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Computation of Power of a Motor in Electric Vehicle under City Traffic and Dynamic Conditions

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Abstract

In this paper author used a novel method to calculate the power of a motor for electric vehicles under complex scenario of city traffic and dynamic conditions. The main focus is to model a power train of an electric vehicle in traffic congestion scenario where more than 50 vehicles are present and the driver has to maintain a fix distance with the cars which are in its immediate front and back and to vary speed and acceleration of its car non-linearly according to traffic demand so as to avoid any collision with neighbouring front and back cars. A traffic congestion scenario with more than 50 vehicles is considered to calculate variable acceleration and velocity of electric vehicle, the braking rate of the driver is also considered since in such traffic congestion use of brake by the driver will be quite high.

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To make the result more accurate the author has taken 10 different velocity and acceleration values at 10 different time interval and for each time interval the author has calculated the power of the motor and finally taken the average of all 10 values to calculate more accurate value of power of a motor. The author also considered all types of possible losses and dynamic conditions like rotational inertia to model the power train of the electric vehicle. The author tried to lay more emphasis to dynamic and city traffic conditions, since while designing electric vehicles most of the time the power of a motor is calculated under steady state conditions. Due to limited life of a battery in electric vehicles, in coming future the electric vehicles will be more popular for city traffic and to travel short distances where a vehicle don't need high top speed and acceleration since city or urban traffic worldwide is congested.

Keywords

Power, Motor, Electric Vehicles, Gear Loss, Rotational Inertia, Acceleration, Velocity.

Introduction

There is no doubt that with every passing year electric vehicles importance in automobile industry is growing. The main success of electric vehicles will be in developing countries like India which has a high CO_2 emission through different automobiles (2-wheeler, 3-wheeler, and 4-wheeler) in urban areas. Due to rapid modernization in developing world and presence of huge population, the quantity of various automobiles is quite large and countries like India, where very few automobiles follows standard CO_2 emissions norms. So replacing all these urban automobiles with low cost electric vehicles is the first step forward to reduce CO_2 emission in cities. A lot of research has been done on modelling of power train for electric vehicles. In this paper the author used a novel method to model the power train of an electric vehicle. The power of a motor is calculated under city traffic conditions, for city traffic a high power motor is not required since in city traffic high top speed and acceleration is not a necessity as city traffic is quite congested. Considering a complex city traffic scenario the main thing to observe is that the velocity and acceleration are not constant and keep on changing non-linearly, this can be concluded by various urban drive cycles. Calculating power of a motor for electric vehicles under city traffic and dynamic conditions is quite complex and challenging. Most

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people assume steady state conditions and other linear and simple scenario to calculate power of a motor for electric vehicles. This paper tries to dig deep on all possible scenarios while calculating power of a motor for electric vehicles under city traffic condition. All the mathematical calculations are done through MATLAB.

Variable Acceleration

The acceleration of the vehicle can be calculated by equations 1, 2 and 3.

$$X(\beta) = \frac{Y}{\beta} - Z(\beta)^2 \tag{1}$$

$$Y = \frac{746 * H_p}{M} \tag{2}$$

$$Z = \frac{D * A * C_D}{M} \tag{3}$$

where, X is the variable acceleration of the vehicle, Y is the constant Z is also a constant, β is the variable velocity of the vehicle, M is the mass of the vehicle and A is the frontal area of the vehicle, D is the density of the air and C_D is the air drag.

To calculate the variable acceleration from above equations first the variable velocity is calculated, for calculating variable velocity intelligent driver model is used. The intelligent driver model [1]-[7] is defined by equation 4 as shown below:

$$\frac{d\beta}{dt} = X * (1 - (\frac{\beta}{\beta_0})^4 - (\frac{\gamma}{\gamma_1})^2) \tag{4}$$

where,

$$\gamma = \gamma_0 + \beta S + \frac{\beta \Delta \beta}{2(XN)^{1/2}} \tag{5}$$

In the above equation 4 and 5, γ_0 is the minimum distance kept between stand still in a traffic jam, β_0 is the velocity of the vehicle in free traffic, N is the braking deceleration and $\delta\beta$ is the variation or fluctuation in the velocity.

All the values will dependent on a particular city traffic condition. The acceleration in terms of velocity defined in equation 1 is put in equation 4 and the equation 4 is integrated, after calculating the net velocity we can calculate the variable acceleration. The value of both variable velocity and acceleration can be matched with standard value given in some urban cycles shown in Fig 3, Fig 4, and Fig 5. The velocity and acceleration is calculated for all 50 vehicles.

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Drive Train

The Fig 1 shows a block diagram of variable gear drive train used in the propulsion system of electric vehicle. The Fig 2 shows the various forces

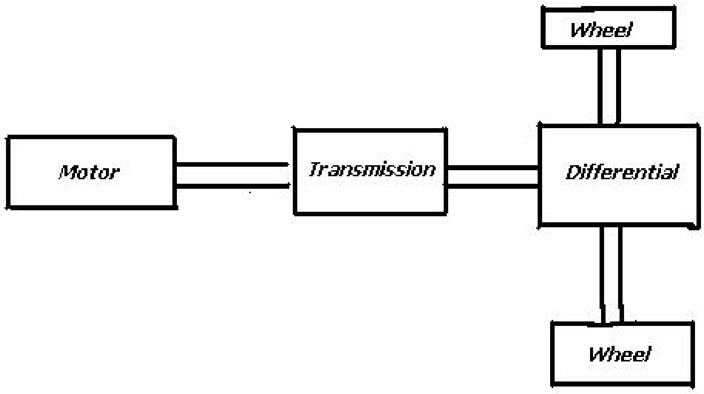

Figure 1: *Drive train of an electric vehicle*

considered in calculating the power of a motor. The various resistance forces as

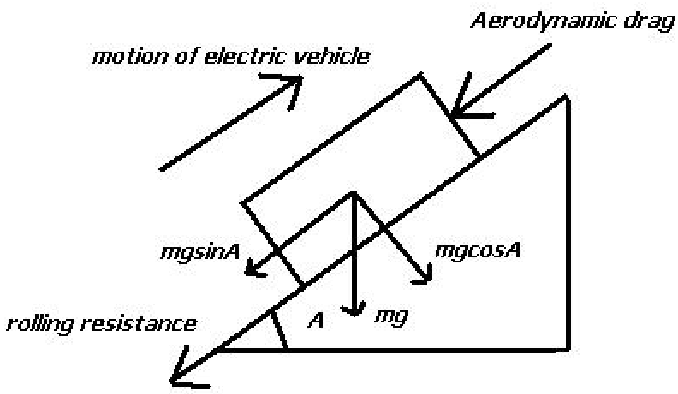

Figure 2: *Road load force components*

shown in Fig 2 are:

1. Rotational inertia

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2. Gravity force
3. Aerodynamic drag
4. Rolling resistance

Rotational Inertia

The torque loss due to inertia [12] of rotating parts are calculated in equation 6.

$$C_{net} = C_{initial} - I\mu \tag{6}$$

Where, Cinitial - initially torque given by the motor, I is the moment of inertia of motor and μ is the angular acceleration of the motor.

Gear ratio amplifies the torque but again the torque is decreased by the inertia losses due to gear and shafts. So net torque delivered to drive shaft will be equal to as shown in equation 7.

$$C_{net1} = (C_{net} - I_1\mu_1)\alpha_1 \tag{7}$$

Where, C_{net1} is the torque left after transmission losses and I_1 is the moment of inertia of transmission and α is the gear ratio.

Torque delivered at axle is reduced by the inertia present at drive shaft but amplified by final drive ratio. Torque delivered at axle is shown in equation 8.

$$C_{net2} = (C_{net1} - I_2\mu_2)\alpha_2 \tag{8}$$

Where, I_2 and μ_2 are the moment of inertia of drive shaft and rotational inertia of the wheels.

The relation between rotational accelerations of the motor, transmission, and driveline and gear ratios is shown in equation 9.

$$I = I_1\alpha_1 = I_1 I_2\alpha_2 \tag{9}$$

The above equations 6 to 9 can be combined to calculate the rotational inertia, which is also known as mass factor and its value, is taken as 1.1.

Gravity Force

Gravity force is given as

$$MgsinA. \tag{10}$$

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Rolling Resistance

The rolling resistance is calculated by equation 11.

$$R_r = \frac{(D_r(D_2V + D_3) * MgCosA)}{1000} \tag{11}$$

where D_r, D_2 and D_3 are rolling coefficient of resistance.

Aerodynamic Drag

The aerodynamic drag is given as shown in equation 12.

$$D_A = \frac{1}{2\rho V * C_D * A_{rea}} \tag{12}$$

where, ρ is the air density, A_{rea} is the frontal area of vehicle and C_D is the aerodynamic drag coefficient.
Some of the values used to calculate to calculate these values are shown in Table 1.

Table 1: *Values of various parameters used*

M	1000 Kg
C_D	0.3
r	0.28m
D_r	1(Concrete Pavement)
D_1	0.0472
D_2	0.0328(Radial Tyres)
ρ	1.19Kg/m3
η	0.8 or 0.9
sinA	0.0665
Gear ratios	1.12, 1.67, 2.73, 4.6, 5.75

Gear Losses

The Gear losses three types of components:

1. Oil churing losses,

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2. Air windage losses and

3. Mechanical losses which mainly consists of sliding losses and rolling losses.

Oil churing losses

The churing loss [8] is defined by the equation 13.

$$P_{churing} = \frac{1}{2} * C_m * \rho * \omega * S_m * r^3 \tag{13}$$

Where, S_m is surface area in contact with the gear, C_m is 20/Re where Re is Reynolds number and its value is < 2000, r is the gear pitch radius and ρ is lubricant density.

Air Windage losses

The air windage [9] losses is defined by the equation 14.

$$P_{windage} = \frac{1}{2} * C_t * \rho * \omega^3 * r^5 \tag{14}$$

with With $C_t = C_f + C_l$

$$C_f = 2.301 * \frac{((3.10)^5)^{4.5}}{r^5} + 0.1011 * [\frac{1}{Re^{0.2}} - \frac{((3.10)^5)^{4.8}}{r^5}] \tag{15}$$

$$C_1 = \epsilon * \frac{Z}{4} * (\frac{b}{r}) * [\frac{1 + 2(1 + x)}{z}]^4 * (1 - cos\theta) * (1 + cos\theta)^3 \tag{16}$$

Where, ϵ is the coefficient for obstacles 0.5 for no obstacles, x is profile shift coefficient, θ is $\frac{\pi}{z-2} * (\frac{1}{\alpha_P} - \frac{1}{\alpha_A})$
α_P and α_A are pressure angle at pitch point and at tooth tip.

Sliding losses

Sliding losses [10] is defined by the equation 17. (Rolling losses are quite small so they are neglected).

$$\Sigma\mu(k) * F(N, K) * V(N, K) \tag{17}$$

With k: teeth whom come in contact .

$$\Sigma F(N, K) * V(N, K) = P_i * \pi * \frac{i + 1}{z1 * i * cos\beta} * (1 - (\epsilon A) + (\epsilon 1)^2 + (\epsilon 2)^2) \tag{18}$$

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With P_i is input power, ϵ_A profile contact ratio and ϵ_1, ϵ_2 are tip contact ratio.

$$\mu(k) = 0.048 * (\frac{\frac{F_{bt}}{b}}{V\Sigma c} * \rho_{redc}) * \eta oil * R_a * X_1 \tag{19}$$

Where, F_{bt} is tangential force at the base circle, R_a is arithmetic mean roughness, X_l is lubricant factor, $V_{\Sigma c}$: sum speed at operating pitch circle and ρ_{redc} is reduced radius of curvature at pitch point.

Total gear loss is equal to sum of churing loss + windage loss+ sliding loss.

The Fig 3, Fig 4 and Fig 5 describe various urban drive cycle. These are the standard drive cycle and recorded in day to day normal traffic conditions.

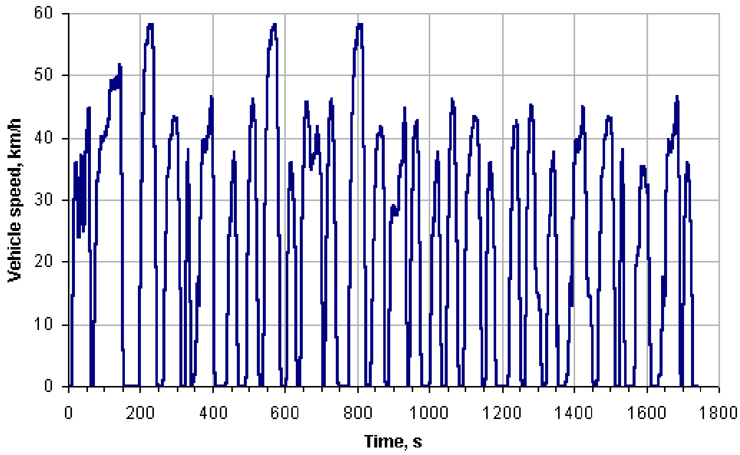

Figure 3: *Braunschweig City Driving Cycle*

Results

The following methods are used to calculate the power of a motor in electric vehicles under city traffic and dynamic conditions. Various parameters have been taken to calculate the power. All calculation is done in Matlab. The result will vary from one city to another depend upon the traffic conditions. The results are shown in Table 2.

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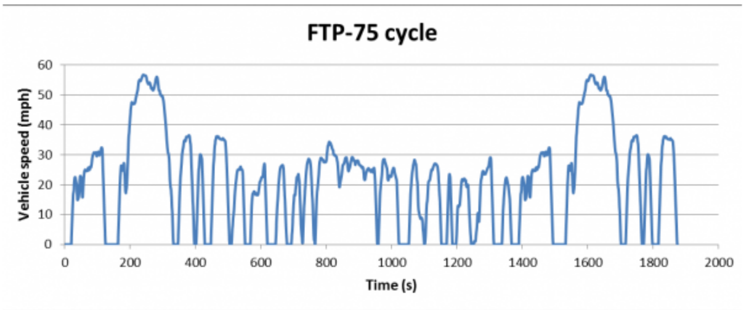

Figure 4: *FTP-75 test driving cycle established by the EPA*

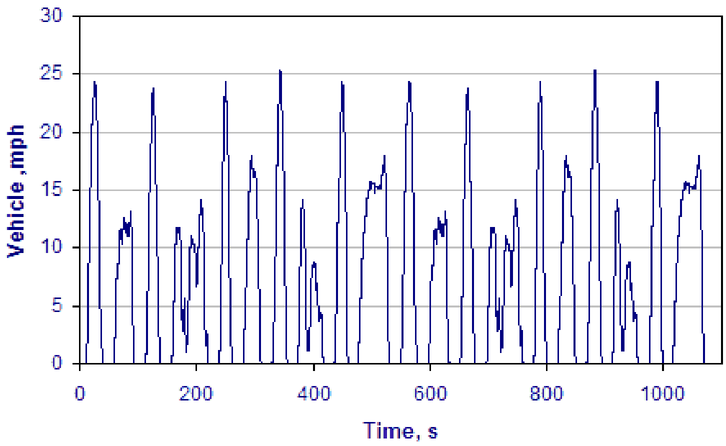

Figure 5: *Manhattan Bus Cycle*

Table 2: *Results*

S.No	No. of Passengers	Variable Velocity (m/s)	Variable Acceleration (m/s^2)	Power of the Motor (in KW)
1	2	0 - 40	0 - 1.2	6 KW
2	4	0 - 40	0 - 1.2	8KW

Conclusion

In this paper the author has shown a possible model to calculate the power of a motor in electric vehicle under city traffic and dynamic conditions. Author has considered all possible cases to calculate power in this complex scenario. The power of the motor can be even less since in high congestion traffic in metropolitan cities speed limit during busy hours is not more than 30 m/sec and acceleration needed is also not more than 0.8 m/sec^2. Author tried to show that plug in electric vehicle can be really successful as public transport in cities where performance requirement is not very high. These results are really helpful to develop a meaningful and low cost public transport in developing countries where CO_2 emissions are quite high due to not following proper pollution norms.

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References

[1] M. Treiber, A. Hennecke, and D. Helbing, `Congested traffic states in empirical observations and microscopic simulations`, Phys. Rev. E, vol. 62, pp. 1805-1824, 2000.

[2] A. Kesting, M. Treiber, and D. Helbing, `General lane-changing model MOBIL for car-following models`, Transport. Res. Record, vol. 1999, pp. 86-94, 2007.

[3] M. Treiber, A. Kesting, and D. Helbing, `Three-phase traffic theory and two-phase models with a fundamental diagram in the light of empirical stylized facts`, Transport. Res. B, Methodol., vol. 44, pp. 983-1000, 2010.

[4] M. Treiber and A. Kesting, Verkehrsdynamik und-SimulationDaten, `Modelle und Anwendungen der Verkehrsflussdynamik`. Berlin: Springer-Verlag, 2010.

[5] A. Kesting, M. Treiber, M. Schnhof, and D. Helbing, `Adaptive cruise control design for active congestion avoidance`, Transport. Res. C, Emerging Technol., vol. 16, no. 6, pp. 668-683, 2008.

[6] A . Kesting, M. Treiber, and D. Helbing, Enhanced intelligent driver model to access the impact of driving strategies on traffic capacity, Philos. Trans. Royal Soc. A, vol. 368, pp. 4585-4605, 2010.

[7] A . Kesting, M. Treiber, and D. Helbing, Connectivity statistics of store-and-forward inter-vehicle communication, IEEE Trans. Intell. Transport. Syst., vol. 11, no. 1, pp. 172-181, 2010.

[8] R. Bones (1989), Churning losses of discs and gears running partially submerged in oil, Proc. ASME Int. Power Trans Gearing Conf., Chicago

[9] Y. Diab, F. Ville, P. Velex (2004) Windage losses in high speed gears, Journal of Mechanical Design.

[10] B. Hhn, K. Michaelis, R. Dbereiner, (1999), Load carrying capacity properties of fast biodegradable gear lubricants. J STLE Lubr Eng

[11] M. Ehsani, Y.Gao, S.E. Gay, and A.Emadi, Modern Electric, Hybrid Electric, and Fuel Cell Vehicles, London:CRC Press LLC, 2005.

[12] T. D. Gillespie, Fundamental of Vehicle Dynamics, Society of Automotive Engineers, Inc., Warrendale, PA, 1992.

[13] R. Pratap, Getting Started with MATLAB 7: A Quick Introduction for Scientists and Engineers, Oxford University Press, 2006.