

# TECHNICAL PAPERS

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### On-center Steering Response

On-center steering response is one of the important parameters which is closely related to the measure of steering responsiveness during high speed lane change or road maneuverability [24]. It is estimated by measuring the degree to which road wheel turns when steering wheel is rotated by 90° towards 1H and 2H side. Plot of steering wheel rotation vs road wheel turn (RH wheel) of existing system and new system is shown in Fig. 10 and Fig. 11 respectively. Based on the benchmark data it was found that the vehicle handling was found to be better when the steering wheel to road wheel steering ratio is between 20:1 to 25:1. Comparison of on-center steering response between existing and new design is tabulated in Table 2. It was found that the on-center response of the new design was slightly higher than the existing system. However, both the systems meet the requirement.

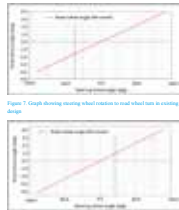


Figure 7 Graph showing steering wheel rotation vs road wheel turn according to design

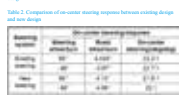


Figure 8 Graph showing steering wheel rotation vs road wheel turn in new design

Table 2. Comparison of on-center steering response between existing design and new design

Parameter	Existing Design	New Design
Steering Ratio	20.5	21.5
On-center Response	0.85	0.90

### Steering Gear Demand Torque Comparison

An attempt was made to compare the steering gear demand torque values between the existing steering system and new steering system. It is the torque required at the steering gear to turn the road wheel. Load

on the front axle considered for the study was 6000N. Torque required to turn the road wheel about the kingpin was estimated. The tire to ball friction considered was 0.4. Kingpin torque obtained was used as a reference torque to determine the steering gear demand torque in the existing and new steering system. The required torque value to the kingpin torque and steering gear demand torque values of both the systems are tabulated in Table 3. It can be seen that for the same kingpin torque, the steering gear demand torque has reduced from 4000 Nm to 3277 Nm in the new system which is approximately 20% lesser than the existing. This will in turn reduce the steering wheel effort to be exerted by the driver to steer the vehicle.

Table 3. Comparison of steering gear demand torque between existing and new system

Parameter	Existing Design	New Design
Kingpin Torque	6000 N	6000 N
Steering Gear Demand Torque	4000 Nm	3277 Nm

### Structural Analysis of Drag Link

Finite element analysis was carried out to study the force-displacement characteristics and modal frequencies of the draglink using ANSYS 14.5. FE model of drag link is shown in the Fig. 12. Non-linear buckling analysis (to check stability) was carried out to estimate the critical buckling load. The boundary conditions defined were, all the three translational degrees of freedom were constrained at one end of the link and it was free to rotate in any direction. At the other end, displacement load was applied along X-axis and other two translational movements were constrained. It was free to rotate about Y and Z axis but constrained to rotate about X-axis.



Figure 12 FE model of the drag link

The force vs displacement analysis of the drag link is shown in the Fig. 13. It can be seen from the plot that the drag link tube becomes unstable only after 47.41N whereas the design requirement is to have buckling strength of atleast 312.5N. So, the design was successfully safe. Three samples of draglinks were tested for validating the



Figure 1 On-axis machine with DC motor Excitation



Figure 2 The voltage drop across as a function of rotor position

Let rotor spins with constant speed by external motor in the direction shown in Fig. 1. The rotor induces magnetic flux through armature winding from one direction to opposite direction. During one rotor turn it reverses two times. So, the armature voltage frequency is double of rotor frequency system. Fig. 1 shows flux and voltage wave form in armature coil as a function of a rotor position. This is changing from zero to maximum in clockwise winding direction and from 180° to 270° rotor position. If value of the flux increased linearly from zero to maximum, the voltage wave form is close to rectangular. In interval, between 22° and 17° rotor position, the negative flux flowing through winding HF decrease from maximum to zero. The induced voltage in winding HF change polarity and has the same amplitude. In interval, between positions 17° and 44°, the flux change direction in winding HF and changes its value from zero to maximum in opposite direction. The induced voltage amplitude does not change. In interval, between positions 44° and 17°, the flux direction from maximum to zero. The voltage in armature coil change polarity and has the same maximum value. In the next half period of the rotor rotation, the all processes are repeated. The frequency of output voltage is

$$f = \frac{N}{60} \times \frac{P}{2} \quad (1)$$

where  $N$  is the rotor speed in revolution per minute  
 $P$  is the DC current excitation, and  $K_v$  is the constant

Winding 'a' and 'A' are identical and can change their function. This is a 4-pole winding circuit, and a can be armature winding. If a load is connected to armature terminals, the current will flow in armature coil Fig. 4. A current carrying conductor in magnetic flux produces a force

$$F = B \times I \times L \quad (2)$$

The torque on the armature is

$$T = F \times R \quad (3)$$



Figure 3 The flux machine in generator mode

$$T = K_t \times I \quad (4)$$

where  $L$  is the root mean square current flowing in the armature conductors,  $R$  is the axial length of the armature wire,  $I$  is the DC field current, and  $K_v$  is the constant coefficient

In the motor mode operation, the armature current must flow in a series of exciting armature voltage and have direction opposite to voltage direction. That is why, in the motor mode operation, there is called a motor of a brush (voltage) system.

If the armature terminal voltage is  $V_a$ , the armature resistance is  $R_a$ , and armature electromagnetic force is  $F_e$ , then for a generator mode operation

$$V_a = E_b - I_a R_a \quad (5)$$

buckling strength by subjecting them to compressive load and it was found that all of the samples met the requirement. The buckling strength values of the drag links are tabulated in Table 4.

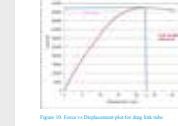


Figure 10 Force vs Displacement plot for drag link tube

Table 4. Buckling strength values of the three drag link samples

Sample	Material	Area (mm²)	Length (mm)	Radius (mm)	Effective Length (mm)	Slenderness Ratio	Critical Load (N)
1	Al 6061	100	100	10	100	10	10000
2	Al 6061	100	100	10	100	10	10000
3	Al 6061	100	100	10	100	10	10000

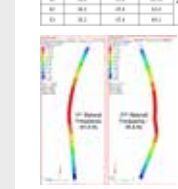


Figure 11 Shape of 17° and 27° mode shape of the drag link

Modal analysis of the draglink tube was carried out to verify the natural frequency of the draglink to be away from the engine excitation frequency and road wheel excitation frequency to avoid resonance. First firing order frequency of the engine was 30 Hz and the road load data for this vehicle was captured and it was found that the maximum excitation frequency of the road wheel was 15 Hz. So, the natural frequency of the drag link first natural frequency was to be greater than 30 Hz. Fig. 11 shows the 17° and 27° mode shapes of drag link. The 17° and 27° natural frequencies were found to be 41.4 Hz and

41.4 Hz respectively. Since, the drag link natural frequencies were much away from the engine excitation and road excitation frequencies, it was passed from high amplitude vibration.

### Vehicle Steering Performance Evaluation

Vehicle was simulated with steering system and subsequently with new steering system for evaluating steering wheel effort and self-centering efficiency. YC of the vehicle with existing and new system was the same. Dynamic steering wheel effort was measured under two circumstances, i) turning the road wheel to extreme condition under vehicle forward motion and ii) turning the road wheel to achieve 15° of 40° in without power assistance (manual effort). The self-centering efficiency is a measure of returnability of the road wheels from fully turned condition to straight ahead condition during vehicle motion. It is measured by calculating percentage by which steering wheel returns towards straight condition from extreme turned condition without 1° overshoot. Multiple trials were carried out for steering wheel effort and self-centering efficiency to assess the accuracy. The comparison of steering wheel effort and self-centering efficiency between existing and new steering system is shown in Table 5. Since, there was a reduction in the steering gear demand torque in the new steering system, the steering wheel effort too got reduced. However, steering gear demand torque and steering wheel effort don't have linear relation because of power assistance. It can be seen from the Table 5 that there is a reduction in steering wheel effort with power assistance by 0.8 kgf for full steering in the new steering system compared to existing steering system and there was 7.3 kgf reduction in effort for manual steering. Also, the self-centering efficiency of the vehicle has got improved by 21.7%. The reduction in the steering wheel effort achieved in the new steering system was mainly because of steering linkage axis reorientation and improvement in the self-centering efficiency was due to reduction in number joints.

Table 5. Comparison of steering wheel effort and self-centering efficiency between existing and new steering system

Parameter	Existing Design	New Design
Steering Wheel Effort (kgf)	15.0	14.2
Self-centering Efficiency (%)	78.3	100.0

### Summary and Conclusions

In this work, steering system design optimization was carried out for larger HPF passenger bus. It was possible to design and package single drag link steering system instead of three gear ratio setup. Higher strength drag link tube material was used to overcome the design and packaging constraints. Numerical analysis of vehicle handling parameters such as heavy steer, on-center steering response and steering gear demand torque effort were compared between existing design and new design. It was found that heavy steer of both the designs was meeting the target. On-center steering response was slightly higher in the new steering system than the existing system.

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