Simulation of Moment Deflection Test on Driver Seat of Car Using Finite Element Analysis

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Abstract: *Improper design and uncomfortable seats imposes a lot of stress upon different body parts of driver. It is the driver who gets more fatigue than the passengers. If the driver seat is not comfortable the comfort or discomfort factors can lead to various injuries related to car seat design. An Indian Alto k10 driver car seat was evaluated for its strength and moment deflection test for rear seat impact. The strength-deflection characteristic of a front automotive seat during rear impact is important to ensure the safety function of seat. The safety function is measured based on a moment test in accordance with government European standard ECE R17, FMVSS 207 and Indian standard AIS regulations. Simulation of the moment test of the Alto k10 seat is done beyond the component level by using a complete seat model formed by integrating the major structural components including the base frame and backrest.*

Keywords: car seat, fea, simulation, modeling.

1. Introduction

The improvements in design of driver seats have been the area of immense interest for the past few years. A design evaluation is done in order to optimize the different parameters performance of driver could decrease and there is possibility of fatigue and various other muscoskeletal disorders which could even lead to possibility of accident. This paper reviews about the various injuries which could reduce the injuries related to backrest and head rest. The included geometric parameters are seat back angle, seat pan angle, seat height, seat width etc. H-point, R-point and head restraint are the design specification used which could describe the correct seating position. A seat is one of the important components of a car. It should be designed following the trends and modern styles of automotive design era. In addition, safety and convenient are required properties of a car driver and passenger. In the recent years, a car model is rapidly changed following the short life cycle of a car. Then car seat design will be developed to support the customer needs and technology change. Computer aided engineering and finite element simulation are essential in order to predict accurately the safety performance of automotive structures in an event of crash. In this work, finite element simulation is used to evaluate the strength and deflection characteristics of a reference automotive front seat in an event of vehicle rear impact. Understanding the strength-deflection characteristics of front automotive seats during vehicle rear impact is important to ensure the safety function of the seat. The safety function is measured based on a moment test in accordance with government ECE R17, FMVSS 207 and AIS regulations. In this work, simulation of the moment test of the reference seat is done beyond the component level by using a complete seat model formed by integrating the major structural components including the base frame and backrest. Simultaneously in order to predict the postural comfort ergonomic evaluation is done. Finite Element Analysis (FEA) is an extremely efficient and economical tool for designing and predicting the performance of structural components in an automobile. FEA is used to guide the design process from conceptual to the detailed stage. The finite element simulations can be used to predict the strength and deformation behavior of models without conducting costly and time consuming physical testing. FEA is also used to validate the design process and help optimize the designed automotive assemblies and components. The increasing functional requirements of safety, comfort, light weight, and other factors for automotive seats have increased the complexity of designing optimized seats. Increased safety requirements to prevent injury during crash events from government regulations have increased the number and severity of strength tests which automotive seats must pass before production. Often both European Union regulations such as ECE R17 and North American regulations such as Federal Motor Vehicle Safety Standards (FMVSS) 202 for seats and their anchorages are required. In addition, automotive Original Equipment Manufacturers (OEM) often exceeds the load requirements of government regulations. The modeling techniques in finite element analysis for accurate prediction are challenged by the complex design of the seating structure when optimized for the often competing requirements of strength for safety, light weight, and comfort functions. Since the safety requirements are based on high speed impact crash tests, automotive seat structures will generally yield under the specified load requirements and thus nonlinear finite element analysis is required, often with surface contact interaction models between parts in assemblies. Most seats have locking adjustment mechanisms for backrest tilt angle, height adjustment, front tilt, slider rail longitudinal adjustments. Accurate, yet efficient finite element models of these locking mechanisms are a challenge for the analyst. Because of the different functionalities of the seat, different materials are used, for example, Poly Urethane foam for the seating surfaces for comfort, and stamped steel sheet or high pressure die cast magnesium alloy, and other high strength materials for structural frames.

Paper ID: 02014992

299

2. Literature survey

Sitting comfort and discomfort are defined as independent entities associated with different factors; discomfort is related to biomechanics and fatigue factors and comfort to a sense of well being and aesthetics. Comfort could be categorised as static comfort and dynamic comfort by Wolfel (2008). Static comfort is related to right posture in this back rest inclination angle it could be also be calculated by load due to gravity. But two main factors which affect the static seating comfort are pressure distribution of the cushion and the back rest angle. Similarly in dynamic comfort seat transfer function which is affecting the driver seat. Seat transfer function is related to the vibration produced on the seats. Various parts of body are affected during driving but design of headrest along with neck support should be provided to increase the car comfort. The head rest should be adjusted as mentioned by Franz (2012). There are various factors which affect the headrest and neck support, but which effects most is the pressure distribution between head and head rest, material of foam and the position of head and neck support. In order to prevent from whiplash injury which occurs when there is rear impact on neck or head region an articulation was done on upper part of the seat back rest by Denis (2012). This articulation was done 43.5cm above the H-point with an average sitting height of 88cm. The concept of articulated seat was meant to give support to back so that person could be in its natural posture. The pressure distribution between human and seat varies as it depends upon the seating position. In pressure distribution the pressure is lowest at the intervertebral disc for the most comfortable posture acc to Zenk (2012) and pressure is up to 0.5 bar at this position while it is 1.6 bar at the upright seat position. Similarly back support or back rest comfort is also important. Comfort is directly related to drive experience. Climatic conditions effects the driver condition therefore thermal comfort plays an important role in improving the driver as by Cengiz (2007). An experimental study was done on ten participants for 1hr on sunny day. It was carried out air temp of 25 degree celsius in fiat mera (car's name). From this it gave a conclusion that for evaluating the thermal comfort skin wittedness data are more important than skin temp data. Waist area has maximum temperature as compared to other areas. Vibration produced in the car seat creates the discomfort for the driver and its effects the performance of the driver. An experiment was performed by Wassim (2003) with the surface electromyography (SMEG) tool which is used to study the muscle activity. Two seats were taken one with vibration effect on it and another with comfortable seat without vibration. The performance with vibration seat was worse. Subjective discomforts were reported when subject was in car seat for 150 min. For achieving a correct ergonomic design and comfort in automobile seat joint angle are necessary to work with. Joints such as ankle, knee, hip, shoulder and elbow should be optimized according to Susanne 2014. The research was to detect the different joint angles which are used frequently in interior car design. Thirty different sources were taken on automobile sitting posture till date. In today's competitive market customer expectation continue to rise. It therefore becomes difficult for producer to develop its product based on consumer needs. Thus in order to provide the qualitative nature of the consumer to produce some methods have been developed which could transform qualitative parameter into numerical value in order to improve the produce. One such method is heuristic multi criteria decision making technique by Hamed (2012). Another is axonometric design principle by Kolich (2006) for the comfortable automatic seats. Seat back rest angle, head rest and seat rest angle should be adjusted properly in order to provide the driver comfortable. Ergonomic design process is the most referred in study of car driver posture. The design of driver posture with seat, head and back rest are related which effect the posture of driver seat. The interaction of car driver body with cushion and backrest was done with multi-factor method. The optimum lumbar flexion angle was calculated which is an indicator of postural comfort (Giuseppe et al. 2002).

3. Problem definition

The objective of the work is to accurately simulate the moment test on the reference automotive front seat in accordance with ECE R17, FMVSS 207 and AIS standards. The finite element simulation of the reference seat is conducted beyond the component level by using a complete seat model formed by integrating the major structural components of the backrest, connector, base frame, and slider rails. Contact within the seat structure is defined in order to simulate joints between side flanges and cross tube members of the base frame. Contact modeling is also used to simulate the interaction of the body form with different components of the seat. Height adjustment, front tilt adjustment and the backrest tilt angle adjustment locking mechanisms are represented in the finite element model using rigid connections. The bolt connections between different parts in the model are represented using multi-point constraints. An elastic-plastic material model is used to model the structural components of the seat. Different grades of steel with low, medium, and high strength are considered for the different components. In order to confirm the strength requirements, moment deflection characteristics of the seat are studied in accordance with ECE R17. The moment test is simulated using two complementary loading cases, constant horizontal force and constant angular velocity on the reference seat with in order to evaluate the performance of the seat. Since the ECE R17 regulations do not provide precise specifications for the height of the applied force and test setup for the body form pivot mechanism, a study is conducted in order to understand the influence of body form rotation and height of the body form above the H-point. The influence of plastic material properties of different grades of steel used for the seat model, front mesh contour on the backrest and connection between the backrest and connector are modified to analyze the influence of load path on moment deflection characteristics of a seat.

4. Methodology

4.1 Geometric Modelling of Reference Seat

A geometric model is used to represent the physical seat. The geometric modeling of the Alto K10 seat is carried out in the Computer-Aided Engineering software CATIA which is capable of producing precise solid and surface geometry. Finite element models associated with the geometric model of the seat are created in order to analyze the strength of the

Paper ID: 02014992   300

seat. Surface geometry is used to represent the seat components because the structural members are manufactured by forming sheet metal. The dimensions of the reference seat were measured a close representation of the important geometric parameters to the physical seat are modeled. Detailed surface models of the major seat structural members including the backrest, connector and base frame which are the major load bearing components were drawn CATIA, see Figure. Appropriate measured thicknesses were associated to different surfaces of the geometric model. The task always starts with FE modeling of seat structure. In modeling the seat structure is prepared according to the dimensions of seat with the help of CATIA.

Figure 1: Alto k10 seat without seat cover

Automotive seats provide comfort, ergonomics and safety to the occupant while traveling. The primary function of a seat is to provide seating space for the passengers and support them in the event of accidents. Most automotive seats are designed in a similar fashion with an adjustable seating space and back support providing ideal ergonomic driving conditions. Seats essentially consist of a skeletal structural frame work designed to carry load. Body contact areas are covered with PUR foam. The structural framework provides shape and strength to the seat while PUR foam provides comfort and ergonomic driving conditions.
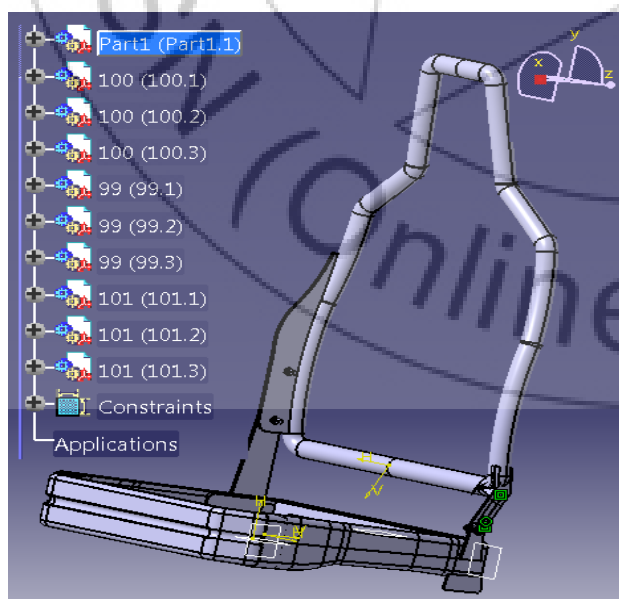

Figure 2: Shows the modeling of assembled parts the internal structure of Alto k10 seat in CATIA V5

4.2 Importing and meshing Geometric seat model

After the file is made it is save as in CATIA it is then converted into <.igs format>. It is then imported to finite element simulation software ANSYS. Automatic meshing is done.
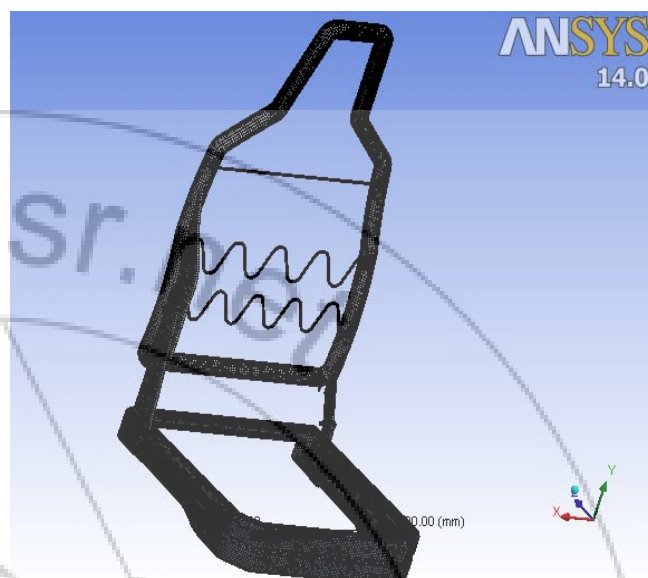

Figure 3: Shows the meshed portion of different parts

4.3 Different material properties used in seat structure

(a) Material Property Chart for Different Grades of Steel

Table 1

	Low Strength Steel	Medium Strength Steel	High Strength steel
Density(g/cc)	7.85	7.85	7.85
Young's modulus (E) (Gpa)	210	210	210
Poisson's ratio	0.29	0.29	0.29
Yield Strength (MPa)	305	350	365
Ultimate Tensile Strength (MPa)	365	515	635
% Elongation at break	20	30	24

(b) Input Data to ANSYS for Different Grades of Steel

Table 2

		Low Strength Steel	Medium Strength Steel	High Strength Steel
True stress	Yield strength	305	350	365
	Ultimate tensile Strength	438	669.5	787.4
True strain	Initial strain	0	0	0
	Strain at failure	0.182	0.2623	0.215
Plastic strain	Initial Plastic strain	0	0	0
	Plastic Strain at failure	0.18	0.262	0.212

Paper ID: 02014992

4.4 Method used for Simulation of moment deflection tests

The moment versus angular deflection of original equipment manufacturer (OEM) seats was measured using the test procedures defined by SAE J879, Section 4.2. In this procedure the force (FN) is applied about the H-point (SAE J826), normal to the torso line (SAE J383), at the seat back upper cross member as in figure. The actual loading device used was the head form defined in FMVSS 202 S5.2(c) connected to a loading arm which rotated about the H-point (fig.). The initial torso line angle with respect to the vertical is phiI The loading arm rotational displacement was controlled such that the nominal displacement rate was 2 deg./s. The rotational displacement was released at the same rate as applied. The moment (FNxD) about the H-point gave a measure of the seat back resistance to the applied displacement.
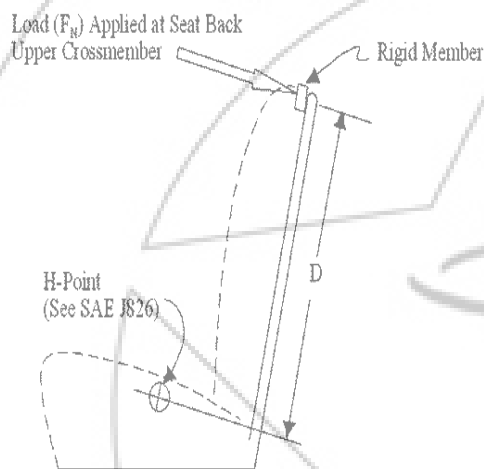

Figure 4: Force at upper cross member creates (FN*D) about the H Point

The seat was installed on a jig simulating the vehicle floor with the seat placed in its rearmost position. The initial seat back angle was its normal driving position as defined by the OEM and determined from the torso line of the three dimensional H-point manikin (SAE J826). The torso line angle was 22 degrees from the vertical for all seats except one. The moment and deflection data were acquired at a rate of 100 Hz during both the load application and release phases. The applied moment was calculated to an accuracy of 1%. Angular measurement was accurate to within 0.5 degrees. In designing the loading arm, the goal was to have the initial applied load perpendicular to the torso line. If this were the case the force perpendicular to the torso line would simply be the measured load (FM) and the moment about the H-point generated by this load would be FM multiplied by the length of the load arm long axis (L). Because of differences in seat design it was not always possible to have FM perpendicular to the torso line. This made it necessary to correct for the actual direction of applied load when calculating the moment about the H-point. In making this moment correction certain assumptions were made. It was assumed that the normal vector of the seat structure at the point of contact with the head form was perpendicular to the torso line. Further, the frictional component of the applied load was ignored so that only a normal force was applied to

the seat structure. Therefore, the measured load (FM) was a component of the normal load in the direction of the load cell. Finally, it was assumed the point of contact on the head form was along the axis passing through the center of the load cell and head form. A further refinement of the correction factor would have been to consider friction at the point of contact with the seat structure and to not make any assumption about the normal vector of the seat back structure. Assuming static friction and therefore no relative movement between the head form and seat, this would have resulted in a difference in final calculated moments of at most 2-3% from the moments calculated in this report. However, almost immediately after loading is applied relative motion occurs, resulting in dynamic friction. Accounting for dynamic friction would be very difficult and would change the calculated moment by a negligible amount. Figure shows the test geometry in detail. The torso reference line (line with dimension D) and the long axis of the loading arm (line with dimension L) have angular orientations which differ by the angle Theta. Thus, the force measured by the load (FM) has the following relationship to the force normal to the torso line (FN).

$$FN = FM/\cos(Theta) \qquad (1)$$

The moment about the H-point generated by this Normal force is given by eq. (2).

$$MH = FN * D \qquad (2)$$

Because the long axis of the loading arm and the torso line, usually only varied by a few degrees the correction was relatively minor with MH varying from FM * L by only a few percent.
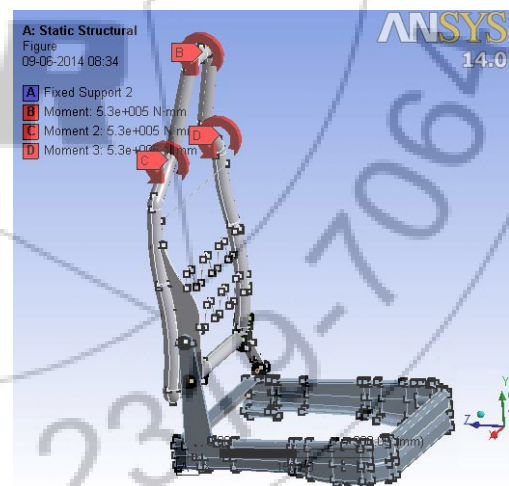

Figure 5: shows the moment applied on the backrest of car seat structure above the H-point in ANSYS

5. Result and Discussion

As mentioned in Table No. 1 and 2 different grades of ductile steel were considered. Each grade had the same elastic properties. Changing the ultimate strength of steel used on the major load bearing components does change the component stress, but had only a small change in the moment deflection characteristics of the model. The low strength steel (yield strength 305 MPa, ultimate strength 365

Paper ID: 02014992

302

MPa) on the backrest does not influence the moment deflection characteristics of the seat and the model shows similar performance when medium strength steel (yield strength 350 MPa, ultimate strength 515 MPa) is used. The connector with high strength steel (yield strength 365 MPa, ultimate strength 635 MPa) showed slightly improved strength when compared to medium strength steel (yield strength 350 MPa, ultimate strength 515 MPa). Using a high yield strength steel material (yield strength 475 MPa, ultimate 635 MPa) for the connector increases the maximum moment supported by a small amount.
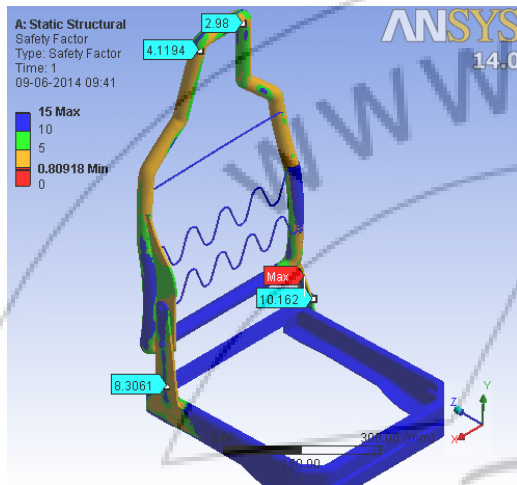

Figure 6: Shows the max stress produced at joints

Due to the maximum stress produced at the joints of the seat failure chances are more which put a big question mark on the safety of Indian standards cars.

6. Conclusion

The following conclusion could be drawn from this:

1. Seat should be designed by dual rectilinear mechanism as single rectilinear mechanism could not withstand the maximum deflection produced according to ECE R17 and AIS standards.

2. Although 3300 in.-lb may sound like a significant standard, FMVSS 207 has been widely criticized in the automotive safety community since its inception. It does not represent an improvement over earlier designs, therefore these standards should be updated time to time and should be increased from 3300 in-lbs (373 Nm) to 12000 in-lbs.

7. Future Scope

- Simulate other tests for seat components such as the sled test and seat belt test in accordance with government regulations on the reference automotive front seat.
- The polymeric mesh model for the resting surface of the backrest with detailed PUR foam and fabric cover material model should also be included for simulation.

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