gear ratio,
2. compute and plot the maximum acceleration $a_{\max} = \left(\frac{dV}{dt}\right)_{\max}$ as function of τ_g.
3. Compute and plot the theoretical and actual time required to reach a speed $V = 100$ km/h starting from the minimum vehicle speed.

3 Computation of the fuel consumption for the NEDC driving cycle

The fuel consumption can be easily computed if it is known the map reporting the specific fuel consumption. Such information are available for each team in the data file pln_team#.txt. In fact, the *pme* $[bar]$ and the specific consumption q $[g/hph]$ are available at each rotational speed ω_e of the engine for different configurations of the throttle.

The process allowing to compute the fuel consumption starts from the acquisition of vehicle speed V, the gear engaged τ_g and the computation of the power needed for motion P_n at each operating condition. Being P_n equal to the power available at the wheels P_a, the power exploited by the engine at a certain rotational speed can be easily computed as $P_e = P_n/\eta_t$. Therefore, at each operating condition, the *pme* can be computed using equation of the Power at the engine shaft as function of the *pme* and ω_e while ω_e can be computed as:

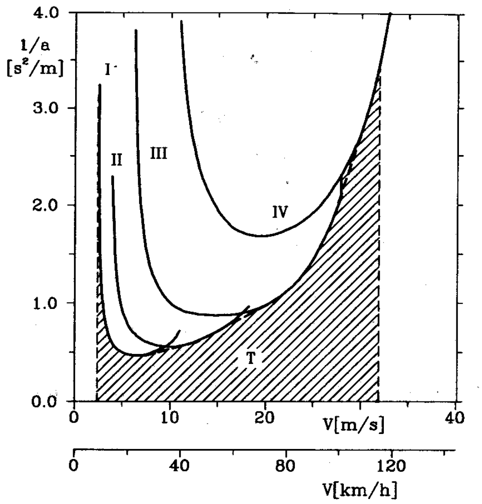

Figure 4: Inverse of the maximum acceleration as function of the maximum speed. The dashed area represents the theoretical time required to pass from speed V_1 to speed V_2.

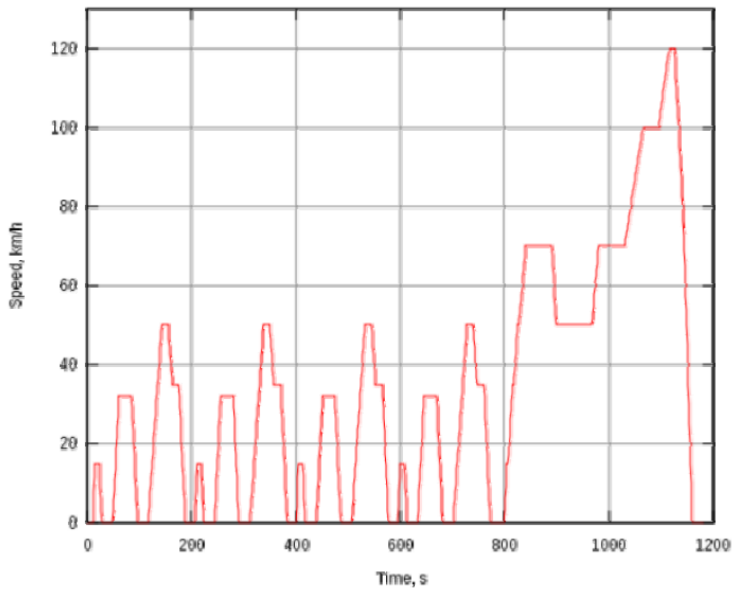

Figure 5: NEDC Driving Cycle.

$$\omega_e = \frac{V}{\tau_g \tau_f R_e}. \tag{9}$$

At each rotational speed of the engine ω_e, the knowledge of the *pme* leads to identify the corresponding specific consumption q. A double linear interpolation is frequently needed as both the engine rotational speed ω_e and the *pme* coming from the operating conditions doesn't match the data of the engine map. It is possible the realize a linear interpolation also between the minimum value of *pme* at a certain rotational speed and the value with the curve at null engine efficiency ($q = 1/H\eta_e$; $H = 4.4 \cdot 10^7 \ J/kg$).

It is therefore possible to compute the fuel consumption Q $[l/100km]$ in the different operating conditions. It is given by the following expression:

$$Q_i = \frac{1}{\eta_t}\left(\left(AV_{mi} + BV_{mi}^3\right) + m_e V_{mi}\frac{V_{i+1} - V_i}{t_{i+1} - t_i}\right)(t_{i+1} - t_i)\,\frac{q}{\rho_f}, \tag{10}$$

where

$$V_{mi} = \frac{V_{i+1} + V_i}{2},$$

while ρ_f is the fuel density ($\rho_f = 739 \ kg/m^3$).

Expression 10 is used only if P_n is positive. If P_n is negative (the engine is driven by the external load) $Q_i = 0$ as the fuel flow is locked. If the engine is running at idle ($V_i = 0$), the fuel consumption is computed as

$$Q_i = Q_m\,(t_{i+1} - t_i)\,,$$

where Q_m is the volumetric flow at idle (consider $Q_m = 0.62l/h$). The fuel consumption can therefore be computed as

$$Q = \sum_{i=1}^{i=n} Q_i.$$

Following the above considerations, it is required to:

- compute the volumetric fuel consumption Q $[l/100km]$ for the driving cycle NEDC (Figure 5).

References

[1] G. Genta, "Meccanica dell'Autoveicolo", V edizione, *Levrotto & Bella*, Febbraio, 2000.

[2] G. Lechner, H. Naunheimer, "Automotive Transmissions-Fundamentals, Selection, Design and Application", I edizione, *Springer*, Febbraio, 1999.

[3] M. D. Artamonov, "Motor Vehicle, fundamentals and design ", *Mir*, Mosca, 1976.