Design for Manufacture and Assembly of an Automated Dish Washing Machine

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Abstract. This paper was a research done at a local university in Zimbabwe. Dishwashing by hand involves scrubbing, rinsing and drying of dishes which is time consuming and laborious when done on a large scale. Each dining hall at the university uses about one thousand plates per meal and the university is understaffed thus the dishes are not thoroughly cleaned. A dishwashing machine is thus a necessity for the university. Researching of literature was done and information on the current designs of dishwashers, their operations, merits and demerits was gathered. A case study on the university was carried out using interviews and questionnaire. The dishwasher for the university was designed and it uses pressurised water jets to clean the plates. The pressurised water jets are produced by a pump installed in the dishwasher. The plates are put into the dishwashing using a rake conveyer system which is automatically controlled. The von Mises stresses of the system were analysed using Solidworks and they were in the desired range. Deflections were also done using Solidworks. Specifications and drawings of the dishwashing machine were developed. Materials of the design were selected concentrating on reduction of cost through minimising the number of parts retaining its function.

Keywords: Design for manufacture and assembly (DFMA), automated · Dish washing machine

1 Introduction

Dish washing machines are devices that are used to clean and dry dishes and kitchen utensils. When using a dish washing machine the dishes are put into the racks and the machine is closed, the dishes are showered by pressurised, hot and soapy water jets until they are clean. This machine can clean any type of kitchen utensil. The cleaning of dishes by hand involves scrubbing, rinsing and drying of the dishes. There is use of detergents in the washing and some of the detergents have long time effects on the hands [1]. The process of hand dish washing takes a lot of time and consumes a lot of energy and water [6]. This has resulted in the design and manufacture of dish washing

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machines that can clean dishes using minimum energy, minimum water and taking less time [9]. The existing dish washing machines are expensive and the maintenance costs are high thus there are not common in Zimbabwe.

1.1 Background of the Study

The first dishwashing machine was manufactured in the middle of the 19th century. A patent of the first device was signed in 1850 by Joel Houghton [2]. The machine was crank operated and built from wood. When cranked, water would make its way through the wood plumbing and spray over the dishes. A woman named Josephine Cochrane who was very wealthy improved on that invention and manufactured the first successful dish washing machine [7]. These dishwashers could not dry the dishes thus the dishes were dried by hand. The water for washing was also heated manually using wood thus they were not effective. They also wasted a lot of water.

Dish washing technology continued improving and the recent dish washing machines are far much better than those in the 19th and 20th centuries. The recent dishwashing machines are now more helpful than ever. They have a water efficiency of about 4 to 6 gallons of water per cycle [4]. The electricity usage has reduced by about 15%. These dishwashers produce less sound than the previous ones. Some of them even have soil sensors and innovative dish rack designs. Due to the increase in water and energy efficiency, the recent machine take a lot of time as compared to those of the 20th century. The 20th century machines took 60 to 80 min per cycle but the recent ones take about 120 to 140 min. All the improvements have led to the increase of the cost of dishwashing machines thus they are not common in developing countries.

Dishwashers are a reproducing ground for possibly unsafe organisms, new research has uncovered. Scientists found that the warm, soggy condition in dishwashers is perfect for the development of growths including Exophiala, Rhodotorula, and Candida parapsilosis – yeast-like species that can be hurtful to individuals. On the off chance that breathed in, these parasites can colonize the lungs and cause contaminations that can be hard to treat. The elastic seals in dishwasher entryways are an ideal rearing ground for organisms and that a few sorts, for example, Exophiala.

About 500 plates, 1000 pieces of cutlery and 500 cups are used per meal in a dining at the university, there is no enough manpower for dishwashing thus dishes are not thoroughly cleaned.

The major objectives of the research are:

- To design a dish washing machine for the university that washes 500 plates, 1000 pieces of cutlery and 300 cups per hour.
- To design a machine which requires minimum or zero human assistance.
- To design a machine that can be manufactured by locally available resources.

2 Literature Review

Dish washing involves preparation, filling, washing, rinsing and drying (Fig. 1).

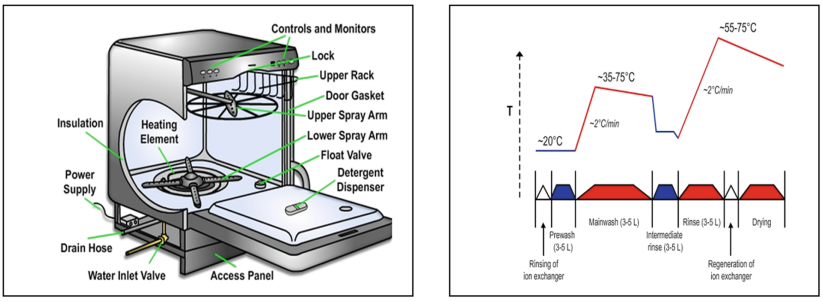


Fig. 1. a. Parts of a dishwasher b. Dishwasher cleaning cycle

Despite the fact that part of human exercises are robotized in the present aggressive world. There is a slack in robotized dish washer. A few machines are as of now planned with the assistance of high speed water jet; henceforth there is a possibility of uncleanliness and not evacuating extreme strains in dishes. Keeping in mind the end goal to defeat the above issues an exceptional machine called—Automatic Dishwasher Machine" with rollers, brush and water fly presented in this work. By consolidating dishwasher with roller component utilizing brush and water stream, it is conceivable to clean the articles viably than alternate machines and with no labor [11].

3 Materials and Methods Used for Design

For mechanical drawings, Solid Works 2015 software was used. SolidWorks (stylized as SOLIDWORKS) is a solid modeling Computer-Aided Design (CAD) and Computer-Aided Engineering (CAE) computer program that was run on Microsoft Windows in this research. It is a solid modeler, and utilizes a parametric feature-based approach to create models and assemblies. The dish washer designed has the following parameters as in Table 1. The selection was done as steps in SolidWorks. The response of a section relies upon the material selected to the part. SimulationXpress must know the flexible properties of the material of the part. You allocate material to the part by picking a material from a material library. Materials in SOLIDWORKS have two arrangements of properties, visual and physical (mechanical). SimulationXpress utilizes the physical properties of the materials characterized in the SOLIDWORKS Material library. Materials can be isotropic, orthotropic, or anisotropic. SimulationXpress bolsters isotropic materials as it were (Table 2).

Table 1. Parameters used in the design

Parameter	Quantity
Water efficiency	10 gallons per cycle
Time per cycle	15 min
Number of plates per cycle	300 plates
Type of plates	Melamine
Energy efficiency	10 joules per circuit
Number of rakes	2
Dimension	0.7 × 0.7 × 1 m
Plate area	0.0625 m^2
Plate thickness	3 mm

Table 2. Components and quantities to be designed

Component	Quantity
Centrifugal pumps	2
Spray arms	2
Water collector pipes	1
Racks	2
Housing	1

To Assign/Modify a Material to a Part:

1. Click Choose Material (Material tab of the SimulationXpress wizard).
2. In the Material dialog box, expand the class of materials and select a material.
3. Click Apply.
4. Click Close
5. Click Next.

You can also assign a material by right-clicking the part in the SimulationXpress study tree and clicking Apply/Edit Material (Fig. 2).

Approximately 12,000 students need to eat three times a day.

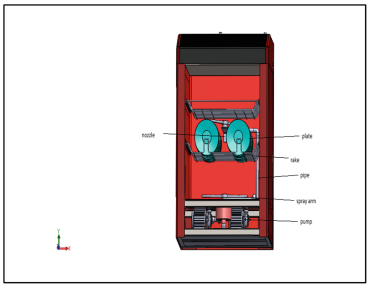


Fig. 2. Designed dish washing machine

4 Simulation and Results

4.1 Water Jet Arrangement

The arrangement of the jet of water for design was shown below in Fig. 3.

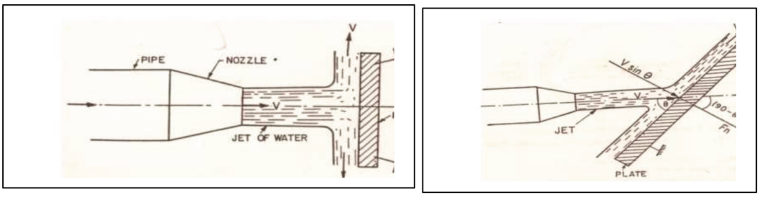


Fig. 3. a. Water jets on horizontal plate b. Inclined plate

$F_x = \rho a V^2 = 1000 \times 3.14 \times 10^{-6} \times 3.98^2 = 0.0497$ N (Horizontal plane). This is the force acting in horizontal plane.

$F_x = \rho A v^2 \sin^2 \theta = 1000 \times 3.14 \times 10^{-6} \times 3.98^2 \times \sin^2 60°$; $F_x = 0.0373$ N for inclined plane.

From the Darcy equations the researchers calculated the losses due to friction, $h = \frac{4flv2}{2dg}$; but $\text{Re} = \frac{1030.4*1.141}{1.14*10} = 14035$ and the flow is turbulent, so the Darcy equation must be used. To determine the value of friction factor:

Relative roughness = k/d = 0.000 08*0.04 = 0.002. From the Moody chart in appendix 1, for $\text{Re} = 1.4 \times 10^{-4}$ and relative roughness of 0.002.

f = 0.008; $h = \frac{4x0.008x1.65x3.98x3.98}{2x9.81x0.030}$; $h_f = 1.1$ m, $h_i = 1.1 + 0.55 + 1.25 + 1.5$; $h_i = 4.5$ m; Energy = ρghQ = 1000*9.81*4.5*5 $\times 10^{-5} = 0.720725$ KW. 1 HP pump with a flow rate of 30 litres per minute with a head of 4.5 m and pressure of 0.2 bar was selected (Fig. 4).

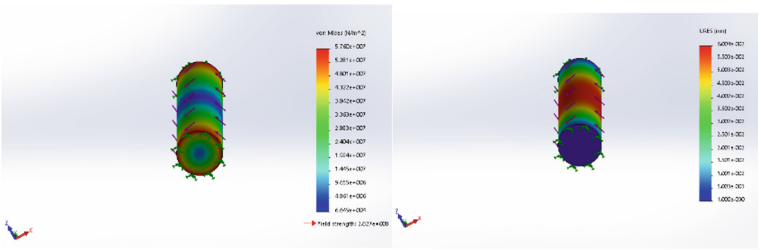


Fig. 4. a. The stress analysis of the shaft b. The displacement analysis of the shaft

4.2 Stress Analysis

$$\sigma_x = \frac{p}{\pi r2} = \frac{100 * 10^{-3}}{4 * 30 * 10^{-3}} = 18.7\text{MPa}; \sigma_y = \frac{p}{2\pi rl}; = \frac{120 * 10^{-3}}{2 * 30 * 10^{-3}} = 33.3\text{MPa}$$

$$\sigma_{1,2} = \frac{\sigma_x + \sigma_y}{2} + \sqrt{\frac{(\sigma_x - \sigma_x)^2}{2} + \tau_{xy}^2};$$

$$= \frac{(16.7 + 33.3) * 10^6}{2} + \sqrt{\frac{(16.7 * 10^6 - 33.3 * 10^6)^2}{2} + 200 * 10^{5^2}} = 48.2\text{MPa}$$

$$\sigma_v = \sqrt{\sigma_x^2 + \sigma_y^2 - \sigma_{L\sigma_x^2} + 3\tau_{xy}^2};$$

$$\sqrt{(16.6 * 10^6)^2 + (33.6 * 10^6)^2 - (16.8 * 10^6 * 33.5 * 10^6) + (3 * (10 * 10^6)^2)}$$

$$= 49.1\text{MPa}; \sigma_d = \frac{S_y}{n}; = \frac{350}{3}$$

$$= 116\text{MPa}.$$

4.3 Stress Analysis on the Melamine Plate

Calculation of slenderness ratio is as follows: $S = \frac{Le}{r}$; But $r = \sqrt{\frac{I}{A}}$; $r = \sqrt{\frac{0.03}{0.0067}}$; $r = 12.33$

$$S = \frac{0.03}{12.33}; S = 0.0045; S_{cr} = \sqrt{\frac{2\pi^2 E}{\sigma_y}}; S_{cr} = \sqrt{\frac{2\pi^2 24 * 10^9}{200 * 10^6}}; S_{cr} = 204.56$$

Calculation of the critical load: Since S = 0.0045 < S_{cr} = 204.6 the melamine plate is a short column thus the following equation is used for the critical load $P_{cr} = \sigma_y A(1 - (\frac{\sigma_y}{4\pi^2 E})\frac{Le^2}{r}$; $P_{cr} = \sigma_y A(1 - (\frac{\sigma_y}{4\pi^2 E})\frac{Le^2}{r}$; $P_{cr} = 4.345\ kN$.

Since 4.345 is > 1.020 from the water jets the melamine plates will fail due to the water pressure. The detailed drawings are shown in Fig. 5.

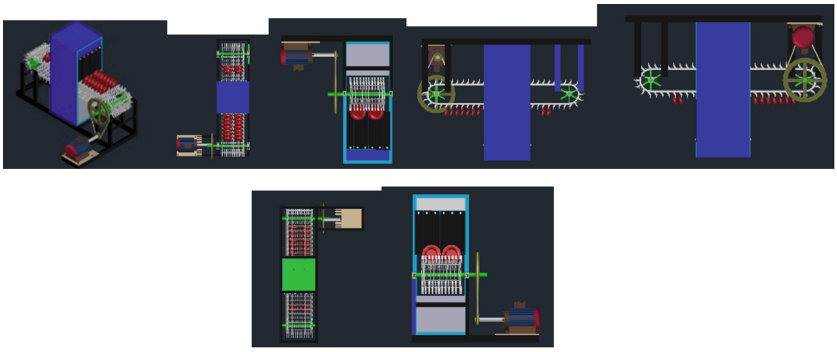


Fig. 5. a. Detailed full drawing b. Top view c. Front view d. Right hand side e. Left hand side f. Bottom side g. Back view

5 Discussion and Recommendations

The number of pumps was reduced from four to two since the dirty water from the dishes will be drained by gravity the water collector then to the sewer system thus no need for the two pumps to pump dirty water from the washer. The following were allocated materials as follows and suggested prices to buy the materials were put across. The dishwasher uses a lot of detergents to disinfect the plates. This can be improved by using pressurised heated water. Heated water will also resulting in the dishes drying faster (Table 3).

Table 3. Part list and materials

Part name	Description	Quantity	Unit price (US$)	Cost
Drive shaft	Carbon steel	1	$2.00	$2.00
Motor		1	$90.00	$90.00
Pump		1	$100.00	$100.00
Bearing	Gray cast Iron SN	1	$11.00	$11.00
Belt	Steel	1	$30.00	$30.00
Pulley	Brass	2	$11.00	$22.00
Spray arms	Copper	2	$5.00	$10.00
Pipes	Copper	30	$1.00	$30.00
Housing	Cast stainless steel	1	$10.00	$10.00
Water collector	Gray cast iron SN	1	$2.00	$2.00
Idler	Gray cast iron SN	2	$2.50	$5.00
Stand	Cast stainless steel	1	$4.50	$4.50
Pipe connectors	Copper	20	$0.65	$13.00
Total				**$329.50**

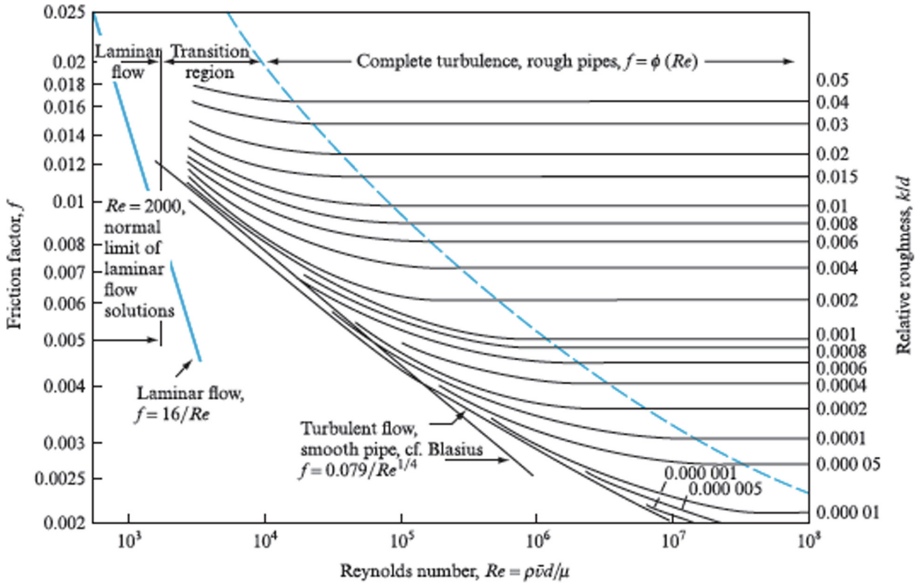
6 Conclusion

The research was a success, next step is to install this dishwasher at the university. The university community will benefit a lot in coming up with this dishwasher. A dishwasher is a mechanical gadget for cleaning dishware and cutlery. Not at all like manual dishwashing, which depends generally on physical scouring to expel dirtying, the mechanical dishwasher cleans by showering high temp water, ordinarily in the vicinity of 45 and 75 °C (110 and 170 °F), at the dishes, with bring down temperatures utilized for sensitive items. A blend of water and dishwasher cleanser is pumped to at least one turning shower arms, which shoot the dishes with the cleaning blend. Once the wash is done, the water is depleted, more heated water enters the tub by methods for an electro-mechanical solenoid valve, and the flush cycle starts. After the flush cycle completes and the water is depleted, the dishes are dried utilizing one of a few drying techniques. Ordinarily a flush guide, a synthetic to decrease surface pressure of the water, is utilized to lessen water spots from hard water or different reasons. Plates will be very much clean than manual washing.

Notwithstanding local units, mechanical dishwashers are accessible for use in business foundations, for example, lodgings and eateries, where a substantial number of dishes must be cleaned. Washing is led with temperatures of 65–71 °C (149–160 °F) and sanitation is accomplished by either the utilization of a promoter warmer that will give a 82 °C (180 °F) "last flush" temperature or using a substance sanitizer.

The new age best-in-class machine beat the earlier age unit by a vast edge. It did likewise measure of work however utilized significantly less vitality and water. The advancements on the new designed dishwasher at university are at present available and accessible for manufacture and use. These advancements increment the productivity of the dishroom and take care of numerous upkeep issues, and likely increment the lifetime of the machine while guaranteeing appropriate machine task. The generous cost investment funds and low straightforward payback time influence a sensible business to case to resign even high-proficiency machines early.

Appendix 1: Moody Diagram



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