Design and Analysis of a Mechanical Bus Seat Recliner

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Abstract—Seat recliners are integral components of seats of all automobiles for improved comfort and safety. Seat recliners are the devices used for adjustment of automotive seat backs as per the comfort of the occupant. Bus seat recliners are placed at the bottom of seat since the gap between two seats in buses are lesser. In this paper, the mechanical type of recliner is designed and analyzed.

The linear type recliner mechanism provides selective, lockable adjustment of the seat back between any one of the plurality of reclined seating positions. The arm pivotally connects the recliner mechanism and backrest. The rack includes the plurality of teeth formed on one side of rack. A toothed sector lockable engaged with teeth in rack for in and out of locking engagement with rack. While engaged with rack, the sector prevents the axial movement of rack within the housing, thereby prevents the pivotal movement of the seat back relative to seat cushion. The biasing member cam helps for biasing the sector towards engagement with rack.

The existing bus recliner mechanisms are studied. In those the sector is disengaged by rotating with rack. Because of that number of teeth in sector cannot be increased. In this paper the sector disengaged with rack linearly. So number of teeth is increased and the locking strength is improved and the mechanism is also simple and compact. The complete mechanism is modeled with dimensions as per the theoretical calculations. Then the model is meshed in hypermesh and analysis is conducted. The static strength analysis is conducted in locked condition and the results are verified.

Keywords—Linear recliner, Static structural analysis, HYPERMESH, ABAQUS

I. INTRODUCTION

The recliners are of different types which are Lever type recliner used in car seats (ex: Hyundai-Santro, Ford - Fiesta). Rotary recliner used in car seats (ex: Ford Ikon). Linear recliner used in buses, coaches. In this paper, we concentrated in linear recliner. In India, the pneumatic types of bus recliners are used. It withstands only less no. of cycles. It has less life. In foreign countries, the mechanical types of bus recliners are used. The mechanical type recliners have longer life than pneumatic type. It is preferred to design the mechanical type of linear recliner.
the seat cushion member and supports a pawl plate transmitting forces thereto from a rod when in a latched position. The anchor shaft extends through the slot to prevent longitudinal movement of the pawl plate while allowing the pawl plate to rotate about an axis parallel to the longitudinal axis of the rod.

A pair of guide plates guides the pawl plate to move in an arc transversely into and out of engagement with the rod between the latched and unlatched positions. An actuator pin extends laterally from the pawl plate and a lever is supported on an axle which is supported for rotation by the housing. The lever includes a slot surrounding the pin for moving the pin in an arc to rotate the pawl plate between the latched and unlatched positions. The housing is supported on the anchor for guiding movement of the pawl plate between the latched and unlatched positions [2].

A constant engagement linear recliner assembly is provided for implementation with a seat assembly. The constant engagement linear recliner assembly includes a recliner rod in constant mesh engagement with a gear system. As the gear system is caused to rotate, the recliner rod moves linearly with respect to the linear recliner assembly. The linear motion of the recliner rod translates into pivotable motion of a seat back relative to a seat [3].

A linear recliner assembly is provided having a recliner rod slidably supported within housing. The recliner rod is selectively engaged with a pawl which is fixed within the housing. The recliner rod is in contact with a cam which is operable to force the recliner rod into engagement with the pawl or enable the recliner rod to fall out of engagement with the pawl. The cam is biased in a first position by a biasing mechanism, such that the recliner rod is engaged with the pawl. The linear recliner assembly is implemented into a seat assembly for enabling an operator to select a plurality of recline positions of a seat back relative to a seat [4].

II. OBJECTIVES OF PAPER

- To design and analyze the mechanical type bus seat recliner assembly for given load.
- To increase the strength of locking
- To make the assembly, simple and compact

Advantages of this design compared to earlier designs

Fig.3. Comparison of sector disengaging by rotary and linear movement

In earlier design as shown in the Fig.3, the sector is disengaged by rotating with rack and so the gap between them is increased. There should be a minimum gap of 2mm at unlocked condition. So the number of teeth in sector cannot be increased. If it increased further that gap will increase. That has avoided in current design by linear movement.

III. METHODOLOGY

The following methodology is adopted in the paper to meet the above mentioned objective.

- Make the geometry in AutoCAD and find the movement.
- Model the geometry of linear recliner in CATIA. Assemble it
- Meshing of the model using HYPERMESH to get accuracy
- Importing the geometry to ABAQUS and to give contact properties of the parts. Applying material properties, boundary conditions and load.
- Performing Static Structural Analysis.

IV. WORKING PRINCIPLE AND SPECIFICATIONS

- Maximum moment to withstand = 100kgm
- Maximum reclining range backward from design position = 45°
- Design position is 20° from vertical
- Return torque = 2.8kgm
- Lever operating force = 40N

When the lever is released (Fig.4), the shaft connects the cam and lever. So if lever rotates, the shaft rotates and in turn cam rotates. The lever can rotate only about 18°. At 18° the lever will hit the housing to stop the movement of lever. When the lever is rotated about 18°, the cam rotates about 18°, the cam will move the sector up vertically for 3.2mm by push through in sector. Now the occupant can move the backrest to the desired position. The rack will move as per the backrest adjusted. The rack is connected to the arm. The arm is connected to the backrest. If the back rest rotates the arm also rotates. If arm rotates backwards, the rack (Fig.5.) will compress the helical compression spring. The rack will engaged with the different set of tooth in sector and locked when
the lever is locked due the helical torsion spring. The slot in rack is used to arrest the movement of housing and rack.

Fig. 4. Mechanism during locked condition

Fig. 5. Mechanism during unlocked condition

V. DESIGN CALCULATIONS

A. Sector

The rack typically includes a plurality of teeth formed on one side of rack. A toothed sector lock ably engages with rack for preventing axial movement of rack the sector plays the main role in strength. Since the sector disengages linearly with rack, the no. of teeth in rack can be increased. Each tooth receives the force acting on sector. Dimensions of the sector are calculated as given in the Table.1.

Table.1. Calculation of number of teeth in sector

<table>
<thead>
<tr>
<th>Dimensions of the sector:</th>
</tr>
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<tbody>
<tr>
<td>Thickness =5mm</td>
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<tr>
<td>Push through diameter=5mm</td>
</tr>
</tbody>
</table>

B. Rack

The rack is a part in which the sector gets engaged during locked position. The rack provides the axial displacement when the back rest is adjusted. The slot is provided in the rack to arrest the movement of housing and the maximum displacement of rack when backrest is adjusted. The one end of rack is connected to the arm. The arm ispivotally connected to the backrest. The calculation for the number of teeth in rack is given in Table.2.

Table.2. Calculation of number of teeth in rack

<table>
<thead>
<tr>
<th>Calculation of No. of Teeth in Rod</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length of the rod required to get 45° rotation of backrest</td>
</tr>
<tr>
<td>2* L sin 45°</td>
</tr>
<tr>
<td>No. of teeth in rack required to get extra travel</td>
</tr>
<tr>
<td>No. of teeth in rack (Tn)</td>
</tr>
<tr>
<td>40 teeth</td>
</tr>
</tbody>
</table>

C. Cam

When the lever is released in upward direction, the shaft rotates in turn the cam will rotate. The cam will rotate about 18 degree in clockwise. As a result of that the sector will go up only vertically in 3.2mm. In such a way that the cam shape is designed. At the locked condition, the bottom arc of cam will not touch the sector push through and at the unlocked condition the upper arc will not touch the sector push through to avoid friction.

D. Sector guider

The sector guider is a part placed in right and left side of the sector. It guides the sector in such a way that the left and right movement of sector is arrested. It is riveted with housing.

E. Helical torsion spring

This spring helps in bringing the cam and sector to the original position when the lever is left free. The spring is assembled over the shaft. One end of the spring is stretched inside the shaft and the shaft is stacked to prevent the spring coming out. Other end is connected in the opening present in housing. The dimension of the
The helical compression spring is fitted in between the housing end and rack end. When the backrest is adjusted backwards the spring will gets compressed and locked at the required position. If the backrest is left free the compression spring expands and brings the backrest to the design position. The dimension of the spring is calculated and is shown in Table 4.

<table>
<thead>
<tr>
<th>Table 3. Calculation of helical torsion spring</th>
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<tbody>
<tr>
<td>Helical torsion spring</td>
</tr>
<tr>
<td>1. Lever operating force (F)</td>
</tr>
<tr>
<td>2. Distance (L)</td>
</tr>
<tr>
<td>3. Angle of cam to disengage</td>
</tr>
<tr>
<td>4. Initial tension angle of spring</td>
</tr>
<tr>
<td>5. Total angle</td>
</tr>
<tr>
<td>6. Moment(N)</td>
</tr>
<tr>
<td>7. Deflection (ε)</td>
</tr>
<tr>
<td>8. Modulus of elasticity(G)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 4. Calculation of helical compression spring</th>
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</thead>
<tbody>
<tr>
<td>Helical compression spring</td>
</tr>
<tr>
<td>1. Return torque required (F)</td>
</tr>
<tr>
<td>2. Force acting in spring(Fc)</td>
</tr>
<tr>
<td>3. Stiffness(K)</td>
</tr>
<tr>
<td>4. Mean wire diameter(θ)</td>
</tr>
<tr>
<td>5. No. of coils</td>
</tr>
<tr>
<td>6. Mean coil diameter(θ)</td>
</tr>
<tr>
<td>7. Solid length(L)</td>
</tr>
<tr>
<td>8. Free length(Lk)</td>
</tr>
<tr>
<td>9. For initial compression the length is taken as</td>
</tr>
</tbody>
</table>

The arm is connected with the rack and backrest. The arm shape is changed in such a way that the deflection of rod in angular movement is avoided. There should be only linear movement of rack during the working (Table 5).

<table>
<thead>
<tr>
<th>Table 5. Material Properties of parts</th>
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<tbody>
<tr>
<td>NAME</td>
</tr>
<tr>
<td>Cam</td>
</tr>
<tr>
<td>75C6 Grade 5</td>
</tr>
<tr>
<td>Sector</td>
</tr>
<tr>
<td>16 MnCr5</td>
</tr>
<tr>
<td>Pivot</td>
</tr>
<tr>
<td>EN 1A(L)</td>
</tr>
<tr>
<td>Guide pin</td>
</tr>
<tr>
<td>EN 1A(L)</td>
</tr>
<tr>
<td>Shaft</td>
</tr>
<tr>
<td>EN 1A(L)</td>
</tr>
<tr>
<td>Operating lever</td>
</tr>
<tr>
<td>ILSH411</td>
</tr>
<tr>
<td>Housing front and back</td>
</tr>
<tr>
<td>ILSH411</td>
</tr>
<tr>
<td>Rack</td>
</tr>
<tr>
<td>GSTE-420TM</td>
</tr>
<tr>
<td>Sector guide</td>
</tr>
<tr>
<td>GSTE-420TM</td>
</tr>
<tr>
<td>Spring</td>
</tr>
<tr>
<td>Pail 1 Grade 3</td>
</tr>
<tr>
<td>IS-4545</td>
</tr>
</tbody>
</table>

The modeling tool used for the present work is CATIA V5 R14. Some features of the tool are highlighted below. Knowledge driven automation which enables reuse of engineering information across very complex products. Integrated collaboration which leverages the innovation of all members of the product development team. Production proven applications, which integrate the complete engineering lifecycle from concept through manufacturing. The recliner parts are modeled with dimensions as per calculations, and assembled at locked condition in design position. The required clearance between the parts is given.

The springs are modeled in pre-stressed condition and assembled with required clearance. Then the model is converted to IGES file and imported to HYPERMESH. Table 5 shows Bill of materials parts. Fig.7 shows the three dimensional view of the recliner assembly and Fig.8 shows recliner assembly without housing.

Fig. 7. Modeled recliner assembly in CATIA
The model is meshed in hyper mesh to get accuracy. The meshing tool used for present work is HYPERMESH.

A. Element description

Once the choice of modeling type is done, it is essential to look for the elements that will be used for the modeling type. For the present work, solid elements are used.

There are three types of commonly used solid elements namely brick, wedge and tetrahedron. Order of solid elements varies from linear, quadratic and cubic. For the 3D Simulation of recliner assembly, the standard 3D C3D8 and C3D6 continuum 3 dimensional elements are selected.

C3D8: continuum 3 dimensional 8noded elements are selected

3D Solid
8nodes, 3-D-space
DOF: Ux, Uy, Uz

Fig. 9. 8-noded brick element

C3D8: continuum 3 dimensional 6noded elements are selected

3D Solid
6nodes, 3-D-space
DOF: Ux, Uy, Uz

Fig. 10. 6-noded triangular prism element

The quality index values are set initially and the values obtained after meshing should be lower than the set values. The equivalence, connectivity and duplicate elements are checked for the meshed part. The normal are checked for the meshed part. Some features of the tool are highlighted. Altair HYPERMESH includes many enhancements that can help improve productivity. Major improvements have been made in importing CAD data, geometry cleanup and surface meshing. The performance of HYPERMESH while handling large models has been improved. The model of recliner assembly from CATIA is converted to IGES file and then geometry is imported to HYPERMESH. The component collector is created for all parts. The surface of the parts is meshed first using shell elements and then dragged to required thickness using solid elements. The solid section is assigned for all the parts. Then the material collector is created for all the parts and the material and its properties are specified. The springs are not considered for meshing. Fig. 11 shows meshed model of recliner assembly. In ABAQUS by selecting the starting and ending point of spring, it can be created. The solid elements are selected for the parts. In analysis the stiffness of spring is specified.

B. Contacts

The contact between the parts in assembly is given for static analysis to transfer the load from one part to another. In HYPERMESH, the surface contact pairs are selected.

The inner surface and outer surface of required parts are selected. Similarly for all the parts the contact pairs are created and surface to surface contact is given. The input file is imported to analysis package ABAQUS. The contact itself behaves as a constraint for analysis. The load applied will transfer to the parts which are in contact. Fig. 12. shows meshed recliner assemblies in ABAQUS after giving contact properties

C. Properties of materials

The value of young’s modulus, Poisson ratio, density values are applied as given here under.

Young’s modulus for steel =210000 MPa
Poisson’s ratio=0.3
Density =7800 kg/m$^3$
VIII. ANALYSIS

The analysis is done in ABAQUS. The model from hyper mesh is imported from hyper mesh to ABAQUS as input file. The static analysis is conducted at locked condition in design position to find the deformation of whole mechanism and each parts in static strength test.

A. Boundary conditions and Load application

As per specifications, the recliner has to withstand a load of 100kgm of torque when applied in the backward direction at a distance of 0.5m from the center of the recliner.

The boundary conditions and loads applied for static analysis are shown in Fig. 13. They are

- In housing, the four rivets are fixed in all degrees of freedom
- The load is applied at the distance of 500mm from the center of rotation of arm by selecting 20 nodes over there.
- \( F=\frac{M}{d} = \frac{100\text{kgm}}{0.5\text{m}} = 2000\text{N} \)
- Load applied on each node is \( \frac{2000}{20} = 100\text{N} \)

IX. RESULTS AND DISCUSSIONS

The recliner is modeled at locked condition and in design position. The model is meshed in HYPERMESH. The required surface to surface contact is given by creating contact surface pairs. The material properties of the parts are given. The element type is selected. The model is imported from HYPERMESH to analysis package ABAQUS as the input file. The boundary condition and loads are applied in the model in backward direction. The static analysis at locked condition and in design position is conducted. Fig. 14 shows the Vonnmises stress distribution in recliner assembly. The maximum value is 710 MPa and minimum value of 59.17 MPa.

Fig. 14. Vonmises stress distribution in recliner

Fig. 15 shows the Vonmises stress distribution in rack. The maximum value is 710 MPa and minimum value of 59.17 MPa.

Fig. 15. Vonmises stress distribution in rack

Fig. 16 shows the Vonmises stress distribution in sector. The maximum value is 274.6 MPa and minimum value of 0.24 MPa.

Fig. 16. Vonmises stress distribution in sector

Fig. 17 shows the Vonmises stress distribution in cam. The maximum value is 2.382 MPa and minimum value of \( 1.394 \times 10^{-6} \) MPa.

Fig. 17. Vonmises stress distribution in cam
Fig. 17. Vonmises stress distribution in cam

Fig. 18. shows the Vonmises stress distribution in backrest. The maximum value is 288.5 MPa and minimum value of 0.691 MPa.

Fig. 18. Vonmises stress distribution in backrest

Fig. 19. shows the Vonmises stress distribution in arm. The maximum value is 527.9 MPa and minimum value of 5.446 e^{-10} MPa.

Fig. 19. Vonmises stress distribution in arm

X. CONCLUSION

From the results it is observed that the maximum Vonmises stress in various parts are 710 MPa in rack, 274.6MPa in sector, 2.382 MPa in cam, 288.5 MPa in backrest and 527.9 MPa in arm.

- The maximum stress induced in the assembly i.e. 710 MPa which is lower than the value of ultimate strength of 16MnCr5 1200MPa.
- The stress induced in rack is higher compared to other parts.
- The mechanism will meet the static strength requirement for the load 100 kg m in backward direction.

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