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Design and Study of Transmission System for Electric Vehicles

Ashwin Chander[1], Madan Kumar[2], Shobith Nambiar[3], Harsh Zaveri[4]
B.Tech Student[1, 2, 3, 4]
Department of Mechanical Engineering
SRM Institute of Science and Technology, Chennai, India

Abstract:
This paper proposes a design for a multi-speed transmission for electric vehicles (EVs).In the present scenario, current electric vehicle manufacturers have deviated from the inclusion of multi-speed transmission systems from their vehicles, keeping in mind the additional bulk, complexity and cost that it adds. But considering the characteristics of an electric motor various modifications (making the system clutch-less and limiting the gear selection to 3-speed) can be made to make the conventional transmission systems suitable for electric vehicles, as multi-speed transmission systems do promise to provide reduced energy consumption and increased efficiency for EVs, hence increasing the "range" of the EV. Also, the benefits of downsizing of the motor and battery components can be gained.

Keywords: Electric vehicles, Efficiency, Electric motors, Transmission systems.

I. INTRODUCTION:

Electric vehicles are gaining attention from the automotive industry, as they are eco-friendly and have lower operating costs than IC engine vehicles. But only after the development of lithium ion batteries, because of its capacity did the demands for EVs rise.

Currently only single speed reducers and motor controllers are used in commercial EVs due to characteristics of electric motors being sufficiently suitable to meet basic driving demands. Addition of a multi-speed transmission system can be advantageous, but only if it is designed specifically for an electric vehicle. As conventional transmissions are designed for IC engines, they disengage the engine power while shifting gears using a clutch. The same is not needed for an electric motor. The transmission keeps the motor in its optimal operating range and matches it with the vehicle speed. This results in lower power consumption and hence higher vehicle range. But manual transmission system tends to be bulky and also consists of constant use of clutch while shifting gears. This leads to power loss and makes it less efficient to be used in electric vehicles. Similarly, conventional automatic transmission systems are not the solution because of the weight it will add to the overall system.

The proposal is the use of three-speed constant mesh gear box. Also, in this kind of gear box the gears are always in a state of mesh and thus removing the possibility of slip between engaging gears. Thus, reducing the transmission losses to a certain extent. Additionally, the frictional clutch is removed, which would have been otherwise used to disengage the prime mover from the gearbox in order to shift gears. Instead, a motor controller can be used, which would regulate the speed of motor while shifting gears.

II. VEHICLE SPECIFICATIONS

For calculating the efficiency difference between the conventional EVs with single speed reducers and an EV using multi-speed transmission (specially designed for EVs), we can compare the various performance graphs of the respective vehicles.

The following are the vehicle parameters considered for the calculations: -

Table.1. Vehicle Parameters

PARAMETER	**VALUE**
Mass of vehicle(m)	1000 kg
Coefficient of Drag (Cd)	0.2
Rated Power	37.2 kW
Wheel Radius(r)	0.251 m
Rolling resistance coefficient	0.015
Frontal area of vehicle	2.2 m^2
Max. Speed	265 km/hr

All the other performance variables of the vehicle were calculated as follows: -

Air resistance: $0.5\ \rho\ C_d\ v^2\ A$
= 202.90 N
Grade resistance: 0
Rolling resistance (F_r): f. G.V.W
(G.V.W = m. 9.81**)**
=147.15 N
Resistance due to acceleration(F_a): δma
= 4547.5 N
Tractive force: µ. (G.V.W)
=4905 N
Total Tractive Effort = 4897.55 N
Total Starting Torque (τ): F_t .r=1229.28 N

III. GEARBOX PARAMETERS

The calculations pertaining to the gearbox are done using the following method. The proposed gearbox is a 2 stage, 3-speed gearbox. We have considered a 50 HP induction motor with a max speed of 2800 RPM and we have assumed minimum speed as 500 RPM.

N_{max} = 2800 RPM

N_{min} = 500 RPM

$R_n = N_{max}/N_{min}$ (or) $R_n = \Phi^{n-1}$

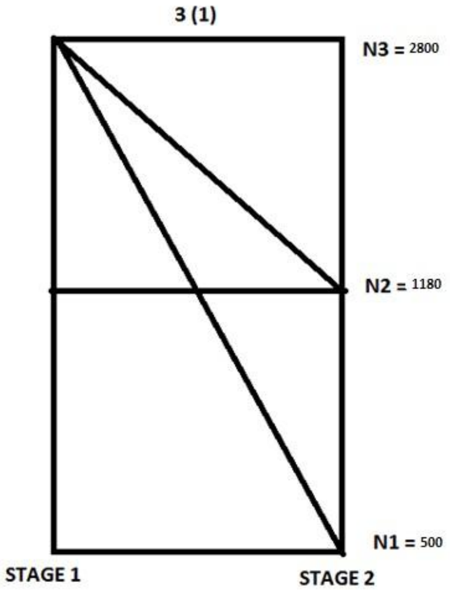
$R_n = \Phi^{3-1}$

$5.6 = \Phi^2$

$\Phi = 2.36$

Assuming R-20 SERIES this satisfies the condition So $N_2 = 500 \times 2.36$

=1180 rpm Speed diagram



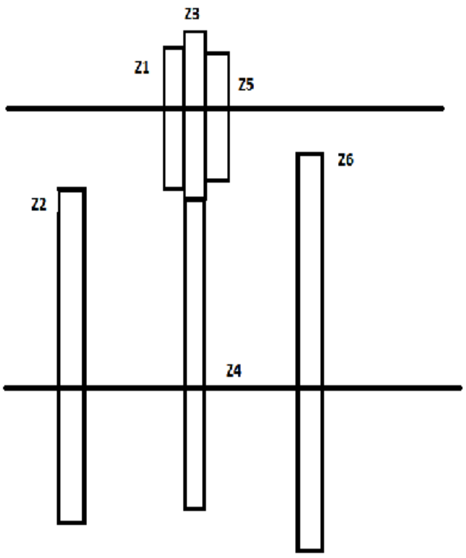


Figure.2. Gear Pairs

First taking gears 5&6

Assuming gear 5 i.e. Z_5=20teeth

So Z_6= 112 teeth

So $Z_1+Z_2 = Z_5+Z_6 = 132$ --- eq.1

Then taking gears 1&2 we get

$Z_1/Z_2 = N_2/N_1$

$Z_1/Z_2 = 0.42$

$Z_1 = 0.42\ Z_2$

Substituting Z_1 value in eq1 we get Z_2= 93 teeth

So Z_1 =39 teeth

Then $Z_5+Z_6 = Z_3+Z_4$

So $Z_3 = Z_4 = 66$

Now,

$Z_1/Z_2 = 0.42$

$*/Z_3/Z_4 = 1$

$Z_5/Z_6 = 0.178$

The following are the parameters for the 3 pairs of gears:

Table.2.Gear Ratios

Pair No.	**Gear Ratio**
1. Z6/Z5	5.6
2. Z2/Z1	2.37
3. Z4/Z3	1

Module for the gears used is taken as 2. (Helical gears are used for this particular gearbox).

IV. GEARBOX DESIGN

Design of a gearbox concept has been developed using CATIA-V5 software. This is a design of 3-Speed gearbox. We have 3 pairs of forward gears and we have excluded the reverse gear considering the power losses during shifting. The gears used are helical type as they are capable of supporting very high loads and forces for longer duration of time. The Lewis Buckingham method has been used for designing the helical gears and shaft. As this concept is meant for electric vehicles, we have also excluded the use of clutch which was otherwise needed to keep the engine or the prime mover running while shifting gears as electric motor can be easily controlled by the means of a motor controller they can be switched on and off easily. In this design the gear pairs are in constant state of mesh and the motor controller will be programmed in such a way that while shifting from a particular gear to the next gear ,it senses the movement of the dog clutch and slows down the motor speed to allow smooth shifting of the gears. Primarily used single speed reducers in EV's are thus replaced by the transmission system.

1.1. CALCULATION OF CENTER DISTANCE:

$a_1 = (Z_5+Z_6/2)m$ $a_2 = (Z_1+Z_2/2)m$ $a_3 = (Z_3+Z_4/2)m$

$a = a_1 = a_2 = a_3 = 136.65$

1.2. CALCULATION OF THE PHASE WIDTH:

$\psi m = b/mn$ $10 = b/mn$

b = 20 mm

1.3. CALCULATION OF LENGTH OF SHAFT:

Assumptions 10mm clearance between the gear and the bearing on both sides Take the distance between the adjacent groups of gears as 20mm Take the total length of two pair of group as 4band for three pairs gear group as 7b

Take the width of the bearings as 25mm $L = 25+10+7b+10+25$

$= 25+10+7 \times 20+10+25$

=210 mm

DIAMETER OF SPINDLE =23.74 mm

DIAMETER OF COUNTER SHAFT =12.83 mm

Helix angle = 15 deg Pressure angle = 20 deg Note:-

The helix angle is measured on the cylindrical pitch surface of the gears. Generally, Helix angle ranges from 15 deg to 45 deg. For design purpose commonly used values are 15, 23, 30 and

45 deg. Lower the helix angle, lesser the end thrust on the gears. Higher value of helix angle results in smoother operation, but more end thrust is exerted.

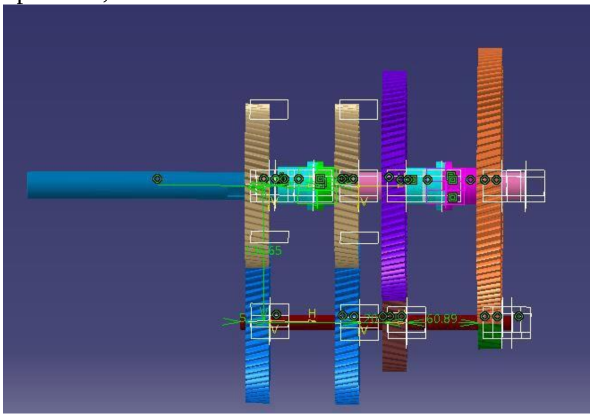
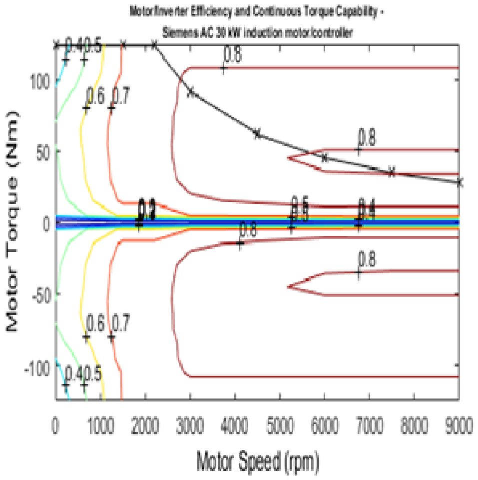


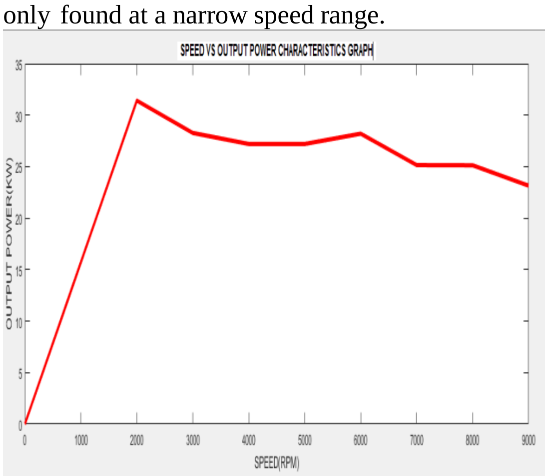
Figure.3. Gearbox design

V. STUDY OF CHARACTERISTICS CURVES OF INDUCTION MOTOR



Graph.1. Torque vs rpm

In this section, the graphs have been plotted, using MATLAB and ADVISOR-2003 software. Here we have considered an electric vehicle of 870 kg powered by a 6 Ah saft lithium ion battery of 36 module. The above graph represents the curve between torque and speed of a 40HP induction motor. It can be understood that electric motor tends to have a high starting torque but the torque tends to decrease with the increase in speed. As the torque and speed tends to vary the output power of the motor also varies. The efficiency of the motor at various operating points tends to be different. The ideal efficiency is only found at a narrow speed range.



Graph.2. Speed(X) Vs Output Power(Y)

The above graph shows the speed and output power characteristics of the induction motor. It explains that with the increase in power which is required by the motor, the peak efficiency differs with the motor speed. The normally used single speed reducers are not capable of adjusting the motor speed and as a result does not help with the efficiency. The aim of using a multi- speed transmission system is to let the motor operate steadily within an ideal efficiency region. This will help in reduced energy consumption i.e use of smaller battery packs and thus help in increasing the range of the electric vehicle.

VI. CONCLUSION

As the world seeks to replace conventional means of locomotion with new and eco-friendly ones, they need to be attractive enough and cost effective to drive the shift towards them. Road vehicles in particular have to have a range comparable to existing fossil fuel vehicles. And laden-vehicles will need to be powered by lesser sized batteries and motors and still have a long range. All the above objectives can be achieved with the incorporation of a multi-speed transmission system, specifically designed for electric vehicles, which will make them energy efficient.

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