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Structural Design of Automatic Seatback Table

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Abstract

In this study, we design a seatback table capable of automatically preserving an equilibrium position even when the seatback angle is changed. Both a vertical movement module—for opening and closing the seatback table—and a hinge guide—for horizontal level preservation—are designed. The opening and closing range of the table is chosen in such a way as to guarantee that the passenger space is not intruded upon when opening and closing the table, as the seatback table moves up and down. To automatically preserve the equilibrium position even when the seatback angle is changed during table use, a link structure interconnected with the recliner is proposed; the link design parameters are determined so that the seatback table can interoperate with the recliner. The proposed mechanisms are validated through a finite element analysis and the production and test of a seatback table prototype.

Keywords: Seatback table, Equilibrium position preservation, Automatic table adjustment, Hinge, Stiffness design

INTRODUCTION

Even though the consumer requirements determining vehicle choice have initially emphasized functional aspects such as velocity and displacement, they are increasingly diversifying into the additional safety, appearance, durability, and comfort areas. Among these new focus areas, the requirement for functionality and comfort of the seat system is increasing daily, and has already become a critical factor in evaluating the overall satisfaction level with the vehicle.

The existence of seatback tables, in particular, greatly improves passenger convenience by providing a temporary workspace capable of holding documents or notebook computers. However, most existing seatback tables are passive and lack functionality and convenience features; further research on the convenience and functionality of seatback tables is therefore required.

Most existing seatback tables are inconvenient to use, because they are manually operated and their slope changes when the seatback angle is adjusted through the recliner, causing discomfort during table use. To solve this problem, a mechanism to preserve an equilibrium position (even when the recliner angle changes) was designed. However, there are two problems in the process of designing an automatically adjusting seatback table. First, the seatback table must not intrude into the space of the passenger using that seat, even when opening and closing. Second, the seatback table must maintain an equilibrium position even when the seatback angle is changed.

Castelli et al. [1] proposed a method to evaluate the usefulness of the workspace of a serial manipulator device based on numerical analysis, which uses the volume and shape of the device as indices. They replaced the table structure by a serial device and set the design parameters and range motion area—with the motion space required for opening and closing the table—as workspace.[2,3]

In the present study, the trajectory of the seatback table was designed in such a way as to preserve the passenger's space; the design parameters of the seatback table were kinematically analyzed to avoid collisions during the opening and closing of the seatback table. In addition, the hinge mechanism of the table was designed in such a way as to maintain the table's equilibrium position during the rotation of the seatback. Furthermore, the structure was designed to satisfy the prescribed test load. The design was validated both through structure analysis and by testing a prototype model.

COMPONENTS AND STRUCTURE OF THE SEATBACK TABLE

The seatback table is a convenience device mounted at the rear of the seat and used by passengers in the rear seat. It consists of a table, a slide for moving the table up and down, and a hinge for fixing and rotating the table. The seatback table is mounted in a sinking slot at the seatback and is opened, when the table is moved up, by rotating on the table hinge connected to the table bracket. The structure supporting the upward movement is composed of a shaft support and screws, a gearbox, a motor, and lead screws. The shaft support is fully fixed at the top and bottom, and plays the role of a guide during the movement in the axial direction, while preventing the rotation of the shaft gearbox.

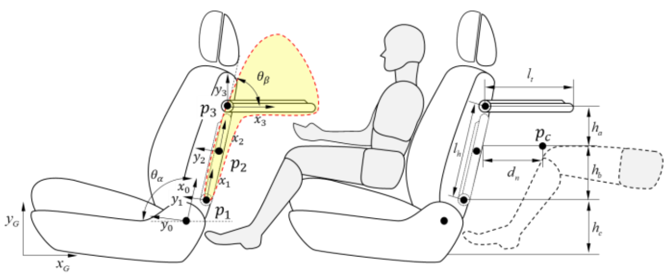


Figure 1: Operating principle of the seat back table

Up and Down Movement of the Table and Design of the Opening and Closing Mechanism

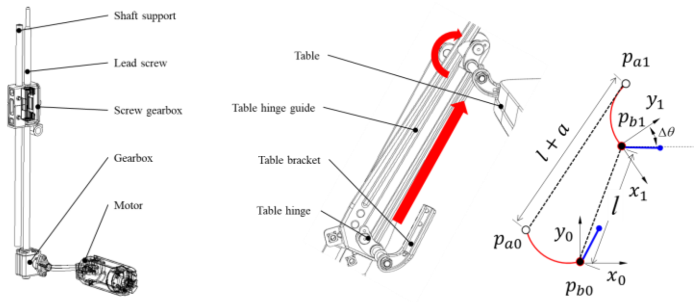
While opening and closing, the table must move without contact with the rear part of the seat or the passenger's body. Therefore, the points corresponding to the passenger's body and the seatback's area were carefully defined.

A general serial device has a large workspace and a simple control element. For design purposes, the seatback table was replaced by a serial device. For the table's link model, the movement area was restricted by defining a set of critical point(p_c) in the movable area and was controlled using a guide slot.

To enable the table opening and closing operations without intruding into the passenger's space, the opening and closing angle (θ_β) of the seatback table was defined as a variable. In contrast, the length (l_t) and up and down movement distance(l_h) of the table were defined as constants.

The seatback table is opened and closed by the angle (θ_α) between the initial position (p_1) and the position selected to avoid interference with the passenger's space (p_2), and by the angle ($\theta_\alpha - \theta_\beta$) between position ($p_2$) and the position where the up and down movement ends (p_3). When the opening and closing actions are finished, the angle of the seatback table becomes 0° again. The movement was restricted by the above-mentioned set of critical point(p_c) used to prevent contact with the passenger during opening and closing.(Figure 1.)

The operating process of the seatback table can be divided into two different phases: table opening and closing during the up and down movement, and equilibrium position preservation when a change in the recliner angle occurs. The movement trajectory of the seatback table from the position that intrudes into the passenger's space during the up and down movement to the final position, and the trajectory of the hinge that maintains the equilibrium position of the table despite the changes in the recliner angle were therefore both carefully designed.



(a) Up and down movement mechanism (b) Table opening and closing mechanism (c) Schematic diagram

Figure 2: Structure of mechanism for seat back table

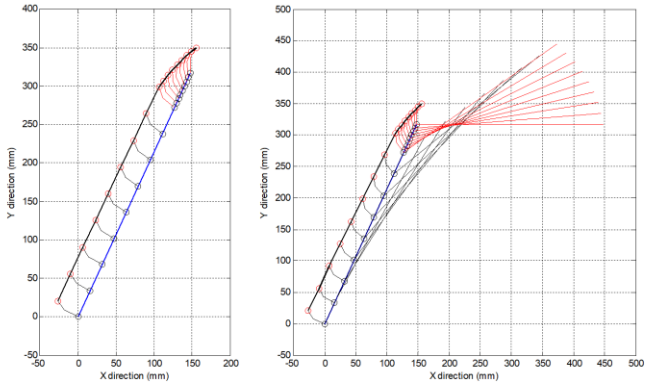
Table Up and Down Movement Mechanism

The rotation velocity of the motor—the power source—is an important factor in the up and down movement, but the gear ratio of the gearbox that converts between linear movement and axial rotation and the pitch of the lead screw thread have also a significant impact on the movement velocity. Finding an appropriate compromise is critical, because the movement precision is inversely proportional to the up and down moving velocity; the prototype was designed with a focus on velocity.

Figure 2(a) shows a schematic diagram of the table up and down movement mechanism. The lead screw whose top is fixed to the same bracket as the one for the shaft support can rotate in the axial direction; at the bottom, there is a gearbox to convert the power from the motor into axial rotation. The screw gearbox moves in the axial direction along the shaft support and lead screw, and the table hinge and bracket move together. The kinetic velocity is determined by the rotation velocity of the lead screw and the lead length.

Table Opening and Closing Mechanism

The table hinge moves up and down along the hinge guideline while the table is simultaneously opened and closed through the bracket. Figure 2(b), (c) shows a schematic diagram of the table opening and closing mechanism. If the table hinge initially at the bottom of the table hinge guide—as shown above—corresponds to arc $\mathrm{p_{a0}} - \mathrm{p_{b0}}$, when the table hinge moves to the top, point $\mathrm{p_{a0}}$ moves to $\mathrm{p_{a1}}$ (by $l + \alpha$) and point $\mathrm{p_{b0}}$ moves to $\mathrm{p_{b1}}$ (by l). As a result of these two different moving distances, arc $\mathrm{p_{a0}} - \mathrm{p_{b0}}$ is rotated to arc $\mathrm{p_{a1}} - \mathrm{p_{b1}}$. While moving along the table hinge guide, the table hinge gradually rotates from the initial position until it reaches the top, when it stops rotating. The rotation of the table hinge determines the table position and determines the angle between the table and the seatback ($\Delta\theta$).



(a) Trajectory for hinge (b) Trajectory for seat back table

Figure 3: Trajectory analysis for seat back table

Figure 3 shows Trajectory analysis for seat back table. The trajectory of the table hinge can be derived from the table opening and closing area setting, and the opening and closing can be controlled by the table rotation.

Design of the Table Rotation and Equilibrium Preservation Mechanisms

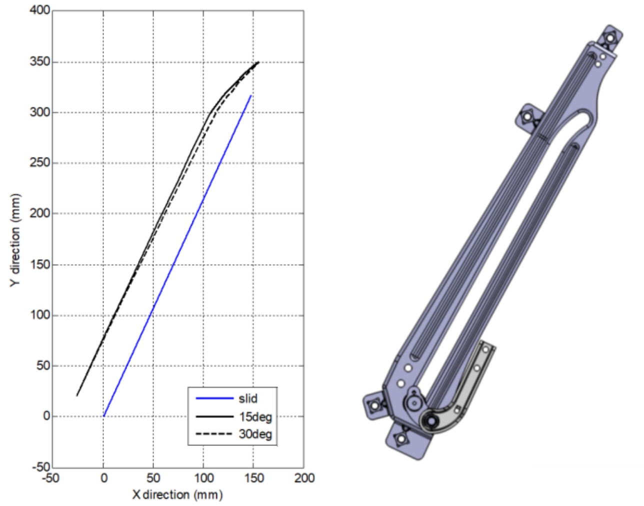
The seatback table equilibrium preservation mechanism is designed to ensure that the seatback table automatically maintains its equilibrium position independently of the seatback slope. For maximum user convenience, the equilibrium position of the seat table is also maintained when the slope of the seat cushion is changed.

The seat used in this study is of the model mounted in the passenger seat of the S Company's C model. It is a power seat of which the recliner, cushion height, and the front and back cushion movement are operated electrically by a motor. Therefore, the angle rate and operation time of the seatback are relatively uniform. The maximum angle of the seatback is approximately 90°, and the time to go from the minimum to the maximum angle is approximately 25 s.

The typical seatback table gets inclined when the seatback slope changes. To improve this, the mechanism presented here was designed to preserve an equilibrium position with the chassis even when the seatback slope changes. The actual operating range was set from a minimum angle to 50° of the seatback, because below that the seatback table could enter in contact with the passenger or the back-row seat.

Setting the Hinge Position for Table Rotation

If the guide hinge is located in front of the recliner a sufficient moving space of the link can be obtained, but it becomes difficult to control it, because of the effect of the interfering part. Therefore, the guide hinge was positioned to the back of the recliner to minimize the interference area and control the link movement. The position of the guide hinge was determined and the link length and hinge position for link control were determined through an analysis of the trajectory of the link tip. The amount of change in table rotation can be controlled by changing the hinge trajectory, and was implemented in the form of a hinge slot. As it approaches the slide part the amount of change in the opening and closing range increases, and the trajectory changes from a 15° rotation (from the table initial to final positions) to a 30° rotation trajectory.(Figure 4)

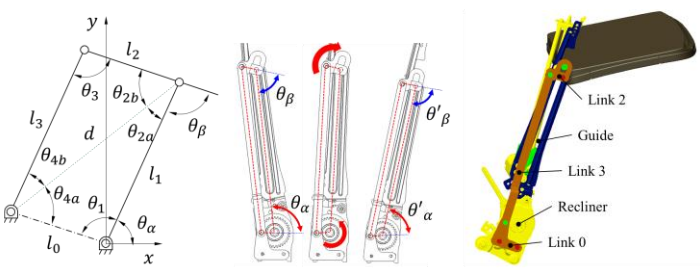


(a) Trajectory for guide hinge (b) Model for guide hinge

Figure 4: Trajectory analysis for guide hinge

Table Equilibrium Preservation Mechanism

To preserve the equilibrium of the seatback table, a parallelogram link device was chosen among the generally used 4-bar links. If the angle of change of the recliner is θ_1 , the equilibrium will be maintained while the adjacent link elements l_0 and l_1 preserve an equilibrium with the link elements facing them. (Figure 5(a),(c))



(a) Keep balance of 4-bar link mechanism (b) Mechanism for table equilibrium (c) Structure of mechanism

Figure 5: Structure of mechanism for table equilibrium

The base link (l_0) is fixed and the operating interval is defined by setting the rotation angle (θ_α) of the base link to the rotation range of the seatback. The operation criteria of the 4-bar link mechanism are, therefore, the base link l_0 and link rotation angle θ_α ; the angles of the remaining coordinates can be calculated using the appropriate trigonometric identities. The link structure designed to preserve the equilibrium of the seatback table is therefore based on the parallelogram formed by the 4-bar link structure whose four elements are the recliner, Link 1, Link 2, and Link 3.

To implement the possibility of horizontal adjustment, the link displacement corresponding to a change in the angle between the seat cushion and the seatback of the recliner was transmitted through a three-step link to the table guide link so that the table opening and closing range could be adjusted according to the rotation angle of the hinge connected to the table bracket. In this case, the value between the table and the table horizontal guide link must be designed by confirming the relationship between the initial angle between the chassis and cushion and the minimum seatback angle through numerical analysis.

The table operation sequence can be summarized as follows: in the initial state, with the table folded in the seatback, the table hinge rises to the horizontal guide link along the table hinge guide. While moving to the top, the table becomes gradually inclined and forms a certain angle with the seatback when it reaches the top of the horizontal guide link. When the seatback slope at the top is changed, the distance between the recliner link and the horizontal guide link changes and the horizontal guide link is rotated by the difference between the horizontal link and the changed length, which affects the table angle change.

This shows the state of the horizontal adjustment links when the angle of the seatback frame changes. While moving from position (state1) to (state3), the distance between the recliner link and the horizontal guide link is changed, but the length of the horizontal link connecting between the two links is fixed. As a result, the horizontal guide link is rotated along the rotation axis of the horizontal guide link, and the trajectory of the guide moved by the table hinge changes. The equilibrium position is maintained because the sum of the recliner rotation angle (θ_α) and the guideline angle (θ_β) stays equal to the sum of the changed angles of the seatback during rotation ($\theta'_\alpha, \theta'_\beta$). The following Figure 5(b) shows a simple illustration of the seatback table horizontal level preservation concept.

STRUCTURAL ANALYSIS AND PROTOTYPE EVALUATION

Structural Analysis

A simulation of the load acting on the table tip was conducted, to confirm the occurrence of deformation and validate the design model. A 300 N load was applied to the table tip during the simulation; the objective was for the permanent deformation of the table not to exceed 20 mm. The following analysis conditions were assumed in this simulation. First, the table was made of plastic and steel and the components were firmly interconnected. Second, the loading condition of the table tip was applied at the top center of the main table, but to consider harsher conditions the point where the guide pin of the table contacts the frame guide was set as the load concentration point. Third, the table was fixed by a hinge bracket. Fourth, the focus was on the permanent deformation of the steel, rather than on the deformation of plastic. Fifth and last, the mesh was created based on unit cubes smaller than the frame thickness.

A half model of the table was used for the frame structural analysis. The hinge part was fixed, and 150 N were applied to the frame tip. The deformation and stress were then checked. The deformation was 3 mm, which satisfied the established requirement.(Figure 6)

The analysis was complemented by checking the deformation of the hinge bracket and the stress concentration part, while considering a safety factor.(Figure 7, Figure 8)

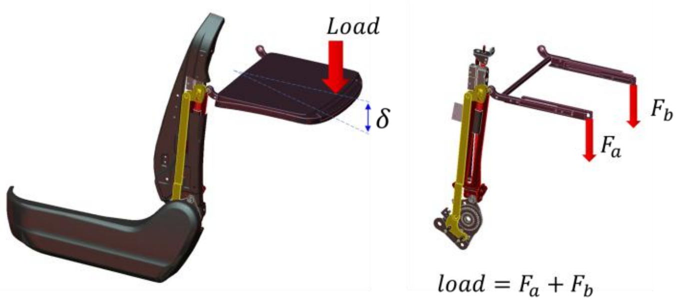


Figure 6: Analysis of the seat back table

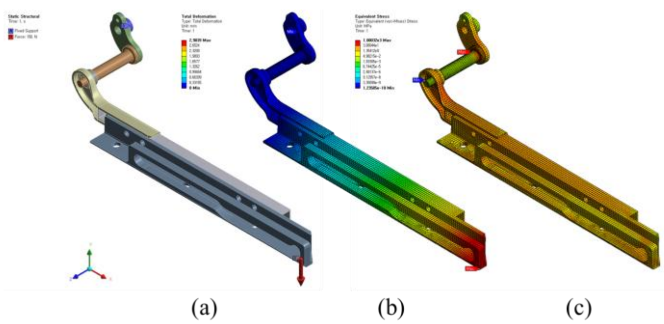


Figure 7: Structural analysis for table frame

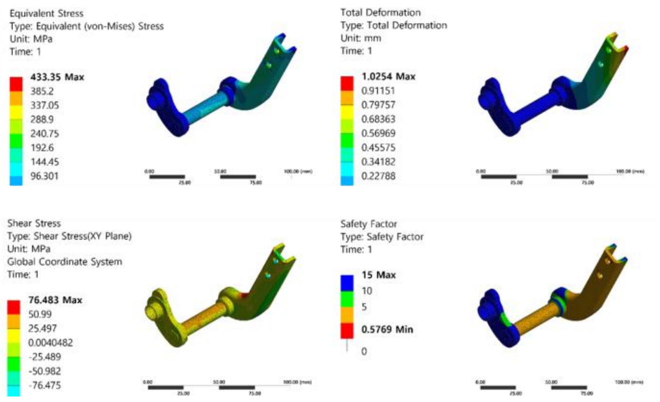


Figure 8: Results for static analysis of table hinge

Production and Test of the Prototype

Prototypes were produced of both the seatback and the seatback table. To minimize frame deformation, the motor was installed at the center position, below the existing frame, and a shaft and lead screw were installed at either side.

For the up and down movement of the seatback table, power was transmitted to the lead screw using a 12 V motor, which, when operating, moved up and down along the lead screw. The up and down movement of the table occurred simultaneously with its opening and closing.

The seatback table maintained an equilibrium position even when the recliner angle was changed. Although the table equilibrium was not perfect, the table position always stayed within the effective equilibrium range while the seatback angle was changed. (Figure 9)

Figure 9: Prototype for Automatic Seatback Table

CONCLUSION

In this study, we designed a vertical movement module for opening and closing a seatback table and a hinge guide for horizontal level preservation. A design with a link structure interconnected with the recliner was proposed; the link design parameters were determined so that the seatback table would interoperate with the recliner. The opening and closing range of the table was chosen in such a way as to guarantee that the passenger space would not be intruded upon when opening and closing the table, as the seatback table moves up and down. Furthermore, the change in the moving trajectory of the hinge according to the changes in the opening and closing range was examined. A mechanism to preserve an equilibrium position even when the seatback angle is changed during table use was designed, and a finite element analysis was conducted. The analysis results showed that the table meets the test evaluation criteria. The validity of the proposed mechanism was verified by producing a seatback table prototype for equilibrium position preservation

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