Design, Analysis and Optimization of Collapsible Steering Column

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Abstract - *In the present scenario transportation has become an important parameter thus it requires the implementation of safety factors in the automobile at low cost which can be afforded even by a common man. Our project deals with the idea of implementing energy absorbing steering column in the car which helps to absorb the impact experienced by the driver during the time of collision at low cost. Energy Absorbing Steering Column (Collapsible steering column) is a kind of Steering Column which minimizes the injury of the driver during a car accident by collapse or breaking particular part of system. Up to now, Steering Column in Crash Analysis had no way to describe these 'Collapse' or 'Slip' by the Axial and Lateral Forces from driver. In this project, I have created a new Steering Column using a Detailed FE Model which can describe such collapse behavior. In this project, I have been modify rigid steering column of Maruti-Alto into collapsible steering column for to save human life during frontal impact.*

Key Words: Energy absorbing steering column (EASC)

1.INTRODUCTION

The automotive steering column is a device intended primarily for connecting the steering wheel to the steering mechanism or transferring the driver's input torque from the steering wheel.

A steering column may also perform the following functions:

- Energy dissipation management in the event of a frontal collision.
- Provide mounting for: the multi-function switch, column lock, column wiring, column shroud, transmission gear selector, gauges or other instruments as well as the electro motor and gear units.
- Offer (height and/or length) adjustment to suit driver preference.

Rigid steering column – The classic design is a rigid steering column. The steering wheel has a rigid connection to the steering shaft which is usually a single-piece item.
EASC (Energy Absorbing Steering Column) is a kind of Steering Column which minimizes the injury of the driver during a car accident by collapse or breaking particular part of system.

In this paper, a case study is performed on an existing steering column of Maruti-800 passenger car. This is a rigid column which under crash situation transfers the energy directly to the driver. Thus causing several injury or even fatalities. So, I am modifying this design from a rigid steering to a collapsible steering column.

1.1 Steering Column

The steering column basically consists of the outer tube which is screwed to the bodywork and the steering shaft.

The steering shaft connects the steering wheel to the steering gear and is supported in an outer tube. It transmits the steering torque.
The following design principles are used in general for steering columns.

a) Rigid Steering Column

The classic design is a rigid steering column. The steering wheel has a rigid connection to the steering shaft which is usually a single-piece item.

b) Steering column with angular adjustment

The angle of the steering wheel can be adjusted with this design. The tilting point is usually in the joint.

c) Steering column with adjustable height

Steering columns with adjustable height can be adjusted telescopically. The position of the steering wheel with respect to the driver can thus be altered in an axial direction.

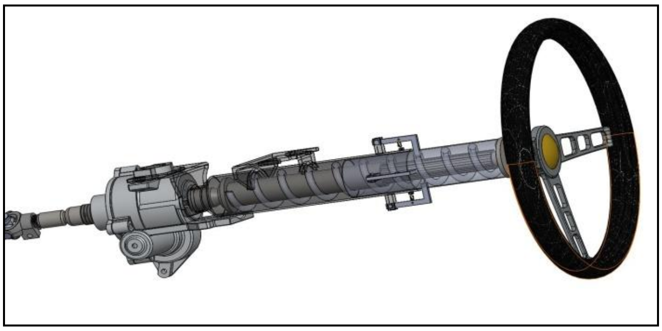
d) Combined adjustment mechanism

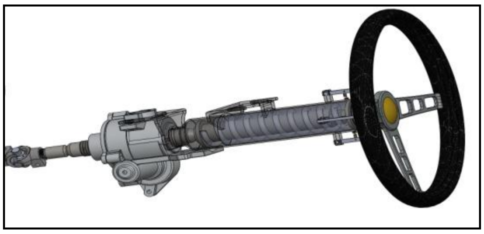
Steering columns with only angular or height adjustment are both compromise solutions. The most favorable position of the steering wheel with respect to the driver is achieved through a combination of both angular and height adjustment.
Steering column would often cause bruising of the face and chest, or in some cases, crushing of the driver's skull. According to the National Highway Traffic Safety Administration (NHTSA), if all road vehicles included collapsible steering columns, '1,300 fatalities and 23,000 non-fatal injuries' could be avoided every year.
Thus Collapsible steering columns are a necessity in automotive vehicles. This is because without the mechanism, the steering column would often impale the driver once the vehicle experienced a sufficient impact. Once implemented, the collapsible steering column can absorb most of the energy received at the front of the vehicle in the event of the

crash. This prevents the energy of the impact from being transferred completely into the driver.

1.2 Rigid Steering Column of Maruti Alto

1.2 Collapsible Steering Column For Maruti Alto





2.DESIGN OF COLLAPSIBLE STEERING COLUMN

DESIGN CALCULATION OF RIGID STEERING COLUMN

Torque = 56 N-M = 56000 N-Mm
Diameter (D) = 16 Mm

Torsional Shear Stress:

$$\frac{T}{J} = \frac{\tau}{r}$$

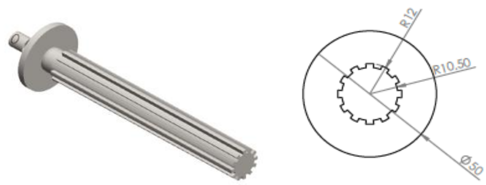
$$\therefore \tau = \frac{T \times r}{J} = \frac{56000 \times 8}{\frac{\pi}{32} \times d4} = \frac{56000 \times 8}{\frac{\pi}{32} \times (16)4} = 69.63 \text{ N/mm2} < 300\ N/mm2$$

Twisting Angle :

$$\frac{T}{J} = \frac{G\,\theta}{l}$$

$$\theta = \frac{T\,l}{G\,J} = \frac{56000 \times 537}{78660 \times \left(\frac{\pi}{32}\right)(16)\,4} = 0.0594\,°$$

DESIGN CALCULATION OF SHAFT WITH OUTER SPLINE:



Torque = 56 N-m = 56000 N-mm
Diameter (D) = 21 mm
No. Of Splines (n) = 12
Contact Length (L) = 28 mm
Torque (T) = Load (P) × Radius (R)

$$P = \frac{T}{r} = \frac{56000}{10.5} = 5333.3 \text{ N}$$

Area = 1.80 × 28 = 50.4 Mm^2

Shear Stress:

$$\text{Shear Stress} = \frac{P}{A} \times \frac{1}{n}$$

$$\therefore \text{Shear Stress} = \frac{5333.3}{50.4 \times 12} = 8.818 \text{ Mpa} = 8.818 \text{ N/Mm}^2 < 300 \text{ N/Mm}^2$$

Torsional Shear Stress:

$$\frac{T}{J} = \frac{\tau}{r}$$

$$\therefore \tau = \frac{T \times r}{J} = \frac{56000 \times 10.5}{\frac{\pi}{32} \times d4} = \frac{56000 \times 10.5}{\frac{\pi}{32} \times (21)4}$$

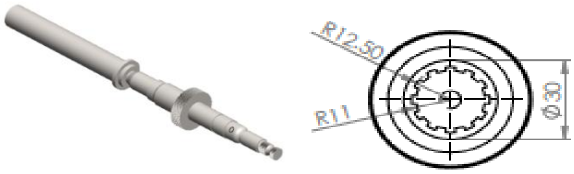
$= 30.79$ N/Mm^2

Twisting Angle:

$$\frac{T}{J} = \frac{G\,\theta}{l}$$

$$\theta = \frac{T\,l}{G\,J} = \frac{56000 \times 28}{78660 \times \left(\frac{\pi}{32}\right)(21)\,4} = 0.00104\,^{\circ}$$

DESIGN CALCULATION OF SHAFT WITH INNER SPLINE:



Torque = 56 N-m = 56000 N-mm
Diameter (D) = 30 mm
Diameter (d) = 25 mm
Contact Length (L) = 28 mm
No. Of Splines (N) = 12
Torque (T) = Load (P) × Radius (R)

$$P = \frac{T}{r} = \frac{56000}{12.5} = 4480\text{ N}$$

Area = 2 × 28 = 56 mm^2

Shear Stress:

$$\text{Shear Stress} = \frac{P}{A} \times \frac{1}{n}$$

$$\text{Shear Stress} = \frac{4480}{56 \times 12} = 6.66\text{ Mpa} = 6.66\text{ N/Mm}^2 < 300$$

N/Mm^2

Torsional Shear Stress:

$$\frac{T}{J} = \frac{\tau}{r}$$

$$\therefore \tau = \frac{T \times r}{J} = \frac{56000 \times 15}{\frac{\pi}{32} \times (D4 - d4)} =$$

$$\frac{56000 \times 10.5}{\frac{\pi}{32} \times [(30)4 - (25)4]} = 20.40\ \text{N/mm}^2$$

Twisting Angle:

$$\frac{T}{J} = \frac{G\,\theta}{l}$$

$$\theta = \frac{T\,l}{G\,J} = \frac{56000 \times 28}{78660 \times \left(\frac{\pi}{32}\right)(25)\,4} = 0.00052\,^{\circ}$$

DESIGN CALCULATION OF IMPACT FORCE:

1. Mass of occupant (m) = 70 kg
2. Car speed (v) = 50 km/hr = (50×1000) / 3600 = 13.88 m/s
3. Stretching distance of seat belt (s) = 1.5 ft = 1.5×0.305 = 0.46 m
4. Initial velocity (u) = 13.88 m/s
   Final velocity (v) = 0 m/s
   Acceleration (a) =
   $$\frac{0 - 13.88^2}{2 \times 0.46} = -209.406\ m/s^2 \ \ldots\ldots$$
   (Retardation)

Impact Force (F) = mass × acceleration = 70 × 209.406 = 14.658 kN

DESIGN CALCULATION OF HELICAL SPRING:

Coil diameter of spring (d) = 8 mm
Outer diameter of spring (Do) = 40 mm
Free length of spring (Lf) = 312 mm
Total deflection (δ) = 125 mm
Active no. of coils (n) = 10
For square and ground end (ή) = n + 2
Mean diameter of spring (D) = Do – d = 40-8 = 32 mm
Free length of spring (Lf) = 312 mm
Spring Index (c) = D / d = 32 / 8 = 4
Pitch of coil (p) = Lf / (ή - 1) = 312 / (12 – 1) = 28.36 mm

Solid length (Ls) = ή × d = 12 × 8 = 96 mm

Maximum load (Pmax) =

$$\frac{G\,d^4\,\delta\max}{8 \times D^3 \times n} = \frac{(80 \times 10^3 \times 8^4 \times 125)}{(8 \times 32^3 \times 10)}$$

$$= 15625\,N = 15.6\,kN$$

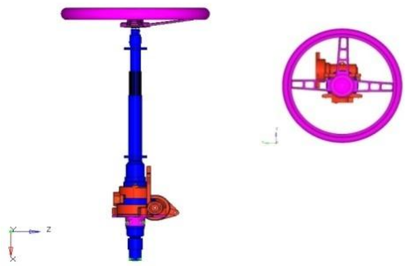
$$\text{Spring rate or stiffness (q)} = \frac{G\,d}{8 \times c^3 \times n} = \frac{80 \times 10^3 \times 8}{8 \times 4^3 \times 10}$$

$$= 125\,N/mm$$

3.FEA OF COLLAPSIBLE STEERING COLUMN

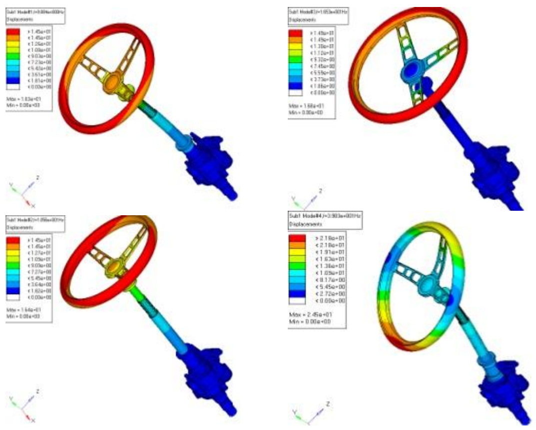
3.1 Finite Element Meshing

Finite Element Meshing: In finite meshing each parts of an assembly is represented in a set of finite element. Meshing is required before analysis because cross-section of each part of an element is different. Therefore stresses induced in each part of an element are different. For stress calculation of each segment of an element, meshing is required.

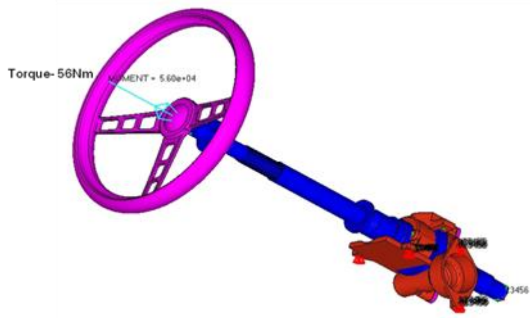


3.1 Finite Element Analysis

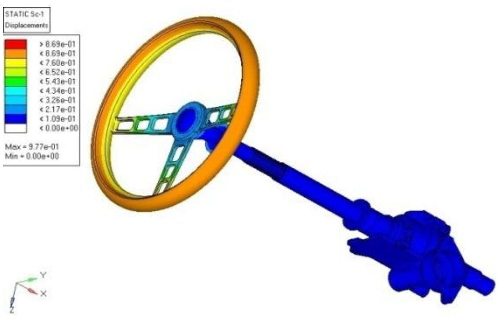
Modal Analysis Of Collapsible Steering Column:



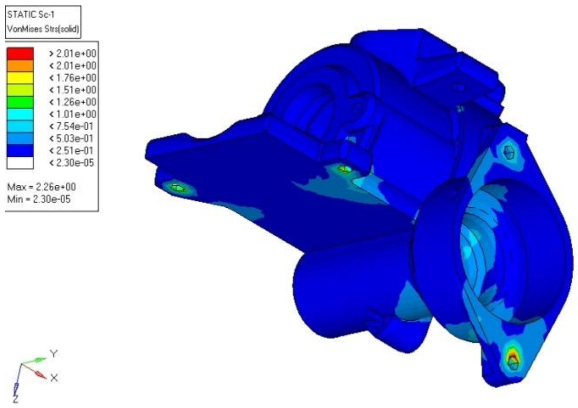
Load and Boundary Condition Of Collapsible Steering Column:



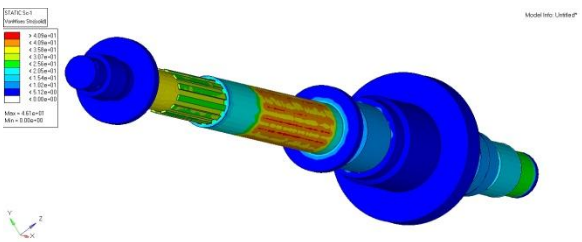
Variation in Static Displacement:



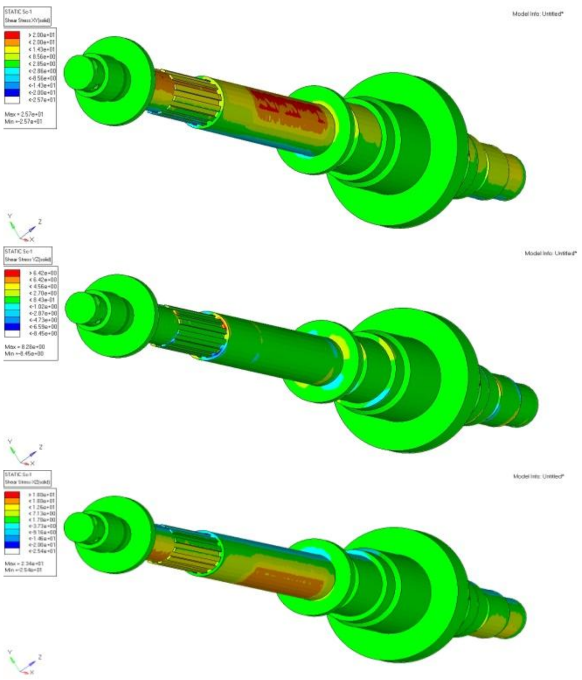
Variation in Von-Mises Stress of Combination Switch Assembly:



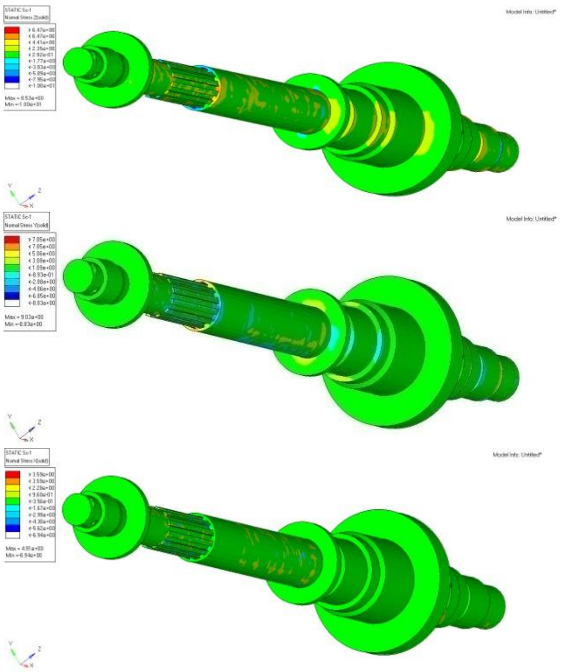
Variation in Von-Mises Stress of Collapsible Steering Column:



Variation in torsional shear stress:



Variation in Normal Shear stress:



4.OPTIMIZATION

4.1 Design Optimization

Rigid Steering Column of Maruti Alto	Collapsible Steering Column of Maruti Alto
1. Torsional shear stress = 69.63 N/mm²	1. Torsional shear stress = 25 N/mm²
2. Impact force does not absorb because of rigid steering column is used.	2. It absorb 15KN impact force because of collapsible steering column is used.

4.2 Cost Optimization

CSC (Maruti Alto)	CSC (Mercedes Benz C-300)
1.Material Used = PN-19, Carbon Fibre	1.Material Used = Carbon Fibre
2.Helical spring is used to absorb impact force during frontal collision of vehicle.	2.In Mercedes Benz C-300, Telescopic design that allows one section of the column to slide into the other.
3. Diagram: 	3. Diagram: 
4. Cost Expenditure: a)Cost of rigid steering column assembly = Rs 29000 /- b)Cost of modified steering column = Rs 4200 /- c) Cost of helical spring = Rs 400 /- d) Cost of locking mechanism = Rs 400 /- TOTAL COST = Rs 34000/-	4. Cost of steering column assembly of Mercedes Benz C-300 is $ 1125 i.e. approximately INR 70,000. ....Ref (www. ebay.com)

5. CONCLUSIONS AND FUTURE SCOPE

Based on the results and analysis the conclusions are as under: Collapsible steering columns are a necessity in automotive vehicles. This is because without the mechanism, the steering column would often impale the driver once the vehicle experienced a sufficient impact. Once implemented, the steering column can absorb most of the energy received at the front of the vehicle in the event of a crash. This prevents the energy of the impact from being transferred completely into the driver.

Collapsible energy absorbing steering column can be effectively used in all-terrain vehicle to provide safety to the driver. This system is cheaper than the other safety items like air bag and collapsible steering column and the important thing is its retractable needs no replacement. It absorbs nearly about 15KN of the load given to the driver and thereby providing safety to the driver. Only if the load exceeds the maximum absorption capacity of spring the load would be directly acting on the driver. However the damage to the driver is reduced. Hence it can be used in an ATV to improve the safety of the driver.

Scope for Future Work:

There is much scope in design of intermediate steering shaft to minimize its defect due to twisting, vibrations etc. Spring and Ball arrangement should be made at the connecting surface to optimize design this will provide better stability and less vibrational defects in intermediate steering shaft as well as column. For making the Shaft better the Shafts ends should be made thicker where the coupling is to be used at the and were the universal joint used at the end. The material properties at both the ends should be made different and instead of circular cut at the ends it any other shapes should be tried for more better results.

REFERENCES

[1] Rince Wins, Dhanesh Chatta & Anish Nair, "Design of Pneumatic Collapsible Steering column", International Journal on Theoretical and Applied Research in Mechanical Engineering (IJTARME), ISSN : 2319 – 3182, Volume-2, Issue-2, 2013.

[2] Tae Hee, Lee Byung Ryul, Ham Seong Oh, Hong, "Study On Steering Column Collapse Analysis Using Detailed Fe Model", NHTSA, "Laboratory Test Procedure For FMVSS 203 -Impact Protection for the Driver from the Steering Control System", 1990.

[3] Lukas Hormacek, "Design And Optimalization Of Racing Car's Steering Column", Number 4, Volume IX, December 2014.

[4] Malge Sangeeta Ganesh, G. P. Patil , N. A. Kharche, "Performance of the Structural Analysis of Ford Car Steering Rod", International Journal of Research in Advent Technology, Vol.2, No.2, February 2014.

[5] Tyan, T., Vinton, J., Beckhold, E., Zhang, X. etal, "Modeling of an Advanced Steering Wheel and Column Assembly for Frontal and Side Impact Simulations" SAE Int. J. Mater. Manf. 7(2):366-401, 2014.

[6] Bengt Pipkorn Autoliv,Yngve Håland Autoliv, "Car Driver Protection At Frontal Impacts Up To 80 Km/H (50 Mph)", Paper Number 05-0102.

[7] Zeeshan Qaiser, Omer Masood Qureshi Khalil Aslam, Awan Hassaan Ahmed, "Numerical investigation of usage of patterned collapsible energy absorbers in steering column of an automotive vehicle" Aerospace science & engineering (ICASE), 2013 International conference on 21-23 Aug.2013, Pgs:1-4.

[8] Ratko Menjak, Karen A. Boswell, Sainan Feng, James P. Kelly, Brian J. Magnus,Wayne M. Steverson, "Collapsible steering column assembly", Patent no. US7455321B2, Nov.25,2008.

[9] Tyan, T., Vinton, J., Beckhold, E., Zhang, X., "Modeling of Adaptive Energy Absorbing Steering Columns for Dynamic Impact Simulations", SAE Int. J. Master. Manf. 7(2):337-365, 2014.

[10] Kiran Manohar Deshmukh, Ashish Kumar Singh, "An Improved Collapsible Steering Column Assembly", Patent No.232456, 27-Mar-2009.

[11] M.Balaji , MalarMohan, "Redesign the Steering Column Assembly with Crimping Method" IOSR Journal of Mechanical and Civil Engineering (IOSRJMCE), Volume 11, Issue 2 Ver. VII (Mar- Apr. 2014), Pg.No. 84-89.

[12] Gabriel Catalin Marinescu, Nicolae Dumitru, Victor Otat, "Analysis Of The Torque Applied To The Steering Wheel In Static Conditions", International Journal Of Engineering, ISSN 1584-2665, 2013.