Anti-submarine Performance of an Automotive Seating System

- A DoE study

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ABSTRACT

The anti-submarine performance of an automotive seating system depends on many factors like seat characteristics, occupant position, impact speed and restraint systems. This paper presents optimization of seat structure for complex anti-submarine performance using Design of experiments (DoE) approach. MADYMO software's hybrid approach has been utilized in the evaluation of anti-submarine performance. Taguchi's orthogonal array is used to identify the effect of contributing parameters with reduced number of iterations. The optimization software iSIGHT is used to automate the design process for different parameters. The paper also presents the benefit of MADYMO hybrid simulations in compressing the product development cycle time.

Key Words: Submarine, DoE, MADYMO, iSIGHT, FEA, Crashworthiness

INTRODUCTION

Evaluation of vehicle and sub-system crashworthiness by Computer Aided Engineering (CAE) has driven virtual simulation and prototyping, and thereby reducing physical prototyping and testing costs and also the development cycle time.

The use of advanced tools such as MADYMO [1], LS-DYNA [2], iSIGHT [3] etc coupled with high- performance computing has made this a reality.

The enhancement of the seating system performance leads to better occupant safety. The primary objective of any seating system designer is to quickly explore various alternatives available in the design space, while ensuring the safety of the occupant. The number of parameters or variables that influence the performance of seating system is large making the design process quite complex.

DoE has rescued the designer in arriving at the optimal design. The evaluation of these designs using a finite element crash simulation is time consuming and tedious while rigid body simulation does not permit the designer in assessing the part performance completely. The hybrid approach in MADYMO, using combination of flexible and rigid body simulations allows optimizing the part design with reasonable accuracy.

This paper presents the anti-submarine performance optimization of car driver seat using hybrid approach of MADYMO software. In this model complete seat is assumed to be rigid except the part under consideration. The simulations have been carried out with 50th percentile hybrid III male manikin with restraint systems, in dynamic crash conditions. Effects of front cross pressing design parameters are quantified and their optimal settings are identified.

SEAT SUBMARINING

Design of seat system is very critical for occupant safety. Stringent requirements are laid by automobile manufacturers and safety organizations with various criterion (NCAP, FMVSS, ECE etc), to ensure the occupant safety. More and more safety features are being included to protect the passenger during crash. The seat performance is an important contributor to the occupant safety. The design factors for seat understructure are evaluated for frontal crash situation in this paper.

Submarining is the process where the lap belt slips off above the ASIC (Anterior Superior Iliac Spine) and results in abdomen and spine injuries. The submarine movement mechanism of manikin is shown in Fig. 1.

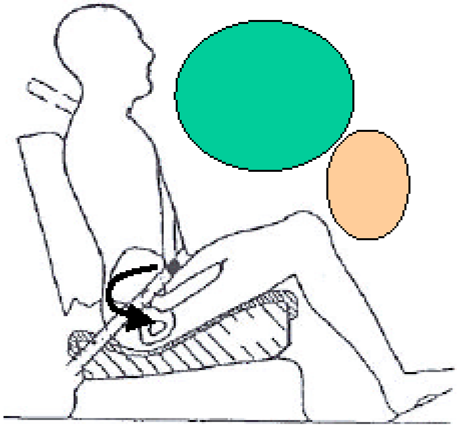

Fig.1: Submarine movement of manikin

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In a full frontal crash, following variables/factors may affect the anti-submarine performance of the seat

1. Impact speed
2. Occupant position
3. Belt anchor angle
4. Restraint system parameters
5. Seat characteristics.

During initial stages of the design the seat designer identifies the optimal values of these anti-submarine factors there by ensuring the occupant safety.

There is no direct measurement of anti-submarine performance of seat in the literature but can be compared in terms of

1. Forces on ASIC
2. Pelvis rotation and acceleration
3. Belt to Pelvis angle
4. Belt forces
5. Pelvis movement

PROBLEM DESCRIPTION

Front cross pressing (FXP) member is part of seat under-structure as shown in Fig. 2. It is a cross-member below the seat cushion connecting the in-board and the out-board side of the seat side members. FXP member resists the occupant dynamic impact load, absorbs energy and distributes the load to the side members and the floor mounts. FXP member is an important influencer in the anti-submarine performance.

The challenge is to identify the optimum thickness of the FXP that should have least FXP deflection and keeping pelvis acceleration within the prescribed limit.

LS-DYNA explicit solver has been used in the initial phase of the design for crashworthiness evaluation. The input parameters based on the LS-DYNA analysis and previous experience is then leading to a suitable model in MADYMO software, a FE and multi-body simulation tool that is extensively used in the automotive industry.

MADYMO MODEL

A typical seating system is assemblage of many systems and sub systems. Fig. 2 shows typical structure of car driver seat.

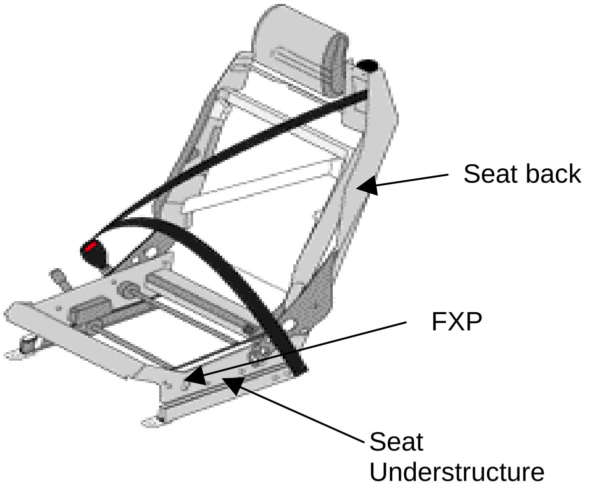

Fig.2: Typical automotive seat

The equivalent MADYMO model of the seat with seat cushion and seat back assemblies are represented by two rigid planes with appropriate force-deflection curve as shown in Fig. 3. The floor is taken as reference space, which is rigid. Appropriate mass properties are assigned to all rigid bodies.

A full frontal crash pulse is applied to manikin and full seat structure except reference space.

The FXP is modeled as a deformable body. The finite element model of the FXP is idealized by 990 shell elements and 1050 nodes as shown in Fig. 4. The deformable FXP is assumed to be held rigidly at ends.

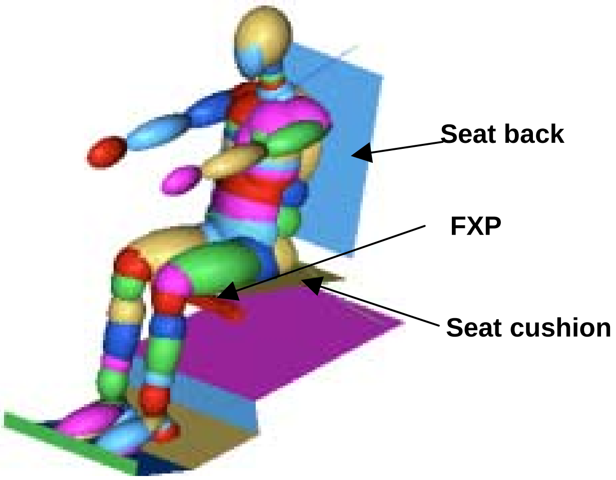

Fig. 3: Representative seat model with 50th percentile manikin in MADYMO

Fig.4 Deformable front cross pressing (FXP)

iSIGHT – AN OPTIMIZATION TOOL

iSIGHT is a process integrator which integrates simulation tools, to solve engineering design problems in a structured manner. iSIGHT automates the execution control, data exchange and iterative adjustment of design parameters, guided by the problem formulation and specified design exploration tool [3].

MADYMO- iSIGHT INTERACTION

The present DoE process has been automated using iSIGHT. The adopted coupled MADYMO - iSIGHT approach has been outlined in Fig 5. The existing setup has MADYMO solver running on UNIX environment and iSIGHT working on Windows XP environment, integrated together with interface Services For UNIX (SFU).

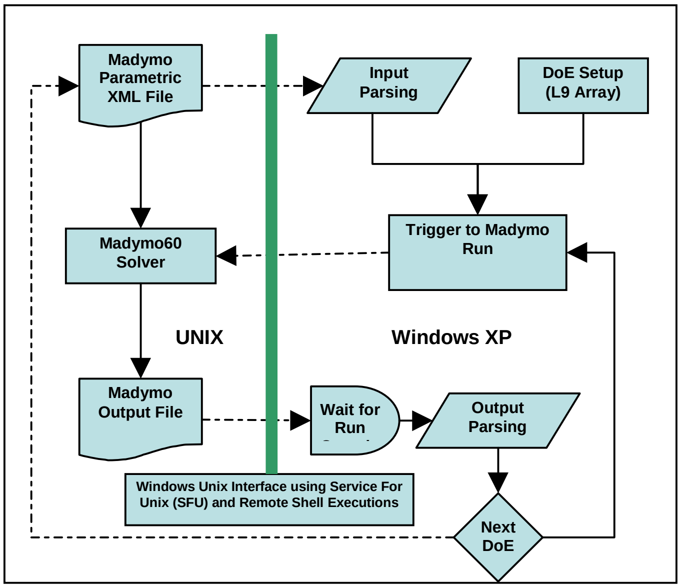

Fig.5: Flow diagram: MADYMO- iSIGHT interaction

DESIGN OF EXPERIMENTS

Two different design configurations of FXP with ranges of sheet thickness and materials are analyzed. Cushion characteristic is included as contributing factor to demonstrate its effect on anti-submarine performance. The Table 1 indicates the design space considered in the current work.

Factor/Level	Level1	Level2	Level3
A) FXP Design	Design1	Design2	-
B) FXP Material	CR1	HR4	DP500
C) Sheet Thickness (m)	0.0015	0.002	0.0025
D) Cushion Characteristic	CC1	CC2	CC3

Table1: Contributing factors with levels

Standard L9 table is selected from Taguchi's set of orthogonal arrays for DoE [4-5]. L9 table is suitable for up to 3 levels of 4 factors.

Taguchi's L9 table for the considered study is shown below in Table 2.

Run	Factor A	Factor B	Factor C	Factor D
1	Design1	CR1	0.0015	CC1
2	Design1	HR4	0.002	CC2
3	Design1	DP500	0.0025	CC3
4	Design2	CR1	0.002	CC3
5	Design2	HR4	0.0025	CC1
6	Design2	DP500	0.0015	CC2
7	Design1	CR1	0.0025	CC2
8	Design1	HR4	0.0015	CC3
9	Design1	DP500	0.002	CC1

Table 2: Run plan

RESULTS & DISCUSSION

The Pareto chart (Fig 6) and Main effect plot (Fig 7) illustrates the contribution of design variables on FXP deformation. Cushion stiffness and thickness has significant effect on the FXP deformation.

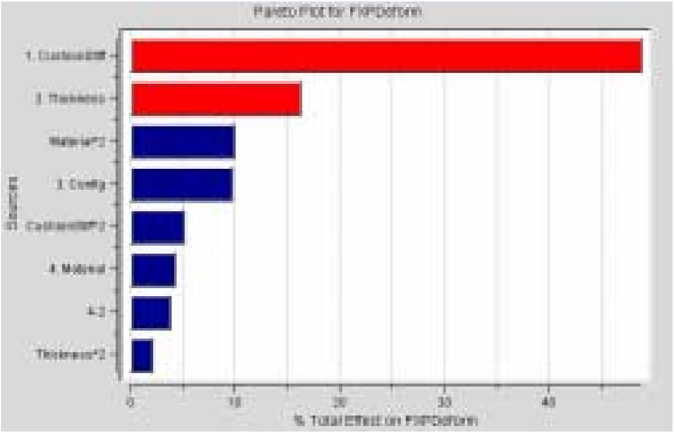

Fig. 6: Pareto chart for FXP deformation

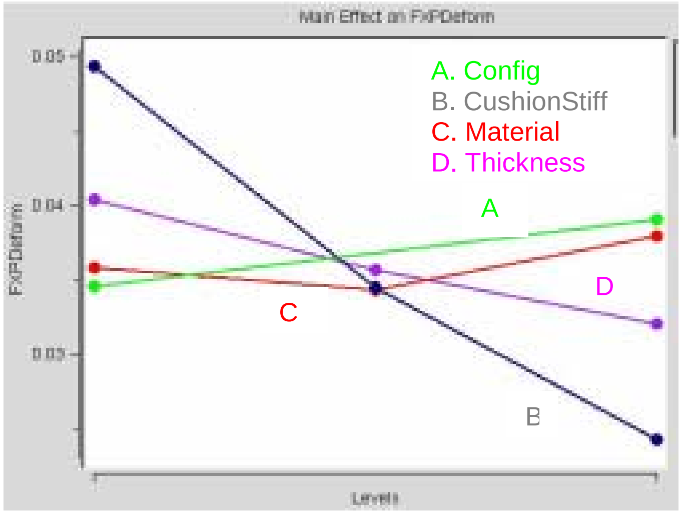

Fig. 7: Main Effect Plots for FXP deformation

The Fig 7 indicates the materials CR1 and HR4 give almost same FXP deformation. However, CR1 is cost effective and hence selected as FXP material. It is found that the cushion stiffness has the linear effect on the response (FXP deformation). Design 1 of FXP is found to be stiffer.

It is found that higher thickness results in lesser FXP deformation with undesirable increased pelvis acceleration. Studies show that pelvis acceleration should be less than 76g to avoid the abdomen injuries. Challenge was to trade-off thickness of FXP for FXP deformation (parameter affecting submarine directly) and pelvis acceleration. Fig 8 shows the plot for FXP deformation and Pelvis acceleration against FXP thickness.

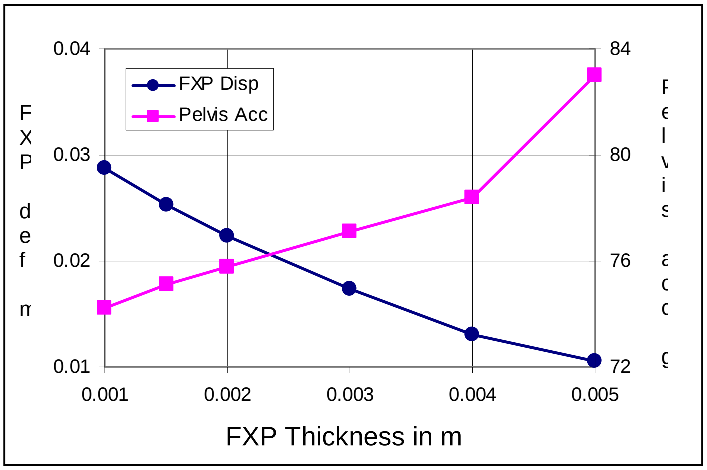

Fig. 8: Thickness optimization

As shown in Fig. 7, the FXP thickness of 0.002 m will limit the pelvis acceleration below 76g. This thickness will results in 0.0224 m of FXP deformation. Current design of FXP gives 0.036 m deformation with 74g pelvis acceleration. Hence, approx. 36% reduction in FXP deformation is achieved without scarifying the pelvis acceleration significantly.

CONCLUSION

In the present work the anti-submarine performance of a seating system has been studied. MADYMO and iSIGHT tools have been effectively deployed in the complex DoE problem. This design study has given the following combination of system variables for best performance and cost effective solution.

FXP Thickness = 0.002 m

FXP material = Cold rolled Steel (CR1)

FXP Design = Design1

These settings hold well with seat of cushion characteristics CC3.

MADYMO made it possible to complete this complex exercise in short duration. Average machine time for each run is around 10 minutes with 440 Hz PA8500 processor of HP J5000 UNIX system as compared to 15+ hrs for LS-DYNA on same hardware.

A methodology of arriving at a suitable combination of design parameters to achieve a favorable occupant response and seating performance is highlighted in this paper. A case study of seating system under-structure has been used to illustrate.

This methodology can be extended to optimize the structures at system/sub system level for different injury indices in different crash conditions.

This work illustrates the immense benefit of quick assessments for virtual simulation and prototyping through CAE.

Use of such tools and techniques coupled with experience on handling such tasks, would help the automotive design community.

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