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Experiment and Simulation Correlation of Steel Ball Impact Test on Clothes Washer Console

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Abstract - **Dynamic analysis of clothes washer console is required to determine its strength under accidental free falling weight. This study focuses on impact analysis of clothes washer console. Free falling steel ball of 0.535 kg weight is dropped on clothes washer console from a specified height, meanwhile acceleration is measured at specific location. High degree of non-linearity is involved during the steel ball impact which includes non-linearity due to material and geometry. Due to which analytical calculations are insufficient for predicting the strength. Hence the objective of the work was to generate experimental data for correlation with the impact simulation. Experimental Steel ball impact testing was done on the console, a 3-dimensional finite element model of the washer console was developed and an impact simulation was performed in LS-Dyna solver.**

Keywords —* *Comparison of experimentation and simulation, Dynamic Analysis, Impact, LS-Dyna, Steel Ball Test, Washer Console

I. Introduction

Console of washing machine is one of the significant parts of a clothes washer. The Console assembly belongs to the Aesthetics section of the washer. Console is a subsystem that interfaces between the user and the machine to select various options for washing viz. wash cycle, cycle time, water level, soil level, etc. Thus the console assembly enables the user to control the modes of operation of the washer. Though it is aesthetic part still its design based on structural strength is important. The washer console is the outer most part in contact with the surrounding. Hence it must have sufficient strength not only to sustain the effect of the interior functions but also the effect of environment around it. The Console is susceptible to various mechanical loads especially impact throughout its entire product life. Thus in order to withstand these loads the Console is subjected to a number of Product safety tests.

In order to confirm product safety UL has specified some standards for home appliances. Underwriters Laboratory abbreviated as UL works with customers and stakeholders to support the responsible design, production, of products and innovations of today and tomorrow. Each and every system of home appliance machine has to pass the given UL test. As per the UL Standards the component belonging to Console assembly primarily designed as per aesthetics requirements but at the same time it has to be strong enough to withstand the loading condition given in UL2157 standard [9]. The parts or System which belongs to the Console Assembly must be sufficiently strong enough.

Various product safety tests specified by the UL are conducted on the aesthetic parts like the console, door, Cabinet, etc. One of the important tests enlisted under the Product Safety Tests is the 6.8J Ball Impact Test.

It is difficult to quantify the stresses and strain generated due to impact on the parts like the console experimentally or analytically due to significant part, measurement and material complexity. Hence the impact analysis can be quantified in some measureable quantities like acceleration history data and can be correlated with significant accuracy.

From literature survey it is observed that for impact analysis difference in experimentation and numerical simulation results is 10 to 15 percent, but no research has been done on impact analysis of clothes washer console. Moreover no standard success criteria of correlation are defined for replacement of experimentation with numerical simulation. So the objective of study is to Correlate Impact test and Numerical simulation of impact tests of clothes washer so this correlation can be useful as a basis for simulation of other similar impact test, thus reducing the need for impact test.

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II. LITERATURE SURVEY

In the paper named 'Crash Simulation of a Vertical Drop Test of a B737 Fuselage Section with Overhead Bins and Luggage', Karen E. Jackson and Edwin L. Fasanella[1] have generated the test data for correlating the experimental data with simulation model. The paper consists of description of the finite element model and an assessment of the analytical/experimental correlation. They had provided modifications to be done to improve the correlation results. The objective of the work is to correlate the experimentation data with the simulation.3-dimensional finite element model of the console was developed and an impact simulation was performed in LS-Dyna. An explanation of the finite element model and an assessment of the experimental correlation are presented. The simulation and experimental results were correlated with percentage error of 25%.

Fehmi Mullaoğlu, Fatih Usta, Halit S. Türkmen, Zafer Kazancı, Demet Balkan, Erdem Akay[2] in their paper titled as 'Deformation behavior of the polycarbonate plates subjected to impact loading' investigated the dynamic response of polycarbonate plates subjected to the projectile impact in different velocities. In this study a numerical analysis was carried out by the plate clamped at all edges and the impacting steel projectile was modeled as a rigid body. Penetration and perforation characteristics of polycarbonate plates were examined for different locations of the plates. Thus, maximum plastic strain, stresses energy absorbed, and von Mises by the plate were calculated. The simulation results were evaluated and discussed in detail. The variations of plastic strain, deformations, and stresses with respect to impact velocities were studied. The experimental investigation concluded stating the maximum plastic deformation was observed at the constrained edges as compared to the plate center. Due to rigid constraint the transverse plate deflection was minimized and all the projectile energy was consumed in local material deformation that results in a dent near to the plate edge.

In the report of PCB Electronics named "IMPACT AND DROP TESTING", [3] they had provided the calculations based on which the force sensor can be chosen. Newton's II law of motion or work/energy principle was used to evaluate the value of energy being imparted by the impacting object to the affecting object. Test data shows that Newton's math model can be used to select the proper capacity of force sensor.

In the paper, "Drop test and crash simulation of a civil airplane fuselage section" cited by Liu Xiaochuan, Guo Jun, Bai Chunyu, Sun Xiasheng, Mou Rangke[4] have studied crashworthiness of a civil airplane fuselage section. They have performed the drop test of civil airplane fuselage section at specified speed. The paper consisted of finding the relations between the loading speed and the average ultimate shear, tension loads and was represented by logarithmic functions. Numerical simulation of the drop test was performed by using the LS-DYNA. A correlation was setup between experimentally and simulation acceleration for the aircraft fuselage section. Deformation of the structure and acceleration at typical locations were measured. The crash kinetic energy absorbed by plastic deformation and several structural failures were spotted.

Oguzhan Mulkoglu, Mehmet A. Guler, Hasan Demirbag in their paper named, "Drop Test Simulation and Verification of a Dishwasher Mechanical Structure", [8] have performed vertical and inclined drop test analysis of the dishwasher. Critical regions in the design were found by conducting experimentation as well as simulation in LS-Dyna. The analysis focused at developing FEA model of the dishwasher to analyze the drop test behavior. Deformation characteristics of packaging material were studied.

III. SUMMARY OF EXPERIMENTATION DETAILS

Experimentation was done at Whirlpool of India lab in Pune. The experimental results obtained were used for correlation with numerical simulation. Experimentation is carried out according to UL746 standard which is for electrical parts of the home appliances like washing machine console, door, etc. Underwriters Laboratory Standards Inc. (UL) is an independent non-profit organization providing global conformity assessment programs and services. UL is a world leader in standards development. UL is recognized for its unrivalled technical expertise. UL's standards for safety are used to evaluate and certify products and system. These standards for safety are useful for manufactures to help them design products and system to meet the requirements for certification. There are regulatory authorities like UL, ANSI, CSA, and ASTM etc. who review the standard requirements to determine what products and systems are to be used.

Experimentation was done on the clothes washer console to gather acceleration data during steel ball impact testing. The experimental setup was as shown in the figure 1. Acceleration was measured at a specific location. It was not possible to attach accelerometer exact below the impact location due to risk of damaging the accelerometer sensitivity. Hence the accelerometer was located at specified location from point of impact and acceleration has been measured.

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Figure 1: Experimental Setup

The accelerometer positions are as shown in the figure 2. The accelerometer A1 was placed at 105mm from knob centre and 148mm from the bottom surface of fascia. The accelerometer A2 was placed at 240mm from knob centre and 95mm from the bottom surface of fascia.

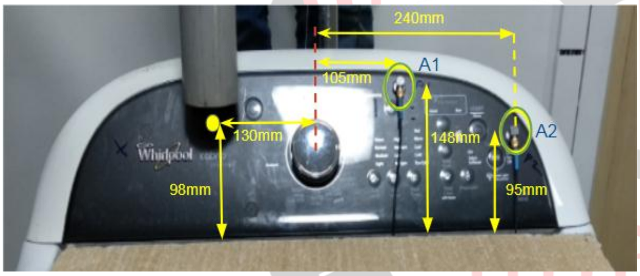

Figure 2: Accelerometer mounting and Ball Impact Position

UL specified steel ball was used for testing purpose. The steel ball has mass of 0.5 kg and diameter of 50.4mm [7]. To change the impact energy during testing based on the energy calculations, the pipe consisting of holes at specific height locations was used as shown in the figure 3. Half a kg mass is freely dropped on the console twice from the heights of 7.5-in and 10-in respectively as shown in the figure 3. Location for impact as shown in the figure 2 was at 130mm from knob centre and 98mm from the bottom surface of fascia. Three experimental runs were conducted for each of the two heights. Initially the steel Ball was inserted inside the pipe and positioned at a particular height using a retention pin. The pipe was held over the desired impact location onto the console. The retention pin was removed from the hole so that the steel ball drops at intended location. The above procedure was carried out for different ball drop heights of 7.5-in and 10-in.

Figure 3: Ball guide pipe

Figure 4: Accelerometer axes orientation

The tri-axial accelerometer axes were aligned in the three directions as shown in the figure 4. X axis of the accelerometer was aligned lateral to fascia in vertical direction. Y axis of the accelerometer was aligned lateral to fascia in horizontal direction. Z axis of the accelerometer was aligned normal to Fascia.

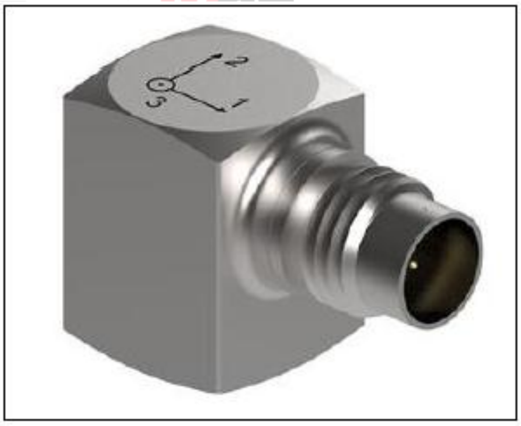

Figure 5: Tri-axial accelerometer

Accelerometer is a device used for acceleration measurement in number of fields such as industry, transport, engineering etc. In engineering commonly accelerometer was used for measurement of vibrations in different systems. Dytran model 3023A2 tri-axial accelerometer was used for experimentation purpose as shown in the figure 5. This accelerometer was available with 10mV/g sensitivity, accessories of model 6200 mounting stud, 4-pin connector, 10-32 tapped hole mounting provision etc.

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Figure 6: DAQ System

The LMS DAQ system with 8 ports for input interface of accelerometer was used for recording of the acceleration as shown in the figure. It processes the data and acceleration results were available in the form of graphs on computer screen. The output obtained from DAQ was in terms of g value.

IV. FINITE ELEMENT MODELING

This study uses the LS-DYNA for simulation of impact analysis of dynamic loading on washing machine console. Acceleration can be enumerated and analyzed in detail which is very difficult in real testing and in analytical method. CAD modeling of the washing machine console assembly was done in Creo 3.0 Parametric.

Table 1: Materials for Console Assembly

Components	Material description
Console Shell	MP 101 PVC RIGID
Top Panel	STEEL, CR - EDDS PER ASTM A1008M
Knob	ABS
Fascia	POLYMER DS1910 HF
PCB	FR4
PCB Tray	PC-ABS
Rigid Ball	Steel

A. *Meshing and Contact Definition Details*

HYPERMESH-14 software is used for meshing of the console assembly. Table 1 enlists the materials of various parts in the console Assembly. The parts listed in above Table 1 are solid parts except the Top Panel. The Top Panel was meshed with 2-D Quadrilateral element [5]. The hexahedral mesh is adopted to simulate solid steel ball. All the other parts except for the Top Panel and the Steel Ball were meshed using tetrahedral elements. Screw connections were meshed with 1-D rigid elements. For reliability and accuracy of finite element simulation result, several methodologies were adopted during the modeling and validation process. The triangular element and pentagonal solids were mostly avoided due to their higher stiffness. PVC was modeled by specifying multilinear stress-strain curve. All the materials except PVC was modeled with *MAT_024 (*MAT_PIECEWISE_LINEAR_PLASTICITY). This is Material Type 24 in LS-DYNA finite element code. The stress strain behavior was treated by a bilinear stress strain curve by defining the tangent modulus, ETAN [10]. The properties required to be specified in model are RO (Mass density), E (Young's modulus) PR (Poisson's ratio) SIGY (Yield stress) [6].

Frictional contacts were modeled using *CONTACT AUTOMATIC SINGLE SURFACE card. This card needed to be provided with static coefficient of friction, dynamic coefficient of friction and viscous damping to generate proper contact forces.

B. *Boundary Conditions*

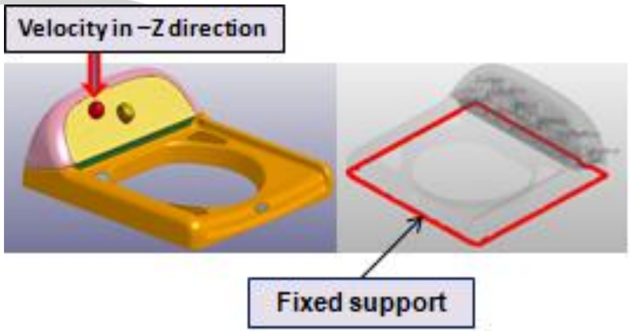

Figure 7: Loading and Boundary Conditions

In actual testing 0.525 kg mass is dropped from 7.5 inch and 10 inch height. Hence velocity was calculated by $v=\sqrt{(2gh)}$ and applied to rigid mass in negative Z direction. So in simulation we placed the steel ball just 1mm above the console and velocities of 984 and 1312 mm/s^2 were provided to the ball. This minimized the calculation time during free falling mass in simulation. FE model with loading and boundary conditions are shown in figure 7. Loading and boundary condition are simulated as same as that in testing. Velocity is assigned to all nodes of steel ball. All degrees of freedom are set to zero for nodes which have fixed support of the top panel. Local coordinate system with Z axes normal to the fascia part was generated in the model and acceleration was found in that direction.

V. RESULTS AND DISCUSSION

A. *Experimentation Results*

Experimentation consisted of three trials for each height of 7.5-in and 10-in respectively. The output of the accelerometer was recorded as shown in the figure 8 below. The accelerometer provided the peak value at each impact.

The variation in the Z-acceleration results is as shown in the figure 9.

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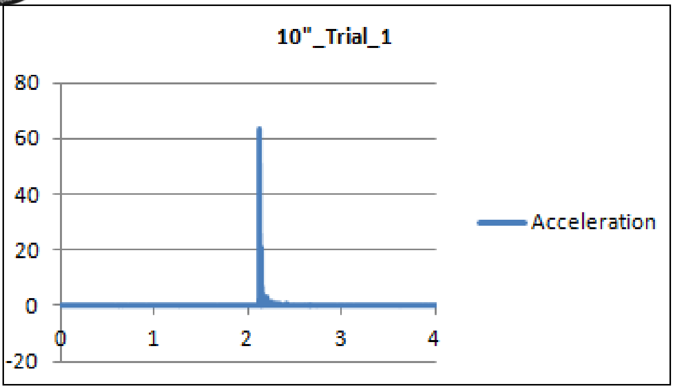

Figure 8: Accelerometer Output

As seen from the variability chart, the acceleration levels of the accelerometer have increased with the height of the impact. Similarly the accelerometer 1 has greater reading than the other as it was installed near to the impact.

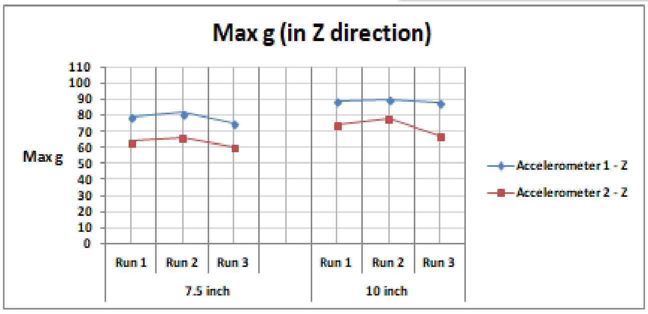

Figure 9: Variability chart

B. *Experimentation Results*

The acceleration contour for the console is as shown in fig below. In the fig. 10 contour of Z-acceleration at the point of impact is very high. The graphs of acceleration obtained from the simulation are as shown in the figures 11 and 12.

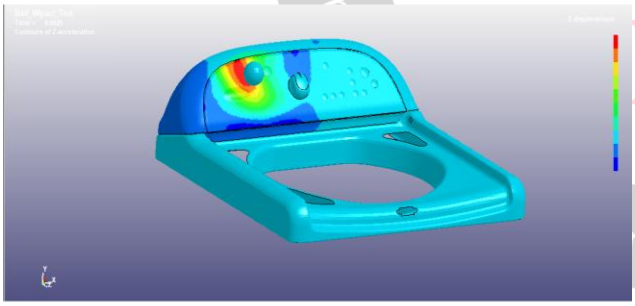

Figure 10: Z-acceleration contour

C. *Experimental and simulation Correlation*

The simulation acceleration time histories were correlated with the experimental data obtained from accelerometers located at the fascia. Figure and shows the correlation of the acceleration time history graphs. The experimental graphs which were obtained as an impact pulse were zoomed to get the exact pattern of the impact accelerations. These were compared with the simulation graphs.

The experimental graphs which were obtained as an impact pulse were zoomed to get the exact pattern of the impact accelerations. These were compared with the simulation graphs.

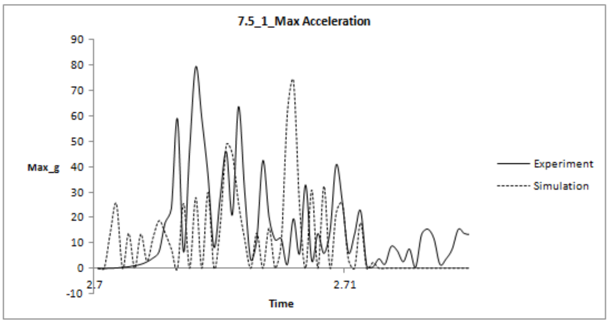

Figure 11: Accelerometer outputs at 7.5" drop height

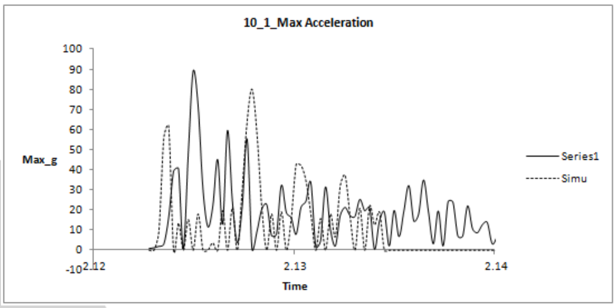

Figure 12: Accelerometer outputs at 10" drop height

Table 2: Experimental and Simulation - Error Percentages

Console Acceleration Error Percentage			
Drop Height		Accelerometer 1 - Z	Accelerometer 2 - Z
7.5 inch	Run 1	6.86	5.69
	Run 2	9.87	9.52
	Run 3	1.93	-0.20
10 inch	Run 1	10.21	12.75
	Run 2	11.17	14.62
	Run 3	9.20	6.32

The error percentages between experimental and simulations are shown in the above table. The maximum error could be seen in the second sample run of 10-in for accelerometer 2. The average error for FEA Simulation is 8.15%.

VI. CONCLUSION

The impact analysis of Console Assembly was performed to establish correlation between experimentation and numerical simulation. FE software LS-DYNA was used to develop finite element model of experimental tests. Results of this FE analysis were compared with lab test in Global Technology and Engineering Center, Whirlpool of India Pune. Acceleration measurement was carried out using triaxial accelerometers. From acceleration data obtained, it can be concluded that the acceleration levels increase with increase in the ball drop height. Thus, indicating that as the impact energy is increased the acceleration level also increases. Lab test and simulation results show average 8-10% of variation. Thus, FEA simulation and experimental steel ball impact testing show satisfactory correlation. Further investigation and study for making the material model will help to establish simulation as a standard process for such type of analysis.

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