Improvement of Wash Performance and Energy Efficiency in Top Load Washers

Dissertation Work carried out at

Panasonic India Pvt. Ltd.

Plot No.1, Village Bid Dadri, Jhajjar, Haryana

Submitted in partial
fulfillment of requirements
for the degree of

Master of Engineering
in
Production Engineering
by

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July 2022

THAPAR INSTITUTE
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CERTIFICATE

I hereby declare that the thesis entitled **"Improvement in Wash Performance and energy efficiency in Top Load washers"** is an authentic work carried out as partial fulfillment of requirements for the degree of **Master of Engineering** in **Production Engineering** at **Thapar Institute of Engineering & Technology, Patiala** under the supervision of Dr. Vinod Kumar **(**Associate Professor, TIET); Dr. Ravinder Joshi **(**Assistant Professor, TIET) and Mr. Chandan Sarkar (HOD, R&D Washing machine, Panasonic), during July 2021 to June 2022.

Date: - 26th July 2022

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It is certified that the above statement made by the student is correct to the best of my knowledge and belief.

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Acknowledgment

Despite the fact that I completed my dissertation work, it would not have been possible without the assistance of other people, whose collaboration allowed me to complete this work successfully. I take the opportunity to express my heartfelt gratitude to my supervisors **Dr. Vinod Kumar** and **Dr. Ravinder Joshi** for their unreserved guidance, constructive suggestion and encouraging me at important junctures in this research work. I appreciate the helpful advice and thorough direction that helped me refine my scientific writing and conduct the additional study. I was really inspired and grateful to work under their direction throughout the entirety of my dissertation work.

I would like to express my gratitude towards **Mr. Chandan Sarkar** (HOD, Washing machine R&D), **Mr. Sandeep Sharma** (Deputy Manager, WM R&D), **Mr. Anand Kumar Yadav**(Senior Designer, WM R&D) for their guidance and support in every way possible. I also thank all Panasonic factory members and supporting staff for the help they extended to me for the completion of this research project.

I am thankful to **Dr. T. K. Bera**, Head of Mechanical Engineering Department, Thapar Institute of Engineering and Technology for providing necessary help to carry out this thesis work. I appreciate the aid and cooperation I received from the ME department's office personnel at TIET during my studies.
I view this chance as a significant turning point in my professional progress. In order to achieve my intended professional goals, I will make every effort to utilise newly acquired skills and information to the fullest extent feasible and to keep working to enhance them.

Thank you for your constant support!

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Nomenclature

The table below presents the nomenclatures used in the present work.

WM: Washing machine

TL: Top loader

FL: Front loader

PP: Polypropylene

SS: Structural Steel

DFA: Design for assembly

DFM: Design for manufacturing

DR: Design review

CR: Cost reduction

PI: Panasonic India

CFD: Computational fluid dynamics

CAM: Computer aided manufacturing

ROI: Return of Investment

K-e model: K-epsilon model

Improvement in Wash performance and Energy Efficiency of Top Load Washers

Abstract

Washing performance and energy consumption of a washer has been considered as the center of concern for the industry of household washers. This work comprises the detailed evaluation of the factors and parameters involved in the result of the wash quality and the energy consumption, algorithm study and modification and the proposal of the effective design changes in the dynamic parts of the top loader back panel washing machine. For the comparison study, reference machine called WascatorFOM71CLS is used for 8kg top load washer. Test runs have been conducted after considering the treatments finalized through Design of Experiment (DOE). Results are obtained by conducting the performance test as per IEC 60456:2010 and Schedule 12 of Bureau of Energy Efficiency for wash quality and energy results. Optimization involved three factors i.e. wash time, motor on-time and water quantity. All the inputs are as per the IEC standard starting from the load conditioning to the result calculation. Running high wash time, high On-time and high water quantity contributed most optimized results considering both the fore mentioned objectives. Taking these results forward new stain removal dedicated program developed named Stain Master+ and tested accordingly in the laboratory. Also for the objective of the improved wash performance and optimized energy consumption, design changes in the most dynamic part of the washer called Pulsator. Algorithm of the new stain master+ program has been modified from the existing Strong Wash Program. Structural and CFD analysis is done for the comparison of the existing and new pulsator design with turbulent intensity

Keywords: *Design of Experiment, top loader, IEC, BEE, wascator, algorithm, pulsator, turbulent intensity*

1. Introduction

1.1 Washing Machine

Since the turn of the 20th century, washing in washing machines has been studied. The washing cycle was initially defined by Sinner as a function of four variables: temperature, time, mechanics, and chemistry. If one of the parameters loses intensity, the loss must be made up for by raising one or more of the remaining parameters. Wet cleaning, however, also heavily relies on the parameter water. Numerous studies have already demonstrated how washing parameters affect how well a wash is done. The majority of these investigations use changes in particular stain monitors to assess the washing performance. When comparing various machines, a normalised approach is necessary (Rainer Stamminger et al.,2016)

The results of effective laundering or dry cleaning include clean, crisp, hygienic clothing as well as pristine and crisp home linen. Laundry is both an art and a science. It is a science since it uses methods and principles that are based on science. It is also an art since its application necessitates the mastery of specific abilities in order to produce outcomes that are pleasing to the eye. All are aware that the amount of fibre, the type of yarn used, the methods used to make the fabric, the finishes applied to the fabric, and the intended use of the fabric all affect how to care for and maintain various fabrics. Additionally, we are aware of how laundry is done, how stains are removed, the importance of water, the suitability of soaps and detergents, washing techniques, finishing treatments, ironing and hot pressing, and folding. Now let's quickly go over the tools needed for these activities. Three equipment kinds are primarily used in daily life:

A. Washing Equipment
B. Drying Equipment
C. Ironing/Pressing Equipment

A significant portion of washing is done manually at the home level using tools including buckets, bowls, basins, scrubbing boards, and brushes. Basic washing machines have been added in some instances.

1.1.1 Washing Equipment

There are two different sorts of washing machine models: top loading (where the clothes are loaded from the top) and front loading.

These machines may also be:

(a) Fully automatic: These machines feature controls that can be adjusted for each use at a single time, including water filling, water temperature, wash cycle, and number of rinses. The operator doesn't need to take any more action.

(a) Semi-automatic: These devices frequently need the user to intervene. In these machines, rinse water needs to be filled and discharged after each cycle. Typically, these machines have two tubs.

(c) Manually operated: In these machines, the operator must perform at least 50% of the work manually.

The following tasks are carried out by an automatic washer:

(a) Water filling.

(b) Water Level Control is another crucial component. The level of the water either manually or automatically controlled.

(c) Controlling Water Temperature: The device has a button and a dial or a panel indicator that enables temperature selection within the water. Washing and rinsing may take place at the same temperature or at a different one.

(d) Laundry: The idea behind every washing machine is to keep the fabric moving to remove the filth, in the washing solution.

(e) Rinse: The crucial portion of the wash cycle is this one. The clothes may seem dull and grey and smell harsh if the rinse is not complete.

(f) Water Extraction: The pace at which the tub spins has a direct impact on how much water is removed from the clothing while it is being spun. The range of the speed is 333-1100 rpm. Because it may result in wrinkles that are challenging to iron out, spinning almost completely dry is to be avoided. The ideal speed is between 600 and 620 rpm.

Figure 1: Panasonic Back Panel heater Model

The majority of homes have an iron and a temporary or permanent workspace. The act of ironing is used to remove wrinkles brought about by use or during washing. Sleeves, trouser legs, and pleated skirts can all benefit from pressing to create creases. Irons have a hot, smooth metal surface. Most electric irons come equipped with an internal thermostat that allows you to change the temperature to suit the fabric. A system for creating steam while the iron is in use may also be present. The iron weighs somewhere between 1.5 and 3.5 kg. Lightweight irons are preferred for domestic use. Heavy irons may be needed for heavier items like bed coverings and curtains.

1.2 History

The washing machine is a household item that has fundamentally altered how clothing are washed. To get the clothing clean, washing them needed a lot of physical effort, which was a difficult household duty. Prior to the development of the washing machine, garments were cleaned and washed by being agitated with a conventional pounder, which has short, stool-like legs, scrubbed on a washboard, and squeezed with a mangle**.**

For a variety of washing machines that required warm water to be filled and agitated the clothing with revolving drums, gyrators, or dollies, roughly 2000 patents were obtained in Great Britain and America between 1851 and 1871. The majority of these devices required manual cranking, and garments frequently became tangled in the whirling dolly components. The tangling of the clothing was a challenge that was solved by inventors employing an oscillating motion.

Electric motors were included into washing machine designs in the first decade of the 20th century, although manual methods remained the norm until far into the 1920s. Domestic washing machines were widely used at the period, and ones like the one seen were typical because to the increased accessibility of electric power. However, the issue with water heating didn't go away until the conclusion of World War II. Some businesses created mangle-like wringers in their sleek, top-loading washing machines during the post-war era, and others had enhanced automated controls that required less monitoring. While front-loaders are now the norm in Europe, top-loading ones have gained popularity in America (Sergio A et al.,2003)

The latter kind can save space and is typically installed in the kitchen. This is among the factors that have contributed to styling's significant influence on washing machine design in Europe from the 1960s to the present. By adapting the power usage to the amount of the load, washing machines nowadays are substantially more energy-efficient. In Europe, new machine generations are now being

created that will be even more energy-efficient and will do away with the need for environmentally hazardous detergents.

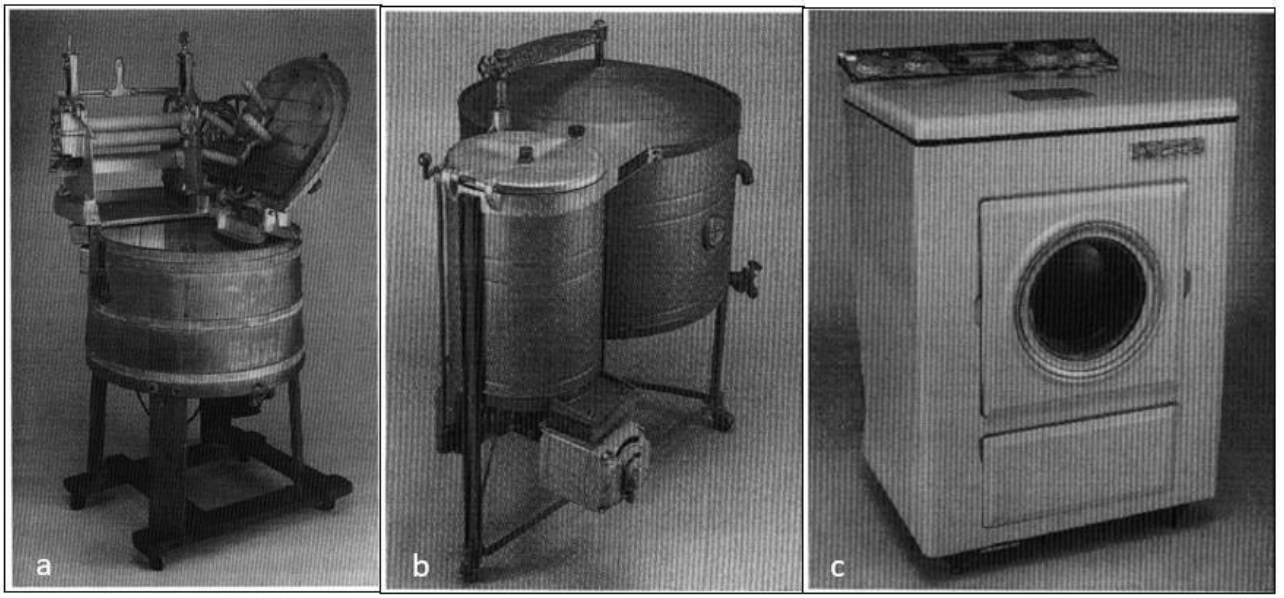


Figure 2: Wooden domestic washing machine with a dolly style agitator(a),Riby twin-tub washing machine,1932(b),Front-loading washing machine,1961(c)

(Source: Sergio A. et al.2003)

1.3 Working

In a typical washing machine, the garments are forced through water and detergent by a central agitator that pushes them around throughout the whole wash cycle. The middle spindle, or agitator, features fins or vanes to make sure that your clothing move freely inside the drum, forcing dirt and grime out. However, although being more efficient at eliminating filth, the agitator may be rough on your clothing, and delicate materials may see significant wear and tear over time in them.

The main agitator of washing machines is optional. An impeller, a low-profile revolving hub, serves in place of the agitator to stir up the contents of the drum as it revolves. Your clothing are cleaned by the turbulence since it moves them, and since they don't hit a central spindle, wear and tear is reduced overall. However, although being gentler on your clothing, it could not wash as effective at eliminating dirt as an agitator machine, and since your clothes are practically tumbling about, there is a very high chance that they will become tangled.

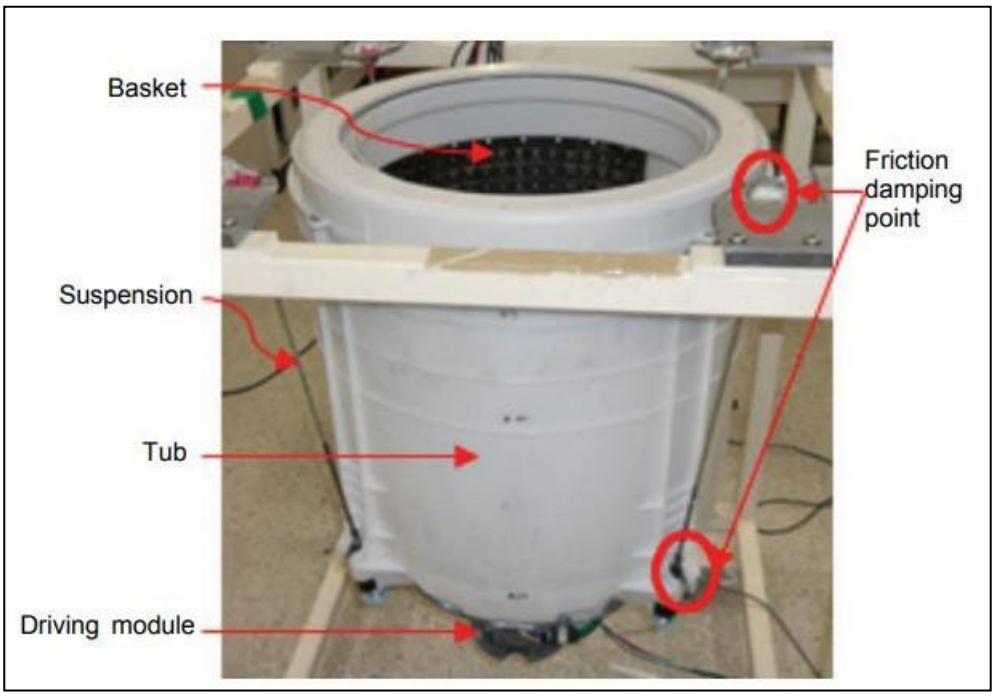


Figure 3: Washing Machine system with a tub, basket, driving module and suspension

(Source: Taejin Kim et al.2012)

Both of these models use a lot of water because the agitator or the impeller swishes the water around while your clothes are being washed to extract dirt from the fabric. The third kind, HE washing machines, use a revolving drum similar to front-loading washers to save water use. In this instance, there are two drums: the outer drum, which contains water throughout the wash cycle, and the inner drum, which rotates and has paddles on the side to clean your clothing. Your garments are hoisted and tossed against the walls to clean them as the inner drum rotates and regularly changes direction.

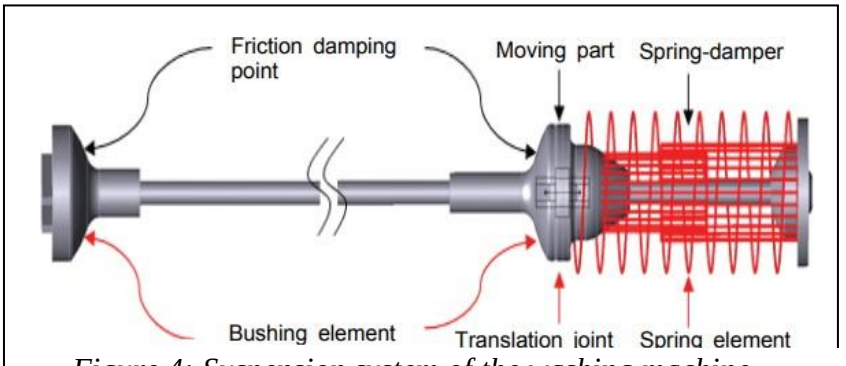


Figure 4: Suspension system of the washing machine

(Source: Taejin Kim et al.2012)

1.4 Background of the Research

In the industry of laundry washers, there are a number of technical concerns for the marketshare commitment. Customer oriented, economically feasible and environment friendly aspects are welcomed only and that's why it's a challenging task to update in response of the customer as well as to the environment. Considering these two aspects, few objectives like wash quality, spin performance, rinse performance, water consumption and energy consumption are known worldwide in the laundry industry.

Laundry washing involves the removal of the water soluble dirt and impurities (Boyano et al. 2017).These are controlled by the most renowned factors of Sinner's Circle: washing temperature, wash time, chemistry and the mechanical work. "Chemistry" Stands for the ingredients of the detergent and the amount of detergent. Likewise, "mechanical action" refers to the motor duty cycle, "time" refers to the length of the wash cycle. One more and important factor that has to be considered is "water" i.e. known as inner circle in the Sinner's Circle.

Almost every family in the globe has a washing machine, which is an extensively used device. The use of washing machines for laundry in homes has increased in place of hand washing as a result of the rapid economic development and increase in global population. Washing machines are made to thoroughly clean garments while maintaining the integrity of the fabric. The majority of housewives use fully automatic washing machines as a result of increased female employment and job simplification strategies. The image of the brand was the primary motivator for the majority of respondents, followed by dependability, superior quality, and word-of-mouth recommendations (P Kantheti, 2016).

The behaviors and responses of consumers to product design and marketing must be understood by manufacturers. Customer loyalty to the company is influenced by how happy they are. As a result, a major issue for market-driven product design is now satisfying the needs of both existing and potential customers. In order to increase consumer happiness, it is vital to look into how product attributes influence that satisfaction (Wang et al.,2019). The exterior, human-computer interface, and idea trends in the secondary and tertiary markets must alter according to specific environmental conditions, human traits, habits, and cognitive capacities of washing machine users.

In addition to fundamental operations like washing and spinning to dry clothes, reduced vibration is fast becoming a crucial performance metric for washing machines. The drying process in an automatic washing machine uses the spinning motions of a basket, whereas the washing process uses the oscillating motions of a basket. During both washing and spin drying, a motor sends power via a belt to the exact same revolving axis of the basket. Following the washing mode, the spin drying mode is used to dry the laundry. Clothes have a tendency to bunch up while in the washing phase, generating an unbalanced mass in the basket. When the basket spins at a relatively high speed during the drying cycle, such unbalanced mass can lead to severe vibration issues (S. Bae et al.,2002).

A hydraulic dynamic balancer is one type that can be utilized with washing machines. The upper rim of the basket is where the balancer, which holds salt water, is attached. A number of the hydraulic balancer may use a variety of fluids, including fresh water, salt water, and oil. The hydraulic balancer, which rotates with the basket and serves as a counter, and liquid mercury. Due to its inherent properties, mass places salt water to the other side of the disequilibrium. The hydraulic balancer is therefore more effective. superior to a solid balancer. The distribution and size of the counter mass are established by the balancer's internal design and rotational speed (S. Bae et al.,2002).

Figure 5: Hydraulic Balancer

(Source: S. Bae et al.2002)

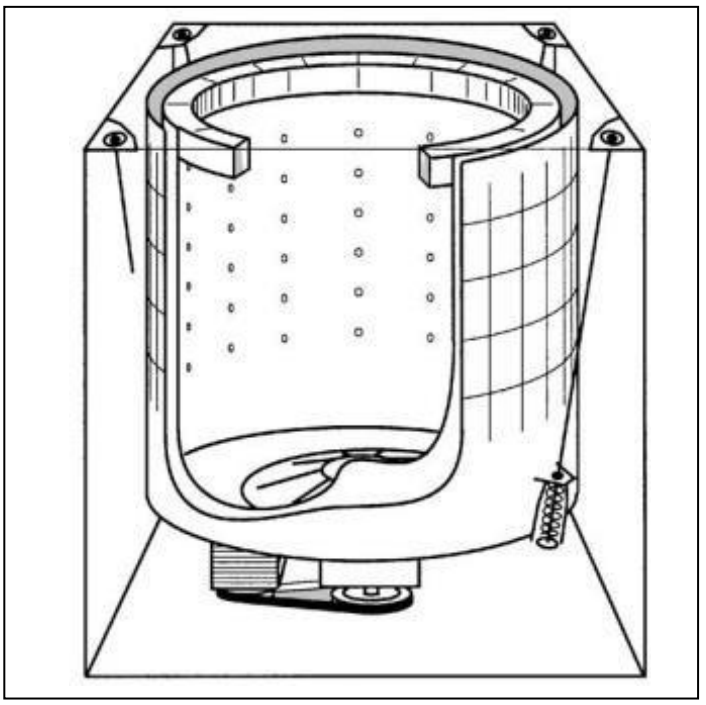


Figure 6: Illustration of a vertical axis washing machine

(Source: S. Bae et al.2002)

2. Objectives

a. To study the influence of the parameters that can act as the factors for the ultimate response of wash performance and energy consumption using DOE.

b. To develop a new program named Stain Master+ program claiming atleast 50 stains removal taking care of energy efficiency

c. To suggest necessary design changes in the dynamic part of the washer called pulsator for the sake of enhanced wash quality with least energy consumption.

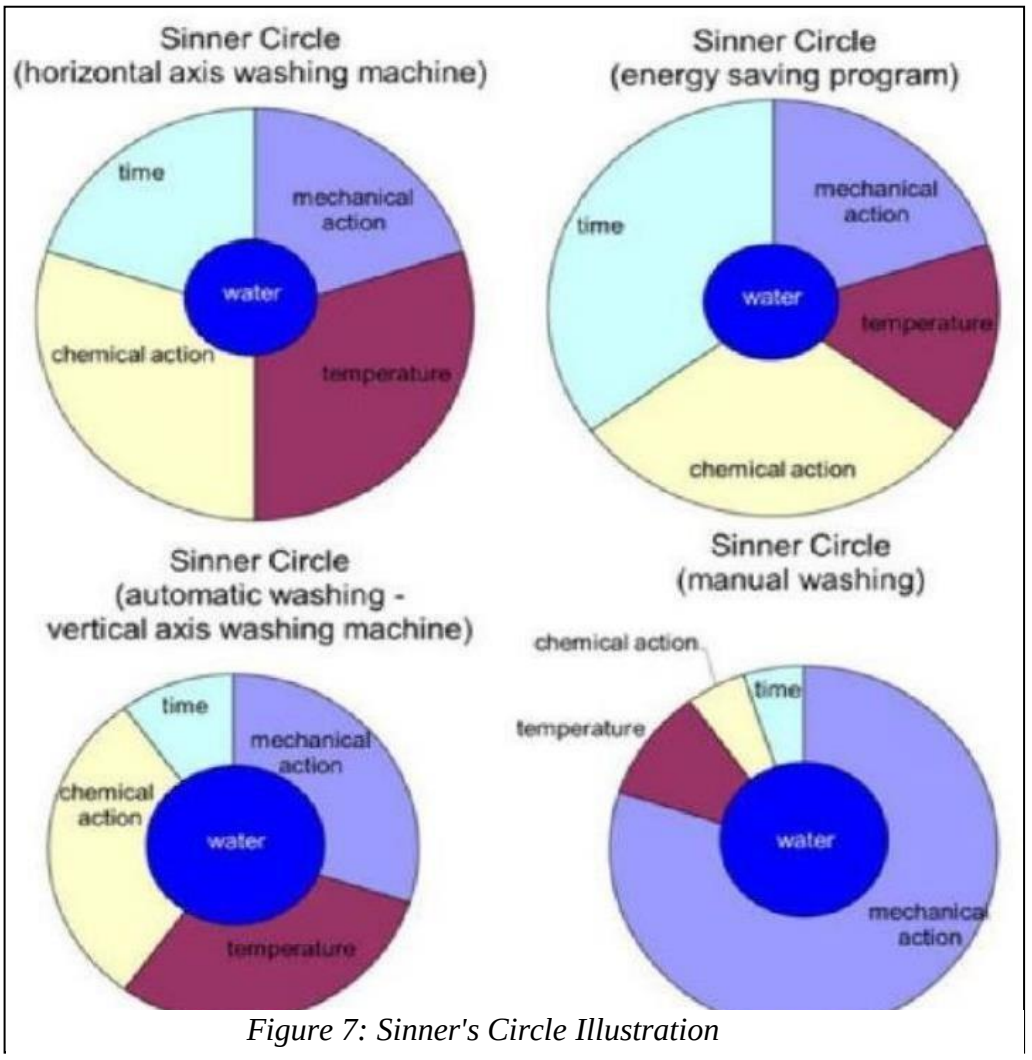


Figure 7: Sinner's Circle Illustration

(Source: Boyano et al.2017)

For achieving the same result, factors depend on each other. On increasing one, other must be adjusted accordingly for getting the same result. Different configurations and environmentconditions demands different share of the factors in the circle. Considering the other significant criteria to be looked upon, energy efficiency demands very crucial steps belonging to the design as well as to the programing algorithms being used in the control unit of the washers. The environment impact of washers eventually caused by electricity, water consumption and detergent consumption.

There are a number of suggestions for exploiting the energy efficient options in the washers. Motor design inclusive of the type of motor used and the duty cycle of the motor can be a suffice option for the exploration. Other can be usage of high end sensors for automatic load sensing of the clothes so that optimal water and detergent amount can be used to avoid overheating and sensible wash with energy efficient way (Faberi et al. 2007). Half loaded washers theoretically lead to the reduction of 50% in the energy as well as in the water consumption. But practically, a reduction of around 20% can be done using load sensors (Josephy et al. 2011)

Though achieving the optimized setting of the parameters for best combination is aimed, modification in the program algorithm can also be made for the same objective. Program modification is generally preferred first as it doesn't require any demanding investment. Non achieved objectives but necessary ones requires design changes also. Since design changes require handsome amount of mold investment, it usually kept as the last option for any project. We generally play within the algorithm of the wash programs of the washer. An algorithm is a well-developed, organized approach to solve a complex problem. Algorithm is a step by step solution to a problem.

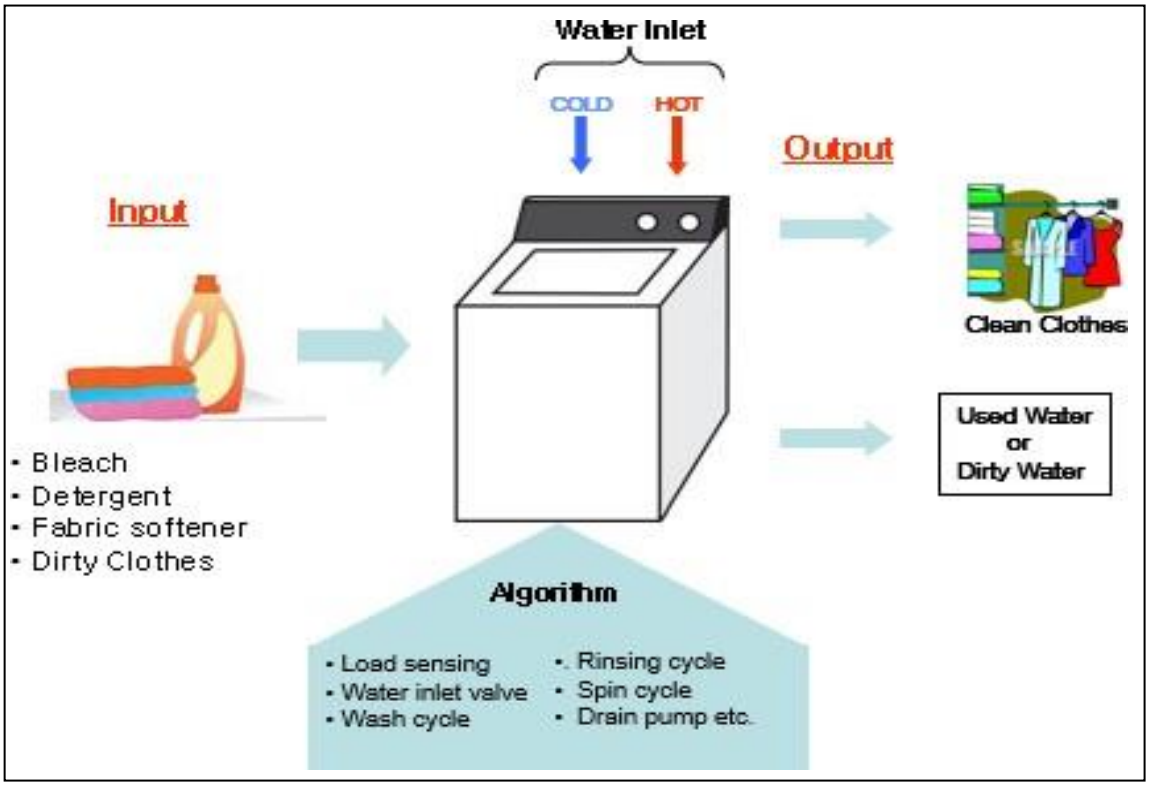


Figure 8:Development of an algorithm

2.1 Significance of the work

The present research work comprises the delineated comparison of the potential factors contributing to the desired outputs .Since we are concerned with both the customer as well as the environment , hence opted wash performance and energy efficiency as the corresponding potentials factors which can be effectively visualized and varied. There is a limitation of the alterations of factors because of the limited capabilities and change scope in the algorithm of the control unit. Test runs to be conducted will be as per the IEC 60456:2010 standard and Schedule 12 of BEE standard for washing machine. Standard inputs are suggested for the accurate and desired results. In India, Energy Star Ratings are given as per defined range of energy in kWh/Cycle/kg in the Schedule 12 of BEE standard. Testing procedure and methods are as per IEC standard. Test runs are finalized after conducting Design of Experiment for getting the optimum setting for best results taking over the existing setting results the improvement purpose with current possible alternatives.

After getting the finalized setting of the parameters from DOE , we can effectively use the results in the algorithm modification of an existing program for the sake of improvement in the wash quality and the energy efficiency. Further under the same scope we can deliberately introduce some design changes which would definitely require the analysis of the results causing after the changes. But the design changes must be economical to the manufacturing process as well as the mold investment with the shorter period of ROI (Return of Investment).

In the present work, analysis has been done with respect to the turbulent intensity measure in existing as well as the new design of the pulsator. Since turbulence is the most desirable measure in the world of washers, this is aimed to increase by design modification. Turbulence effectively increases the wash quality and also decreases the energy consumption for the same level of wash quality.

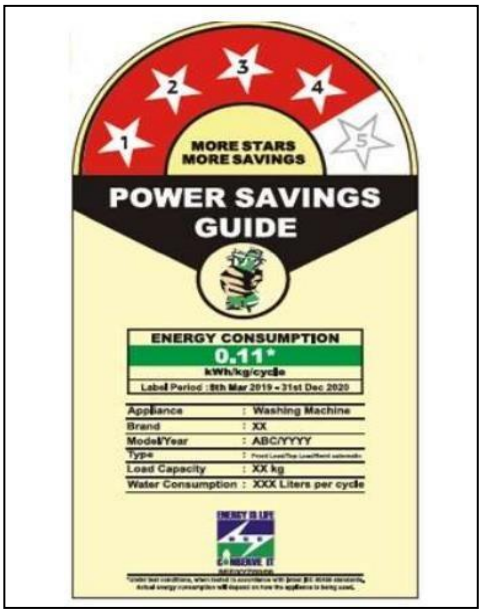


Figure 9: Energy Label for Washing Machines

(Source: BEE schedule 12,Rev 3,2019)

3. Literature Review

3.1 Parameters affecting Wash Quality

Literature study suggested sequential method of approaching the performance testing with horizontal axis washer and also gave a detailed comparison with the reference machine Launder-Ometer. The work is based on the european standard EN20105 for the testing and study purpose. Effect of wash time, detergent dosing, variable temperature and mechanical effect has been studied in detail (Hanna K.2007). According to a different study, extended wash times may make up for low wash temperatures, but high temperatures would still persist above the long wash times. According to this study, dirt that has been removed from clothing may reappear on it after washing. (Lloyd and Adams.1989). International standard IEC 60456:2010 gave all performance testing procedure starting from the load preparation to the result recording (Boyano et al. 2017).

3.2 Parameters affecting Energy Consumption

Effect of low temperature on the energy savings is studied and usage of the low temperature washing detergent is considered to explore. Application of effective load sensors to reduce energy and water consumption to the fullest. Around 20% energy and water waste can be reduced effectively using load sensors (Josephy et al.2011). Design changes like using load sensors and motor type preference can

preferably reduce the energy consumption. Using blushless DC motor can extensively provide energy saving as well as provide the speed variation feasibility to the programming algorithm (Faberi et al.2007). Laundry washing in the households usually differs a lot in terms of water and energy consumption across the world. But due to different consumer habits regarding the washing and usage ,the ideal way of practicingin most sustainable way is yet to be preached (Christiane P. and Stamminger R. 2010).

3.3 Stain removal and design approach in washers

Due to its ease of producing intricate shapes, injection molding is one of the most popular production processes utilized by the plastics industry. To decrease the rejection of plastic components, Taguchi and Anova, among others, have improved these process parameters. Some scientists use FEA simulation approaches to decrease plastic component rejection (Yogesh S. Khairnar,2018). A screw and an external heating source are used to melt the material, which is then injected into a mold to create the desired result while the mold cools. Currently, goods made via injection molding can be made from a wide variety of materials (Fu et al.,2019)

Many defects, including warpage, sink marks, weld lines, and tensile strength, are generated by processing conditions, according to Sahai investigations. Some of these variables are the melting point, mold temperature, injection pressure, injection time, cooling time, runner type, number of gates, gate size, packing pressure, packing time, and others. As a result, injection molding products need production control of processing parameters (Sahai and Verma, 2021). Polypropylene (PP) was used as a specimen to investigate the effects of melt temperature, packing pressure, and injection pressure on the tensile modulus and elongation. Melt temperature and packing pressure were demonstrated to be pertinent parameters for the elongation response, however only melt temperature was determined to be crucial for the tensile modulus. (Goyal et al , 2022).

Re-identifying and recreating manufactured artefacts is design. The main goal of this scientific study is to change industrial design's emphasis from a concern for objects to one for relationships between things and human behaviour. Due to the varied environmental conditions, human factors, habits, and cognitive abilities of washing machine users in the secondary and tertiary markets, the external appearance, human-computer interface, and idea trends during the design process must be distinctive (Meina Wang,2018).

3.4 Research Gap

As per existing research studies, comparison between the factors and the responses have been made for the washing performance but only for the horizontal axis washers (Hanna K. 2007). Also the energy usage hasn't been studied in depth with simultaneous settings for wash performance. Due to costly experimental runs, there is a restriction of the number of the runs. Hence approach of DOE is adopted for extracting the maximum information with minimum resources. Conclusive results has been made through analysis and optimization tools of the capable statistical software. Optimum setting of the factors with suitable levels has been suggested for desired result of wash and energy performance. On the other hand , a Washing machine program algorithm has not been studied in any of the research in such a detail for purpose of creating a new wash program . Also the design modification challenges and approaches are mentioned in the analysis and simulation research of the injection molding ,but it is not in such a depth specifically for the pulsator .

4. Experimentation

4.1 Research Design

The work is based upon descriptive research design. A full and accurate characterization of a group, situation, or phenomenon is the goal of descriptive analysis.It helped in exploring and answering the most optimized condition for achieving the best possible results in response to the experimental and financial restrictions. One of the most capable tool of the statistics Design of Experiment has been used for assistance for getting the desired output.

The schedule 12 of Bureau of Energy Efficiency specifies the requirement for collaborating within the energy labeling application for all styles of washing machines included under the scope of IEC 60456 and IS 302-2-7 supposed for household and similar use, being synthetic, imported and sold in India. In specific, this scheme specifies the following: wash performance,rinse overall performance, energy consumption, water intake ,water extraction overall performance (residual water content material).Also from the conclusion of the experiment , research moved ahead with the objective of developing a new strong stain master program which has the capability to remove at least 50 daily stains which have classified as the cold water stain, hot water stain, Oil stain and water soluble.

Needs of the customer tends to change eventually and the product development .The product design is the most critical and governing stage which needs to be taken care of . In india , product

design and innovation hasn't brought to the superior level yet and hence foreign designs are still in great demand and assistance is required in the country for the purpose.

Here creative design methodology (CDM) has been adopted. Innovative Design Methodology works with advancement. The recommendation of better thoughts isn't exclusively subject to the degree of information on the creator. Contingent on the reasoning style of a planner, his/her insight degree may once in a while antagonistically influence the innovativeness. To offer inventive and further developed arrangement of a framework, age of thoughts is the principal prerequisite. Contingent upon the scientist's reasoning capacity, the relationship among innovativeness and information can be described. It is recognizable that imagination is probably going to ascend with the increment of information, for innovative reasoning style, while it arrives at immersion on the off chance that the creative mind follows a customary style.

This approach uses the idea of Ideality. The ideality of the framework is expanded for accomplishing better execution. A few gradual changes in the framework are made to eliminate the struggles. TRIZ(Theory of Inventive critical thinking) with its logical inconsistency grid and 40 creative standards, is one of the most broadly utilized strategies to determine such contentions existing in the framework.

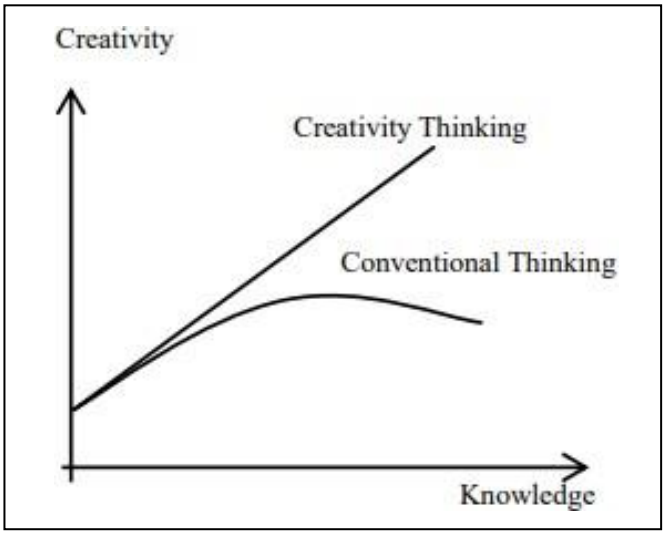


Figure 10: Relationship between knowledge and creativity

(Source: Sameera Muffazal and S M Muzakkir, 2017)

4.1.1 Design modification approach

For the purpose of enhancing the wash quality and reducing the energy consumption, the idea of turbulence is adopted. It is well known fact that increase of turbulence is the boon to the world of washers. So any change in the design will focus on the increasing the turbulence. This can be achieved by adding the ribs to the structure. It will increase the strength also as well as increase the turbulence. The dynamic part that is most suitable for this is the pulsator. So the changes in the surface and material will be the focus of research for our objective.

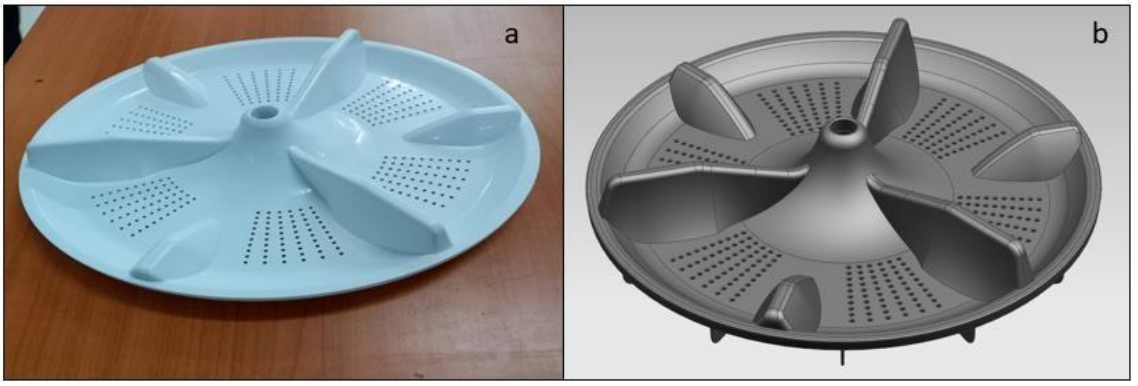


Figure 11: Existing pulsator sample(a),3D model(b)

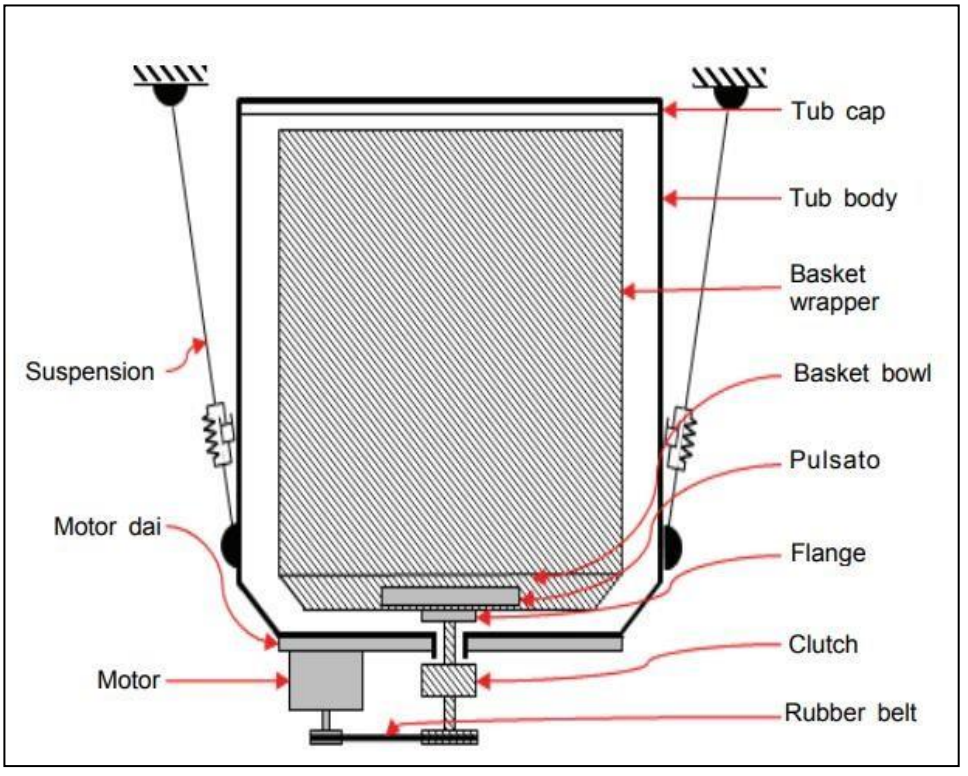


Figure 12: Simplified model of a washing machine

(Source: Taejin Kim et al.2012)

The figure 12 shown has all the working parts of the top loader washing machine. Since inner drum (basket bowl) and the pulsator are the most dynamic part of the machine. Pulsator has been selected as it allows the scope of changes in the surface design of the part while in inner drum already the ribs are allotted which can't be changed as much.

4.1.1.1 Addition of ribs

Existing design of pulsator has 3 full wings and 3 half wings. If ribs are added to the half wings it largely introduce the turbulence in the flow. Ribs can also be added to the full wings but it can make the molding difficult as the full wings are more steeper and ribs addition would definitely create problem due to lesser draft angle.

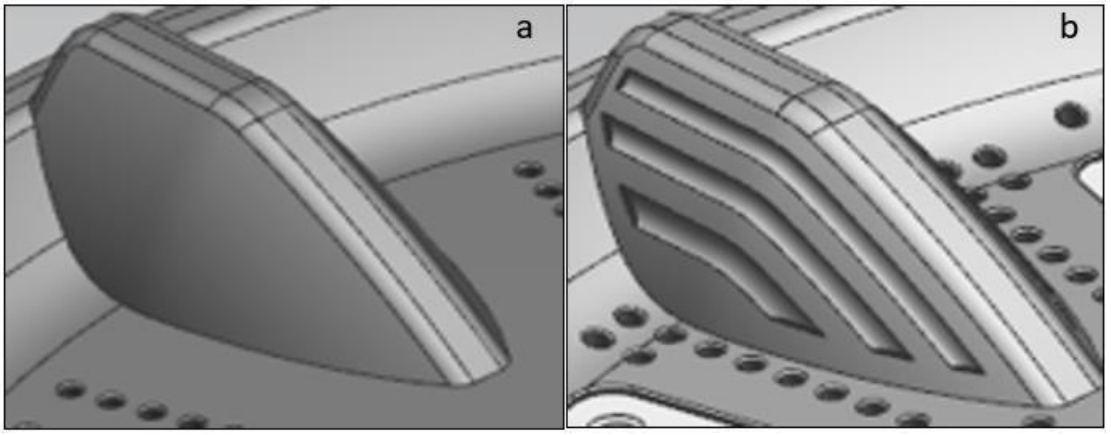


Figure 13: Existing pulsator without ribs(a),3D model with ribs addition(b)

4.1.1.2 Addition of Structural steel with diamond shape embossing

The second desirable change in the pulsator is the base surface. Current material of the pulsator is Polypropylene (PP), but the surface should be much hardened and non smooth. So diamond embossing is suggested just like the inner drum of same shape and size. Due to this the holes on the base surface must be adjusted accordingly.

After implementing both the changes in the design, new pulsator shown in fig 15 is the final design of the pulsator. It has Stainless steel plates inserted in between the base surface. It will be manufactured by insert molding and also add up come cost to the manufacturing process as compared to the earlier.

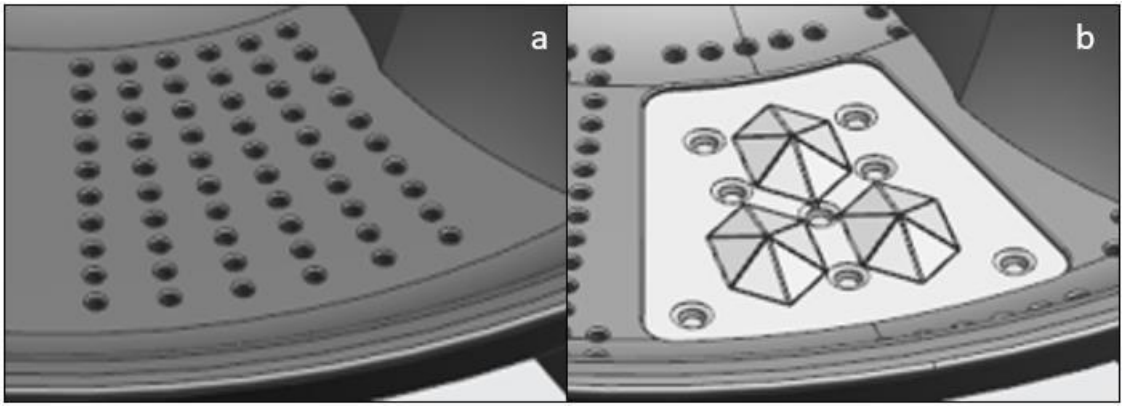


Figure 14: Existing pulsator without SS embossing(a),3D model with embossing(b)

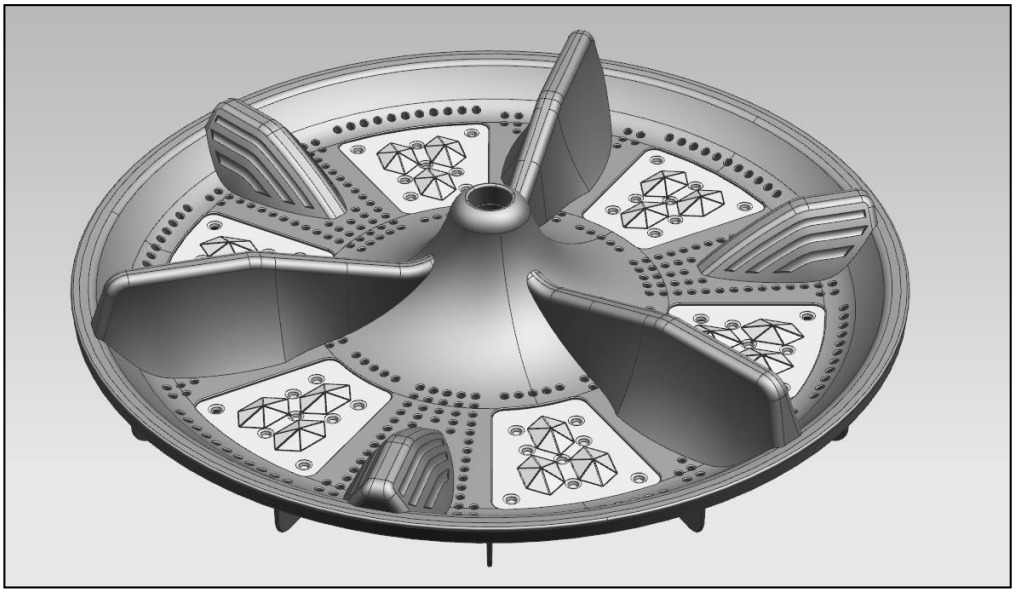


Figure 15: 3D Model of new pulsator

4.2 Research Approach

The research approach for the review was based upon the deductive technique. The research approach to scientific knowledge that most people equate with empirical inquiry is indeed a deductive method. DOE conducted involved three factors, Wash Time, Motor On time and Water Amount with two levels of High and Low each. These factors have been finalized after doing brainstorming and with the help of fishbone diagram. Developing a new program taking the base

of the current strong jeans program with the necessary changes in the algorithm focusing on the Motor on time and the temperature at different water levels of the program .

Doing the design changes in the existing one is the most challenging and the critical task to do as it requires the DFM (Design for Manufacturing) and DFA (Design for analysis). Here the changes suggested have taken care of both the critical points. Approach is to justify the changes by doing the structural analysis and the CFD analysis with the focus on the turbulency created over the existing design.

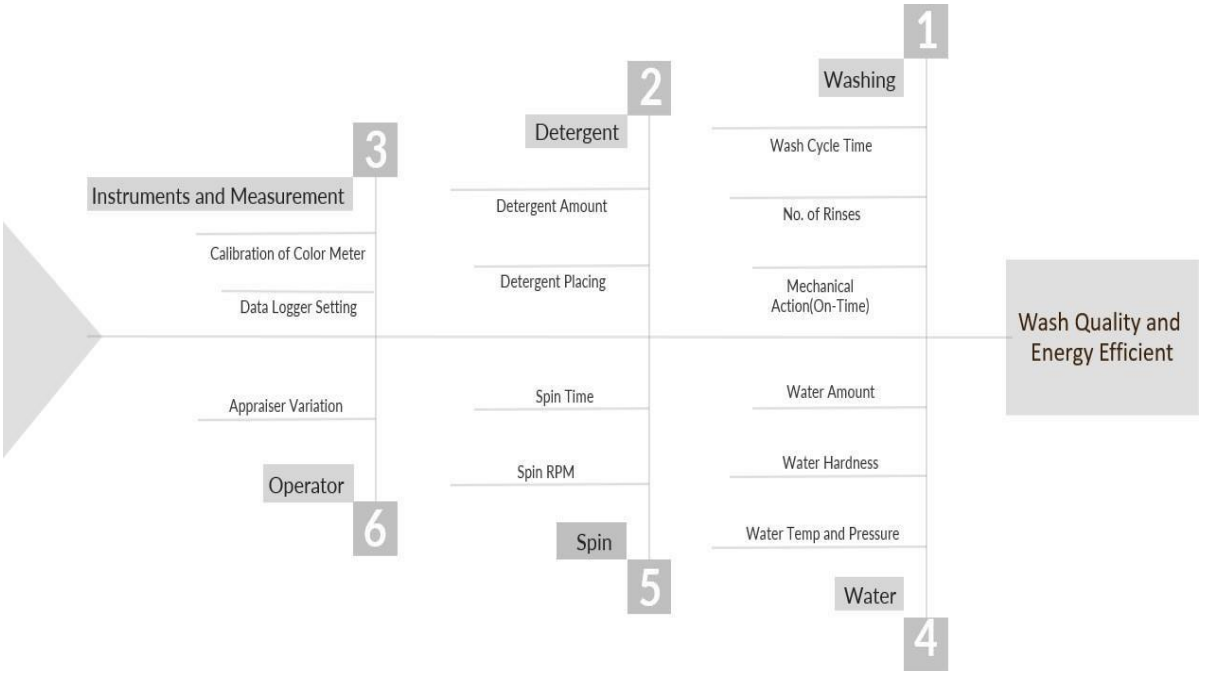


Figure 16: Fishbone diagram for potential factors

After considering the experimental and circumstantial challenges of the setup and limited change scope due to algorithm of the control unit, DOE conducted for most important factors listed below along with their suitable levels.

Table 1 : Factors and levels allotted to the experiment

Factors	Low	High
Wash Time	6 min	9 min
On Time (Motor)	1 sec	1.2 sec
Water Amount	60 L	64 L

Test procedure adopted are suggested in IEC 60456:2010 and below are the overview of the procedure and the calculation methods of the results which will be used as the response in the experiment.

4.2.1 Algorithm modification for Stain Master+

The approach for the modification and development of new program from the previous well established program has been taken in to account. One of the well known program for the same machine is Jeans program which lies in strong category. There are maximum 10 water levels in the program which results different washing results on selection according to load. Following are the parameters which are modified with the logic of wash performance:

a. **Temperature**: The temperature at different water level needs to be understood according to the need of the program. As stain master program is very strong in nature and it is supposed to remove at least 50 stains at all water levels, so temperature at lower water levels also changed from 40 °C to 60 °C.

b. **Duty Cycle**: Duty cycle is the most critical and variable parameter in the algorithm. A number of different programs can be made just by playing with duty cycle smartly. Since duty cycle with 0.8 Sec motor on time is set for current Jeans program, Motor on time will be modified to 1.2 sec which will give better wash quality with minimum energy consumption.

Figure 17: Basic operations in an algorithm of a program

There is a detailed stepwise algorithm for every program where the parameters can be varied according to the requirement of the program.

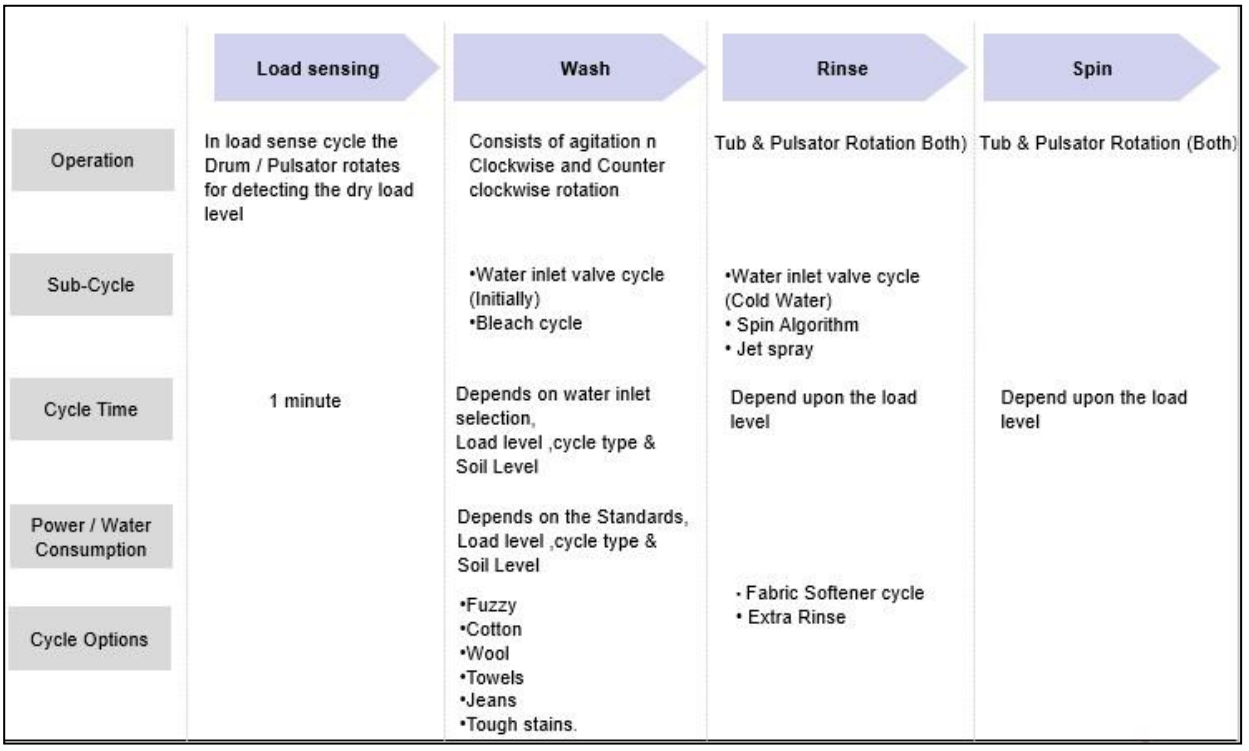


Figure 18: Detailed operations in an algorithm of a program

Stain Master+ program has been modified from the existing strong Jeans program. The parameters that has been varied are temperature and the duty cycle. Following is the detailed algorithm of the new stain master+ program.

Table 2: Algorithm of stain master+ program

STEP	PHASE	OPERATION	Water Level									
			1	2	3	4	5	6	7	8	9	10
1	WASH	Load Sensing(s)	-	-	-	-	-	-	-	-	-	-
2		Water Filling (90%) (min)	2	2	2	2	3	3	3	4	4	4
3		Agitation(s)	10	10	10	10	10	10	10	10	10	10
4		Fill + Agitation (s)	30	30	30	30	30	30	30	30	30	30
5		Delay(s)	10	10	10	10	10	10	10	10	10	10
6		Refill (100%) (min)	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
7		Soak(s)	38	38	38	38	38	38	38	38	38	38
8		Heating (°C)	60	60	60	40	40	40	40	40	40	40
9		Total Main Wash (min)	20	20	20	20	20	20	20	20	20	20

10	1ST RINSE	Drainage(min)	1	1	1	1	2	2	2	3	3	3
11		Balance Spin (min)	1	1	1	1	1	1	1	1	1	1
12		Intermediate Spin (min)	3	3	3	3	3	3	3	3	3	3
13		Stop Inertia (min)	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
14		Water Filling (min)	3	3	3	3	4	4	4	5	5	5
15		Rinse Wash (min)	3	3	3	3	3	3	3	3	3	3
16	2ND RINSE	Drainage (1/3rd) (min)	1	1	1	1	2	2	2	3	3	3
17		Balance Spin (min)	1	1	1	1	1	1	1	1	1	1
18		Intermediate Spin (min)	3	3	3	3	3	3	3	3	3	3
19		Stop Inertia (min)	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
20		Water Filling (min)	3	3	3	3	4	4	4	5	5	5
21		Rinse Wash (min)	3	3	3	3	3	3	3	3	3	3
22	SPIN	Drainage (min)	1	1	1	1	2	2	2	3	3	3
23		Balance Spin (min)	1	1	1	1	1	1	1	1	1	1
24		Final Spin (min)	6	6	6	6	6	6	6	6	6	6
25		Inertia Spin (min)	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5

4.2.2 Testing Procedure

4.2.2.1 Performance test procedure*:* The following table describes the points to be checked in the earliest phase:

Table 3: Testing Procedure for household Top load washer

(Source: IEC 60456:2010)

Lab Condition	23±2°C
Water condition	50± 20 ppm, 35±5°C
Program Selection	Normal Wash

Load Preparation and Load Composition	a. Load conditioning: 20±2°C, 65% RH b. Load Distribution: For 8Kg Load Bedsheet - 3, Pillowcase-12, Towel-25+ extra adjustments c. Swatches Stitching- 8 d. Load Placement: As per IEC standard.
Detergent Mixture	a. TAED (Bleach Activator): 3% b. Sodium Perborate Tetrahydrate: 20% c. Base Powder: 77%
Program Selection	a. Normal Program (36 min) with 6 min Wash Time b. Normal Program (36 min) with 9 min Wash Time

Table 4: Detergent Dose (Source: IEC 60456:2010)

Load type and Reference Programme	Test Washing Machine		Reference machine Type 1	
	Dose Hard Water (refer to 5.2.2.2)	Dose Soft Water (refer to 5.2.2.2)	Dose Hard Water (refer to 5.2.2.2)	Dose Soft Water (refer to 5.2.2.2)
Cotton – all reference programmes except Cotton 20 °C and Cotton 30 °C	54 g + 16 g/kg	36 g + 10,7 g/kg	155 g	100 g
Cotton – Cotton 20 °C and Cotton 30 °C only	54 g + 8 g/kg	36 g + 5,3 g/kg	78 g	52 g
Synthetic/Blends	54 g + 16 g/kg	36 g + 10,7 g/kg	125 g	80 g
Wool	54 g + 16 g/kg	36 g + 10,7 g/kg	70 g	46,7 g

Detergent dose will be as per soft water and cotton 30°C program. Here from the table 4 ,it can be seen that 36g +5.3 g/kg will be applicable for the required test.

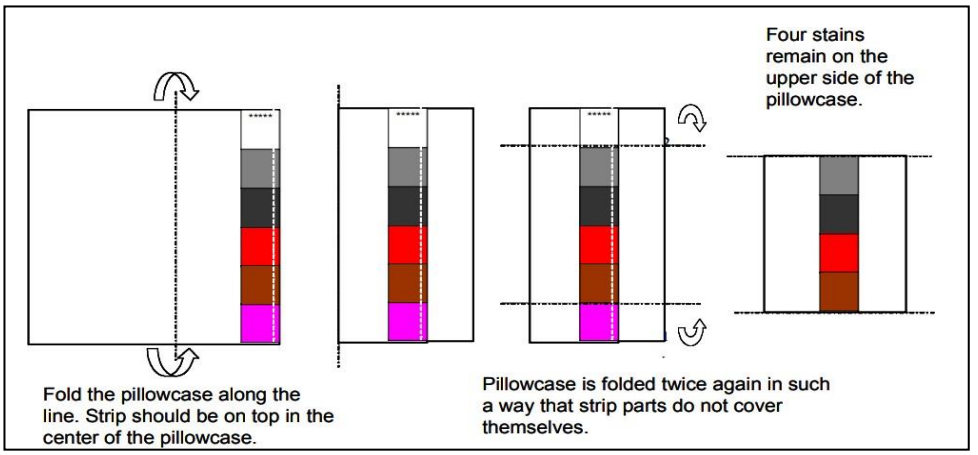


Figure 19: Testing towel with test swatch folding method

(Source: IEC 60456:2010)

4.2.2.2 Stain Master+ program test procedure :

Stain Master+ Program is aimed to claim 50 stain removal feature in upcoming Back Panel heater model top loader washer. Algorithm for this program is being developed by taking base of one of the existing strong jeans program. Changes and modification is being done only in the temperature parameter and Duty cycle in the program. These changes are done at different water levels of the program.

Currently Panasonic claims:

1) Sweat
2) Sauces
3) Collar/Cuff
4) Curry
5) Germ Clean

Figure 20: Existing 5 stains claimed by Panasonic

4.2.2.2.1 Stain Strip Preparation:

a) Wash Base cloth 2 time and Dry it.
b) Cut it 20 x 15 mm as shown in Fig.
c) Make circle of ϕ 40mm as shown in Fig.
d) Apply stain inside the circle
e) Put it for drying as per cure time(to dry hang it)

4.2.2.2.2 Test Procedure:

1. Prepare stain strips
2. Stitch strips with towel
3. Add detergent

4. Complete stain cycle
5. Dry stain strips
6. Visual Inspection

4.2.3 Testing Equipment and resources

4.2.3.1 Testing Equipment for performance testing

There are very sophisticated instruments that have been utilized for the data recording and test conduct. However, the objectives includes the wash performance and Energy recording so the concerned equipment includes Spectrophotometer, Power Analyzer, Flowmeter, Testing Clothes, Test Swatches, Load Conditioner, Reference Machine (Wascator).

4.2.3.2 Testing Equipment for Stain Master+ test

Figure 21: Spectrophotometer(a), Wascator (b), Load Conditioner(c), IEC-A detergent(d),SPB4(e), TAED(f)

Following are the equipment needed for the completion of Stain Master+ program test and verification :

Equipments:

a) Type of stains
b) Base cloth (White cloth)- 100% cotton
c) Scissor
d) Permanent Marker
e) Scale

f) Detergent
g) Standard Load

4.2.4 Sampling technique and data recording

Design of Experiment has been implemented stepwise starting from planning, screening, analyzing and then ending with optimizing with response optimizer. A full factorial design opted with 2 replications, 1 block and 1 Centre point.

4.2.4.1 Wash Performance Calculation

The stain test strips are taken out of the test load at the end of the programme after each test run is finished. The test strips must be flattened and dried before obtaining reflectance measurements. The unsoiled test piece that makes up the stain test strip and each of the different soil types are measured for tristimulus Y reflectance in order to determine washing performance (IEC 60456). A spectrophotometer should be used to capture reflection measurements since it provides information on all the stains present in each swatch.

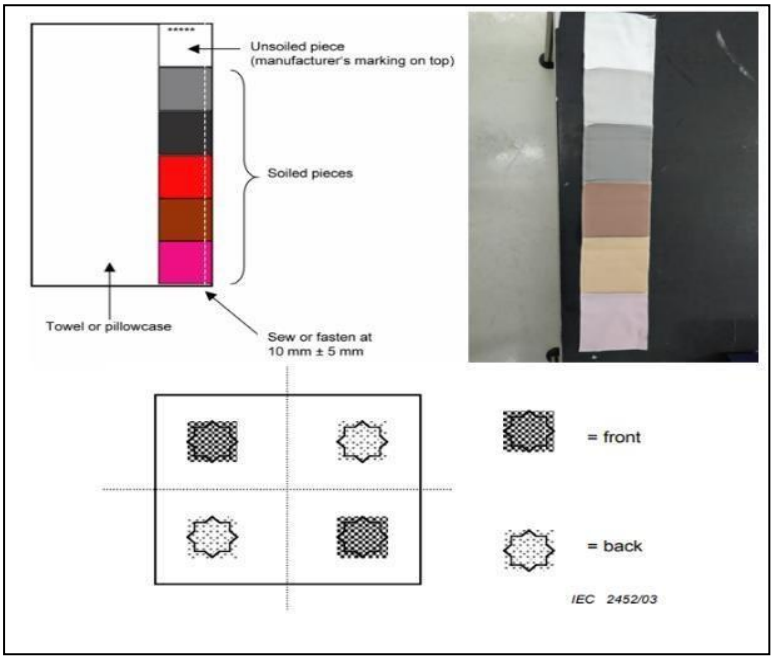


Figure 22: Test strip with soiled and unsoiled strip to be measured at prescribed 4 positions

(Source: IEC 60456:2010)

4.2.4.2 Energy consumption calculation

The data of energy got recorded by the help of power analyzer and data logger which records accurate energy reading in each of the cycle along with the details of the duty cycle of the motor used. The specified unit for energy consumption is kWh/cycle/g(Schedule 12,BEE). DOE conducted after designing the model and readings of both the responses are taken as per the run order of the treatments.

Table 5: Responses as per the suggested run orders of the experiment

RunOrder	CenterPt	Blocks	Wash Time(Min)	On Time(Sec)	Water amount(Ltr)	Wash Quality %	Energy(Wh/Kg/Cycle)
1	1	1	6	1.0	60	88.0	8.5
2	1	1	9	1.2	64	93.8	10.9
3	1	1	6	1.0	64	87.8	8.7
4	1	1	6	1.2	64	89.2	8.9
5	1	1	9	1.2	64	93.8	10.8
6	1	1	9	1.0	64	90.5	9.2
7	1	1	9	1.0	64	90.3	9.0
8	1	1	9	1.0	60	90.9	10.2
9	1	1	6	1.0	64	87.6	8.5
10	1	1	9	1.2	60	94.0	14.1
11	1	1	6	1.2	60	89.5	9.1
12	1	1	9	1.0	60	91.0	10.2
13	1	1	6	1.0	60	87.8	8.4
14	1	1	6	1.2	64	89.2	8.8
15	1	1	9	1.2	60	93.8	13.9
16	1	1	6	1.2	60	89.4	9.0

4.2.5 Stain collection for stain master+ program

Stain collection process was directional and systematic with phase approach. Initially almost 55 stains were planned to be tested and verified with around 48 hours of curing time. Then the swatches according to the test procedure were to be washed corresponding to the requirement of load.

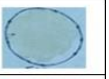
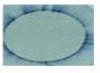
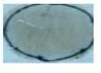
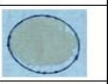
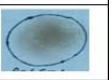
Before stain collection proceedings stain segregation according to the behavior type is necessary. Hence a detailed segregation matrix has to be formed among the cold water stain, hot water stain,oil stain and water soluble stain. Individual employees evolved into "laundries" or "drycleaning" businesses. Here, the buyer gives the items to be cleaned and then returns a few days later to pick up the completed goods. A person or a business might be the client. Larger laundries frequently have many centres or stores located across the city. Some laundries furthermore offer services for moving goods to and from the client. This is particularly hence, when it comes to establishments like hostels, modest hotels, eateries, and including little medical facilities and nursing homes.

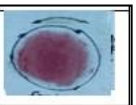
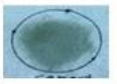
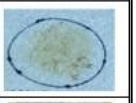
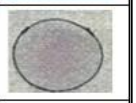
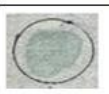
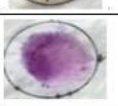
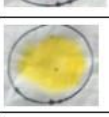
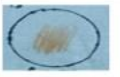
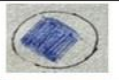
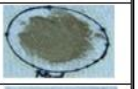
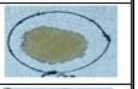
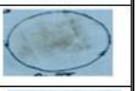
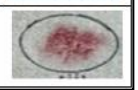
Table 6 : Stain Segregation matrix

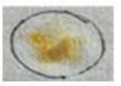
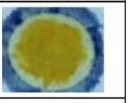
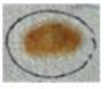
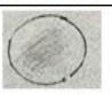
Sr. No.	Cold Water stain	Hot water Stain	Water soluable	Oil Stain
1	Egg	Crayons	Keshar Powder	Butter
2	Chocolates	Eye liner	Fruit Juice	Shoe Polish
3	Mosquito Repellant	Ink	Soft Drink	Hair Oil
4	coffee	Cough Syrup	Ice Cream	Kitchen Stain
5	Honey	Cosmetic Stain	curd	Lubrication Oil
6	Snack	glue	Softener	Grease
7	Tea	Mud	Baby Food	Hair Spray
8	Tomato Soup	cocoa	Milk	Pickle
9	Vinegar	Rust	Coloured Chalk	Mustard oil(cooking Oil)
10	Grass	Candle Wax	Perfume	
11	Red Sand	Lipstick	Red Wine	
12	Fruit Jam	Tomato		
13	Cigarette	Brown Sugar		
14	Cement	Baby care Lotion		
15	Ginger Garlic Paste	Sticky Stain		
16	Pencil	Ointment		
17	Ketchup			
18	water colours			

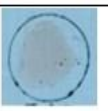
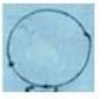
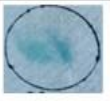
Following table consists information of stains, maker, preparation of stain method, drying time:

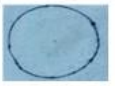
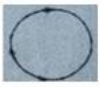
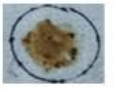
Table 7: Drying time , applying method and maker of each stain

Sr. No.	Stain	Maker	Preparation on the stain material	Drying time	Photo
1	Sauces	-	Registered	-	-
2	Egg	-	apply by brush one layer	48 Hrs	
3	Chocolates	Dairymilk	rub one layer on cloth	48 Hrs	
4	Mosquito Repellant	Odomas	5 drops	48 Hrs	
5	coffee	Nescafe	3 drops	48 Hrs	
6	Honey	Viraat	5 drops	48 Hrs	
7	Snack	samosa	rub one layer on cloth	48 Hrs	
8	Tea	Lipton	3 drops	48 Hrs	
9	Vinegar	-	3 drops	48 Hrs	
10	Red Sand	brick powder	rub one layer on cloth	48 Hrs	

11	Fruit Jam	Kissan	apply by brush one layer	48 Hrs	
12	Cement	ambuja	rub one layer on cloth	48 Hrs	
13	Ginger Garlic Paste	V-pure	apply by brush one layer	48 Hrs	
14	Red Wine	Sula	5 drops	48 Hrs	
15	Softener	comfort	5 drops	48 Hrs	
16	Green Chutney	-	apply by brush one layer	48 Hrs	
17	Garam Masala	MDH	5 gram	48 Hrs	
18	Jamun	-	rub one layer on cloth	48 Hrs	
19	Mango Juice	-	apply by brush one layer	48 Hrs	
20	Coller Cuff	Registered	-	-	-
21	Crayons	Apsara	rub one layer on cloth	48 Hrs	
22	Eye liner	eyeliner	rub one layer on cloth	48 Hrs	
23	Ink	Pilot	rub one layer on cloth	48 Hrs	
24	Cough Syrup	Corex	5 drops	48 Hrs	
25	glue	oddy	apply by brush one layer	48 Hrs	
26	Mud	-	apply by brush one layer	48 Hrs	
27	cocoa	coffe beans	apply by brush one layer	48 Hrs	
28	Rust	-	rub one layer on cloth	48 Hrs	
29	Candle Wax	candle	rub one layer on cloth	48 Hrs	
30	Lipstick	color code	rub one layer on cloth	48 Hrs	

31	Tomato	-	rub one layer on cloth	48 Hrs	
32	Brown Sugar	Jaggery	rub one layer on cloth	48 Hrs	
33	Baby care Lotion	Jonson	apply by brush one layer	48 Hrs	
34	Sticky Stain	scotch	rub one layer on cloth	48 Hrs	
35	Ointment	bitadean	apply by brush one layer	48 Hrs	
36	Soup	Catch	5 drops	48 Hrs	
37	Pencil	Natraj	rub one layer on cloth	48 Hrs	
38	water colours	Fevicryl	5 drops	48 Hrs	
39	Cigarette	classic	smoke 3 time	48 Hrs	
40	Fruit Juice	real	5 drops	48 Hrs	

41	Soft Drink	Coca cola	5 drops	48 Hrs	
42	Ice Cream	Amul	5 drops	48 Hrs	
43	curd	Amul	5 drops	48 Hrs	
44	Baby Food	Horlicks	5 gram	48 Hrs	
45	Milk	Amul	5 drops	48 Hrs	
46	Coloured Chalk	chalk	rub one layer on cloth	48 Hrs	
47	Perfume	Deniver	spray 5 time	48 Hrs	

48	Kitchen Stain	Veg-curry	apply by brush one layer	48 Hrs	
49	Butter	Amul	melt,apply by brush one layer	48 Hrs	
50	Hair Oil	Amla	5 drops	48 Hrs	
51	Lubrication Oil	WD-40	5 drops	48 Hrs	
52	Grease	Waxpol	apply by brush one layer	48 Hrs	
53	Hair Spray	local	spray 5 time	48 Hrs	
54	Pickle	mango	apply by brush one layer	48 Hrs	
55	Mustard oil(cooking Oil)	Fortune	5 drops	48 Hrs	

Dryers are utilized in industrial and institutional settings in addition to outdoor drying.
In dryers, there are two different circulation systems:

(a) Air is circulated at a high speed while being reasonably cool. Under the front panel, room air enters the dryer, flows over the heat source, through the clothing, and out the exhaust. As a result, the room's temperature and humidity remain normal.

(b) Heat-producing air is gently circulated. A tiny fan draws air into the dryer through perforations at the top, through the clothing, and out the exhaust after it enters the dryer and passes over the heat source.

4.2.6 Fluent analysis of the design changes

Design changes in the pulsator needs to go with structural and the CFD analysis and hence both are performed sequentially.

4.2.6.1 Structural Analysis

Following are input for the structural analysis:

a. Load - 705.6 N (8kg cloth load + 64 kg water load)
b. Material - Polypropylene (PP) for existing Pulsator
c. Material - Stainless steel for new pulsator (Plates) and PP for rest pulsator
d. Element order - Quadratic
e. Elements for existing Pulsator - 306811
f. Nodes for existing Pulsator - 560776
g. Elements for new pulsator - 1256302
h. Nodes for new pulsator - 2247691

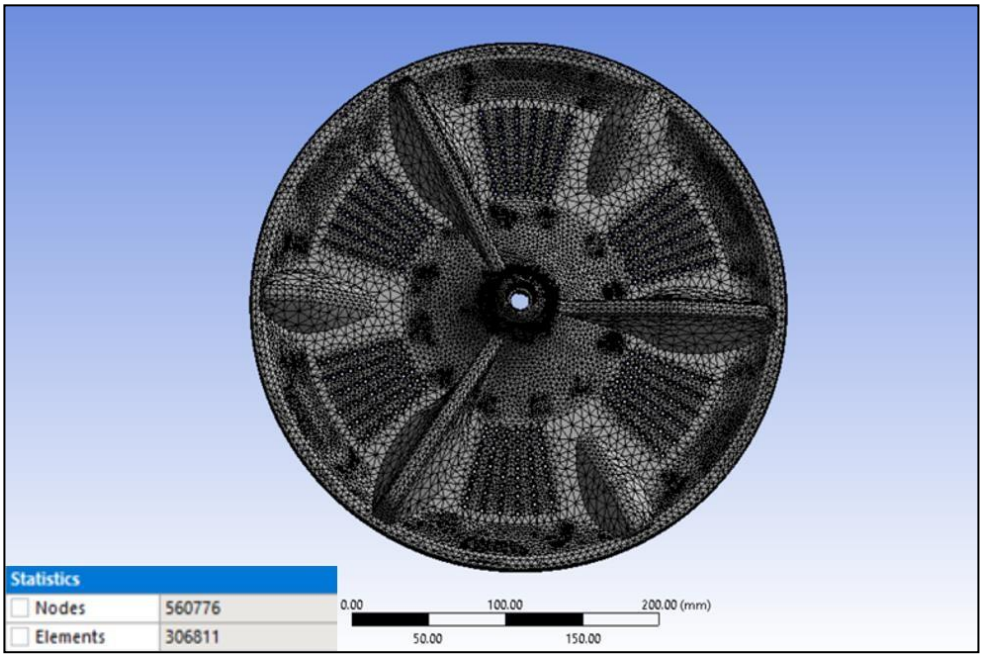


Figure 23: Meshing of existing pulsator: Structural analysis

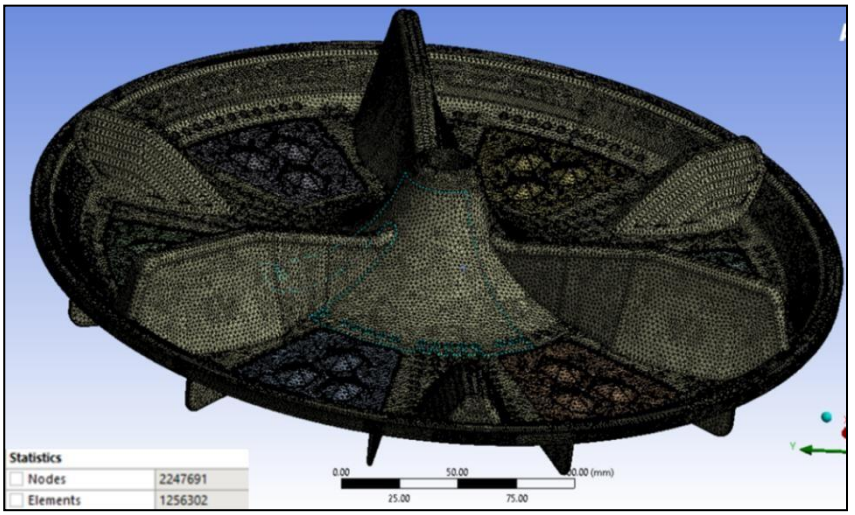


Figure 24: Meshing of new pulsator: Structural analysis

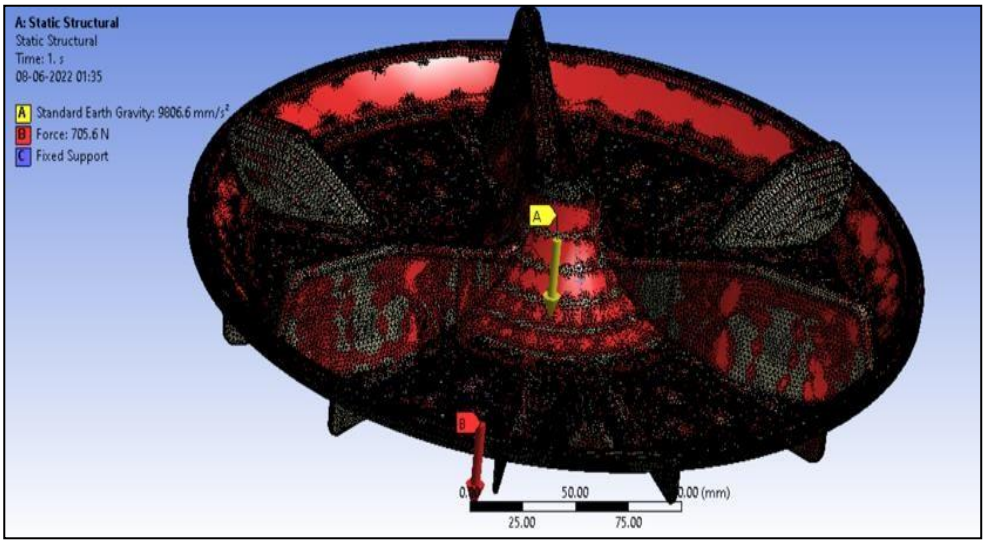


Figure 25:Loading and support condition: Structural analysis

4.2.6.2 Fluent turbulence analysis

Following are input for the Fluent analysis:

a. Moving wall - Bottom surface (Pulsator) and the side wall (Inner drum)
b. Material - Polypropylene (PP) for existing Pulsator
c. Material - Structural steel (SS) for new pulsator (Plates) and PP for rest pulsator
d. Element order - Linear
e. Elements for existing Pulsator - 4136485
f. Nodes for existing Pulsator - 776726
g. Elements for new pulsator - 7330572
h. Nodes for new pulsator - 1368113

It is feasible to improve and manage stiffness without sacrificing tensile strength by changing the processing parameters. It has been established that getting a high molecular orientation depends on the molding's thickness. For the narrow cross section moldings, traditional injection molding may provide a high degree of molecular orientation (Gurhan Kalay and Michael J Bevis,1997)

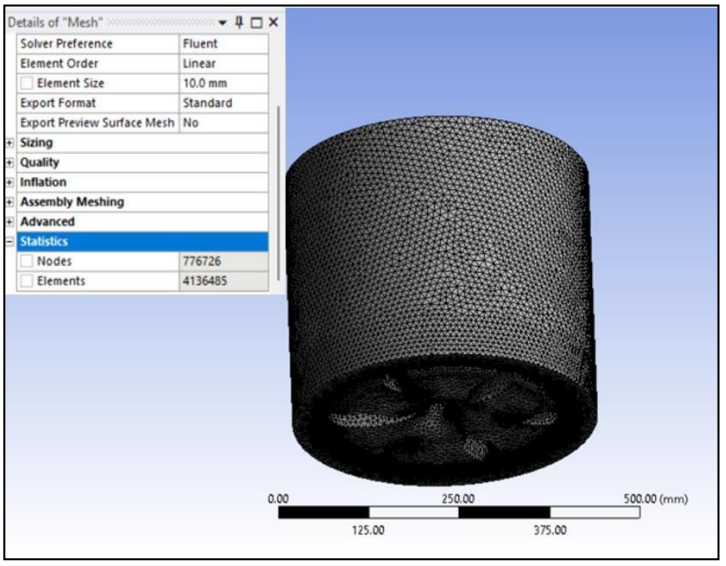


Figure 26:Meshing of existing pulsator : CFD analysis

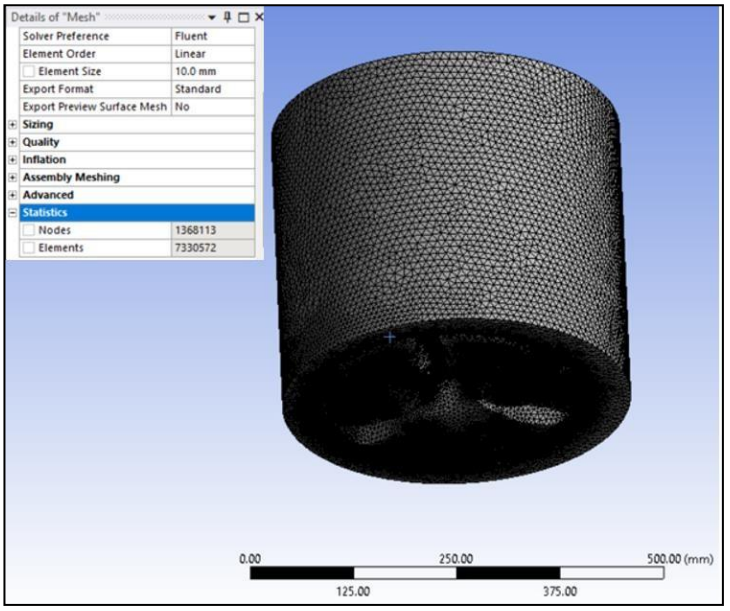


Figure 27:Meshing of new pulsator : CFD analysis

5. Observations

5.1 Results and Discussion

5.1.1 Design of Experiment results

The proposed run order of the experiment with full factorial design and 2 repetition underwent the performance testing with the standard of IEC 60456:2010 and BEE. Optimization of the parameter setting has been done for the best results of the washing performance and energy consumption.

a. For wash quality, all the main factors and interactions are significant except BC and AC. Pareto chart plotted shows the significance of the factors in figure 5.
b. For energy consumption, all the main factors and interactions are significant in the response.
c. Main effects and Interactions have been plotted to show the behavior of the factors and their interactions among the levels. Wash quality is better with high wash time, high on time and low water quantity. On Contrary, energy consumption is lower with low wash time, low on time but high water quantity. Plots are described in figure 6.

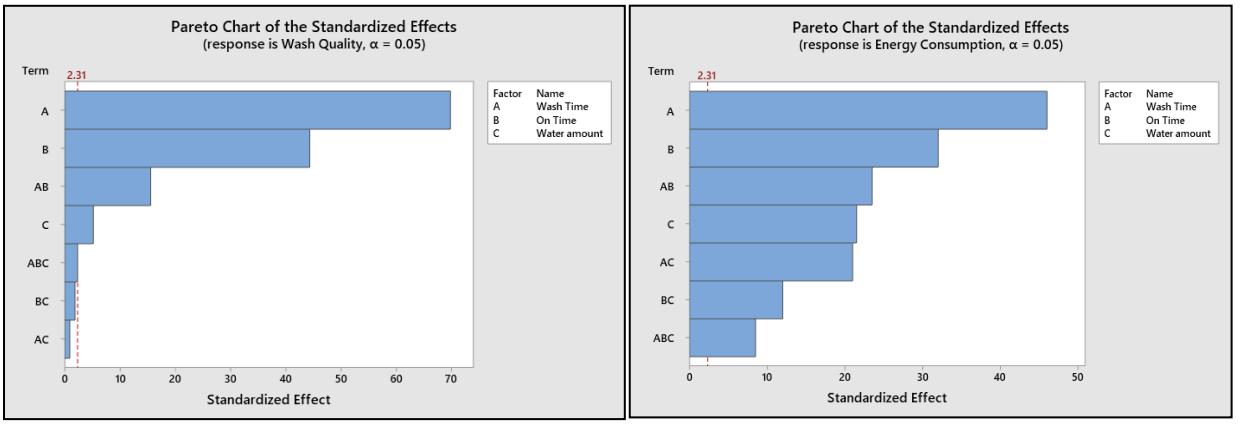


Figure 28: Pareto chart for the responses showing the significance of the factors

The Significant factors are provided through Minitab analysis tool which further assists in the optimization of the parameters when both wash quality and energy are recorded simultaneously. Following are the factorial plots of the analysis with main effect and interaction comparison.

In order to lower the cost of raw materials, machine weight is decreased while washing capacity is raised. In order to improve energy efficiency, the spin speed is also rising. With them, its vibration issue progressively becomes worse. Companies have employed passive tactics to reduce vibration, such as adding more springs and dampers or putting a counterweight to the tub to enhance the moment of inertia (Hee Tae Lim et al.,2010). Recently, they have started introducing products that use balancing technology to attach devices like liquid balancers or ball balancers that compensate for mass imbalance in the drum, or they have started introducing products that use vibration-reducing technology that uses double stage dampers, an improved version of traditional friction dampers.

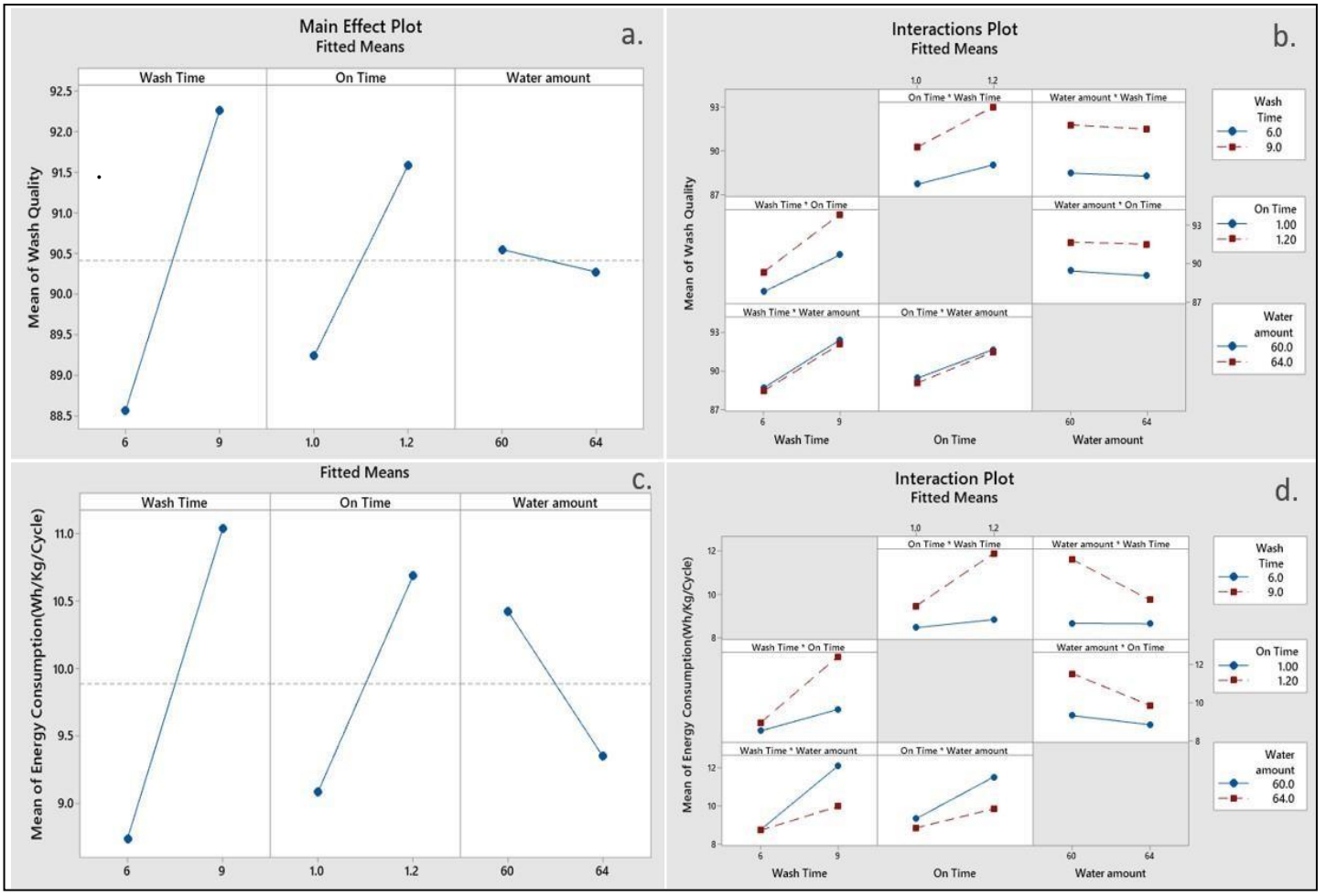


Figure 29: Main Effect for wash quality(a), Interaction Plot for Wash quality (b), Main Effect Plot for Energy Consumption (c), Interaction Plot for Energy Consumption(d)

The last step after analysis of the design is the response optimization by setting the target as maximum, minimum or giving any specific target. As per the BEE regulation of Energy Star Rating, ranges have been formulated by the authority. Following is the prescribed rangesaccording to the star rating to be given.

The drive system's vibration starts off as dynamic response vibration in the slower part of the washing device's spin cycle and changes to steady state vibrations as the speed rises. Depending on how stiff the drive system is, the flexible mode may manifest itself in the steady state vibration zone, and the vibrational phases of the tub and drum may change. The possibility of a fast-moving collision between the drum and the tub exists. In the existing drum-type washing machine, the design of a large capacity is limited because the large gap between the components needs to be secured due to this vibrations and consistent vibration (Hee Tae Lim et al.,2010).

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.106066	99.89%	99.79%	99.55%

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	7	79.9875	11.4268	1015.71	0.000
Linear	3	77.1525	25.7175	2286.00	0.000
Wash Time	1	54.7600	54.7600	4867.56	0.000
On Time	1	22.0900	22.0900	1963.56	0.000
Water amount	1	0.3025	0.3025	26.89	0.001
2-Way Interactions	3	2.7725	0.9242	82.15	0.000
Wash Time*On Time	1	2.7225	2.7225	242.00	0.000
Wash Time*Water amount	1	0.0100	0.0100	0.89	0.373
On Time*Water amount	1	0.0400	0.0400	3.56	0.096
3-Way Interactions	1	0.0625	0.0625	5.56	0.046
Wash Time*On Time*Water amount	1	0.0625	0.0625	5.56	0.046
Error	8	0.0900	0.0113		
Total	15	80.0775			

Table 8: Model Summary for Wash Quality

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.1	99.83%	99.69%	99.34%

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	7	48.1175	6.8739	687.39	0.000
Linear	3	36.0225	12.0075	1200.75	0.000
Wash Time	1	21.1600	21.1600	2116.00	0.000
On Time	1	10.2400	10.2400	1024.00	0.000
Water amount	1	4.6225	4.6225	462.25	0.000
2-Way Interactions	3	11.3725	3.7908	379.08	0.000
Wash Time*On Time	1	5.5225	5.5225	552.25	0.000
Wash Time*Water amount	1	4.4100	4.4100	441.00	0.000
On Time*Water amount	1	1.4400	1.4400	144.00	0.000
3-Way Interactions	1	0.7225	0.7225	72.25	0.000
Wash Time*On Time*Water amount	1	0.7225	0.7225	72.25	0.000
Error	8	0.0800	0.0100		
Total	15	48.1975			

Table 9: Model Summary for Energy Consumption

Since, this is merely the qualification criteria, the responses are aimed at much higher standards as the BEE standard is just the bench mark for the testing. But for improvement purpose the targets are set as high as possible according to the real test results. So the optimization phase suggests that running at wash time 9 minutes, on time 1.2 seconds and water amount 64 Litre gives the most optimum result here.

In order to carry out the duties entrusted to it by the Energy Conservation Act, BEE coordinates with authorised customers, designated agencies, and other organisations. It also recognises, locates, and makes use of the infrastructure and resources already in place. The Energy Conservation Act includes provisions for promotional and regulating activities.

Table 10: Pre- Qualification criteria for Semi-automatic and Top Loaders

(Sources: Schedule 12, Rev 3, BEE)

Parameter	**Minimum requirement**
Wash Performance (Soil Removal %)	≥ 80%
Water extraction performance (RMC value)	≤ 75%
Water consumption (maximum)	≤ 23 L/kg/cycle
Rinse efficiency	≤ 2.25
Top loaders & semi-automatic machines -Cotton 30 °C Valid from 8th March 2019 to 31st December 2020	
Star rating	**Energy consumption (E) per cycle kWh/kg/cycle**
1-star	0.0171 < E ≤ 0.0185
2-star	0.0158 < E ≤ 0.0171
3-star	0.0145 < E ≤ 0.0158
4-star	0.0132 < E ≤ 0.0145
5-star	E ≤ 0.0132

The following performance criteria must be met by the product. The manufacturer is required to present the test report from a lab that has been accredited by NABL/ILAC/APLAC. This lab can be owned by the manufacturer or a third party, and it must be able to conduct tests in accordance with IEC 60456: 2010 and its revisions. In the BEE check/challenge testing of the sample drawn, these would be additional metrics assessed in addition to energy usage (Schedule 12, Rev 3, BEE).

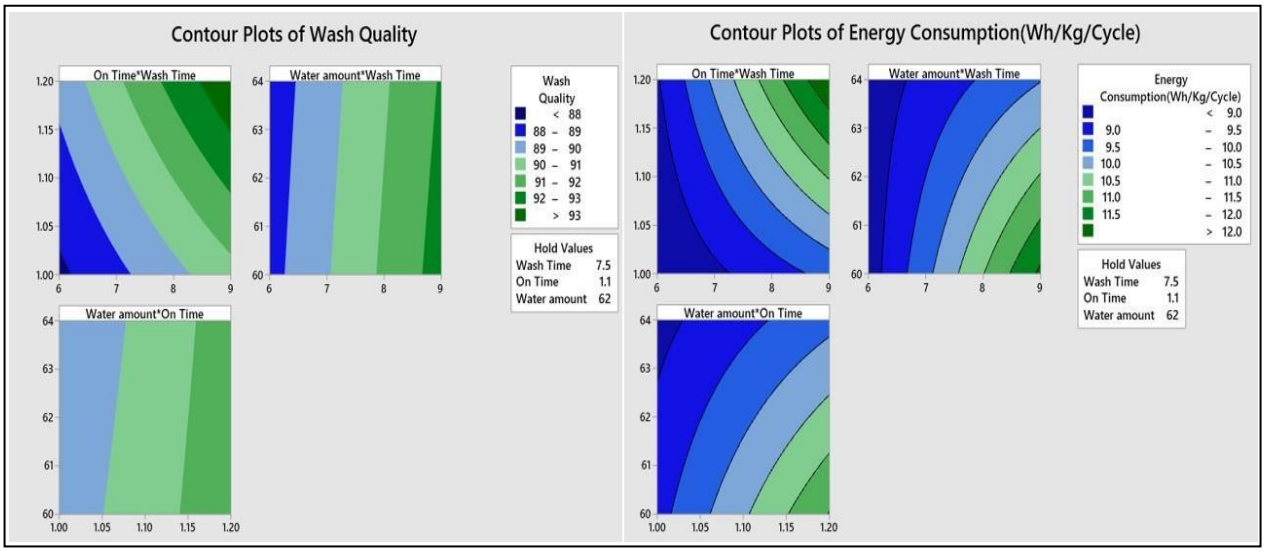


Figure 30:Contour Plots for the interaction consideration

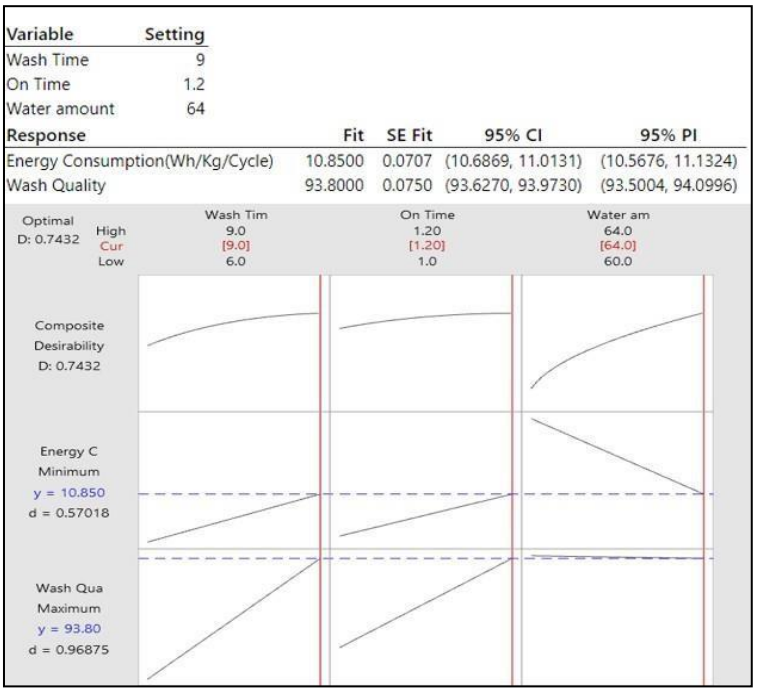


Figure 31:Result of the response optimizer with optimum response

5.1.2 Stain Master+ Program results

Stain master program after being developed by modification through existing strong Jeans program various tests have been performed to check the validity of the stain removal ability and confidence scope of the program's claim. The tests were performed in two phases due to unavailability of some stain sources and insufficient cleaning in single wash.

Following are the results of the two phases tests:

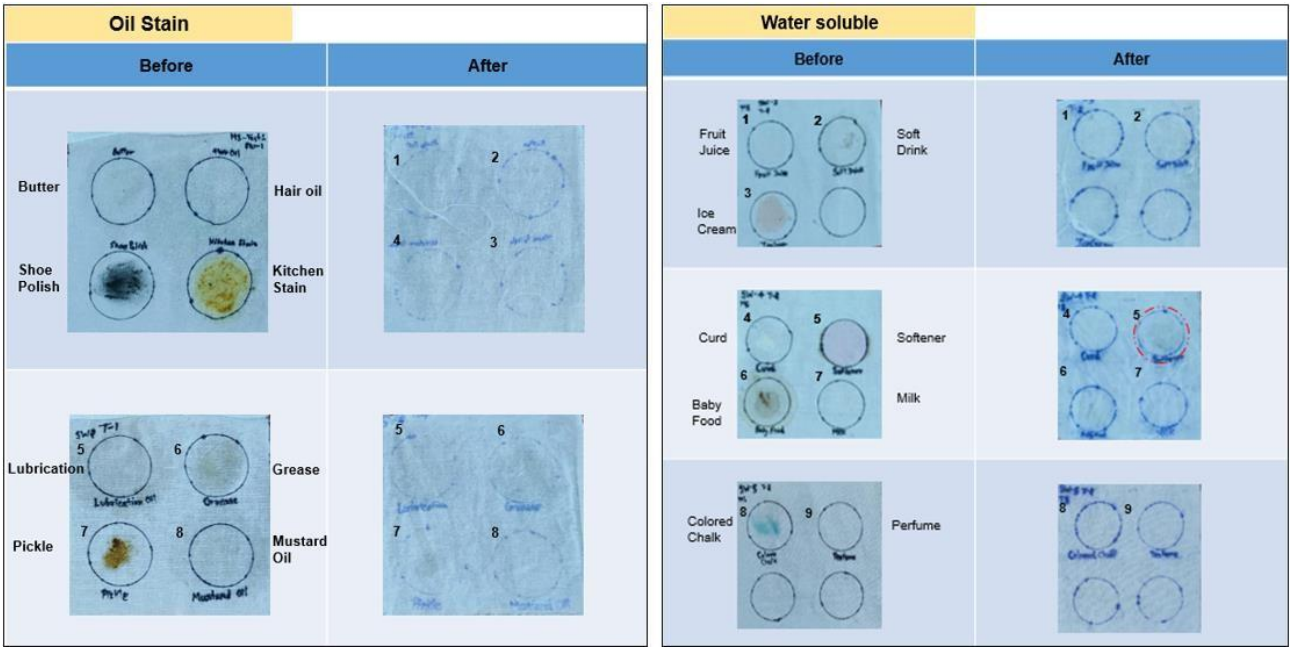


Figure 32:Oil stains and Water soluble results

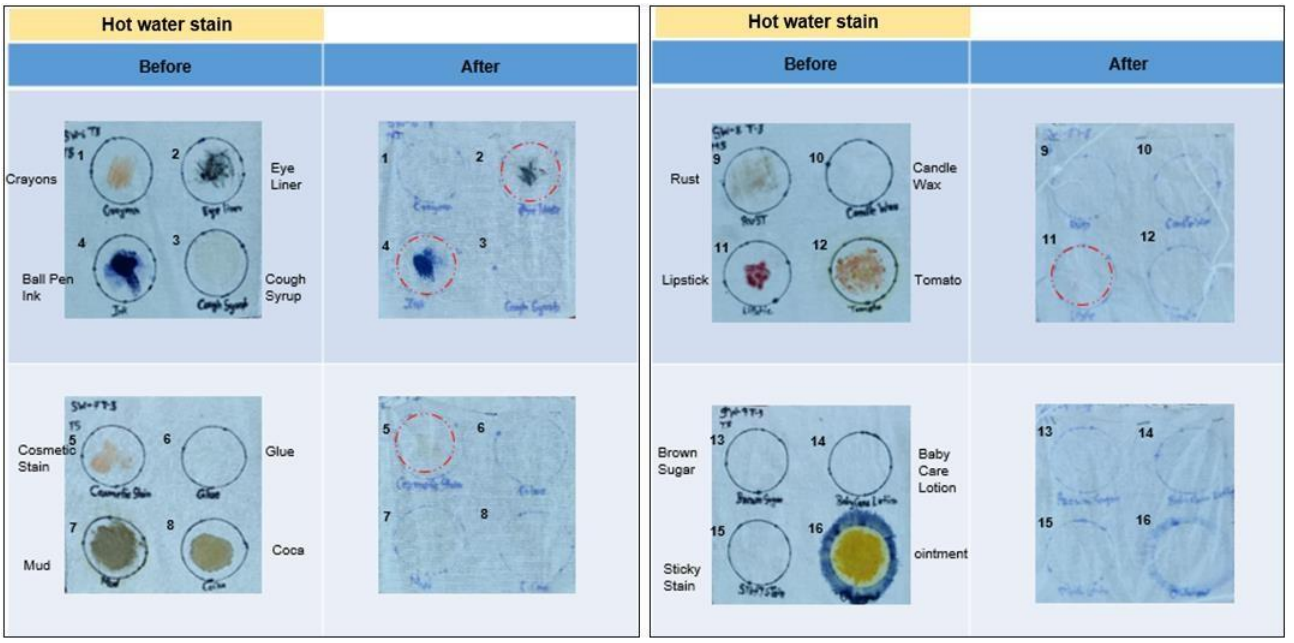


Figure 33: Hot water stains results

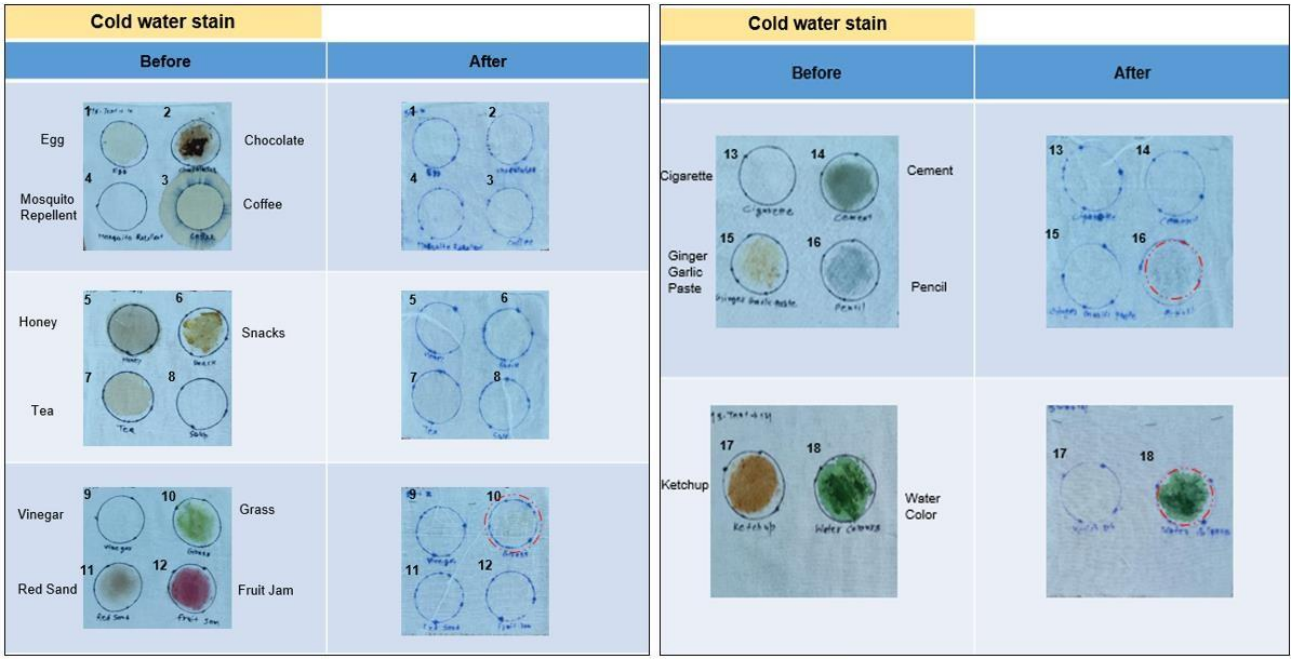


Figure 34: Cold water stains results

Out of these stain tests some of those not get properly cleaned and some also not available at the time of the test. Overall result data have been formulated in the figure shown below.

Oil Stain	Clean
Butter	✓
Shoe Polish	✓
Hair Oil	✓
Kitchen Stain	✓
Lubrication Oil	✓
Grease	✓
Hair Spray	NT*
Pickle	✓
Mustard oil(cooking Oil)	✓

Hot water Stain	Clean
Crayons	✓
Eye liner	×
Ink	×
Cough Syrup	✓
Cosmetic Stain	✓
glue	✓
Mud	✓
cocoa	✓

Hot water Stain	Clean
Rust	✓
Candle Wax	✓
Lipstick	✓
Tomato	✓
Brown Sugar	NT*
Baby care Lotion	NT*
Sticky Stain	✓
Ointment	✓

Cold Water stain	Clean
Egg	✓
Chocolates	✓
Mosquito Repellant	NT*
coffee	✓
Honey	✓
Snack	✓
Tea	✓
Soup	NT*
Vinegar	✓
Grass	×
Red Sand	✓
Fruit Jam	✓

Cold Water stain	Clean
Cigarette	NT*
Cement	✓
Ginger Garlic Paste	✓
Pencil	×
Ketchup	✓
water colours	×

Water soluble	Clean
Keshar Powder	NT*
Fruit Juice	✓
Soft Drink	✓
Ice Cream	✓
curd	✓
Softener	×
Baby Food	✓
Milk	✓
Coloured Chalk	✓
Perfume	✓
Red Wine	NT*

Figure 35: Result of phase 1 of stain master test

The phase 1 results have suggested to go to for phase 2 proceedings where the non-tested stains gets tested and also the insufficient cleaned stains in all the existing programs of stain dedicated like sauce, collar, sweat, curry, germ clean. The phase 2 results are as follows:

Table 11: Stain Segregation for Phase 2 of test

Sr. No.	Cold Water Stain	Hot water Stain	Oil Stain
1	Softner	Shoe Polish	Pickle
2	Mosquito Repellent	Baby care Lotion	Hair Spray
3	Vinegar	Grass	
4	Red Wine	Cigrette	
5		Water Color	
6		Pencil	
7		Eyeliner	
8		Ink	
9		Cosmetic	
10		Lipstick	
11		Brown Sugar	
12		Soup	

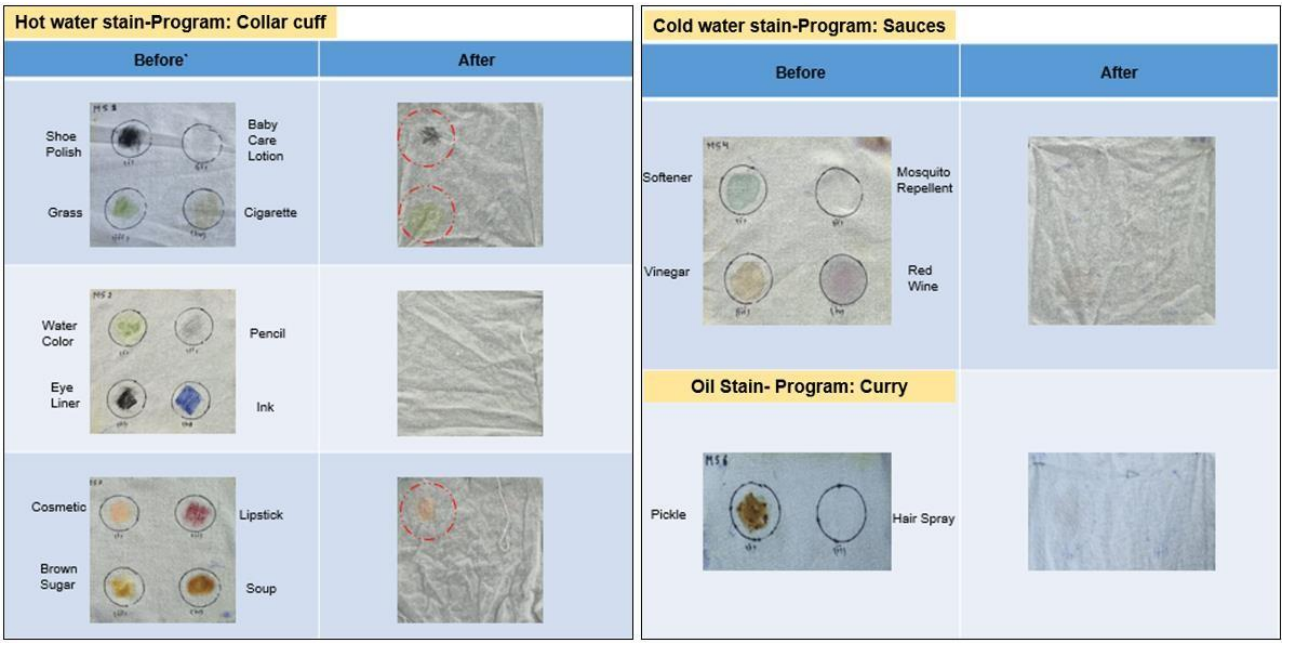


Figure 36: Phase 2 results for pre existing programs

Out of these phase 2 tests some stains not got removed which have been mentioned in the figure shown below:

Hot water Stain	Clean
Shoe Polish	×
Baby care Lotion	✓
Grass	×
Cigarette	✓
Water Color	✓
Pencil	✓
Eye liner	✓
Ink	✓
Cosmetic	×
Lipstick	✓
Brown Sugar	✓
Soup	✓

Cold Water stain	Clean
Softener	✓
Mosquito Repellent	✓
Vinegar	✓
Red Wine	✓
Oil Stain	**Clean**
Pickle	✓
Hair Spray	✓

Figure 37: Result of phase 2 of stain master test

Total 54 stains tested for both the phases where overall 50 stains cleaned and 1 stain not tested. So after the conduct of these 2 phases of stain master validity test we are now in a position to claim 50 stains removal capability of the new Stain Master+ program confidently. Below shown table is showing the consolidated result and all the 50 Stains which are being claimed.

Table 12: Stain master+ program claimed stains

Stains Claim							
1	Sauces	15	Softener	29	Candle Wax	43	curd
2	Egg	16	Green Chutney	30	Lipstick	44	Baby Food
3	Chocolates	17	Garam Masala	31	Tomato	45	Milk
4	Mosquito Repellant	18	Jamun	32	Brown Sugar	46	Coloured Chalk
5	coffee	19	Mango Juice	33	Baby care Lotion	47	Perfume
6	Honey	20	Coller Cuff	34	Sticky Stain	48	Kitchen Stain
7	Snack	21	Crayons	35	Ointment	49	Butter
8	Tea	22	Eye liner	36	Soup	50	Hair Oil
9	Vinegar	23	Ink	37	Pencil		
10	Red Sand	24	Cough Syrup	38	water colours		
11	Fruit Jam	25	glue	39	Cigarette		
12	Cement	26	Mud	40	Fruit Juice		
13	Ginger Garlic Paste	27	cocoa	41	Soft Drink		
14	Red Wine	28	Rust	42	Ice Cream		

Stain Type
Cold Water Stain
Hot water Stain
Water Soluble
Oil Stain

5.1.3 Structural and CFD analysis results

Design modifications that has been discussed earlier require the strength as well as the turbulence study of the pulsator. Material of existing pulsator is polypropylene which has tensile strength of 27 MPa. Addition of SS plate in between the base surface of pulsator has tensile strength of 156 MPa. Analysis of both pulsators has suggested that the new design is well above the actual requirement in terms of strength as well as the turbulency.

5.1.3.1 Structural analysis results

Structural analysis of both the pulsators is at acceptable level. The analysis includes the parameters like total deformation and equivalent stress. Investigating how the insert component shape affects the surrounding polymer's tendency to shrink and, in turn, the dimensional correctness of the injection-molded part, was one of the key goals of this study. In all three of the tested materials, inserts had an impact on shrinkage. When compared to parts without inserts, moulded component with different types of insertion (angular and round) showed significantly reduced shrink parallel and normal to the flow direction, even though angular-shaped inserts generally provided shrinkage

demonstrated considerably lesser shrinkage parallel and normal to the flow direction compared to parts without inserts.

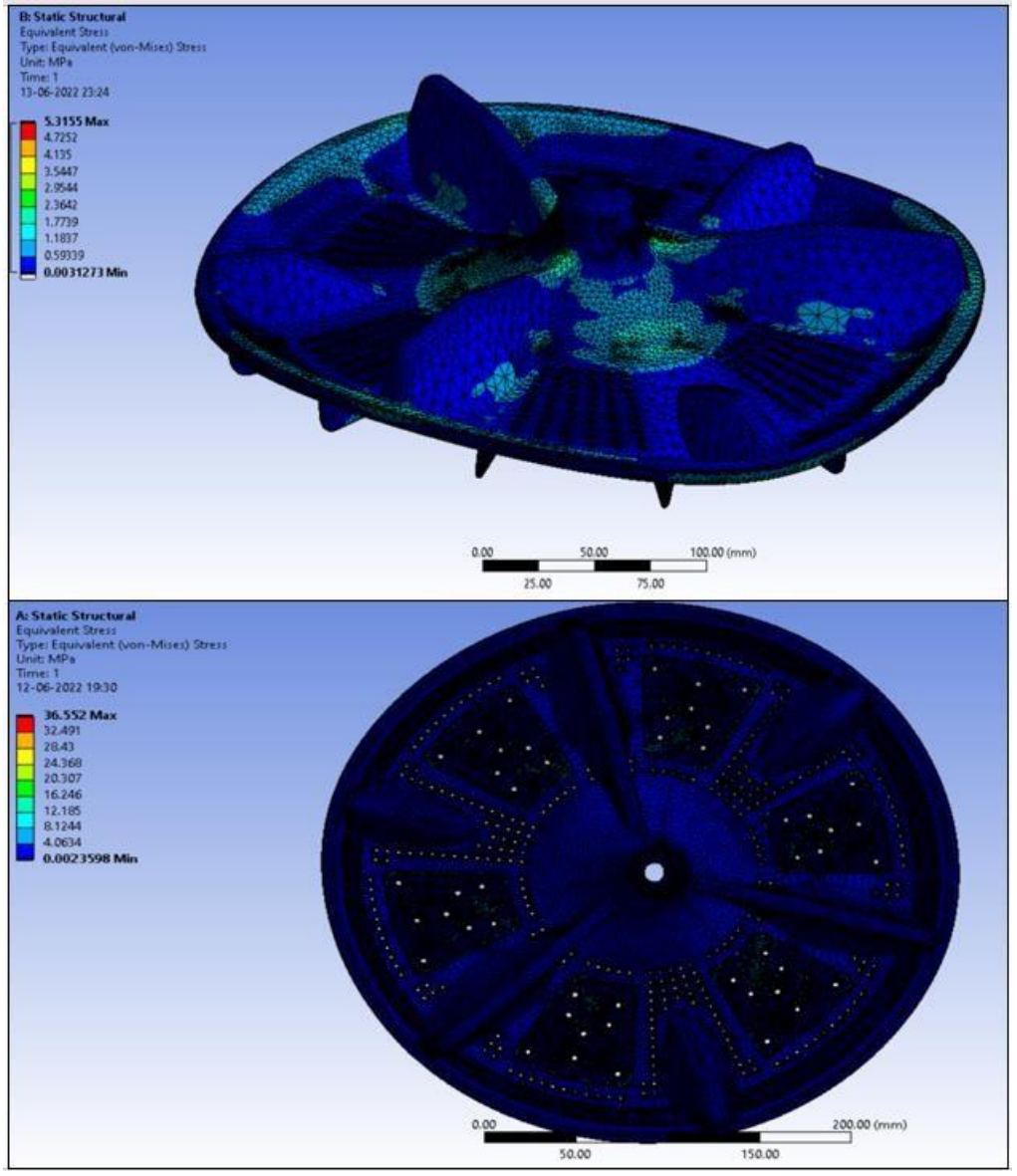


Figure 38: Equivalent stress profile of existing and new pulsator

The maximum equivalent stress achieved in the case of existing pulsator is 5.31 MPa while the ultimate tensile strength for PP is 27 MPa. So the FOS comes to be 5.08 which fair enough in this case. Also if the equivalent stress for the new pulsator is considered, maximum stress is 36.552 MPa while the UTS for SS is 186 MPa.

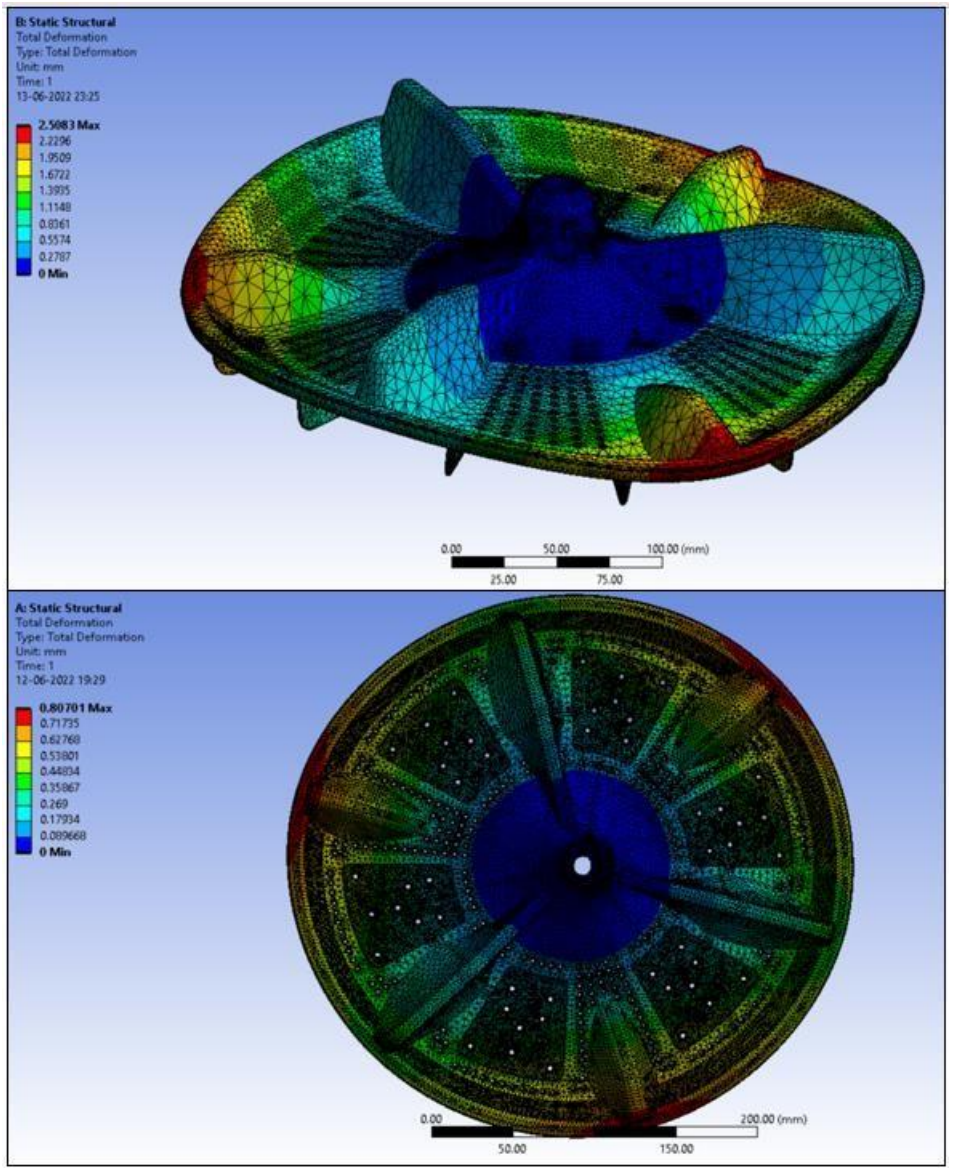


Figure 39: Total deformation profile of existing and new pulsator

5.1.3.2 CFD analysis results

Turbulence study for the new pulsator design has to go through the fluent analysis as the study of comparison and improvement in wash quality. The results of the analysis suggested that the new design of pulsator is way above in terms of turbulence which has the direct impact on the wash performance. The comparison between the total pressure on the profile of the pulsator also done.

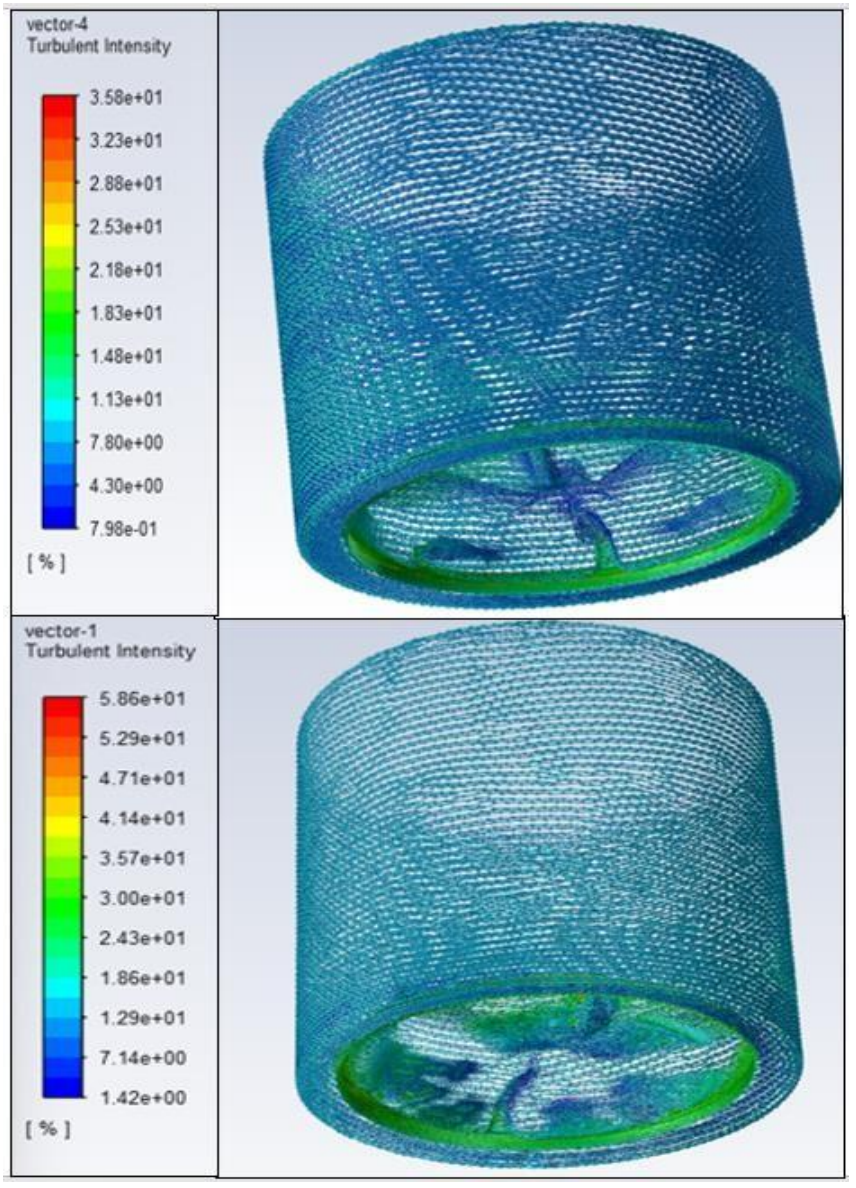


Figure 40: Turbulent Intensity profile of existing and new pulsator

When present in a flow field, turbulence's ability to improve mass transfer is one of its key properties. The fluid velocity determines the concentration distribution inside the reactor, which in turn affects the reaction rate, and the turbulence intensity makes sure that smaller scales mix quickly. With a fermenter that had three axial impellers at the top and a radial impeller at the bottom, gas-liquid simulations that included models for gas dispersion, bubble coalescence and breakdown, and inter-phase mass transfer. The area closest to the impellers i.e., where the turbulence intensity is greatest has the highest mass transfer coefficient.

For each velocity component, turbulent intensity is calculated as the root mean square of the velocity variations in relation to a typical mean flow velocity Uo (Delgadillo et al.,2013).

The ratio of the root-mean-square of the velocity variations to the mean flow velocity is known as the turbulence intensity. Turbulence intensities of 1 percent or less are often regarded as low, while those of 10 percent or more are regarded as strong. A fair approximation of the turbulence strength at the inlet border should be possible from outside, measured data. The turbulence intensity in the free stream, for instance, is often accessible from the tunnel characteristics if you are simulating a wind-tunnel experiment. The free-stream turbulence intensity in contemporary low-turbulence wind tunnels may be as low as 0.05 percent.

For internal flows, the history of the flow upstream has a complete bearing on the amount of turbulence at the inlets. You can employ a low turbulence intensity if the flow upstream is undeveloped and undisturbed. The turbulence intensity might reach a few percent if the flow is completely established. The formula below, which was derived from an empirical correlation for pipe flows, may be used to determine the amount of turbulence at the centre of a fully formed duct flow:

$$I \equiv \frac{u'}{u_{avg}}$$

Eq (1)

A single polymer composite (SPC), which is lightweight, very strong, and easily recyclable, may be created by combining the reinforcing and matrix of a polymer material. With a short cycle time and a large processing temperature window, the insert injection moulding technique may be utilised to accomplish the repeated manufacturing of SPC products. However, because injection moulding is a very complex process, it is necessary to understand the impact of a number of significant aspects in order to customise SPCs in the future to particular applications (Jian Wang et al.,2021).

As the variable processing parameters, four crucial injection moulding parameters barrel temperature, injection speed, injection pressure, and holding time were chosen. The single-factor experimental approach was used since the impacts of various injection moulding factors are complicated and nonlinear.

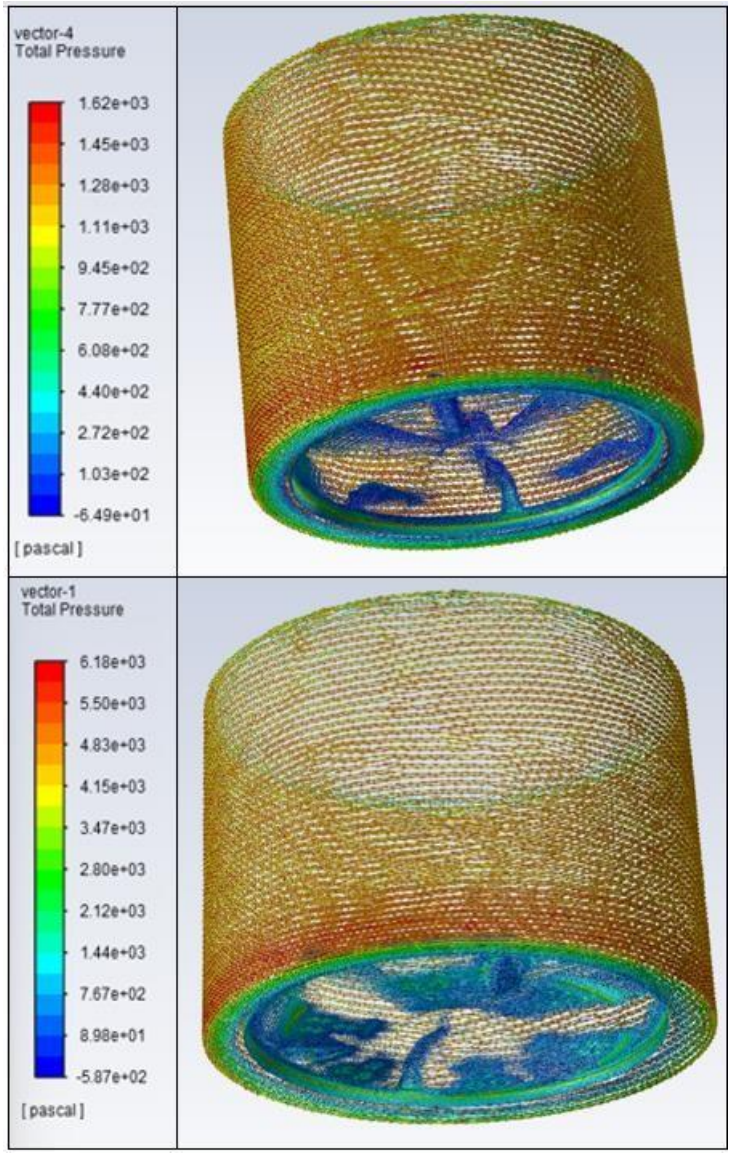


Figure 41: Total pressure profile of existing and new pulsator

Contour plots for the turbulent kinetic energy has also been analyzed which clearly indicates the improvement in the turbulence over the pulsator and water profile.

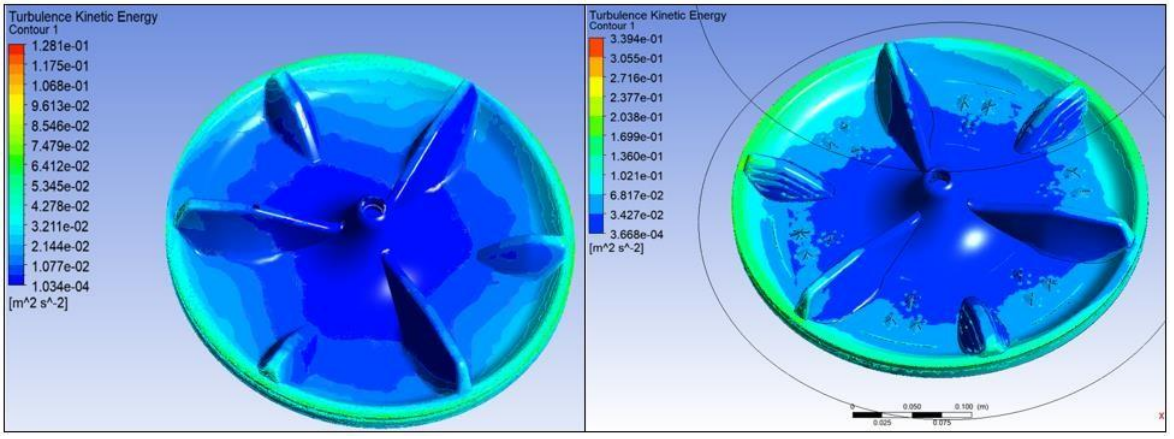


Figure 42: Contour plots of turbulency for existing and new pulsator

The turbulent Kinetic Energy for existing pulsator has the maximum value of 0.128 m^2/s^2 while in the modified design the same value comes to be 0.339 m^2/s^2.This has proved a large improvement in the turbulency.

6. Conclusion and Recommendation

6.1 Conclusion

Based on the discussion above it may be concluded that,

- For best wash performance, wash time should be kept at high level, On time should be kept at high level and water amount should be kept at low level.
- For best energy consumption, wash time should be kept at low level, On time should be kept at low level and water amount should be kept at high level.
- Optimum setting for best result of both responses suggests all the factors wash time, Ontime and water amount is kept at high level.
- Algorithm modification focused on the temperature alteration and the motor duty cycle has proved a positive impact has removed at least 50 stains of daily usage with great wash performance
- Design modification in the existing pulsator delivered improved scenario of wash performance as it has increased the turbulence level more than twice.
- Design changes like addition of ribs on the wings and SS embossing plate on the base surface definitely decrease the energy consumption for the same wash quality level.

6.2 Application and Future work

Design of Experiment is one of the most capable statistical tool to provide most practical solution to the problems related to improvement and concept design in the research and in industry as well. There were some experimental limitation present due to algorithm restriction of control unit and design constraints. To explore the more vibrant analysis with more number of factors and levels can be done for more robust result across all the parameters affecting the response. More data gives more precision. More complexities can be resolved through Screening designs with more resolution which hasn't been utilized this time.

The second major future scope can come with the mold design and DFM (Design for manufacturing). Any changes in the existing design comes along with several challenges with respect to the ROI, mold investment and manufacturing challenges. Algorithm development is the field of immense scope. Since in the development and modification of the algorithm of the program, minimal investment is required unlike the design change. Hence the washer industry has great demand of algorithm developers and modifiers which greatly influence the market value of any washing machine. As customer attracts towards the new features very readily, so industry works for cost optimization with the customer satisfaction.

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