

A Literature Review on Collapsible Steering Column

Imran J. Shaikh

M. Tech Student

*Department of Mechanical Engineering
ACET Nagpur, Maharashtra, India*

M. Sohail Parvez

Assistant Professor

*Department of Mechanical Engineering
ACET Nagpur, Maharashtra, India*

M. Shakebuddin

Assistant Professor

*Department of Mechanical Engineering
ACET Nagpur, Maharashtra, India*

Abstract

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, Collapsible Steering Column for low budget passenger car had no way to describe these 'Collapse' or 'Slip' by the Axial and Lateral Forces from driver. In this paper, I have created a collapsible steering column from rigid steering column using a Detailed FE model which can describe such collapse behavior.

Keywords: Steering column, Design and Optimization of steering column

I. 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 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.

II. 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.

In this project, a case study is performed on an existing steering column of 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, we are modifying this design from a rigid steering to a collapsible steering column.

III. LITERATURE REVIEW

Rince Wins, Dhanesh Chatta & Anish Nair [1] had studied the steering wheel is the important part of the four wheeler thus cause of fatal injury for drivers in frontal collision. When frontal collision occurs, due to the kinetic energy of driver or occupant body, it moves forward against steering wheel and wind shield. Actually in a frontal collision forces will be first transmitted through driver's feet which act as fulcrum so the body will rotate about it. Driver head & chest hit the steering or windshield which may cause severe injury or death. For the taller driver steering works as fulcrum. Considering the injury potential of steering wheel we are presenting a new idea Pneumatic Collapsible Steering Column.



Fig. 1:

A. Collapsible Steering Column

When the steering column was first invented, it consisted of a single long steel rod which connecting the steering wheel to the steering gear box. While this single-piece construction was efficient, and effective in controlling the vehicle, it soon became apparent that its design was unsafe in frontal collisions. Under the single-piece system, when such an impact occurred, the steering column would often impale the driver as it was rammed toward the rear of the vehicle. A collapsible steering column is a mechanism that is used to transfer power from the steering wheel into the steering gear box, which transfers power to turn the wheels of a vehicle. Existing collapsible steering columns still consist of a long shaft that connects the steering wheel to the steering gear box. However, the collapsible design is composed of an inner and an outer sleeve, engaged tightly together with a number of steel bearings in between the sleeves. These steel bearings are pressed into the metal sleeves, and are held in place with a strong safety resin, which is designed to harden and then shatter when a specific level of pressure is applied.

In the event of a frontal impact, the steel bearings between the sleeves break free, allowing the inner sleeve to be moved further into the outer sleeve in telescopic fashion before enough pressure is achieved to ram the whole steering column into the driver. In this manner, the energy received through a frontal impact is completely absorbed by the steering column's collapsible parts.

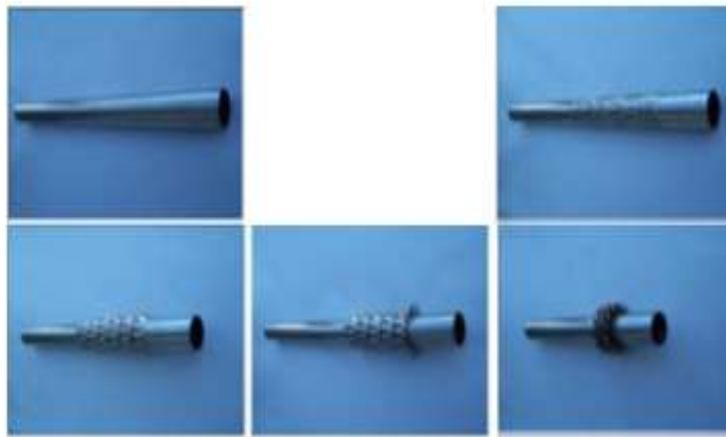


Fig. 2: Collapsible steering column

B. Working Of Pneumatic Collapsible Steering

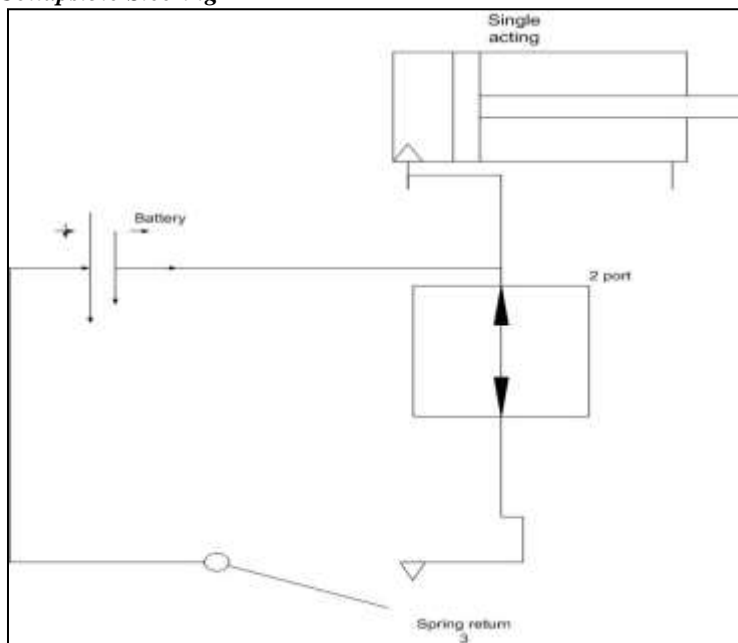


Fig. 3: Pneumatic Collapsible Steering

Assume that a vehicle is fitted with PCS system. Front side of the vehicle is arranged with some mechanical switches. Thus when frontal collision occurs, one or more mechanical switch will get compressed. Thus circuit will get closed and DC current flows to the solenoid valve from battery. Thus the compressed air from Pneumatic cylinder suddenly escapes through the solenoid valve. Thus the steering will get collapsed.



Fig. 4: Column Collapse distribution of sled test

Tae Hee, Lee Byung Ryul, Ham Seong Oh, Hong [2] had studied collapse analysis of steering column by using detailed finite element model 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. 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 paper, we have created a new Steering Column using a Detailed FE Model which can describe such collapse behavior. In this paper, detailed model of a steering column can be applied to the FE-occupant full vehicle analysis. Therefore steering column collapse analysis method was established and also studied various characteristics such as sub structure analysis, correlation and detailed modeling. In this study, we have selected 4 types of representative Steering Column (type A, B, C, D) to develop an FE model that satisfies the above terms. Using this, we established a Steering column analysis method through the following procedures.

- 1) Steering column static compression test correlation
 - Build capsule pin fracture model and correlation.
 - Build curling plate model and component correlation.
 - Fastening load and friction component correlation
- 2) FMVSS203 Body Block Test Correlation.
- 3) Verification of detailed column model using Madymo Input and Sub-Structure analysis.

C. Friction Component Load Correlation

Friction component load is the friction force that rises from collapse ring used in steering columns of expended tube type. Collapse Ring is a friction component that exists between the steering column housing and the main tube of the column. In this study, the steering column of type B and D uses these friction components. Correlation was conducted under the assumption that all friction force of steering column rises from the collapse ring. Collapse ring uses rigid material. After analyzing the result of the static compression test results of column type B and D, we set the friction component load on α - β kgf to conduct the correlation.

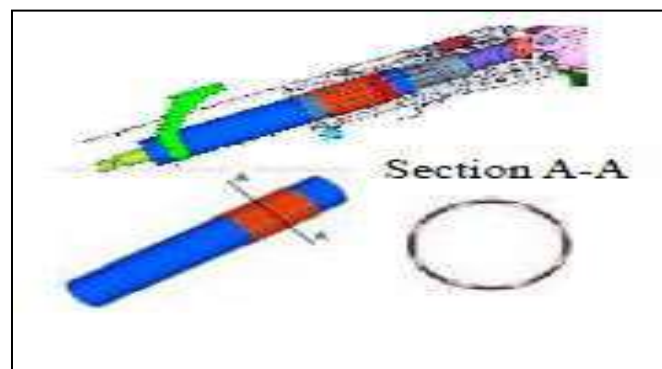


Fig. 5: Friction component load correlation

Figure shows schematic diagram representing the modeling of friction component. As shown in the picture, the collapse ring (red line) and column tube (blue line) have a minute slant and step. This slant and step lead the tube's deformation when collapse progresses in the direction of the red arrow. In order to compensate for the deformation at the initial state, we conducted a pre-analysis of moving the collapse ring forward from δ mm behind the original location. The stress of the tube can be adjusted by pre-stress condition using initial stress shell card and you can attain the target friction force.

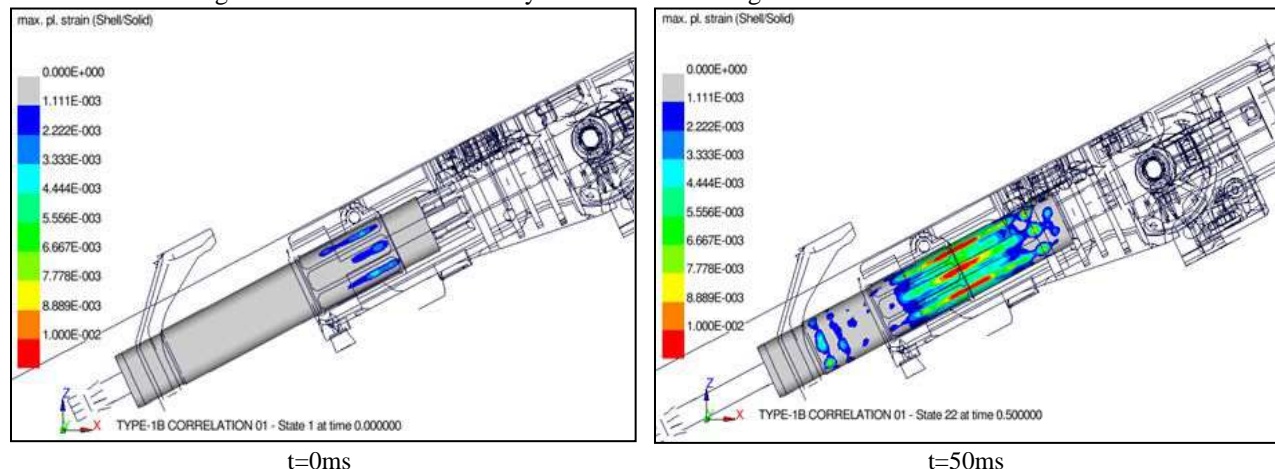


Fig. 6: Stress contour of column (before/after)

S.Nithyananth, A.Jagatheesh, K.Madan, B.Nirmalkumar [3] presented most conventional and general steering arrangement to turn the front wheels using a hand operated steering wheel which is positioned in front of the Driver. The steering column, which contain an universal joint which is part of the collapsible steering column which is designed to allow it to deviate from a straight line according to the Roadmap. In convertible four wheel steering with three mode operation, three steering modes can be changed as needed which assists in parking at heavy traffic conditions, when negotiating areas where short turning radius is needed and in off road Driving. The project carried out by us made an impressing task in the field of automobile industries. It is very usefully for driver while driving the vehicle. This project has also reduced the cost involved in the concern. Project has been designed to perform the entire requirement task which has also been provided.

D. Working Principle of Three Mode Steering

1) 1st mode operation

When the lock nut is removed, the steering operation is carried out in normal condition. That is only front wheels steer.

2) 2nd mode operation

In 2nd mode operation when the lock nut is inserted, the other two modes can be used. When the gear arrangement is pushed to one position, the bevel gears get engaged and the steering of rear wheel is ensured and is in same direction as that of the front wheels.

3) 3rd mode operations

When the gear arrangement is moved to other side, the bevel gear disengages and the bevel gear gets engaged. Due to spur gear arrangement, the rear wheel steers in opposite direction to the front wheel. This results in third mode steering. Three steering modes can be changed as needed which assists in parking at heavy traffic conditions, when negotiating areas where short turning radius is needed and in off road Driving.

Malge Sangeeta Ganesh, G. P. Patil , N. A. Kharche [4] presented by steering shaft is a media between steering wheel and steering box in overall steering system. In this Paper Various Structural analyses such as Static-Structural, Modal Analysis of a steering rod are done. Static-structural analysis is capable to find out deformation in body in which Von-mises stress are calculated and this state that up to what extent the deformation in the rod occurs. while modal analysis is important in vibration point of view. i.e. Vibrations in body can be calculated up to what frequency the steering rod can sustain the load or Harmonic frequency of the body From above Optimization of steering rod can be done. In this paper structural analysis is done to find the maximum deformation of the steering rod and stresses in the steering rod and it is noted that the deformation is negligible and the stresses by von-mises stress are below the yield point stress so the steering rod is safe. Maximum deformation occurs at the corner points of the circular hole at both the ends of the rod and the stresses are also maximum at the corner points. Modal analysis is done to calculate the Harmonic Frequency of the rod. The frequencies of the rod are calculated in five sets. In all five stages behavior of the rod is different i.e. it varies from 1Hz to 39.66Hz. From this it is clear that Harmonic frequency is 39.66Hz. Further this frequency can be used to do the Harmonic analysis of the steering rod and for Optimization.

E. Performance of Modal Analysis

Modal analysis is important in vibration point of view. i.e. Vibrations in body are calculated up to what frequency the steering rod can sustain the load or Harmonic frequency of the body. Use modal analysis to determine the vibration characteristics (natural frequencies and mode shapes) of a structure or a machine component while it is being designed. It also can be a starting point for another, more detailed, dynamic analysis, such as a transient dynamic analysis, a harmonic response analysis, or a spectrum analysis.

***** INDEX OF DATA SETS ON RESULTS FILE *****

SET	TIME/FREQ	LOAD STEP	SUBSTEP	CUMULATIVE
1	4.8258	1	1	1
2	5.7182	1	2	2
3	6.4204	1	3	3
4	7.7571	1	4	4
5	39.660	1	5	5

1) In First Mode of Vibration

Maximum deformation of 1.61793 mm is obtained in this mode in the male shaft at the frequency value of 4.8251 Hz. The deformation is negligible in this mode.

2) In Third mode of vibration

The frequency value is increasing with slight increment in deflection. This will affect the performance of steering rod and its twisting. The values obtained in this mode are 6.42035 Hz frequency with 1.25014 mm deflection.

3) In Fifth Mode of Vibration

Here the maximum frequency with maximum deformation. Above this frequency value shaft may damage due to maximum deformation. The maximum deformation of 2.20442 mm is obtained on frequency value of 39.66 Hz.

Tyan, T., Vinton, J., Beckhold, E., Zhang, X. et al. [5] presents paper on the final phase of a study to develop the modeling methodology for an advanced steering assembly with a safety-enhanced steering wheel and an adaptive energy absorbing steering column. For passenger cars built before the 1960s, the steering column was designed to control vehicle direction with a simple rigid rod. In severe frontal crashes, this type of design would often be displaced rearward toward the driver due to front-end crush of the vehicle. Consequently, collapsible, detachable, and other energy absorbing steering columns emerged to address this type of kinematics. These safety-enhanced steering columns allow frontal impact energy to be absorbed by collapsing or breaking the steering columns, thus reducing the potential for rearward column movement in severe crashes. Recently, more advanced steering column designs have been developed that can adapt to different crash conditions including crash severity, occupant mass/size, seat position, and seatbelt usage. These advanced steering columns incorporate adaptive features, mechanically or pyrotechnically activated, to add flexibility in absorbing impact energy of different levels.

In the final phase of the study, the focus is the modeling of an advanced steering wheel and column assembly that can be used in frontal and side impact simulations. In the first phase of the study, ten component and subsystem tests were conducted to develop the modeling methodology of an adaptive energy absorbing steering column assembly. Three steering wheel assembly tests and eight steering wheel and column assembly tests, with the steering column being mounted in normal and offset angles, were developed and conducted in the final phase of the study. In addition, various dynamic impact speeds, including quasi-static, were considered so that speed sensitivity of the steering wheel and column assembly could be obtained. The final modeling methodology of the steering wheel and steering column assembly is developed based on reasonable correlation achieved with twenty one tests. The developed modeling methodology can be applied to other advanced steering wheel and column assemblies and will enhance evaluation of occupant responses in full vehicle or subsystem simulations. It can also be used in finite element analysis programs and/or coupling of finite element and occupant analysis programs. The final goal of this study is to utilize the developed modeling methodology in vehicle development to occupant safety systems, optimize prototype testing and enable faster development cycle time.

Bengt Pipkorn Autoliv, Yngve Håland Autoliv.[6] presented by the structures of modern passenger vehicles are designed to maintain integrity up to an impact velocity of about 64 km/h (40 mph). The occupant protection system is likewise designed to efficiently protect the occupant up to an impact velocity of 64 km/h. However, there are highways with a 90 km/h (56 mph) speed limit without separation of the lanes and many car occupants still die in severe frontal crashes. To investigate the level of occupant protection at very high impact velocity a full frontal full vehicle rigid wall crash test with a mid-size passenger vehicle was carried out. The impact velocity was 80 km/h (50 mph). A 50%-ile Hybrid III crash test dummy was positioned on the driver side. The dummy results show that the possibility of survival of an occupant in that particular vehicle in such a crash was minimal. With the goal to develop a protection system that in an 80 km/h (50 mph) crash test would result in dummy reading below the FMVSS 208 injury criteria levels a mathematical sled model was developed and a mechanical sled mock-up was set up.

F. Mechanical Full Vehicle Full Frontal Crash Test

In the mechanical crash test carried out a mid-size passenger vehicle was impacting at a 0 degree angle full front into a rigid wall. The closing speed was 80 km/h (50 mph). The vehicle was equipped with a standard 3 point belt system and a driver side airbag. The initiation of airbag inflation was done by the existing sensor and triggering system in the vehicle. A 50% -ile Hybrid III crash test dummy was positioned according to FMVSS 208 specification in the driver side of the vehicle (Figure 1). In the dummy, head acceleration, chest acceleration, upper neck force, upper neck moment, chest deflection and femur force were recorded. In addition both lap and shoulder belt forces were recorded. Vehicle acceleration was measured on the tunnel, trunk and the left and right b-pillar.



Fig. 7: Occupant position in full vehicle crash Test

Zeeshan Qaiser, Omer Masood Qureshi Khalil Aslam, Awan Hassaan Ahmed. [7] presented by Collapsible energy absorbers are encouraged in the field of automotive in the past decade due to their good energy absorption characteristics. Impact energy absorbers dissipates maximum amount of energy during an axial impact. Impact of steering wheel with ribs of driver during an accident is an area of prime concern. A patterned steering column is proposed in the present work which turns into inverting tube and absorb good amount of energy during an accident. The inversion process is induced in steering column by embedding sinusoidal patterns over it. This process is numerically investigated by using commercially available non-linear solver LS-DYNA (TM). Different steering column arrangements are studied and force-displacement results are analyzed in this work. A study is performed to investigate and compare energy absorption parameters of conventional and proposed design of steering column. The results show that the energy absorption with proposed sinusoidally patterned steering column is better than conventional steering column.

Ratko Menjak, Karen A. Boswell, Sainan Feng, James P. Kelly, Brian J. Magnus, Wayne M. Steverson. [8] described that a collapsible steering column assembly preferably has a collapsible steering shaft that extends rotatably along a centerline and a collapsible column that houses and co-extends with the shaft. The column preferably has inner and outer tubes that retract telescopically when the column collapses. An energy absorbing (E/A) device has a member that preferably is a strap engaged between the inner and outer tubes and controls the collapse of the column generally via a high load stage and a low load stage of operation. The member is preferably elongated axially having a distal end that is looped over and spaced radially outward from the remainder of the member. The distal end is disengagably attached to the outer tube via a pin received in a hole in the distal end and a fuse engaged operably to the pin and attached to the outer tube.

The E/A device preferably exerts a variable resistance along collapse stroke of the column. In one embodiment of the present invention, the E/A device variably accommodates: low load stage for use with, e.g., a smaller driver, lower speed of vehicle, and/or the driver being belted; the high load stage is preferably for use with, e.g., a heavier driver, high speed of vehicle, and/or the driver being unbelted driver. Such an embodiment may include one plastically-deformable strap with two stages. Another embodiment of the present invention provides a three stage E/A device accommodating minimum, middle and maximum loads or E/A capabilities. In either the two or three-stage embodiments, which stage to be appropriately applied will depend on selective activation of one or more of the fuses, that are preferably of a pyrotechnic type, in response to conditions determined from sensors measuring: vehicle speed, weight of driver, seat position and belt function.

The present invention provides the ability to match E/A to load curves of different shapes during collapse of the column. The present invention achieves this result, in either of the two abovementioned embodiments with a single, one piece strap that deforms without friction to ensure a stable E/A process with maximum simplicity and low cost.

Tyan, T., Vinton, J., Beckhold, E., Zhang, X. [9] described that The objective of this paper focused on the modeling of an adaptive energy absorbing steering column which is the first phase of a study to develop a modeling methodology for an advanced steering wheel and column assembly. Early steering column designs often consisted of a simple long steel rod connecting the steering wheel to the steering gear box. In frontal collisions, a single-piece design steering column would often be displaced toward the driver as a result of front-end crush. Over time, engineers recognized the need to reduce the chance that a steering column would be displaced toward the driver in a frontal crash. As a result, collapsible, detachable, and other energy absorbing steering columns emerged as safer steering column designs. The safety enhanced construction of the steering columns, whether collapsible, detachable, or other types, absorb rather than transfer frontal impact energy. Recently, more advanced steering column designs with adaptive features, mechanically or pyrotechnically activated, have been introduced for different crash conditions, including different crash severity, occupant mass/size, seat position and seatbelt usage. These steering columns are able to absorb different impact load conditions ranging from high impact load for larger and/or unbelted crash dummies in higher severity crash tests to low impact load for smaller and/or belted drivers in lower severity crash tests. With the steering column designs becoming more complex, the modeling of a steering column with advanced safety features also becomes more challenging.

To optimize prototype testing and enable faster development cycle time, an attempt was made to model the steering assembly with advanced safety features. The modeling study was divided into two phases, with the first phase focusing on the modeling of an adaptive energy absorbing steering column as discussed in this paper. The modeling of an advanced steering assembly, with a safety-enhanced steering wheel and an adaptive energy absorbing steering column for frontal and side impact simulations, was developed in the second phase of the study and will be presented separately. To provide information for modeling methodology development, component and sub-system tests were developed and conducted to understand the mechanical behaviors of different energy absorbing features as well as the performance of the adaptive mechanism in the steering column design. Different dynamic impact speeds, including quasi-static tests, were also included in DOE test matrices so that collapse speed sensitivity of the steering column components could be obtained. Finite element modeling methodology was developed and presented based on its correlations with the steering column component and sub-system tests.

M. Balaji, Malar Mohan. [10] studied that energy absorption load of steering column shaft assembly and reduce failure due to noise. It also reduces the dependency of process parameters which is considered as important factor in existing injection molding process. Energy Absorbing Steering Column is a kind of Steering Column which minimizes the injury to the driver during a car meets accident by collapse particular part of system. The design of the steering column has remained unchanged since its inception; the column still consists of a long shaft connecting the steering wheel to the vehicle's gearbox. Column shaft assembly is made by joining shaft and tube through injection moulding process which has high variation and dependency on process parameters. Energy absorption load will be ensured by periodic inspection of parts and setting parameters. To overcome the

existing problem, we proposed crimping method to join shaft and tube assembly and ensure energy absorption load during the process and improve the performance of the steering column assembly.

This paper deals with the working principle, collapse mechanism of steering components, analysis of existing process, proposal of alternative design and process for intermediate shaft assembly in collapsible steering column assembly and proposed new process design with serration on shaft and tube with crimping method. The design modification of shaft, tube and crimping tool, fixture design. Design of components based on proposed concept, Analysis of proposed process design to meet EA load requirement, Detailed drawings of tools and fixtures of the new system, Develop proto samples, Conduct trials on new design process and establish the process. By this method, the collapse load of shaft & tube can be confirmed during insertion process. By adjusting depth of indent and diameter of punch, various collapse load can be achieved.

IV. IDENTIFIED GAPS IN THE LITERATURE

Most of the researchers have investigated the existing influence of the collapsible steering column like steering column design, structural analysis, modeling of steering wheel and column assembly and steering collapse analysis. Collapsible steering column are a necessity in automotive vehicle. 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 crash. This prevents the energy of the impact from being transferred completely into the driver. There is no work is done on the study of modifying existing rigid steering column to a collapsible steering column.

V. PROBLEM FORMULATION

In today's Automobile industry, there are many passenger cars that do not have collapsible steering column. Due to this the casualties in frontal collision accident is high. There are so many example of the car with rigid steering column is Maruti 800, Maruti Suzuki Alto, Tata Nano. In this paper a rigid steering column is redesigned to make it collapsible which in turn can save lives.

With the help of company standard test specification manuals and design parameter authorized workshop peoples and also with the help of research paper it strongly felt that performance of collapsible steering column. So that in this investigation we will create a newly design collapsible steering column by using existing design consideration of rigid steering column and also optimize optimize the modified steering column by setting the control parameters at optimum level without affecting the engine performance.

VI. RESEARCH METHODOLOGY

1) Data acquisition on existing rigid column.

First to take the actual dimension of rigid steering column of existing four wheeler.

2) Building CAD model of existing design.

Second step is to building CAD model of rigid steering column of existing four wheeler in modelling software such as Catia.

3) Finite element analysis of existing model.

Next step is the analysis of existing model is done by using analysis software such as ANSYS software.

4) Converting rigid column to collapsible column

In this step, rigid steering column is converted into collapsible steering column.

5) Building CAD model of modified design.

CAD model of modified collapsible steering column is building by using modelling software.

6) Finite element analysis of modified design.

Analysis of modified collapsible steering column is done by using Analysis software such as ANSYS software.

7) Optimization of modified design.

Next step is to optimize the modified design of collapsible steering column.

8) Validation of manual design with CAD model design.

9) Finalization of modified collapsible column design for existing four wheeler.

VII. CONCLUSIONS

Therefore a safer steering column design called collapsible steering column is design by replacing unsafe single-piece steering column i.e. rigid steering column.

The safely enhanced construction of the collapsible steering column, no matter which design is used, absorbs, rather than transfers, frontal impact energy by collapsing or breaking upon impact. In this way, drivers involved in frontal impact collisions are able to avoid the dangers of non-collapsible steering parts.

ACKNOWLEDGMENTS

- I am thankful Prof.Sohail Pervez, and Prof.M.Shakebuddin for their encouragement in all respect.
- I express my thanks to Prof.R.N.Dehankar for extending his support.
- I would like to thank all my teaching staff, Prof.K.I.Ahmad, Prof.Dr. A.M.Langde, Prof.H.A.Hussain, Prof.A.P.Ganorkar , Prof.Nafees Khan, Prof.Ashish, Prof.Mohiuddin for their precious guidance and support.
- I would also thank to all My Friends who had helped and supported me all the time.
- Last but not least, the backbone of my success and confidence lies solely on the blessings of my parents.

REFERENCES

- [1] Rince Wins, Dhanesh Chatta & Anish, "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", Advanced Safety CAE Team / Hyundai Motor Co. Korea, Paper No. 11-0262
- [3] S.Nithyananth, A.Jagatheesh, K.Madan, B.Nirmalkumar, "Convertible four wheels steering with three mode operation", International Journal Of Research In Aeronautical And Mechanical Engineering, Vol.2 Issue.3, March 2014,Pgs: 81-89.
- [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., "Modeling of an Advanced Steering Wheel and Column Assembly for Frontal and Side Impact Simulations", Page no.:366-401,paper: 2014-01-0803.
- [6] Bengt Pipkorn Autoliv,Yngve Håland Autoliv, "Car Driver Protection At Frontal Impacts Up To 80 Km/H (50 Mph)", Bengt Pipkorn Autoliv Research, SWEDEN Hugo Mellander, Traffic Safety Research and Engineering AB, SWEDEN, Yngve Håland, Autoliv Research, SWEDEN 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", International Conference on Aerospace Science & Engineering (ICASE).DOI: 10.1109/ICASE.2013.6785548.
- [8] Ratko Menjak, Karen A. Boswell, Sainan Feng, James P. Kelly, Brian J. Magnus,Wayne M. Steverson, "Collapsible steering column assembly", publication number: US7455321 B2, patents/US7455321.
- [9] Tyan, T., Vinton, J., Beckhold, E., Zhang, X. et al., "Modeling of Adaptive Energy Absorbing Steering Columns for Dynamic Impact Simulations," SAE Int. J. Mater. Manf. 7(2):337-365, 2014, doi:10.4271/2014-01-0802., "Collapsible steering column assembly", publication number: US7455321 B2, patents/US7455321.
- [10] 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), PP 84-89.