DESIGN FOR SUGARCANE MACHINE USING DFMA ANALYSIS

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1. OBJECTIVE:

Improvise the cost efficiency by redesigning a sugarcane machine that is feasible for manufacturing and assembly. Ensure the same torque output is maintained with original and modified product design within a realistic acceptable range.

2. METHODOLOGY:

The DFMA analysis was performed with reference to Boothroyd and Dewhurst's Product Design for Manufacture and Assembly textbook. Comparison study of DFA index (design efficiency) and the total cost for assembly was performed for both the original and modified design. Performed calculations for input and output Torque, Rpm necessary for redesigning the product and choosing appropriate motor HP.

3. DFMA APPROACH:

The new product was designed in such a way that it has simple design, minimum stock removal, avoiding unnecessary fillets, using nominal dimensions, and using standardized tool sizes which are some of the prominent features for manufacturing. In terms of Assembly, the product includes a reduced total number of components, reduced assembly time, reduced size, high DFA index, and reduced labor cost.

4. PROCESS FLOW:

The existing design consists of an output torque of 58.8Nm and output speed of 362.5 RPM. This same torque was carried out for the new design by calculating the gear ratios and gear size. The size of the product was minimized by eliminating the gear box and replacing them with own manufactured gears. This in turn helped in reducing the cost of the motor by replacing them with lower HP ones.

After calculating the number of gears required along with their module and number of teeth, the product was designed using SolidWorks. DFMA analysis was performed on existing model to acquire theoretical minimum number of components and the components that could be eliminated. The new design was based on these findings. The new product was developed by keeping manufacturability and assembly of the product in mind.

5. DESIGN CALCULATIONS:

5.1. EXISTING PRODUCT:

The existing speed of rollers and the torque input was obtained from the IJEAST journal with which the torque and speed output could be found.

Speed input, N_{in} = 1450 RPM Torque input, T_{in} =14.7Nm

Assuming Gear ratio to be 4:1, a reasonable RPM output was obtained.

Gear Ratio, GR= 4:1

Speed output:

$N_{out} = N_{in}/GR = 1450/4$

$N_{out} = 362.5$ RPM

Torque output:

$T_{out} = T_{in} * GR = 14.7 * 4$

$T_{out} = 58.8$ Nm

Motor Power:

$= (T_{in} * N_{in}) / 9549 = (14.7 * 1450) / 9549$

$= 2.232$ KW ~ 2.99 hp

Thus a 3.0 hp motor of 1450 RPM was chosen for the existing design.

Gear tooth calculation:

Assuming gear box ratio to be 2:1, The gear tooth calculation was then proceeded using the 4:1 gear ratio on trial-and-error basis to match the nearest perfection.

GR = Teeth output/ Teeth input

$T_{out}/T_{in} = (30 * 27 * 2) / (15 * 27)$

$= 2 * 2 = 4:1 = GR$

A Gear module of 5.5 for the 27-tooth gear which was available on the market was chosen since that would match the requirements for the center distance.

Module, m= Pitch dia (d)/ no of teeth(t)

$d = 27 * 5.5 = 148.5$ mm

5.2. NEW PRODUCT:

The objective is to match the output torque of 58.8 Nm of the existing product with the new product and to replace the existing motor with a lower hp motor which would in turn reduce its cost.

Motor Power:

A motor with 1.5 hp of 1175 RPM and 168.72 inch-lbs torque was chosen from the McMaster Carr website with reduced price which could meet the required RPM and torque output of the existing product.

Gear Ratio:

$GR = N_{in}/N_{out} = 1175/362.5$

$= 3.241$

Thus, a Gear ratio of 3:1 was chosen for the new design.

Torque input:

Applying the gear ratio,

$T_{in} = T_{out} / GR$

$= 58.8/3 = 19.6$ Nm

Thus, the gear ratio satisfies the condition.

This shows that the input torque requirement from the calculation could be produced by the chosen motor in real time.

Gear Tooth Calculation:

Since the gear ratio is known and considering the center distance for roller gears to be 149 mm from previous design, the number of teeth for the gears could be found on trial-and-error basis.

GR = Teeth output/ Teeth input

$T_{out}/T_{in} = (27* 20 * 15) / (27 * 10 * 10)$

GR = 3:1

A Gear module of 5.5 for the 27-tooth gear, which was available on the market was chosen since that would best fit the requirements for the center distance.

6. PRODUCT DESIGN:

6.1. ORIGINAL DESIGN:

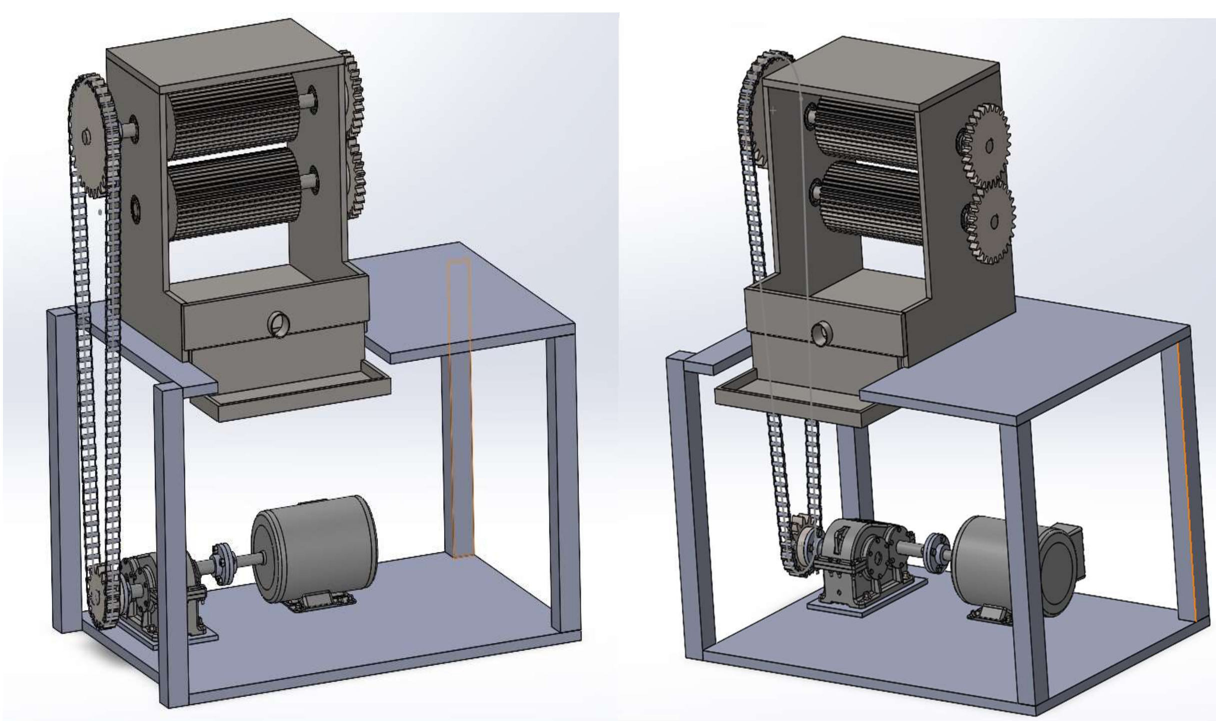


Fig. 1. Original Sugarcane machine

The Existing design was large that would occupy much space and it requires a lot of material input for manufacturing. The product is comprised of a 2:1 gear box, chain sprocket and a table with two bases which are potential candidates for replacement and elimination. Most of the components manufactured internally are welded, increasing the assembly time. This would also make the repair operations complex.

6.2. MODIFIED DESIGN:

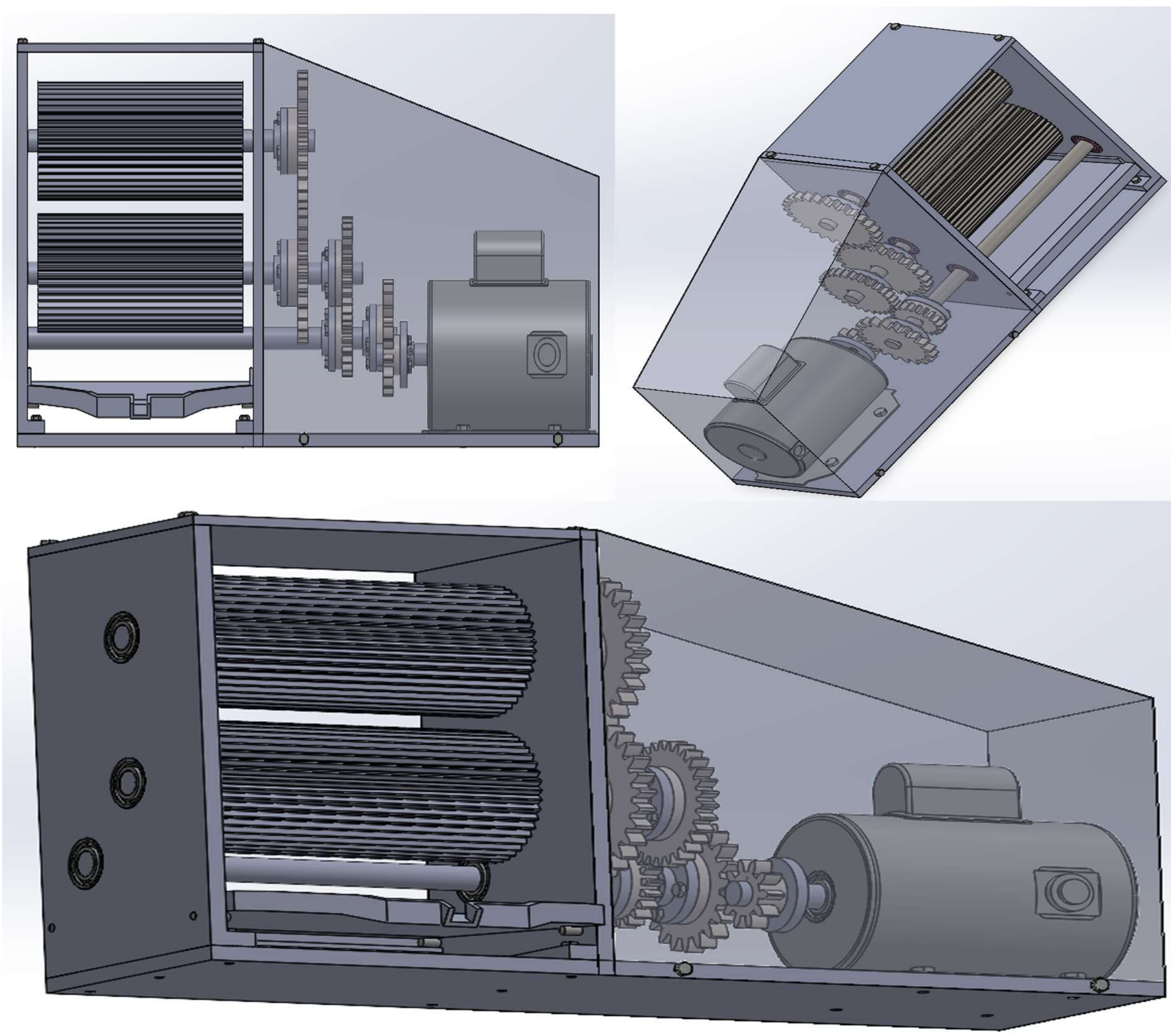


Fig. 2. Modified sugarcane machine

The size of the product is reduced largely in the new in comparison with the existing design. The gear box was replaced with additional spur gears. Since the gear box was replaced, the need for the table could be eliminated easily. To support the additional gears a gear shaft was introduced. All the panels were made into screw fastened assembly eliminating the need for welding, reducing the assembly time drastically. The Juice tray was modified by adding four taper pins to the assembly. The tray could be just placed on the pins and removed whenever needed, which enhances easy cleaning. The 3 hp motor was replaced with a 1.5 hp motor while reducing its cost. A motor-cover covering the entire mechanism was introduced to enhance safety.

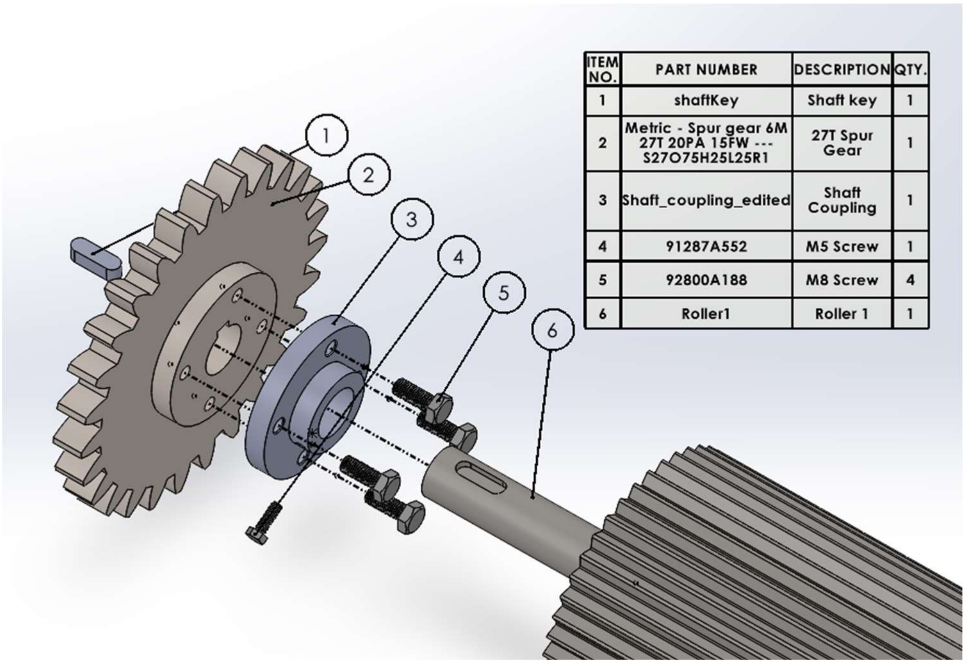


Fig. 3. Gear assembly

The picture shown in Fig.3 is the exploded view of a gear-shaft assembly which accounts for all the different numbered tooth gears used in the existing and the newly designed products.

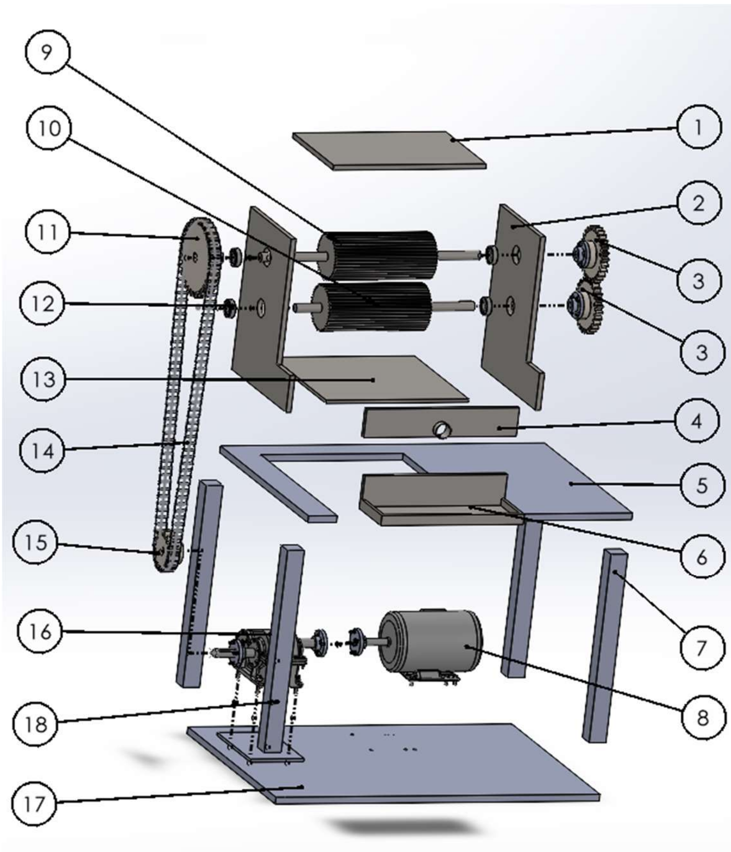
7. PRODUCT DESCRIPTION:

7.1. EXISTING PRODUCT:

7.1.1. Material selection and manufacturing process:

Part	Manufacturing process	Material
Roller	Sand Casting	Stainless Steel
Shaft Coupling	Pressing and Sintering	Carbon-Steel
Shaft keys	Die Casting	Carbon-Steel
Gears	Pressing and Sintering	Carbon-Steel
Left Panel	Bending and Machining Operations	Stainless Steel
Right Panel	Bending and Machining Operations	Stainless Steel
Top Panel	Machining Operations	Stainless Steel
Base Panel 2	Machining Operations	Stainless Steel
Outlet Panel	Die Casting	Stainless Steel
Juice Tray	Die Casting	Stainless Steel
Base Panel 1	Machining Operations	Carbon-Steel
Adjustment Plate	Machining Operations	Carbon-Steel

Bottom Panel	Machining Operations	Carbon-Steel
Legs	Machining Operations	Carbon-Steel



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	TOP	TOP PANEL	1
2	PART4	SIDE PANEL	2
3	METRIC - SPUR GEAR 5.5M 27T 20PA 20FW --- S27O75H40L25R1	27T SPUR GEAR	2
4	PART6	OUTLET PANEL	1
5	PART7	BASE PANEL 1	1
6	JUICE TRAY	JUICE TRAY	1
7	LEG1	RIGHT LEG	2
8	MOTORASSEM	MOTOR	1
9	PART1	ROLLER 1	1
10	PART2	ROLLER 2	1
11	METRIC - SPUR GEAR 7M 30T 20PA 30FW --- S30O75H50L25R1	30T SPUR GEAR	1
12	5972K315	BALL BEARING	4
13	PART5	BASE PANEL 2	1
14	CHAIN_LINK	CHAIN SPROCKET	1
15	METRIC - SPUR GEAR 7M 15T 20PA 30FW --- S15O75H50L25R1	15T SPUR GEAR	1
16	ASSEMBLY	GEAR BOX	1
17	BASE2	BOTTOM PANEL	1
18	LEG2	LEFT LEG	2

Fig. 4. Exploded view of original product

7.1.2. Assembly Steps:

Place bottom panel in a fixture and weld all the four legs to the bottom panel. Screw fasten motor to the bottom panel. Add couplings and keys. Place gear box in a fixture add coupling and keys. Add adjustment panel to the bottom panel and then place the gear box on top of it. Fix them in place with screws. Now screw fasten both the couplings together using nuts. Add 15-tooth spur gear to the gear box shaft while adding keys and couplings along with it. Tighten them with screws. Weld the Base panel 1 to the assembly with four legs.

Place the rollers in a fixture. Insert ball bearings and hammer them. Add left and right panels by hammering them. Add both the 27-tooth gear along with keys, couplings and screw fasten them. Now add the 30-tooth gear, key, coupling and screw fasten them. Now weld the Base panel 2, top panel, outlet panel and juice tray with Roller assembly together. Place the Roller assembly along with the main assembly and weld them. Add chain sprocket at last to the assembly.

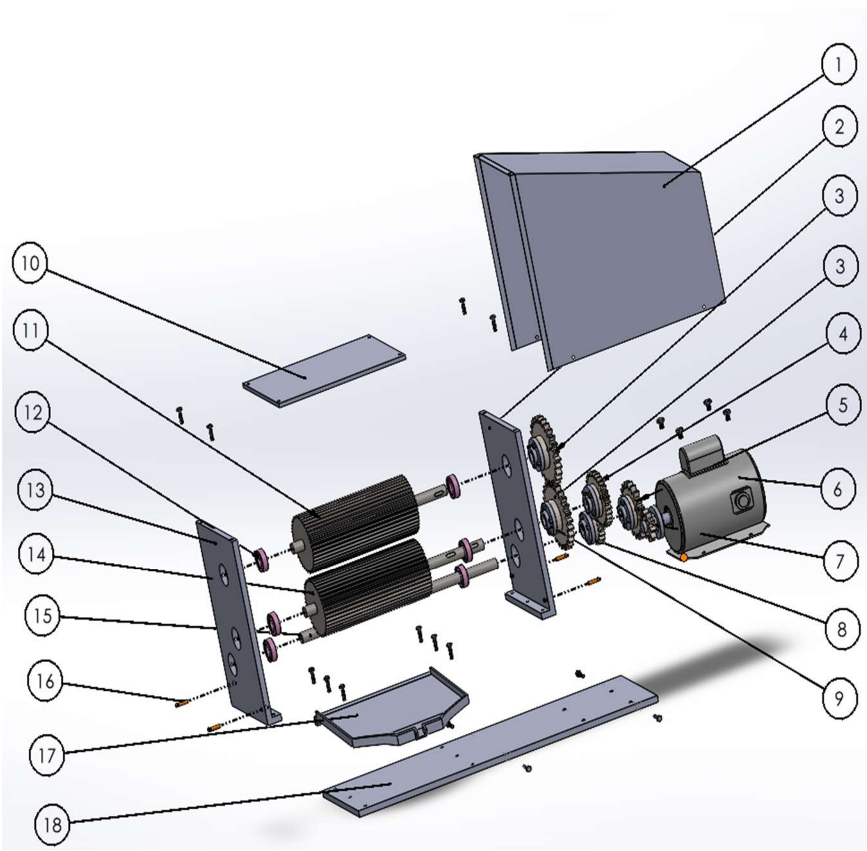
7.1.3. Design for Assembly:

No	Part	No of Items RP	Aplha Symmetry (A)	Beta Symmetry (B)	A+B	Welding length (WL)	Welding Time(TW) WL/8.4	Tool acquire time TA	Handling Code	Handling Time(TH)	Insertion code	Insertion Time(TI)	Total Time TW+ TA+RP* (TH+TI)	Minimum Theoretical Part Count		
1	Bottom Panel	1	180	360	540		0.00		40	4.1	00	1.5	5.60	1	Place in fixture	
2	Legs	4	90	360	450		0.00		10	1.5	03	5.2	26.80	4	Add and hold down	
3	Welding	4			0	560	66.67						66.67	0	Special operation	
4	Motor	1	360	360	720		0.00		42	5.6	13	7.4	13.00	1	Add and hold down	
5	M8_Screws	6	360	0	360		0.00	2.9	10	1.5	50	9	65.90	0	Add and screw fasten	
6	Coupling	1	360	360	720		0.00		30	1.95	02	2.6	4.55	1	Add and hold down	
7	Shaft_key	1	180	180	360		0.00		10	1.5	02	2.6	4.10	1	Add and hold down	
8	M5_Screw	1	360	0	360		0.00	2.9	10	1.5	30	3.6	8.00	0	Add and screw fasten	
9	Gear box	1	360	360	720		0.00		42	5.6	00	1.5	7.10	1	Place in fixture	
10	Coupling	1	360	360	720		0.00		30	1.95	02	2.6	4.55	1	Add and hold down	
11	Shaft_key	1	180	180	360		0.00		10	1.5	02	2.6	4.10	1	Add and hold down	
12	M5_Screw	1	360	0	360		0.00	2.9	10	1.5	30	3.6	8.00	0	Add and screw fasten	
13	Adjustment_plate	1	180	360	540		0.00		20	1.8	13	7.4	9.20	1	Add and hold down	
14	Gear box_Assembl	1	360	360	720		0.00		42	5.6	13	7.4	13.00	0	Add and hold down	
15	M10_Screw	4	360	0	360		0.00	2.9	10	1.5	50	9	44.90	0	Add and screw fasten	
16	Reorientation	1			0		0.00				61	4.5	4.50	0	Reorient and adjust	
17	M8_Screws	4	360	0	360		0.00		10	1.5	12	4.8	25.20	0	Add and hold down	
18	Nut	4	180	0	180		0.00	2.9	00	1.13	40	6.3	32.62	0	Add and screw fasten	
19	Shaft_key	1	180	180	360		0.00		10	1.5	02	2.6	4.10	1	Add and hold down	
20	Coupling	1	360	360	720		0.00		30	1.95	02	2.6	4.55	1	Add and hold down	
21	M5_Screw	1	360	0	360		0.00	2.9	10	1.5	30	3.6	8.00	0	Add and screw fasten	
22	15T_Spur Gear	1	360	360	720		0.00		30	1.95	03	5.2	7.15	1	Add and hold down	
23	Reorientation	1			0		0.00				61	4.5	4.50	0	Reorient and adjust	
24	M8_Screws	4	360	0	360		0.00	2.9	10	1.5	40	6.3	34.10	0	Add and screw fasten	
25	Base panel_1	1	360	360	720		0.00		42	5.6	03	5.2	10.80	1	Add and hold down	
26	Welding	4			0	680	80.95						80.95	0	Special operation	
27	Roller	2	360	0	360		0.00		42	5.6	00	1.5	14.20	2	Place in fixture	
28	Ball bearing	4	180	0	180		0.00		00	1.13	02	2.6	14.92	4	Add and hold down	
29	Hammer	4			0		0.00	2.9			61	4.5	20.90	0	Special operation	
30	Left panel	1	360	360	720		0.00		42	5.6	13	7.4	13.00	1	Add and hold down	
31	Hammer	2			0		0.00	2.9			61	4.5	11.90	0	Special operation	
32	Right panel	1	360	360	720		0.00		42	5.6	13	7.4	13.00	1	Add and hold down	
33	Hammer	2			0		0.00	2.9			61	4.5	11.90	0	Special operation	
34	Shaft_key	3	180	180	360		0.00		10	1.5	02	2.6	12.30	3	Add and hold down	
35	Coupling	3	360	360	720		0.00		30	1.95	02	2.6	13.65	3	Add and hold down	
36	M5_Screw	3	360	0	360		0.00	8.7	10	1.5	30	3.6	24.00	0	Add and screw fasten	
37	27T_Spur Gear	2	360	360	720		0.00		30	1.95	03	5.2	14.30	2	Add and hold down	
38	30T_Spur Gear	1	360	360	720		0.00		30	1.95	03	5.2	7.15	1	Add and hold down	
39	Reorientation	3			0		0.00				61	4.5	13.50	0	Reorient and adjust	
40	M8_Screws	12	360	0	360		0.00	8.7	10	1.5	40	6.3	102.30	0	Add and screw fasten	
41	Top panel	1	180	180	360		0.00		42	5.6	03	5.2	10.80	0	Add and hold down	
42	Welding	2			0	1260	150.00						150.00	0	Special operation	
43	Base panel_2	1	180	180	360		0.00		42	5.6	03	5.2	10.80	1	Add and hold down	
44	Welding	2			0	1640	195.24						195.24	0	Special operation	
45	Outlet panel	1	360	360	720		0.00		30	1.95	03	5.2	7.15	0	Add and hold down	
46	Welding	2			0	400	47.62						47.62	0	Special operation	
47	Juice tray	1	360	360	720		0.00		30	1.95	03	5.2	7.15	0	Add and hold down	
48	Welding	1			0	870	103.57						103.57	0	Special operation	
49	Rolle_Assembly	1	360	360	720		0.00		42	5.6	03	5.2	10.80	0	Add and hold down	
50	Welding	2			0	1660	197.62						197.62	0	Special operation	
51	Chain Sprocket	2	180	0	180		0.00		40	4.1	25	7.7	23.60	1	Add	
													Total	35		
										Total time in Seconds			1553.31			
										Total time in min			25.89			

7.2. NEW PRODUCT:

7.2.1 Material selection and manufacturing process:

Part	**Manufacturing process**	**Material**
Roller	Sand Casting	Stainless Steel
Gear Shaft	Sand Casting	Stainless Steel
Shaft Coupling	Pressing and Sintering	Carbon-Steel
Shaft keys	Die Casting	Carbon-Steel
Gears	Pressing and Sintering	Carbon-Steel
Left Panel	Bending and Machining Operations	Stainless Steel
Right Panel	Bending and Machining Operations	Stainless Steel
Base Panel	Machining Operations	Stainless Steel
Top Panel	Machining Operations	Stainless Steel
Motor Cover	Sheet Metal Operations	Sheet Metal
Juice Tray	Die Casting	Stainless Steel



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	motor cover	Motor Cover	1
2	Right panel	Right Panel	1
3	Metric - Spur gear 5.5M 27T 20PA 15FW ---S27O75H30L25R1	27T Spur Gear	2
4	Metric - Spur gear 4M 30T 20PA 15FW ---S30O75H25L25R1	30T Spur Gear	1
5	Metric - Spur gear 6M 20T 20PA 15FW ---S20O75H25L25R1	20T Spur Gear	1
6	Motor_assem	Motor	1
7	Metric - Spur gear 6M 10T 20PA 15FW ---S10O75H25L25R1	10T Spur Gear	1
8	Metric - Spur gear 4M 20T 20PA 15FW ---S20O75H25L25R1	20T Spur Gear	1
9	Shaft_coupling	Shaft Coupling	5
10	top panel	Top Panel	1
11	Roller1	Roller 1	1
12	5972K315	Ball Bearing	6
13	left panel	Left Panel	1
14	Roller2	Roller 2	1
15	gear shaft	Gear Shaft	1
16	98445A717	Taper Pin	4
17	plate tray	Juice Tray	1
18	Base_panel	Base Panel	1

Fig. 6. Exploded View of New modified Product

7.2.2. Assembly Steps:

Place the rollers in a fixture. Hammer four ball bearings to them. Add left panel and hammer it. Add one more bearing to the left panel. Add the right panel to the assembly and hammer it. Insert gear shaft to the assembly and hammer it with the left bearing. Now insert the last bearing and hammer it. Now reorient and fit the assembly to the base panel and secure them with screws. Place top panel and screw fasten it.

Add both the 27-tooth spur gears to the assembly along with keys and couplings to the roller shafts and screw fasten them. Next add the 30-tooth gear to the roller shaft and 20-tooth gear to the gear shaft, along with keys and couplings and screw fasten them. Insert the 20-tooth gear along with key and coupling to the gear shaft and screw fasten them. Insert taper pins and hammer them. Place the motor in the base panel and secure them with screws. Now align the motor cover with assembly and screw fasten. Finally, just place the Juice tray on top of the taper pins.

7.2.3. Design for Assembly:

No	Part	No of Items RP	Aplha Symmetry (A)	Beta Symmetry (B)	A+B	Tool acquire time TA	Handling Code	Handling Time(TH)	Insertion code	Insertion Time(TI)	Total Time TA+RP* (TH+TI)	Minimum Theoretical part count	
1	Roller	2	360	0	360	0	42	5.6	00	1.5	14.2	2	Place in fixture
2	Ball bearing	2	180	0	180	0	00	1.13	02	2.6	7.46	2	Add and hold down
3	Hammer	2			0	2.9			61	4.5	11.9	0	Special Operation
4	Ball bearing	2	180	0	180	0	00	1.13	12	4.8	11.86	2	Add and hold down
5	Hammer	2			0	2.9			61	4.5	11.9	0	Special Operation
6	Left Panel	1	360	360	720	0	42	5.6	13	7.4	13	1	Add and hold down
7	Hammer	2			0	2.9			61	4.5	11.9	0	Special Operation
8	Ball bearing	1	180	0	180	0	00	1.13	02	2.6	3.73	1	Add and hold down
9	Hammer	1			0	2.9			61	4.5	7.4	0	Special Operation
10	Right Panel	1	360	360	720	0	42	5.6	13	7.4	13	1	Add and hold down
11	Hammer	2			0	2.9			61	4.5	11.9	0	Special Operation
12	Gear Shaft	1	360	0	360	0	42	5.6	12	4.8	10.4	1	Add and hold down
13	Hammer	1			0	2.9			61	4.5	7.4	0	Special Operation
14	Ball bearing	1	180	0	180	0	00	1.13	03	5.2	6.33	1	Add and hold down
15	Hammer	1			0	2.9			61	4.5	7.4	0	Special Operation
16	Reorientation	1			0				61	4.5	4.5	0	Reorient and adjust
17	Base Panel	1	360	360	720	0	42	5.6	13	7.4	13	1	Add and hold down
18	M8_Screws	6	360	0	360	2.9	10	1.5	30	3.6	33.5	0	Add and screw fasten
19	Shaft_Coupling	5	360	360	720	0	30	1.95	02	2.6	22.75	5	Add and hold down
20	Shaft_Key	5	180	180	360	0	10	1.5	02	2.6	20.5	5	Add and hold down
21	27T_Spur Gear	2	360	360	720	0	30	1.95	03	5.2	14.3	2	Add and hold down
22	30T Spur Gear	1	360	360	720	0	30	1.95	03	5.2	7.15	1	Add and hold down
23	20T_Spur Gear	1	360	360	720	0	30	1.95	03	5.2	7.15	1	Add and hold down
24	20T_Spur Gear_6	1	360	360	720	0	30	1.95	03	5.2	7.15	1	Add and hold down
25	Reorientation	5			0				61	4.5	22.5	0	Reorient and adjust
26	M8_Screws	12	360	0	360	8.7	10	1.5	40	6.3	102.3	0	Add and screw fasten

28	M5_Screw	5	360	0	360	14.5	10	1.5	30	3.6	40	0	Add and screw fasten	
29	Motor	1	360	360	720	0	42	5.6	13	7.4	13	1	Add and hold down	
30	M10_Screws	4	360	0	360	2.9	10	1.5	30	3.6	23.3	0	Add and screw fasten	
31	Shaft_Coupling_s	1	360	360	720	0	30	1.95	02	2.6	4.55	1	Add and hold down	
32	Shaft_Key	1	180	180	360	0	10	1.5	02	2.6	4.1	1	Add and hold down	
33	10T_Spur Gear	1	360	360	720	0	30	1.95	02	2.6	4.55	1	Add and hold down	
34	Reorientation	1			0				61	4.5	4.5	0	Reorient and adjust	
35	M6_Screws	4	360	0	360	2.9	10	1.5	50	9	44.9	0	Add and screw fasten	
36	M5_Screw	1	360	0	360	2.9	11	1.8	30	3.6	8.3	0	Add and screw fasten	
37	Top Panel	1	180	180	360	0	10	1.5	03	5.2	6.7	0	Add and hold down	
38	M8_Screws	2	360	0	360	2.9	10	1.5	30	3.6	13.1	0	Add and screw fasten	
39	Taper pins	4	360	0	360	0	10	1.5	02	2.6	16.4	0	Add and hold down	
40	Hammer	1			0	2.9			61	4.5	7.4	0	Special Operation	
41	Motor cover	1	360	360	720	0	42	5.6	13	7.4	13	0	Add and hold down	
42	M8_Screws	4	360	0	360	2.9	10	1.5	30	3.6	23.3	0	Add and screw fasten	
43	Juice Tray	1	360	360	720	0	30	1.95	15	5.5	7.45	0	Add	
											Total	31		
								Total time in Seconds			728.93			
								Total time in min			12.14883			

8. DFA INDEX AND COST CALCULATIONS:

Assuming the average assembly worker's rate as $30/hr.

8.1. EXISITING PRODUCT:

The total time taken for the product to be assembled = 1553.31 s

Corresponding assembly cost = $12.9

Assembly efficiency:

Theoretical minimum number of parts = 35

Considering basic assembly time for one part, $t_a = 3$ s.

DFA index, $E_{ma} = (N_{min} * t_a) / t_{ma}$

$= (35 * 3) / 1553.31$

$= 0.06$ or 6 %

8.2. NEW PRODUCT:

The total time taken for the product to be assembled = 728.93 s

Corresponding assembly cost = $6.07

Assembly efficiency:

Theoretical minimum number of parts = 31

Considering basic assembly time for one part, $t_a = 3$ s.

DFA index, $E_{ma} = (N_{min} * t_a) / t_{ma}$

$= (31 * 3) / 728.93$

$= 0.12$ or 12%

As we can see from the above calculations, there has been an increase in the efficiency of the assembly by two times. The minimum number of theoretical part count was reduced from 35 in the original design to 31 in the new design.

9. CONCLUSION:

The application of DFMA analysis to the existing product helped us to redesign it in a way that it is easy to manufacture and assemble. The assembly efficiency was increased from 6% to almost twice the amount, which is 12%. The overall labor cost for assembly got reduced from \$12.9 to \$6.07 with a decrease of total assembly time from 25.88 minutes to 12.14 minutes, which is almost a 50% decrease from the original figure.

The product was redesigned for manufacturability by keeping the individual part design simple without complex features, maintaining standard materials, standard tool sizes and manufacturing processes, nominal dimensions, minimum stock removal and based on the easy availability of purchased parts in the market.

The existing model has been redesigned successfully while maintaining the same torque output by performing design calculations for the ideal scenario. A few parts of the original product were eliminated and also replaced with cheaper ones thus reducing the overall product cost.