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Determination of the Hinge Position on Joint-type Seatback Frame considering Hybrid Ⅲ Human Body Model

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Abstract

We demonstrate a method for designing a joint-type seatback frame that supports passengers' shoulders depending on their posture in an automobile. We determine the position of a hinge of the joint-type seatback frame that supports a passenger's body part from back to shoulder by adding joints to a typical seatback frame design. Hybrid III, the most frequently used dummy model in automobile design and automobile testing, was used to design a kinematic human virtual linkage model. The kinematic back shape, connected to the seatback according to the human virtual linkage model, as well as hinge position of the joint-type seatback virtual linkage model were determined. The kinematic back shape and hinge position were used to confirm that a non-connect area between the kinematic back shape and seatback decreased relative to that of a typical seatback model. A finite element model of the joint-type seatback frame was created after using the kinematic joint-type seatback model. Then, an FMVSS 207 applied finite element analysis was performed. FMVSS 207 sets a legal standard for automobiles. Results confirm that deformation of the new model is similar to that of the typical model, and that FMVSS 207 was satisfied.

Keywords: Hinge position, Determination, Seatback frame, Hybrid Ⅲ, Human body model

INTRODUCTION

Automobile performance, passenger comfort, and riding comfort are all developing in tandem with automobile technology.[1] The passenger seat is an important component in this context, as it constitutes the main passenger interface. The seat supports a passenger's body and enhances his/her experience by absorbing vibrations from the road while the vehicle is in motion.[2] Moreover, the seat should be comfortable over long journeys. Criteria such as safety, comfort, convenience, and design that universally characterize seat quality are applied differently in automobiles than in typical seats, insofar as the shape of the human body is considered.[3] Convenience systems that consider the human body include a supporter, an extension, and positioning. In particular, a shoulder adjuster system can help reduce tiredness by providing support to the head and shoulder.

Various studies have sought to optimize the strength of a typical seat frame while using lightweight materials. Jung[4] produced an optimal design by using the design-of-experiment (DOE) method to design a seat structure based on high-strength steel (HSS), which is both lighter in weight and stronger than typical steel. Kim[5] compared the stiffness of the seat recliner and its frame in terms of its thickness using HSS.

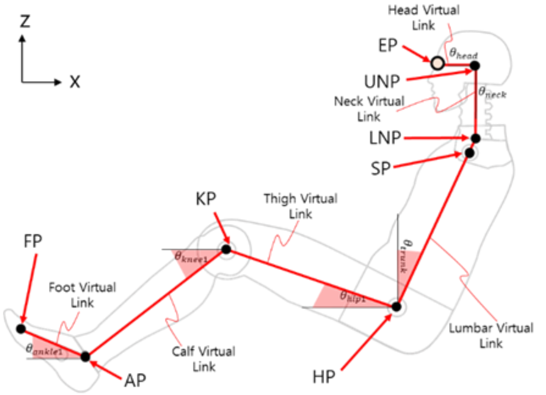
In the context of automobile design, Zuli'zam R[6] considered the postures of a virtual human body model to implement a test dummy placed in an automobile. Park[7] also studied suitable posture in humans by considering the main reference points of the body (eye, hip, foot). Despite a wealth of research on deriving a human body model and analyzing human posture, few studies have focused specifically on how a seat structure interfaces with body posture. However, there is a need to develop seat structures that are both comfortable (incorporating human body features) and sufficiently strong for passenger safety.

This study presents a method for designing a joint-type seatback that supports passengers' backs as well as their heads and shoulders. We determine the hinge point of a joint-type seatback frame by applying a kinematic human virtual linkage model based on the Hybrid III 50th male, the dummy most frequently used for automobile design. Furthermore, using finite element analysis, we identify the strength of the joint-type seatback frame in comparison with that of a typical seatback frame, ensuring that the FMVSS 207 law regulations are met.

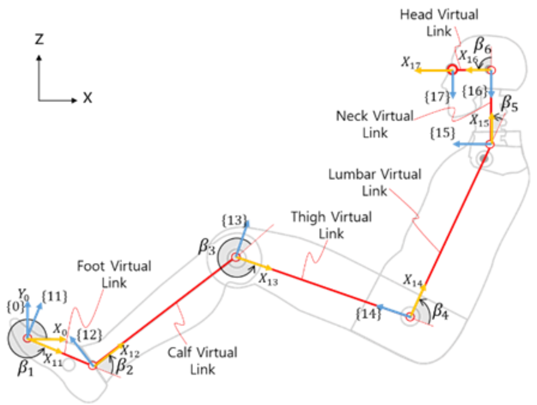
DESIGN OF THE HUMAN VIRTUAL LINKAGE MODEL

Design of the kinematic human virtual linkage model

A typical dummy model represents a skeletal structure in terms of anthropometrically measurable points based on the joints of the human body. In this manner, a virtual linkage model can be created with internal joint points, such as extremities of the foot, ankle, knee, hip, shoulder, neck, or eye. The virtual linkage model shown in Figure 1(a) was created using the Hybrid Ⅲ human body model, based on the distance between joint and joint of the human body. The Hybrid Ⅲ Human body model and 2D template joint angles were applied, and the reference coordinate {0} of the foot point was set. The joint point distances given in Table 1 and the Denavit-Hartenberg notation in Eq. 1 were used to design the kinematic human virtual linkage model shown in Figure 1(b).



(a) virtual linkage model



(b) kinematic linkage model

Figure 1. Virtual link and kinematic coordinates of human body model

Table 1. Joint points and variables of virtual linkage model

Points	Links
FP (Foot Point)	-
AP (Ankle Point)	FVL (Foot Virtual Link)
KP (Knee Point)	CVL (Calf Virtual Link)
HP (Hip Point)	TVL (Thigh Virtual Link)
SP (Shoulder Point)	-
LNP (Low Neck Point)	LVL (Lumbar Virtual Link)
UNP (Up Neck Point)	NVL (Neck Virtual Link)
EP (Eye Point)	HVL (Head Virtual Link)

$${}^0_7T = {}^0_1T\,{}^1_2T\,{}^2_3T\,{}^3_4T\,{}^4_5T\,{}^5_6T\,{}^6_7T$$

$$= \begin{bmatrix} \cos\beta & 0 & -\sin\beta & l1\cos\beta \\ 0 & 1 & 0 & 0 \\ \sin\beta & 0 & \cos\beta & l1\sin\beta \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad \text{(Eq. 1)}$$

Figure 2 shows a kinematic human virtual linkage model, which consists of six virtual links: the foot (FP-AP), calf (AP-KP), thigh (KP-HP), lumbar (HP-LNP), neck (LNP-UNP), and head virtual links (UNP-EP). These six virtual links are all linear, but the lumbar virtual link is different. In anatomical terms, the lumbar has respective joints connected to the thoracic, lumbar, and sacral, and another joint connected to the shoulder. Thus, according to lumbar joints ratio, three important joints can be applied to the lumbar virtual link.

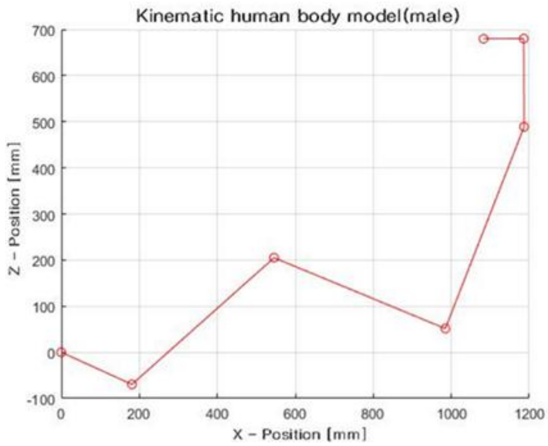


Figure 2. Kinematic design of human virtual linkage model

Back shape design of the human virtual linkage model

The joint-type seatback frame requires a larger area than an typical seatback frame to support the back of the body. The position of a joint in a joint-type seatback frame must be such as to minimize the non-connect surface area between the back and seatback. A first step must therefore be to design the back shape of the human virtual linkage model.

This study linearly derived the back shape of the human virtual linkage model. It uses the point that connects three points which are derived through the three important joints of the lumbar virtual link as well as the head and headrest to represent the linear back shape. The three important joints of the lumbar virtual link are anatomically separated: the first is the shoulder joint, the second is the upper-lumbar joint (the thoracic-lumbar connecting joint), and the third is the lower-lumbar joint (the lumbar-sacral connecting joint). The three joints were projected perpendicular to the back shape of the Hybrid III human body model, as shown in Table 2, to derive the back points of the kinetic human virtual linkage model: the shoulder-back (SBCP), upper-lumbar-back (ULBCP), and lower-lumbar-back connecting points (LLBCP). The head-

headrest connecting point (HHRCP) of the Hybrid Ⅲ human body model was further derived. Using the four connecting points, the linear back shape of the human virtual linkage model was derived, as shown in Figure 3.

Table 2. Back point of kinematic human virtual linkage model

Human virtual linkage model Points	Back shape Points
HRP (HeadRest Point)	HHRCP (Head-Headrest Connecting Point)
SP (Shoulder Point)	SBCP (Shoulder-Back Connecting Point)
UNP (Upper Lumbar Point)	ULBCP (Upper-Lumbar-Back Connecting Point)
LLP (Lower Lumbar Point)	LLBCP (Lower-Lumbar-Back Connecting Point)

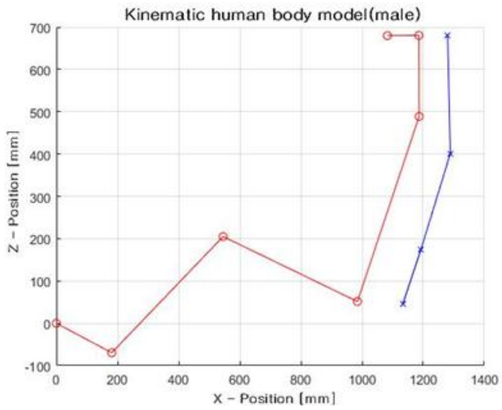


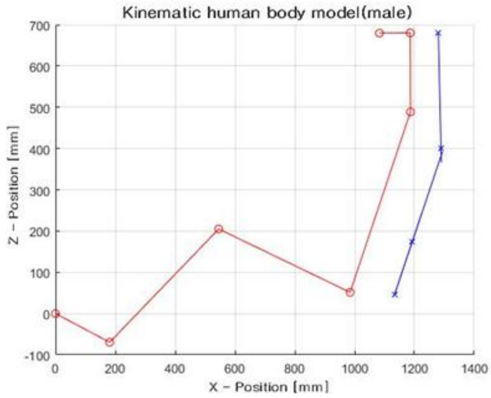
Figure 3. Design of kinematic according to human virtual linkage model

DETERMINING THE HINGE POSITION OF THE SEATBACK FRAME

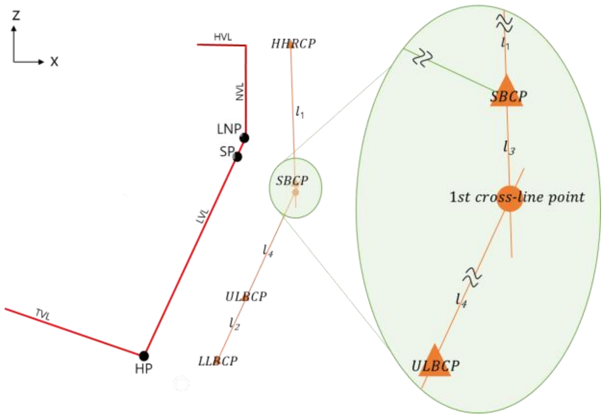
Designing the kinematic seatback virtual linkage model

The second step in determining the hinge position of the joint-type seatback frame was to determine the hinge position of the kinematic seatback virtual linkage model while also considering the back shape of the human virtual linkage model.

Regarding the hinge position of the kinematic seatback virtual linkage model, the initial positions of the seatback recliner and seatback virtual linkage model were designed based on the Hip Point(HP) of the human virtual linkage model to further utilize the four connecting points. As shown in Figure 4, the four connecting points were used to derive the first intersection (1st cross-line point) of the line joining the HHRCP and the SBCP, and the line joining the LLBCP to the ULBCP. The hinge position of the seatback virtual linkage model was determined (see Figure 5) by calculating the second intersection point (2nd cross-line point) from the first intersection point (1st cross-line point) to the seatback virtual linkage model. The second intersection point extends perpendicularly from the intersection point (1st Cross-Line Point) to the intersection point (2nd Cross-Line Point) was derived to determine the hinge position of the seatback virtual linkage model as shown in Figure 5.



(a) kinematic design of hinge point



(b) schematic design of hinge point

Figure 4. Determination method of hinge point

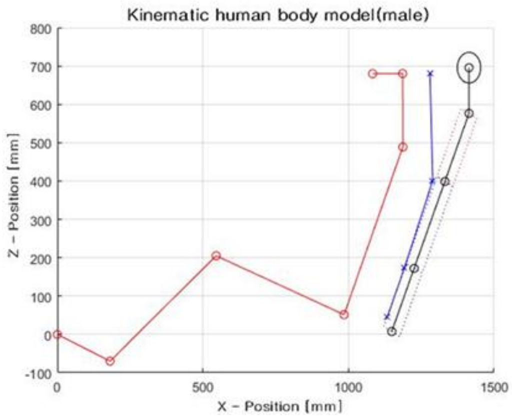


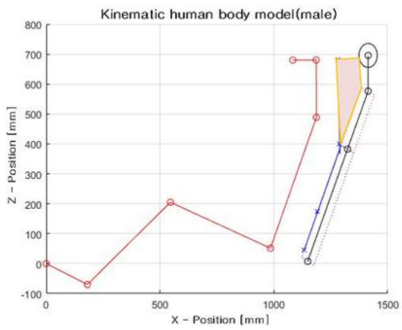
Figure 5. Kinematic design of seatback virtual linkage model

The hinge derived from the human virtual linkage model is 385.4 mm above the foot point in the z-direction. On the other hand, in the seatback virtual linkage model, the hinge was calculated to be 413.95 mm higher than the recliner along the upper direction of the seat back, as stated in Table 3.

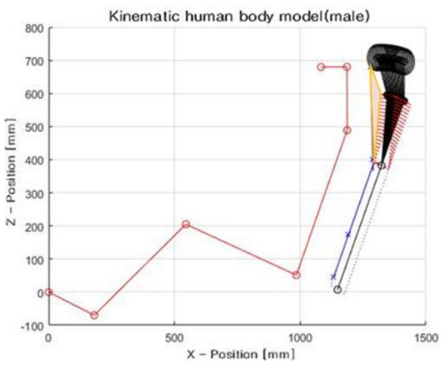
Table 3. Hinge point height

Point to Point	Axis	Distance [mm]
Foot point to Hinge point	Z axis	385.4
Recliner to Hinge point	Seatback upper axis	413.95

To examine the closeness of the connection between the seatback and human virtual linkage models, we compared the regions of no-contact, based on the human virtual linkage model, before and after the addition of the hinge of the seatback virtual linkage model. In a typical seatback frame (i.e., before adding the hinge point in the human virtual linkage model), an area with space from head is observed as shown in Figure 6.a. The passenger must therefore lean the head backward, or rotate the entire seatback forward. However, as shown in Figure 6.b, the non-connect area is reduced by 76% when the seatback upper link is rotated forward, based on the hinge derived in Figure 5. The rotation angle for which the upper link of the seatback virtual linkage rotates forward is 19.1°, thereby increasing the area supporting the passenger's back.



(a) non-connect area of seatback frame before rotation



(b) non-connect area of seatback frame after rotation

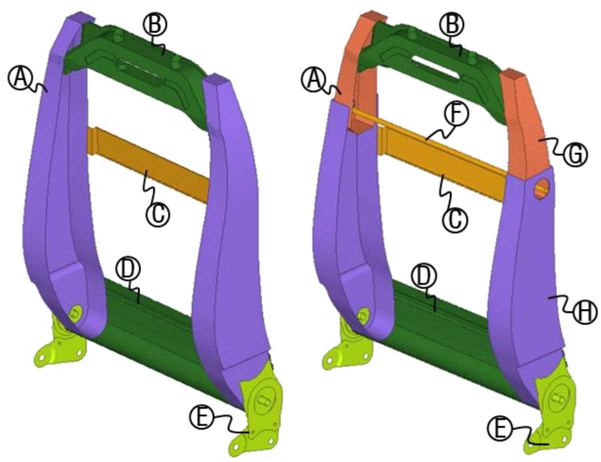
Figure 6. Reduced area and rotation angle of seatback virtual linkage model

Modeling the joint-type seatback frame

This study modeled a typical seatback frame, as well as a joint-type seatback frame, to verify whether the joint-type seatback virtual linkage model (which was kinematically designed) satisfies the static law regulations for automobile seats. The seatback-frame cross section is U-shaped. A typical seatback frame and a joint-type seatback frame designs are shown in Fig. 7. Table 4 lists the constituent components. The upper-side and lower-side frames are divided in the joint-type seatback frame, and the shaft part for rotation was added to allow the upper-side frame to rotate forward.

Table 4. Part name of the seat back frame

Symbol	Name	Symbol	Name
A	Side frame	E	Recliner
B	Upper frame	F	Recliner shaft
C	Middle frame	G	Upper Side frame
D	Lower frame	H	Lower Side frame



(a) typical seatback frame (b) joint-type seatback frame

Figure 7. Modeling of seatback frame

FINITE ELEMENT ANALYSIS

Results and discussion

To verify the strength and safety of the joint-type seatback frame, we compared static analyses of an typical seatback frame and of a joint-type seatback frame. Both frames were assumed to be rigid once the finite element models were defined. When performing the analyses, the FMVSS 207 rear moment, which is the static law regulation test for automobile seat, was applied as shown in Figure 8. FMVSS is a North American legal requirement enforced on all automobiles and designed to protect passengers in various crash situations.[8] Table 5 gives the material property value as SPFC 980 for the finite element analysis, and the thickness of seatback frame was set to 1.2 mm for upper frame, and lower frame, respectively.

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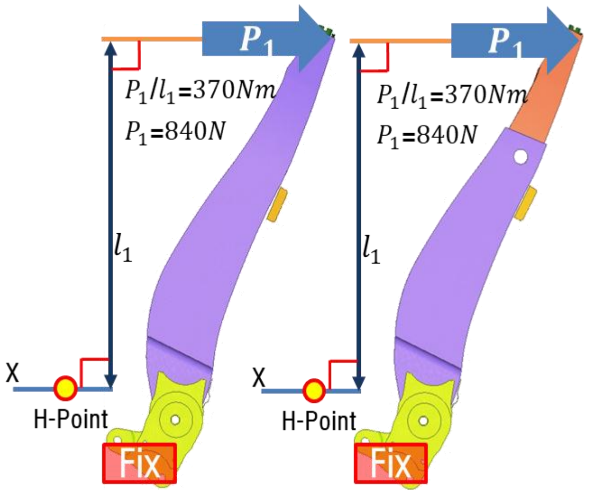


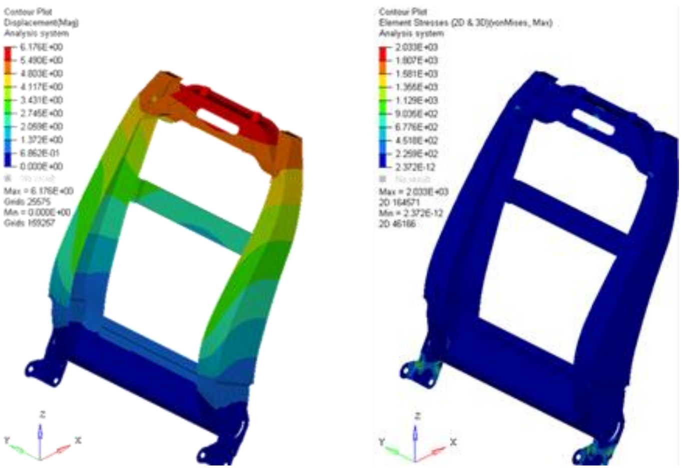
(a) typical seatback frame (b) joint-type seatback frame

Figure 8. Finite element analysis method

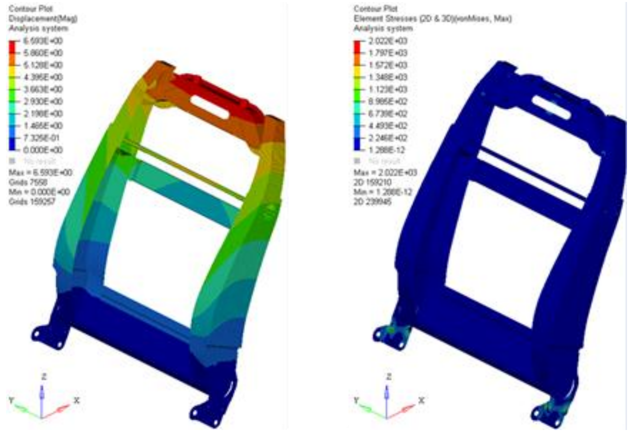
Table 5. Material data of seatback frame

Material	Yield Stress [MPa]	Youngs Modulus [GPa]	Poissons Ratio	Density [kg/mm^3]	Description
SPFC 780	490	314	0.3	7.86*10^6	HSS

The finite element analysis yielded a similar strength as with the typical seatback frame as shown in Figure 9, and the joint-type seatback frame met the requirements of the FMVSS 207 law regulation



(a) typical seatback frame



(b) joint-type seatback frame

Figure 9. FEA results of typical and joint-type seatback frame

Table 6. FEA result of seatback frame

Type	Material	Max Deformation [mm]	Max Stresses [MPa]
Typical	SPFC 780	6.176	2033
Joint	SPFC 780	6.593	2022

CONCLUSIONS

To conclude, the present study proposed a method for determining the hinge position of a joint-type seatback frame. Its aim is to support the part from back to shoulder of a passenger by adding joints to the typical seatback frame and by considering the Hybrid Ⅲ human body model.

The first step for determining the hinge position was to kinematically design the human virtual linkage model using the Hybrid Ⅲ model and anthropometrical data. The lumbar virtual link of the human virtual linkage model was used, based on anatomical data to kinematically design the shape of the back, which is connected to the seatback virtual linkage model. The hinge position of the seatback virtual linkage model was determined using the intersection point of the kinematic back shape. The kinematic seatback, compared to the typical seatback model, shows a 76% reduction in the back shape and the non-connect area. The kinematic seatback virtual linkage model was used to design a joint-type seatback frame that incorporates the typical seatback shape. The finite element analysis was further performed by adopting the law regulation of FMVSS 207. The study results confirm that the deformation in strength of the joint-type seatback frame is similar to that of the typical seatback frame, and that the requirements of FMVSS 207 are met.

Future work should seek to optimize the shape and strength of the joint-type seatback frame

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