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TAGUCHI BASED DESIGN OPTIMIZATION OF SIDE IMPACT BEAM FOR ENERGY ABSORPTION

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Abstract:-*Side impact collisions are the second leading cause of death and injury in the traffic accidents after frontal crashed. Side impact beams are used in the doors to absorb the impact energy and reduce depth of door intrusion, thus help protect the occupant. In a full vehicle test of side impact against a pole, the intrusion characteristics of the complete door assembly are assessed. 'Side impact beams' plays a major role in the behavior of the complete door assembly. In this work, three different cross-sections of the side impact beam are considered. FEA models have been developed to perform three point bend test (quasi-static load test). All investigations are performed using LS-DYNA explicit finite element code. The energy absorption characteristics of different designs are assessed and compared. Optimized parameters are determined by using Taguchi method. Optimal design of 'side impact beam' which is best performing for anti-intrusion is determined.*

Keywords:-crashworthiness, design optimization, side door beam, side impact, taguchi method.

1. INTRODUCTION

Traffic accidents are one of the leading causes of mortality in modern society. Car safety becomes the most important issue immediately in the development of the automobile. Injuries due to road accidents are a problem that can be controlled considerably if adequate attention is given to accident and injury prevention strategies. Therefore, car manufactures now incorporate a wide range of passive safety devices and feature into their vehicles, including airbags, energy-absorbing steering columns, side door beams, etc. Notably, side impact collisions are the second leading cause of death and injury in the traffic accidents after front crashes. Unlike a frontal collision, side-impact collisions are particularly dangerous; that is, the space between an occupant and the side of the vehicle is minimal. There are bumpers, engine and so on to help absorb the energy of the impact in a frontal impact. Hence, occupant has very little protection when a vehicle is struck on its side. To develop a sage and effective passive safety devices are essential for reducing occupant injuries in a side-on crash[1].

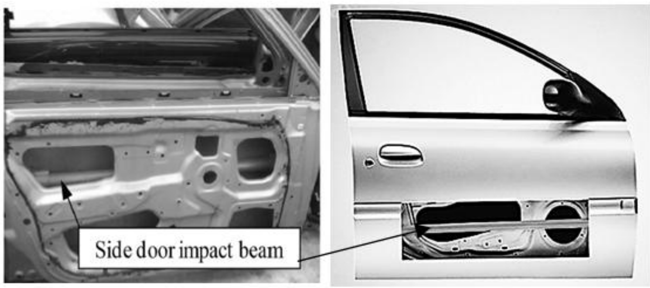

Figure 1: 'Side Door Beam' In Vehicle Front Door[1]

During the test of side impact against a pole, a car is fixed on the special carriage and is pushed against stationary fixed pole at the speed of 29 km/h. The car with a dummy in driver's seat is directed towards the pole in such way, that it were in one plane with driver's head. The 254 mm diameter pole during the impact intrudes into the car cabin. [1, 11]

Vehicles safety is characterized by various tests and regulations, but none of them defines strength characteristics of side doors anti-intrusion beams. To determine the anti-intrusion behaviour of the side door beam, a static load test is to be performed as shown in below image. [1]

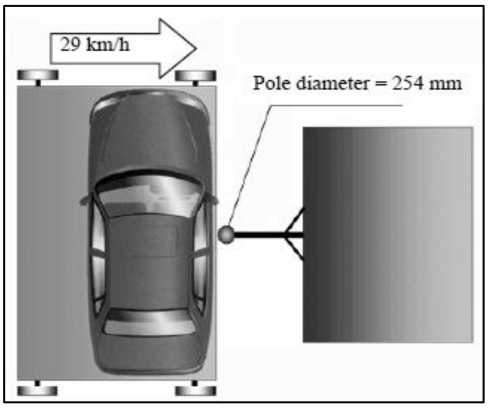

Figure 2: Test of Side Impact To The Pole, According To Euro-NCAP [1, 11]

A three point bend test of the side-door beam punched with a rigid pole was set up. The numerical simulations were carried out using the software LS-DYNA. The design variables are material and cross section of the side door beam. Attention was focused upon finding an optimum cross- section shape of the beam in order to improve the energy absorption character.[1]

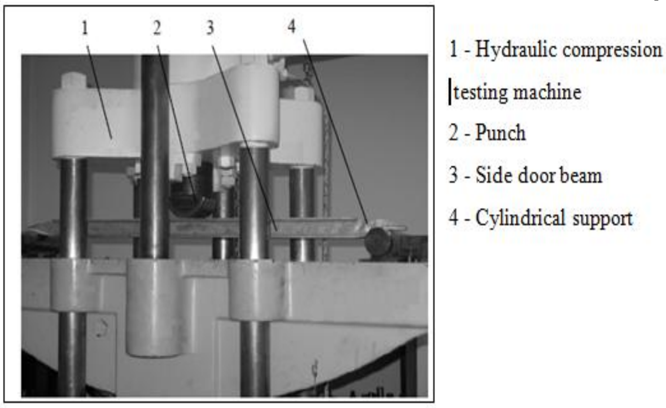

Figure 3: Beam Anti-intrusion Characteristics Testing Equipment [1]

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2. PROBLEM STATEMENT AND OBJECTIVE

2.1 Problem Statement:

Occupant has very little protection when a vehicle is struck on its side. Vehicles safety is characterized by various tests and regulations, but none of them define strength characteristics of side doors anti-intrusion beams.

Different designs of side door beam exist in current cars, which have different energy absorption characteristics. By performing a three point bend test (static load test), the anti-intrusion behaviour of the different designs is to be assessed and compared.

2.2 Objective:

The objective is to perform a three point bend test (static load test) on side door beams with different cross-sections to:

1. Identify the design (cross-section) of side door beam with best specific energy absorption characteristics.
2. Identify the sensitivity of the side door beam to magnitude of load and punch location.

3. METHODOLOGY

1.1 Taguchi Methods

Dr. Genichi Taguchi is a Japanese statistician and Deming prize winner who pioneered techniques to improve quality through robust design of products and production processes Taguchi describes a continuous Loss Function that increases as a part deviates from the target, or nominal value. The Loss Function stipulates that society's loss due to poorly performing products is proportional to the square of the deviation of the performance characteristic from its target value [13].

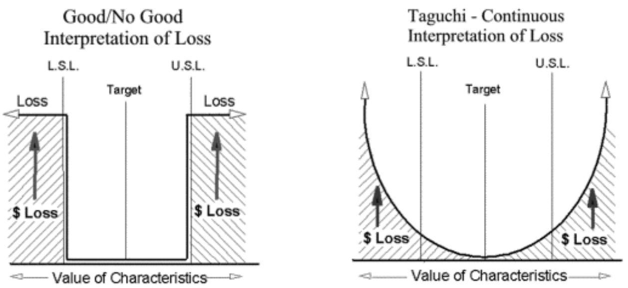

Figure 4: Loss Function, Traditional vs Taguchi[13]

3.1.1 Definition:

Taguchi has envisaged a new method of conducting the design of experiments which are based on well-defined guidelines. This method uses a special set of arrays called orthogonal arrays. These standard arrays stipulate the way of conducting the minimal number of experiments which could give the full information of all the factors that affect the performance parameter. [13]

3.1.2 Designing an Experiment by Taguchi Method

The design of an experiment involves the following steps

1. Selection of independent variables
2. Selection of number of level settings for each independent variable
3. Selection of orthogonal array
4. Assigning the independent variables to each column
5. Conducting the experiments
6. Analyzing the data
7. Inference

3.1 Simulation Setup Overview:

Side impact beam is modelled with first order shell elements, element formulation-16 (Fully integrated shell).

The Loadcase set up used in FEA simulation used to determine the anti-intrusion behaviour of the side door beam:

1. The side door beam is supported on 2 rigid cylinder supports of 40 mm diameter. They are constrained in all 6 degrees of freedom.
2. The side door beam is connected to the support cylinders by 'Extra Node option', to simulate the welding.
3. A punch of diameter 100 mm is used, which intrudes into the side door beam. It is fully constrained in other 5 degrees of freedom.
4. Surface to Surface Contact is defined between
   i. 'Punch' to 'Side door beam'
   ii. 'Cylinder supports' to 'Side door beam'

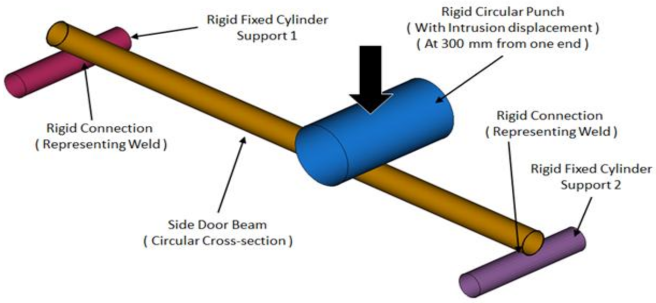

Figure 5: FEA Loadcase to Determine Characteristics of Side Door Beam

3.2 Design Parameters:

Material Name: AISI 1080	
Young's Modulus, GPa	205
Poisson's ratio	0.28
Density, kg/m3	7860
Tangent modulus, Mpa	5669
Yield Strength, MPa	869

3.3.1: Material details:

Listed below are the details of the material used for 'Side door beam'.). Ls Dyna material Mat-24 (Piecewise Linear Plasticity) is used.

3.3.2 Independent design variables considered:

X1: Magnitude of Load

Listed below are the details of prescribed displacement given to the 'Punch' which intrudes into the 'Side door beam'

Profile number and punch displacement		
1	2	3
100 mm	125 mm	150 mm
Uniform punch speed of 2.0 mm/ms		

X2: Location of Load

Three different loading conditions are considered in this evaluation. The location of the intruding 'Punch' from one end of the 'Side door beam' is varied as listed below.

Profile number and punch distance from one end of 'Side door beam'		
1	2	3
300 mm	375 mm	450 mm

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X3: Cross-section details

Three different cross-sections of the side door beam are considered (Circular, Hat shape, M Shape) are shown in figure6 and figure7.

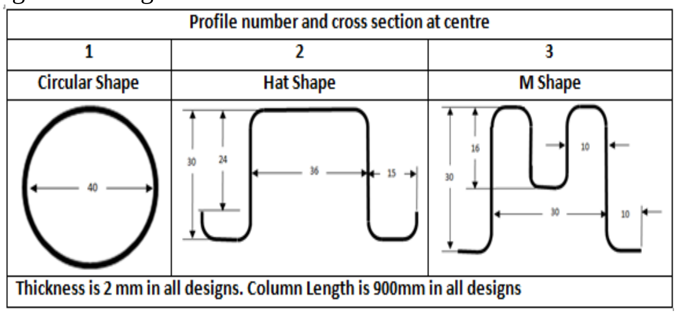

Figure 6: Cross Section Details of Side door beam

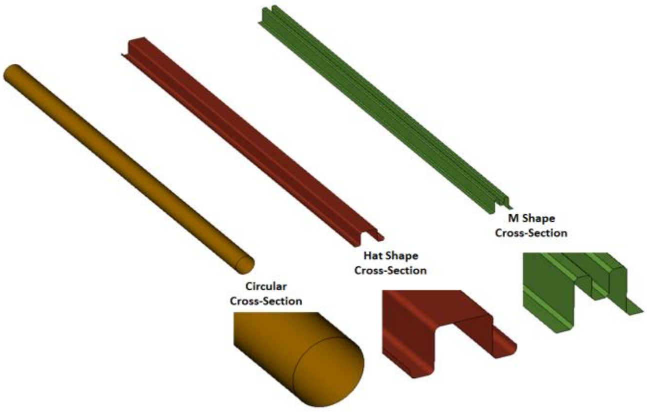

Figure 7: Cross Section considered for door beam

3.3.3 Variable Parameters overview

The variable design parameters and their levels are listed in table-1.

Table 1: variable design parameters

S No	1	2	3
Independent Variables	Cross-section of beam	Location of Punch (from end of beam)	Punch Displacement
Level 1	Circular	300 mm	100 mm
Level 2	Hat Shape	375 mm	125 mm
Level 3	M Shape	450 mm	150 mm

4. FEA Results, Material AISI 1080

Simulation results are listed in Table-2.

Table 2: Simulation Results, Material AISI 1080

$L_9 (3^3)$ Orthogonal array								
		Independent Variables			Outptut Parameters			
		Variable 1	Variable 2	Variable 3	P1	P2	P3	P4
Exp No	Material	Beam Cross Section	Location of Punch	Punch Displacement	Weight (KG)	Energy Absorbed (J)	Specific Energy Absorption (J / KG)	Reaction Force (KN)
A1	AISI 1080	1	1	1	3.55	3280	924	75.6
A2	AISI 1080	1	2	2	3.55	5120	1442	99.1
A3	AISI 1080	1	3	3	3.55	7880	2220	124.0
A4	AISI 1080	2	1	2	3.60	7090	1968	131.0
A5	AISI 1080	2	2	3	3.60	9870	2740	148.0
A6	AISI 1080	2	3	1	3.60	3570	991	75.5
A7	AISI 1080	3	1	3	3.65	10600	2904	162.0
A8	AISI 1080	3	2	1	3.65	3600	986	83.0
A9	AISI 1080	3	3	2	3.65	5870	1608	101.0

4.1 Von Mises Stress Plot, Circular Beam:

Deformation pattern and Von Mises stress of side door impact beam with 'Circular' cross section are shown in figure8.

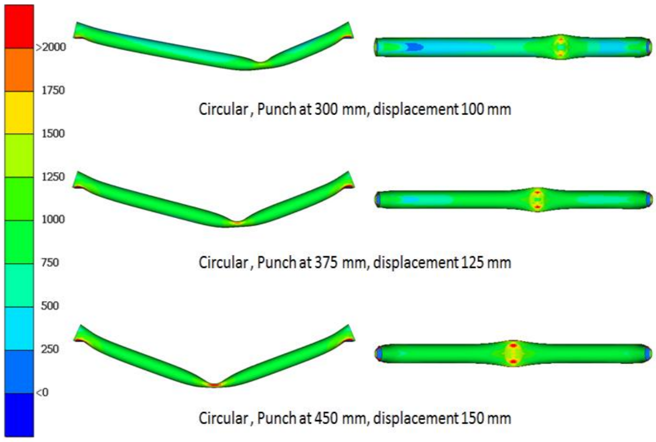

Figure 8: Von Mises stress (MPa), Circular Beam

4.2 Von Mises Stress Plot, Hat Shape Beam:

Deformation pattern and Von Mises stress of side door impact beam with 'Hat' shape cross section are shown in figure9.

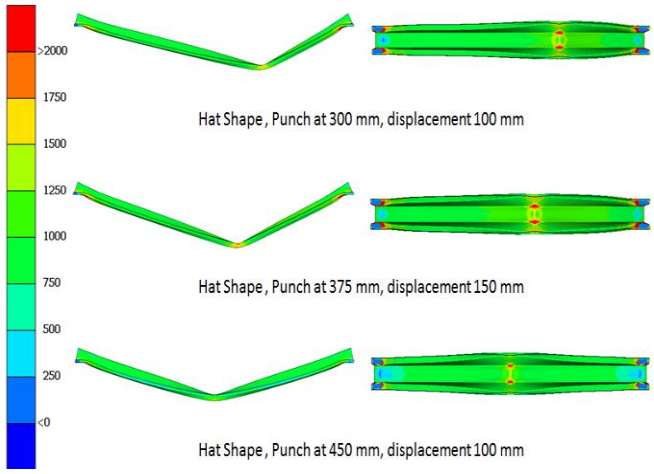

Figure 9: Von Mises stress (MPa), Hat Shape Beam

4.3 Von Mises Stress Plot, M Shape Beam:

Deformation pattern and Von Mises stress of side door impact beam with 'M' shape cross section are shown in figure10.

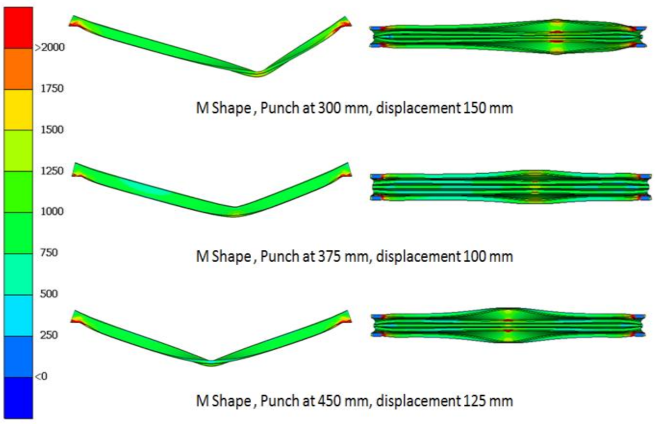

Figure 10: Von Mises stress (MPa), M Shape Beam

4.4 Curve Plot of Energy Absorbed:

The figure-11 shows the 'Internal Energy absorbed' in the load cases of circular cross section beam.

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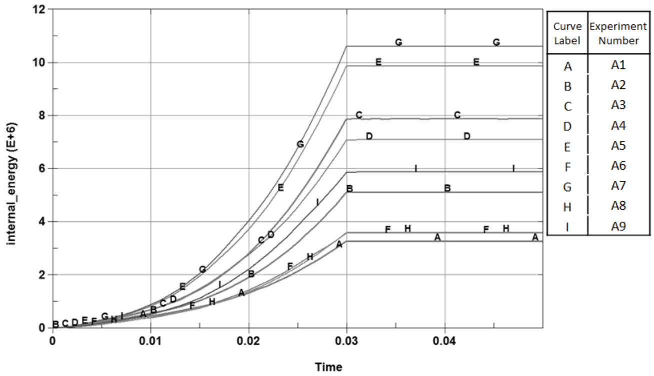

Figure 11: Curve Plot of Internal Energy Absorbed

4.5 Calculation of Factor Averages:

$$\text{Average effect of a factor} = \frac{\text{Sum of all results containing the effects of the factor}}{\text{Number of results included in the sum}}$$

Factor averages of the 3 variables are denoted by 'Vij', where
'i' is variable number
'j' is variable level
From Table-5, the result P3 for experiments A1 to A9 be denoted by Y1, to Y9
Calculations of 'Variable 1' (beam cross section) factor averages,
V11 = (Y1+Y2 + Y3) / 3 = (924 + 1442 + 2220) / 3 = 1529
V12 = (Y4+ Y5 + Y6) / 3 = (1968 + 2740 + 991) / 3 = 1900
V13 = (Y7+ Y8 + Y9) / 3 = (2904 + 986 + 1608) / 3 = 1833
Calculations of 'Variable 2' (Location of Punch) factor averages,
V21 = (Y1+ Y4 + Y7) / 3 = (924 + 1968 + 2904) / 3 = 1932
V22 = (Y2+ Y5 + Y8) / 3 = (1442 + 2740 + 986) / 3 = 1723
V23 = (Y3+ Y6 + Y9) / 3 = (2220 + 991 + 1608) / 3 = 1606
Calculations of 'Variable 3' (Punch Displacement) factor averages,
V31 = (Y1+Y6+Y8) / 3 = (924 + 991 + 986) / 3 = 967
V32 = (Y2+Y4+ Y9) / 3 = (1442 + 1968 + 1608) / 3 = 1673
V33 = (Y3+Y5+Y7) / 3 = (2220 + 2740 + 2904) / 3 = 2621

4.6 Plot of Factor Average Effects:

The below figure-12 shows the 'Factor average effects' of the three independent variables.
Variable 1 (V1) - Cross-section of beam
Variable 2 (V2) - Location of Punch (from end of beam)
Variable 3 (V) - Punch Displacement

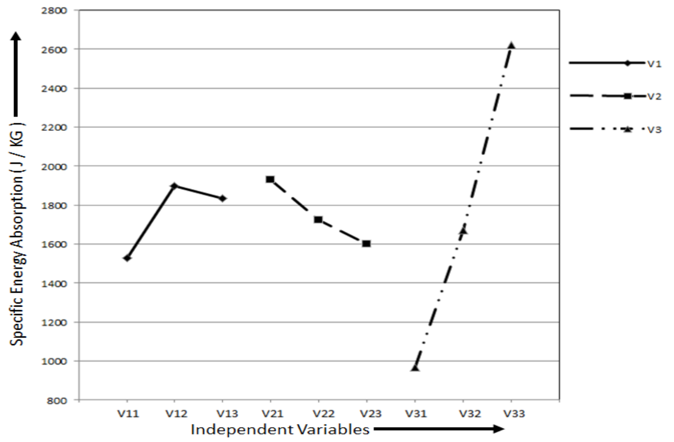

Figure 12: Curve Plot of Factor Average Effects

5. CONCLUSION

From graph shown in figure-12, the following conclusions are made:

1. 'Hat Shape' and 'M Shape' cross section beams have higher 'Specific energy absorption' compared to the traditional used 'Circular' cross section beams.
2. 'Hat Shape' cross section beam has the best energy absorption characteristics.
3. Performance of side door beam is sensitive to location of punch. At punch location of 450 mm, energy absorption is minimal.
4. Performance of side door beam is very highly sensitive to punch displacement. At punch displacement of 100 mm energy absorption is minimal.
5. Minimum absorption of energy by side impact beam is observed in load case with punch located at 450mm from one end, and punch displacement of 100 mm.

REFERENCES

[1] 'Investigation of anti-intrusion beams in vehicle side doors' by E. Cerniauskas, A. Kersys, V. LukoSevicius, J. Sapragonas. Mechanika2010.

[2] 'Optimization of Circular Side Door Beam for Crashworthiness Analysis' by Raja Sharmi Raja Husin, NurLiyana TajulLile, Sazali Yaacob. International Journal of Advanced Science Engineering Information Technology, Oct 2009.

[3] "Modelling, Analysis and Comparative Study of Side Impact Beam" by HarijonoDjojodihardjo, Soo Lin Khai. International Journal of Engineering and Innovative Technology (IJEIT), November 2013

[4] 'Crashworthiness evaluation of side-door beam of vehicle' by T. L. Teng K. C. Chang, T.H. Nguyen. Technische Mechanika October 2007.

[5] "Reliability-based design optimization for crashworthiness of vehicle side impact" by B.D. Youn, K.K. Choi, R.-J. Yang, Gu. Springer-Verlag, Struct Multidisc Optim, 2003

[6] "Preliminary Design of Side Door Impact Beam For Passenger Cars Using Aluminium Alloy" by Mohd , Rafidah Hassan. Center of Advanced Research on Energy, Universiti Teknikal Malaysia Melaka, June 2013

[7] "Simulation of Square Beam Subjected to Side Impact" by A. Farhaninejad, Rizal. Zahari, Barkawi. B. Sahari, Faieza. Abdul Aziz, E. Rasooliyazdi. Proceedings of the World Congress on Engineering and Computer Science 2012 Vol II, October 24-26, 2012

[8] "The Application of Energy Absorbing Structures on Side Impact Protection Systems" by James Njuguna. International Journal of Computer Applications in Technology 2011.

[9] "Optimisation of side impact bar for crash worthiness" by Chien-Hsun Wu, Ching-Pei Liang, Jaw-Haw Lee. SAE International 2005

[10] "Investigation on Hot Stamping Process for Door Beam of Ultra-High Strength Steel" by Hong Xu, Mourui Zhang, ZhengweiGu, Xin Li. International Journal of Engineering Science and Innovative Technology (IJESIT) January 2014

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[11] "Safety Companion 2014" from 'https://www.carhs. de/en/files/carhs/css/images/favicon.ico

[12] "Pole Side Impact, test explained" from 'Euro NCAP.com"

[13] "'Chapter 2 Introduction to Taguchi Method" from 'www.ecs.umass.edu'.