Development and Analysis of Vertical Crisper For Refrigerator

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Abstract- *Crisper is the drawer which helps to keep fruits and vegetables at their best longer. Crisper is typically utilized to store fresh products including a wide variety of fruits and vegetables. Crisper also provides ample storage for items such as luncheon meats, cheese and eggs. Although necessary, because of the very function of these drawers, ensuring they are clean and sanitary at all times can be problematic, especially given the fact that foods stored "out of sight" are often "out of mind" long past the expiration date. Simply stated, foods left within a crisper for too long can quickly decompose, leaving behind a sticky and foul smelling liquid residue. Also, the existing crisper has poor space utilization i.e. if half of the crisper is loaded with food then half space is unused, it has poor accessibility to item stored at bottom and at the back of the crisper. This paper includes development and analysis of a new innovative vertical crisper to enhance the accessibility of food items stored at bottom or back of crisper, to achieve better clean ability and better space utilization. The very first step is concepts generation and evaluation of concepts using Pugh Matrix. Based on highest rating of configuration concept is selected and by using commercial software CAD drawing, simulation is carried out. Testing is carried out on prototype and results are validated.*

Keywords– Numerical simulation, refrigerator crisper, testing.

I. INTRODUCTION

Crisper is basically the drawer in the refrigerator which is utilized to store fresh produce including a wide variety of fruits and vegetables, crisper drawers also provide ample storage for items such as luncheon meats, cheese and eggs. It helps to keep the stored items fresh and preserve them to best longer. Although necessary, because of the very function of these drawers, ensuring they are clean and sanitary at all times can be problematic, especially given the fact that foods stored "out of sight" are often "out of mind" long past the expiration date. Simply stated, foods left within a crisper drawer for too long can quickly decompose, leaving behind a sticky and foul smelling liquid residue.

Presently the refrigerator crisper is poor in accessibility to food stored at back also it has poor space utilization and clean ability. The crisper is made up of transparent material mostly to ensure the clear view of the stored items in the refrigerator crisper. The commonly used material for the crisper is general purpose polystyrene (GPPS) which is of food grade.

Many researchers have carried out the work in the field of design and development of crisper. They proposed new concepts for greater storage space and ease of accessibility.

New configuration of crisper is presented by Nirbhay K. Bhatt and Rahul S. Dudhe [1]. The crisper assembly which they invented includes the support structure and one or more bins to be used to store the item. The guides are used to move the crisper in one direction. After the crisper totally stretched out the bins which are used to store the food items can be slides out partially. The bin is movable from closed position to open position outside the crisper assembly in the direction perpendicular to the motion direction of crisper. In patent "Refrigerator with Enhanced Freezer Compartment Access" David A. Peffley [2] has shown the new refrigerator with enhanced freezer compartment access. The objective of the invention is to provide a new a refrigerator with enhanced freezer compartment access that slides out of the refrigerator in order to have full access to the entire volume of the frame of the freezer. Even still another objective of the present invention is that to provide a new refrigerator with enhanced freezer compartment access that contains guide walls for holding items on racks. The guide walls are movable between a vertical and horizontal position for easy access to the racks.
James W. Lazenby [3] invention is relates to transparent rollout pantry system which is designed to work with any cabinet makers tall pantry cabinets. These pantry cabinets are also referred to in manufacturer's brochures as tall storage or utility cabinets. The system is a combination of vertical rollout units made using any transparent material, such as acrylic, that can be cut and fitted together and then fused to make a strong, self supporting and lightweight unit. Each unit is then supported with two heavy duty drawer guides who are placed at the base or top to carry vertical loads and at least one horizontal heavy duty guide at the opposite end to laterally stabilize the unit. Conventional drawer guides are used and

any conventional guide can be used that will carry the required load. By having a transparent unit and shelves only wide enough to typically support most pantry items, items stored can be easily seen without even rolling out a unit, and then can be easily reached by pulling out the appropriate unit containing the desired item. Clear rollout drawers are also part of the system and will be used in pairs above the rollout units. Drawers are used above rollout units in pairs as they have the advantage that, by being clear, of seeing items through the bottom of the drawer and by having the drawers in pairs, someone can extend one drawer at a one time and reach to the back of each drawer from the sides. This gives more drawer usage than full width conventional shelves.

To make the easy access of regularly used item and to provide pleasant appearance Yoshio Okada et.al [4] invented the rack assembly. In patent they presented the storage cabinet with front and rear rack which can slide in and out from the storage cabinet. They provided the drain pan at the bottom of the racks to collect the water drops from the items placed in the rack assembly.

For maximizing storage, accessibility and energy efficiency Craig Kettles [5] invented the new configuration of refrigerator. Craig Kettles invention provides one or more of the following features: (i) Side access to one or more refrigerated items, (ii) Ease of operation for the user, and (iii) enhanced energy efficiency. In patent named as crisper pan guide system for a domestic refrigerator, Kerry O. Austin et.al [6] described the crisper guide system for a domestic refrigerator. They used rollers and flanges for glides which are attached to the crisper. The only disadvantage of these guides is that they are not fully extendable.

From the literature it is summarized that, it is possible to increase the storage space, its usability and accessibility of the crisper by changing the design of existing crisper. According to authors the storage space and accessibility can be increased by providing side access to the stored food items. The authors also recommend fully transparent crisper to capture the stored items easily.

II. CONCEPT GENERATION AND SELECTION

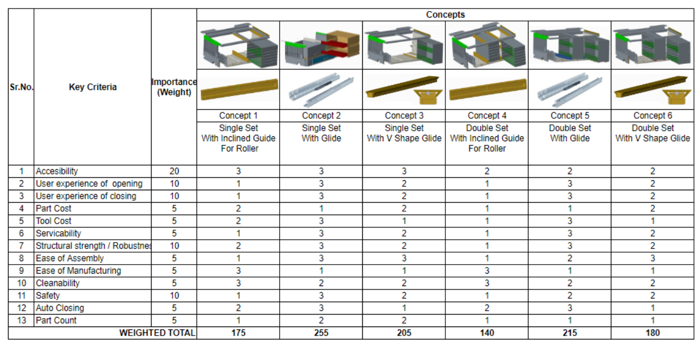
Concept generation is the most critical step in the engineering design process. A concept can be defined as "Concise description of how the product will satisfy consumer needs". Concept generation is a procedure that begins with a set of consumer needs and target specifications and results in an array of product concept design alternatives from which a final design will be selected.

Here the concepts are generated based on the number of sets and the sliding mechanism which can be used for the crisper. Table I show the different concepts which are generated for the crisper.

Table I. Different Concepts of Crisper

Sr. No.	Concepts
1	Single set with Inclined Guide For Roller
2	Single set with Metal Glide
3	Single set with V shape Glide
4	Double set with Inclined Guide For Roller
5	Double set with Metal Glide
6	Double set with V shape Glide

The Pugh matrix approach is used. It helps to determine which concept is more important or much 'better' than others. It is a scoring matrix used for concept selection in which various options are assigned scores relative to criteria. The selection is made based on the consolidated scores.



Sr.No.	Key Criteria	Importance (Weight)	Concept 1 Single Set With Inclined Guide For Roller	Concept 2 Single Set With Glide	Concept 3 Single Set With V Shape Glide	Concept 4 Double Set With Inclined Guide For Roller	Concept 5 Double Set With Glide	Concept 6 Double Set With V Shape Glide
1	Accesibility	20	3	3	3	2	2	2
2	User experience of opening	10	1	3	2	1	3	2
3	User experience of closing	10	1	3	2	1	3	2
4	Part Cost	5	2	1	2	1	1	2
5	Tool Cost	5	2	3	1	1	3	1
6	Servicability	5	1	3	2	1	3	2
7	Structural strength / Robustnes	10	2	3	2	1	3	2
8	Ease of Assembly	5	1	3	3	1	2	3
9	Ease of Manufacturing	5	3	1	1	3	1	1
10	Cleanability	5	3	2	2	3	2	2
11	Safety	10	1	3	2	1	2	2
12	Auto Closing	5	2	3	1	2	3	1
13	Part Count	5	1	2	2	1	1	1
	WEIGHTED TOTAL		175	255	205	140	215	180

Fig. 1. Pugh Matrix

From Pugh matrix concept 2 is selected as it has more score i.e. 255. Concept 2 is having the crisper which is accessible from the left side. The crisper has two crisper plates which slide in and out of the crisper as shown in Fig.2. In this concept use of two bottom mounted full extension glides is proposed rather than using the four guide ways and rollers. The slides used here are self closing type to ensure smooth closing experience of the crisper.

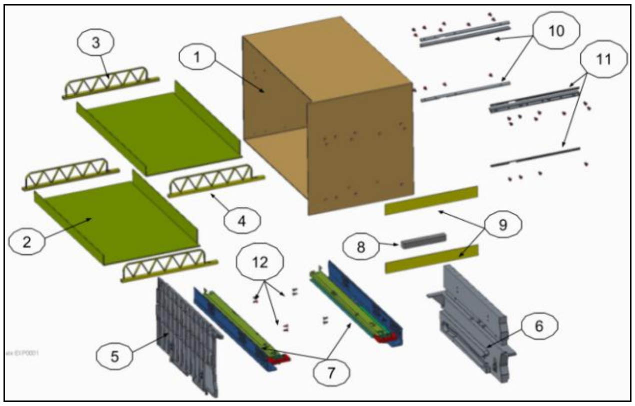


Fig. 2. Crisper Assembly with Exploded View

Table II. Part List and Materials

Sr. No.	Part
1	Crisper
2	Crisper Plate
3	Crisper Plate Side support LH
4	Crisper Plate Side support RH
5	Crisper Support LH
6	Crisper Support RH
7	Glide Pair
8	Handle
9	Decorative Film
10	Crisper Plate Slide support LH
11	Crisper Plate Slide support RH
12	Screw

Fig.2 shows the exploded view assembly of crisper concept which is selected using Pugh matrix and Table II describes the part list.

III. THEORETICAL ANALYSIS OF CRISPER

A. Screw Selection:

The vertical crisper assembly is mounted on the glides and the glides are attached to the left hand and right hand crisper support by means of four screws. So these screws plays important role in holding the crisper assembly and glides when the vertical crisper is stretch out of the refrigerator cabinet for use.

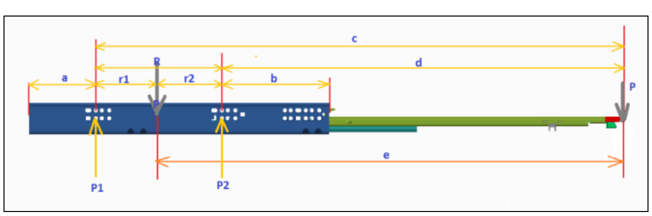


Fig. 3 Load Conditions and Reaction Forces on Glide

To design the screw the shear forces which are going to induce in the screws are need to be considered. Total four screws are used to hold the each glide. The total P Newton force is considered at the right end of the glide when it is fully opened.

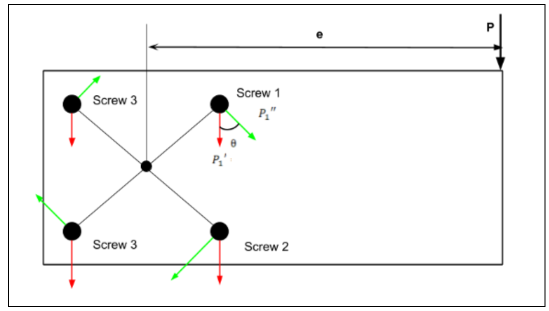


Fig. 4 FBD of Forces Acting on the Screw

The following notations are considered for the formulation which is referenced in Fig. 4.

P = Total force applied, (N)
P_1' or P_2' = Primary shear forces, (N)
P_1" or P_2"= Secondary shear forces, (N)
e = Distance between force applied and reaction force, (mm)
r_1 or r_2 = Distance between reaction force and primary shear force, (mm)
r = Distance of maximum stressed screw from center of gravity, (mm)
P3 = Resultant shear force, (N)
θ = Angle between primary and secondary shear forces, (degree)
τ = Permissible shear stress, (MPa)
S_{yt} = Yield strength of material, (MPa)
d_c = Core diameter of screw, (mm)
d = Nominal diameter of screw, (mm)

Shear forces induced in screws are splits into two i.e. Primary shear forces and Secondary shear forces which are denoted as $P_1{}'$ and $P_1{}''$ respectively as shown in Fig. 4.

The Primary shear forces are given by equation,

$$P_1{}' = P_2{}' = \frac{P}{N} \qquad (1)$$

The Secondary shear forces are given by equation,

$$P_1{}'' = P_2{}'' = \frac{P.e.r}{(r1^2 + r2^2)} \qquad (2)$$

Resultant shear force is the sum of primary and secondary shear forces which is given by equation,

$$P_3 = \sqrt{(P_1')^2 + (P_1'')^2 + 2P_1'P_1''\cos\theta} \quad (3)$$

Now permissible shear stress is given by,

$$\tau = \frac{0.5\,S_{yt}}{FOS} \quad (4)$$

Size of the screw is given by,

$$\tau = \frac{P_3}{A} = \frac{P_3}{\frac{\pi}{4}d_c^2} \quad (5)$$

Diameter of screw given by,

$$d = \frac{d_c}{0.8} \quad (6)$$

The diameter of the screw is calculated as 3.52 mm therefore M4 size screw is selected from the standard screws available in the market.

IV. SIMULATION OF CRISPER PLATE

A. Deflection of Crisper Plate Due to Static Load:

Numerical simulation for the deflection of crisper plate is carried out in the Ansys Workbench software. Rather than carrying out the simulation on whole crisper assembly only crisper plate is considered for simulation. Solid186 quadrilateral elements are used to mesh the assembly of crisper plate. Sweep method is used to mesh the crisper plate with 2 mm element size. Total 429810 nodes and 79106 elements are used to mesh the model. The final meshed model is shown in Fig. 5.

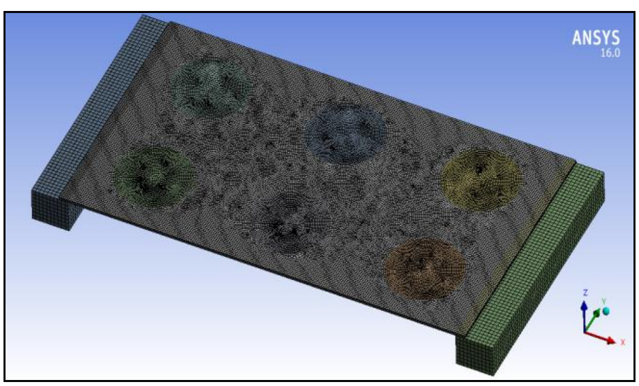


Fig. 5 Mesh Model (Simply Supported Crisper Plate)

Fig. 6 shows boundary conditions applied to crisper plate. The load is applied on the six patches of 80 mm dia. each as per the company standards. The right and left hand side supports are made fixed by fixing the upper surface of the supports. The contacts between plate and support used are frictional contact with 0.15 coefficient of friction applied.

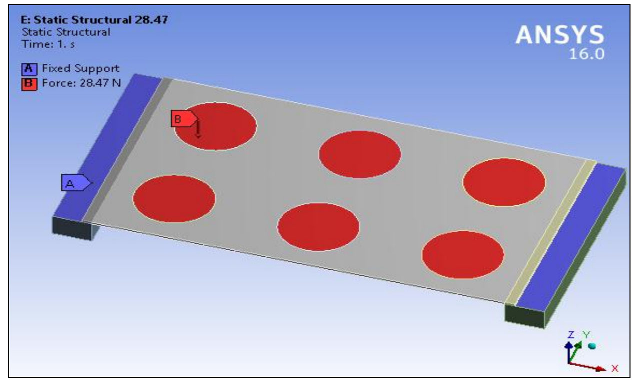


Fig. 6 Boundary Conditions for Simply Supported Crisper Plate

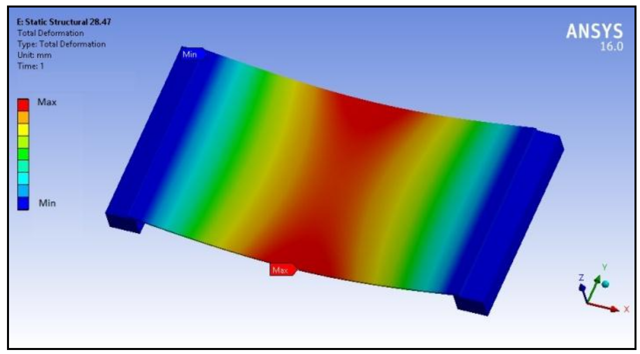


Fig. 7 Static Structural Analysis: Deflection Contour Plot for Simply Supported Crisper Plate

Simulation is carried out for three loads i.e. 8.9 N, 18.68 N and 28.47 N for both simply supported and cantilever load condition. The loads are decided based on the load carrying capacity of the crisper plate. The maximum load carrying capacity for one crisper plate is decided as 28.47 N. Rather than carrying out the simulation directly for maximum load condition only; the two values below the maximum load condition are taken i.e. 8.9 N and 18.68 N. The simulation is carried out also for these two loads. For all three loading condition the deformation is maximum near the centre of the free edge of the simply supported crisper plate. This is because of the six patch loading is used. Table III shows the relative deflection of simply supported crisper plate for different loading conditions. The relative deflection is calculated by assuming the zero deflection at the zero load condition.

Table III Relative Deflection of Simply Supported Crisper Plate

Sr. No.	Load (N)	Relative Deflection (mm)
1	8.9	4.2
2	18.68	8.6
3	28.47	13.1

Fig. 8 shows the static structural analysis; deflection contour plot for cantilever crisper plate in which the maximum deflection is at the cantilever end of the plate.

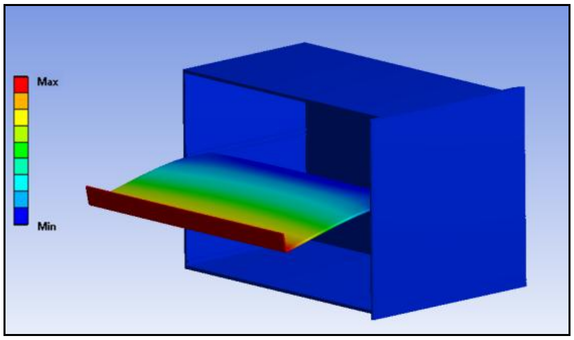


Fig. 8 Static Structural Analysis: Deflection Contour Plot for Cantilever Crisper Plate.

For all the three loads the maximum deflection occurred at the cantilever end of the crisper plate. As there are no any other attachments to the crisper plate the deflection in the crisper plate is large and visible to eyes. Table IV shows the relative deflection of the crisper plate. The relative deflection is calculated in the similar way calculated before.

Table IV Relative Deflection of Cantilever Crisper Plate

Sr. No.	Load (N)	Relative Deflection (mm)
1	8.9	7.8
2	18.68	16.3
3	28.47	24.8

Large deflection of the crisper plate is not suitable for aesthetic representation so the plate configuration is modified to provide more strength to the crisper plate and again simulation is carried out. The next iteration of simulation is performed only for the cantilever condition of the crisper plate, as it is the worst case scenario.

The meshing of the modified crisper plate is carried out with Solid 186 and Solid 187 elements with the element size of 2 mm. Sweep method is used to mesh the crisper plate. Total elements used for meshing are 139307 and the node count is 589675. The meshing of the modified crisper plate is shown in Fig. 9.

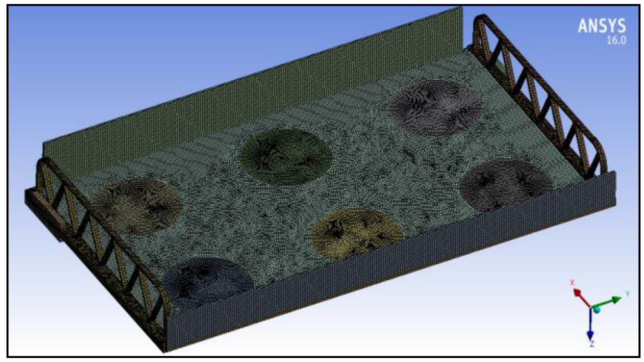


Fig. 9 Mesh Model of Modified Crisper Plate

After the meshing is carried out the boundary conditions are applied to the modified crisper plate. The same loading approach is followed here i.e. six patch loading as per the company standards. As shown in Fig. 10 the cantilever supports are fixed and load is applied on the six patches. After the simulation it is noted that due to the modification in the crisper plate the deflection of crisper plate is reduced drastically as shown in Table V. This is because of the addition of left hand and right hand crisper plate supports. The maximum deflection is occurred at the center of the cantilever portion of the crisper plate as shown in Fig. 11. Also the Von mises stress induced in the crisper plate due to maximum load is 7.34 times less than the yield stress of the material.

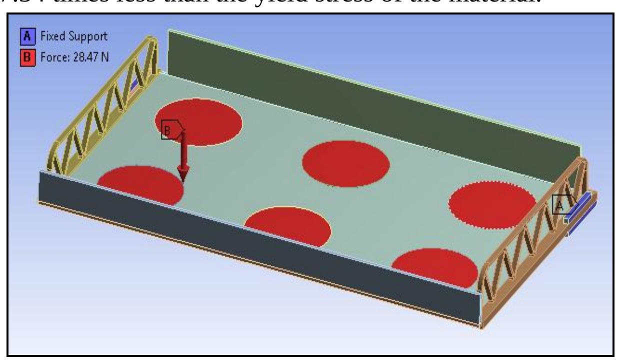


Fig. 10 Boundary Conditions for Modified Cantilever Crisper Plate

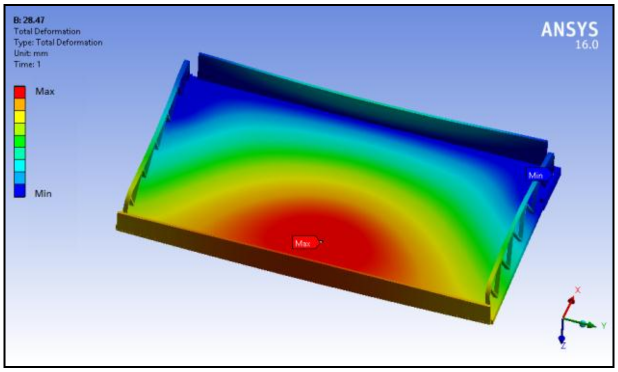


Fig. 11 Deflection Contour Plot for Cantilever Crisper Plate.

Table V Relative Deflection of Modified Cantilever Crisper Plate

Sr. No.	Load (N)	Relative Deflection (mm)
1	8.9	0.47
2	18.68	0.98
3	28.47	1.5

B. Stresses and Deflection of the Crisper Plate due to Impact Load:

To check the safety in case of accidental impact load conditions the impact test simulation is carried out in LS-Dyna and the results obtained shows that the von misses stresses are within the yield limit of the material. The maximum stress is at the point where the support ends as shown in Fig.12. The factor of safety obtained from the stress results is 2.86. Fig.13 shows the deflection contour plot when the crisper plate is get impact of the turkey. The maximum deflection is at the cantilever end shown by the red color.

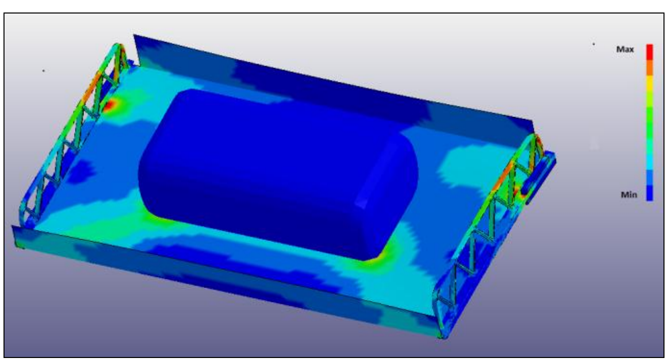


Fig.12 Von Mises Stress Contour Plot

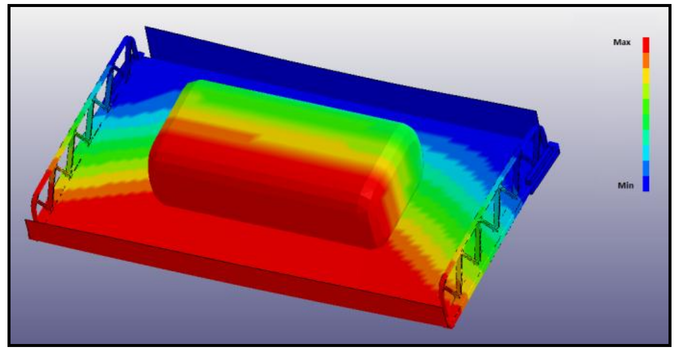


Fig.13 Deflection Contour Plot

V. EXPERIMENTAL ANALYSIS OF CRISPER

A. Deflection Test for Crisper Plate:

Deflection test is carried out on the crisper plate to measure the deflection of the crisper plate when it is subjected to loading. The crisper plate is tested for two conditions. The first one is the simply supported loading condition because when the crisper plate is inside the crisper with food stored inside it acts like the simply supported plate. The second condition is cantilever plate. When the crisper plate is pulled out of the crisper the plate is act like the cantilever plate so it is necessary to test the crisper plate for cantilever load condition. Fig. 14 and Fig. 15 shows the test setup for simply supported loading condition and cantilever loading condition respectively. It consists of deflection gauge, standard weights, deflection gauge stand and supporting structure.

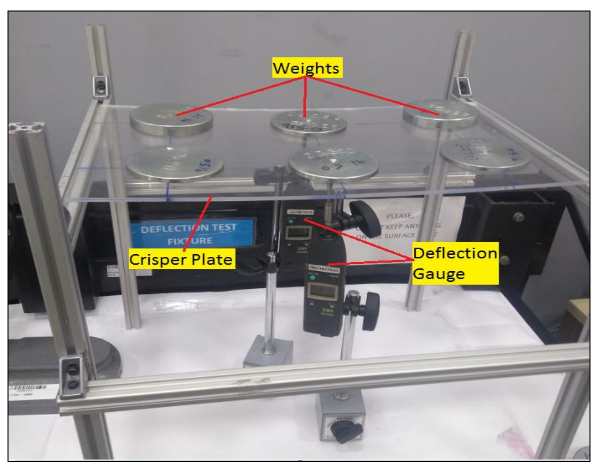


Fig. 14 Simply Supported Condition Test Setup

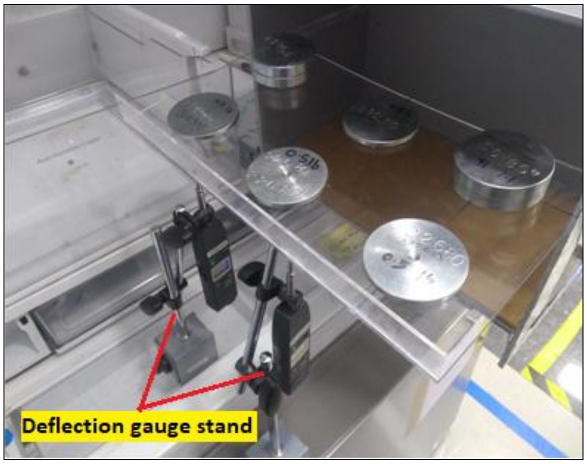


Fig. 15 Cantilever Condition Test Setup

The results obtained from the deflection test are given in Table VI and Table VII in the form of relative deflection for simply supported and cantilever condition of crisper plate respectively. The relative deflection is considered by assuming the zero deflection at the zero load condition.

Table VI Relative Deflection of Crisper Plate for Simply Supported Condition

Sr. No.	Load (N)	Relative Deflection (mm)
1	8.9	4.5
2	18.68	9.3
3	28.47	14.1

Table VII Relative Deflection of Crisper Plate for Cantilever Condition

Sr. No.	Load (N)	Relative Deflection (mm)
1	8.9	8.8
2	18.68	17.5
3	28.47	26

B. Pull/Push Test:

Pull/push test is carried out to measure the amount of force required to pull the crisper out of the refrigerator cabinet and again push the crisper into the refrigerator cabinet. This test is outcome of VOC (Voice of Consumer). Consumer always needs smooth opening and closing experience of crisper i.e. the force required to pull/push the crisper in loaded and unloaded condition should be less. Taking the VOC in consideration the company decides the range of the force required to pull/push the crisper. If the actual force required to pull/push the crisper is in between the range decided by the company then crisper design is acceptable.

Fig. 16 shows the sensorial fixture for pull/push force. It consists of counter weight, PCB, computer, load cell, encoder and slider. The computer is used to feed the signal to the PCB which activates the motor. The motor and encoder are connected with each other which are used to drive the belt. The belt is connected to slider which moves linearly. At the end of the slider load cell is fixed whose output is given to the computer. This output from the load cell gives the force required to pull/push the crisper at every instance over the travel length of the glides.

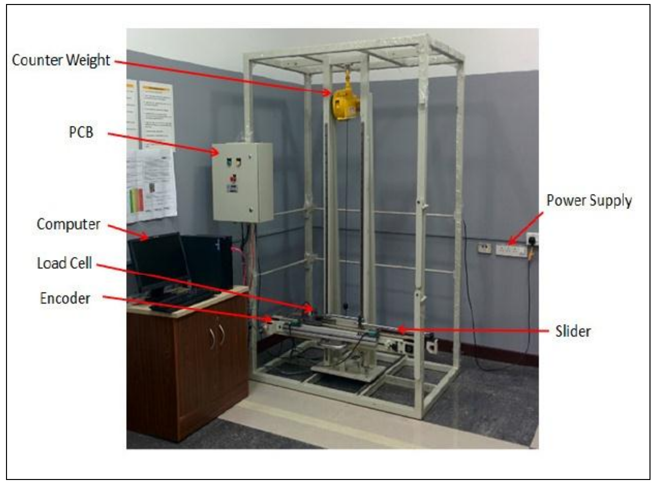


Fig. 16 Sensorial Fixture for Pull/Push Force

C. Experimental Results for Pull Force over Travel:

Experimental results show that the pull/push force varies in the range of positive to negative over the travel as shown in Fig. 17 and Fig. 18.

With Load:

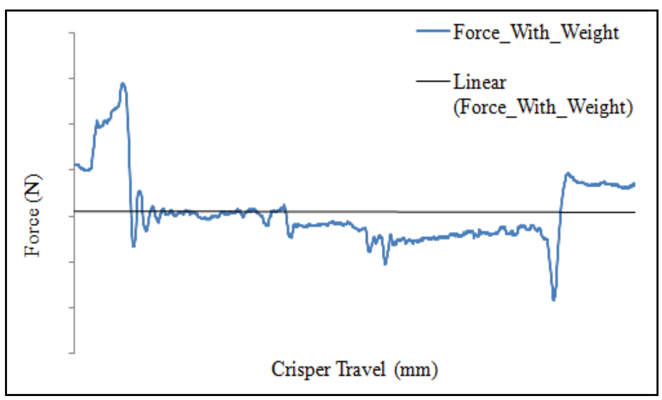


Fig. 17 Pull/Push Force Required (With Load)

Without Load:

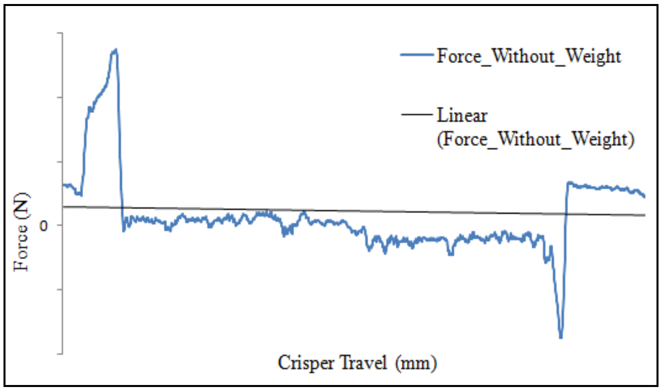


Fig. 18 Pull/Push Force Required (Without Load)

At the start there is peak in force which indicates the resistance to pull the crisper by the damper which is attached to the glide at the back end for auto-closing of the crisper. As the crisper starts to come out of cabinet the required pull force drops due to dynamic coefficient of friction. The peak fall at the end is also due to the damper as it takes time to close. Over the travel there is continuous rise & fall of forces within very short range that is comes due to the vibrations produced in glides due to lateral instability of crisper on glides.

VI. RESULTS AND DISCUSSION

A. Simply Supported and Cantilever Condition of Crisper Plate:

For simply supported and cantilever condition of plate the results of simulation and experimentation are matching with 0-6% error. The results for simply supported and cantilever condition of plate are shown in Fig. 19 and Fig. 20 respectively.

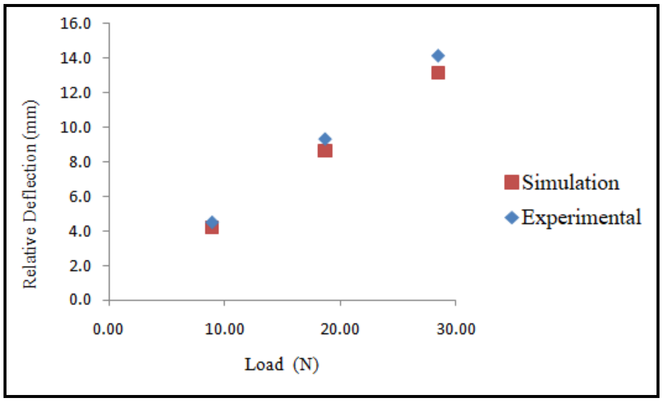


Fig. 19 Relative Deflection Vs Load Graph for Simply Supported Condition of Plate

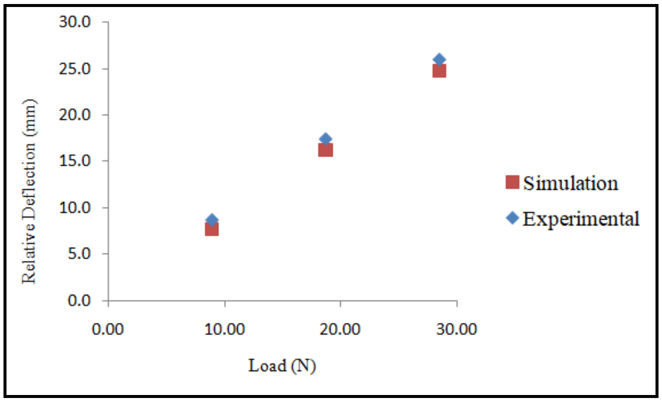


Fig. 20 Relative Deflection Vs Load Graph for Cantilever Condition of Plate

In simply supported and cantilever load conditions the stress generated in the plate are below the yield limit of the material used for crisper plate but the amount of deflection is large so there was a need to modify the crisper plate design to add the strength to crisper plate. After modifying the crisper plate design the results obtained are satisfactory. The results obtained are represented in the Fig. 21 shows the % deflection reduction in the deflection of modified crisper plate as compared with the old crisper plate at different loading conditions. For all loading conditions almost 93 % reduction in the deflection of crisper plate is observed after the modification in the crisper plate.

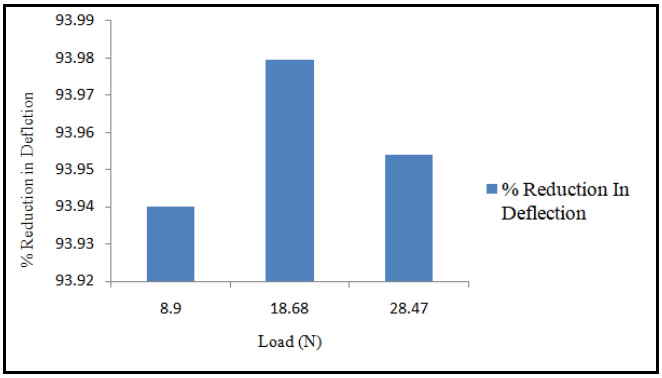


Fig. 21 Comparison of Deflection for Modified and Old Crisper Plate

Fig. 21 shows that the deflection is reduced drastically after modifying the crisper plate design. To reduce the deflection of crisper plate one extra part is added in the assembly which is crisper plate side support.

VII. ACKNOWLEDGMENT

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