

**Design and Optimization of Washing Machine for Value Innovation and
Field Failure Rate (FFR) Reduction**

A Dissertation submitted in fulfilment of the requirements for the award of the degree

of

MASTER OF ENGINEERING

in

Power Systems

Submitted by

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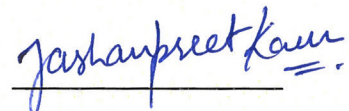
June 2022

CANDIDATE DECLARATION

I hereby certify that the work which is presented in dissertation entitled “**DESIGN AND OPTIMIZATION OF WASHING MACHINE FOR VALUE INNOVATION AND FIELD FAILURE RATE (FFR) REDUCTION**” in fulfillment of the requirements for the award of the degree of **Master of Engineering in Power Systems**, submitted to Electrical & Instrumentation Engineering Department of Thapar Institute of Engineering & Technology (Deemed to be University), Patiala, Punjab is an authentic record of my own work carried under the supervision of **Mr. Om Chand Verma**. The matter contained in this dissertation has not been submitted, neither in part nor in full to any other degree to any other university or institute except as reported in text and references.

Place: Patiala

Date: 2-08-2022



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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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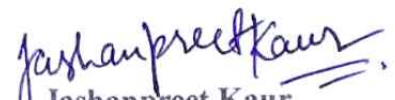

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Acronyms and Abbreviations

Abbreviation	Description
WM	Washing Machine
NDD	Non Direct Drive
PCB	Printed Circuit Board
PTC	Positive Terminal Coefficient
NDF	No Damage Failure
NG	Not Good
IQC	Incoming Quality Control
OQC	Outgoing Quality Control
SMPS	Switch mode power supply
LED	Light Emitting Diode
BEE	Bureau of Energy and Efficiency
IC	Integrated Circuits
FFR	Field Failure Rate
CFCT	Complete functional circuit test
CMOS	Complementary metal oxide semiconductor
IPQC	In-process quality control

ABSTRACT

LG Electronics offers a fantastic opportunity for aspiring engineers to obtain useful exposure in such a big sector and that too in a really supportive and caring culture and people. Here is a summary of the course, despite the fact that the tremendous quantity of work completed and experience gained over the last year cannot be enumerated in a few lines.

My project is titled as “DESIGN AND OPTIMIZATION OF WASHING MACHINE FOR VALUE INNOVATION AND FIELD FAILURE RATE (FFR) REDUCTION”.

At the QA (WM) LGEIL, my work largely involved developing the concept and determining its viability for several other factors, as well as testing the various product components. Modelling is done for the new development and certain machine changes.. It also contains study of various electrical, electronic and mechanical components being used in goods and exploring new possibilities for improvement in quality or reduction in cost.

Objectives of Thesis:

1. A look through of the washing machine, understanding the working principle, thoroughly examining the product to find the scope for optimization.
2. SMPS IC specification optimization, electrolytic capacitor specification upgraded and epoxy coating improvement: In order to reduce failures due to IC burst in input circuit, its spec has to be changed from 650 V to 800 V. This new SMPS IC is without heat sink is only an 8-pin chip. DC link electrolytic capacitor specification has been upgraded from maker MEC CON → SAMHWA 460 V, 220 μ F for improving the quality of power supply in high voltage areas. Also, to prevent PCB and its components from dust and corrosion, conformal coating has to be improved.
3. LE error code detection and analysis for the field failure rate reduction: In order to reduce the LE error code cases in the field the root cause is found out. LE error does not come while testing on the LQC. LE error can have multiple reasons for its occurrence. This error generally found in the field so to decrease the FFR the early-stage detection is done. BLDC motor structure was modified and some process improvements was done in harness and PCB handling at supplier end to control the LE error code.

CHAPTER 1

COMPANY PORTFOLIO

1.1) INTRODUCTION



Figure 1.1: LG Electronics Greater Noida Plant

LG ELECTRONICS PVT. LTD. is a multinational company based in South Korea. With headquarters in Seoul's LG Twin Towers, it is the second-largest electronics manufacturer in South Korea and the third-largest manufacturer of appliances worldwide. The flagship business of the LG Group, one of the biggest chaebols, is LG Electronics. The business includes 75 subsidiaries across the globe that create and produce telecommunications, mobile, home appliance, and television products. Zenith Electronics is owned by and controlled by LG Electronics, while LG Displays is a joint venture with Philips Electronics.

1.2) LG –THE HISTORY

- LG, Lucky Gold Star, which is an old name of this international company that used to produce cosmetics. Later in 1958, LG started electronic manufacturing business under the Gold star brand. The company also developed Korea's first refrigerator, black-and-white television, and telephone that same year. The present name of the company stands for “LIFE IS GOOD” which also serves as slogan of the company.
- Before the company's name was changed to LG, electronic products were marketed as Goldstar, while home goods were provided under the Lucky brand. Zenith Electronics of the United States was purchased in 1995, and Goldstar was renamed LG ELECTRONICS.



Figure 1.2: LG Electronics Seoul Headquarters

1.3) LG ELECTRONICS INDIA

LG Electronics India Pvt. Ltd., a wholly owned subsidiary of LG Electronics, South Korea was established in January, 1997 after clearance from Foreign Investment Promotion Board (FIPB).

The trend of beating industry norms started with fastest ever-nationwide launch by LG in a period of 4 and 1/2 months with commencement of operations in May 1997. LG set up a state-of-the art manufacturing facility at Greater Noida in 1998, with an investment of Rs 500 Crores. This facility manufactured Colour Televisions, Washing Machines, Air-Conditioners and Microwave Ovens. During the year 2001, LG also commenced home production for its eco-friendly Refrigerators and established its assembly line for its PC Monitors at its Greater Noida manufacturing unit. Beginning of 2003 saw roll out of first locally manufactured Direct Cool Refrigerator from plant at Greater Noida. In 2004, LGEIL also up its second Greenfield manufacturing unit in Pune, Maharashtra. The Pune unit produces Televisions, ACs, Refrigerators, Washing Machines, MWOs, Monitors and Phones.

The Greater Noida Production unit is the most Eco-friendly units compared to other LG units. LG acquired a status of most preferred brand among other brands. LG is one of the consumer-friendly companies who identified the evolving change in customer requirements and decided to products based on health benefits. The products offered by LG has consumer friendly features like:

The Colour TV has 'Golden Eye' technology, the AC has 'Health Air System' that cools, MW oven has the 'Health Wave System', refrigerator has the 'PN System', washing machine has the 'Fabric care System'.



Figure 1.3 : LG Electronics Products

1.4) PLANT LAYOUT:

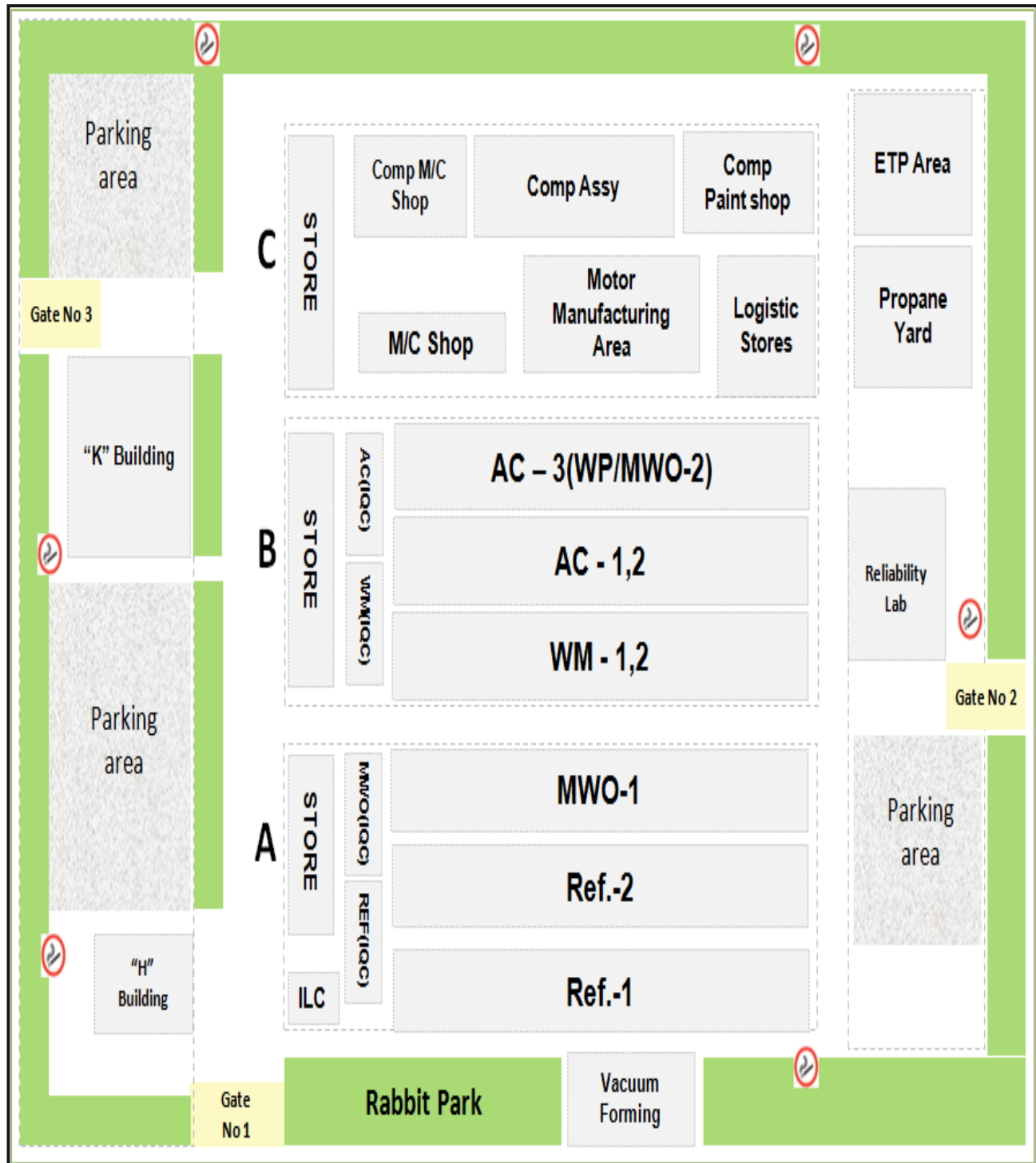
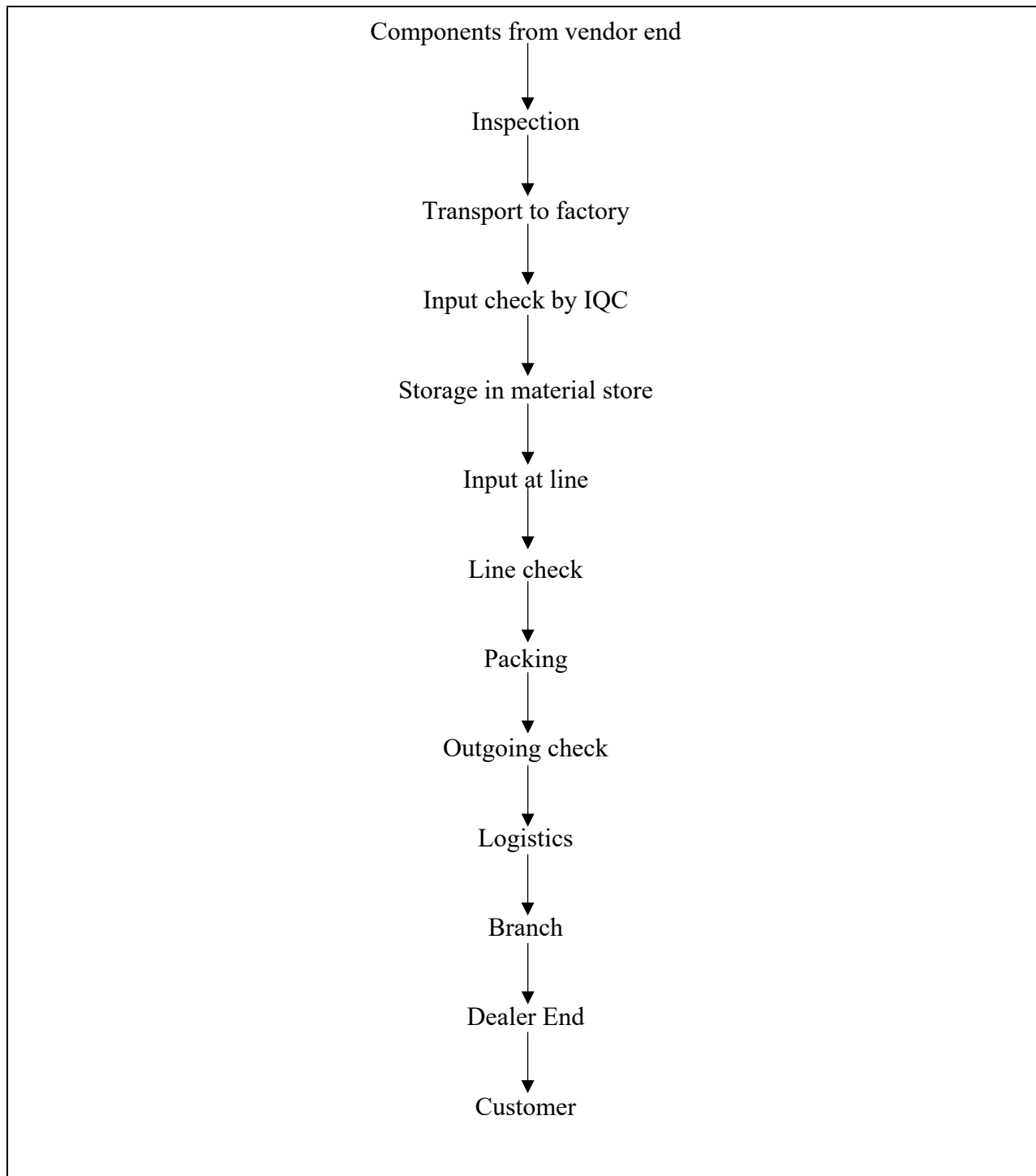
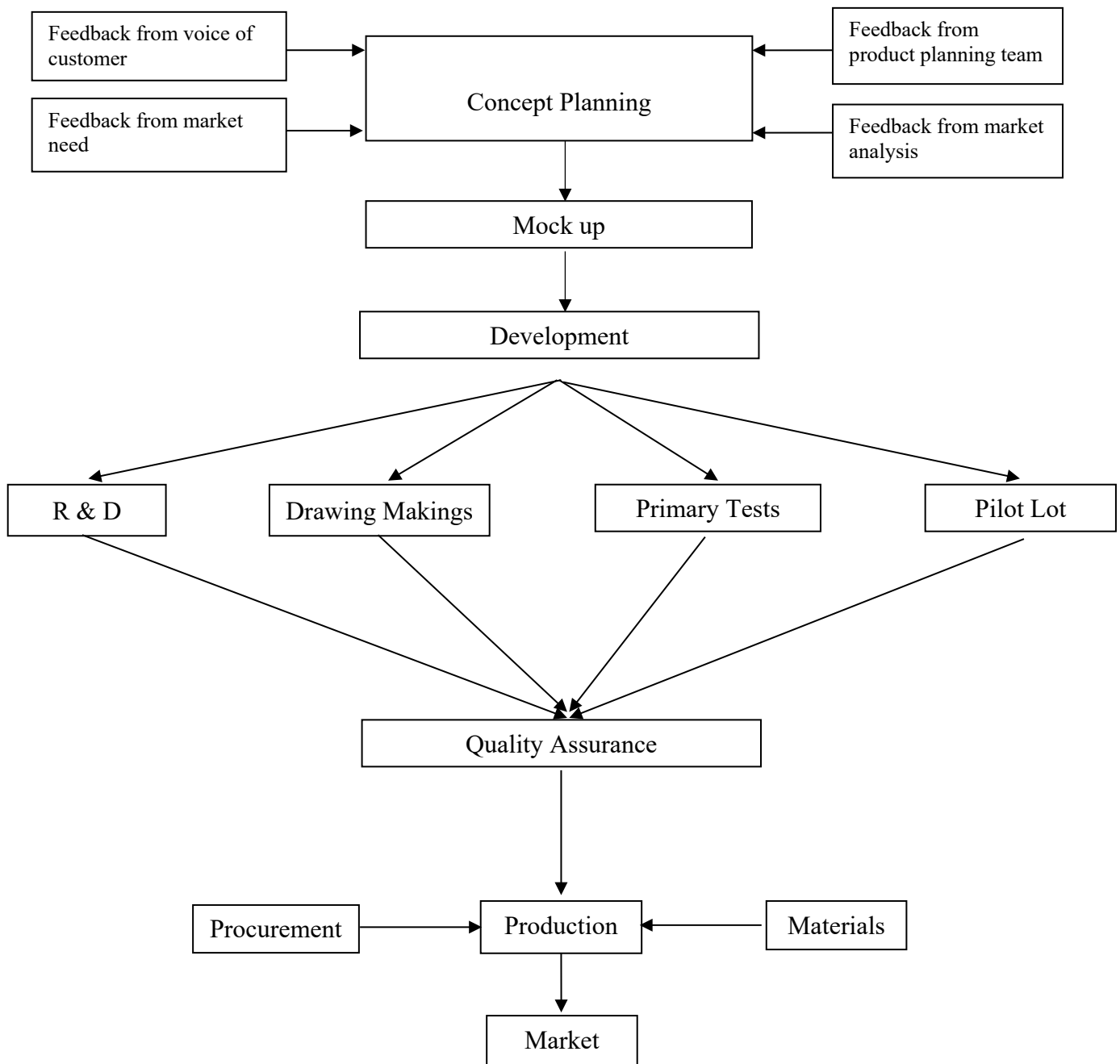


Figure 1.4: Plant Layout

1.5) PRODUCTION CYCLE



1.6) DEVELOPMENT CYCLE:



CHAPTER 2

WASHING MACHINE OVERVIEW

2.1) INTRODUCTION

A Washing machine is a machine that is designed to clean laundry such as clothes, towels, sheets, etc. People used to spend several hours doing their washing by hand before the invention of the washing machine. Immersion, dipping, rubbing, or scrubbing in water is often used to wash laundry, which is usually accompanied by detergent, soap, or bleach. The principle of forcing water through garments to get rid of dirt has been utilized by individuals for several centuries and therefore the modern washing machine will be considered an evolutionary advancement of this method.

Cloth washing is a necessary component of life. It does, however, necessitate a major quantity of your time, effort, and energy, which can be regarded undesirable some times. This eventually led to the development of the electric powered washing machine. The development of such mechanically timed switch-controlled machines progressed, eventually leading to the modern electronic and microprocessor-controlled automated washing machine.



Figure 2.1: Washing machine

2.2) WASHING MACHINE – A LOOK THROUGH

A washing machine is a home appliance that normally uses agitation to wash the various types of fabrics. The agitator's movement causes water to flow into, making a force that forces the covering to manoeuvre the back and the forth within the laundry drum crammed with the water and detergent, rubbing against one another to get rid of the stains.

Moreover, the electrical field created and sustained by incorporating the surfactants aids within the dirt removal.

Jacob Christian Schaffer, a German scientist, also known as the father of washing machine. He published a design for washing machine in 1767.

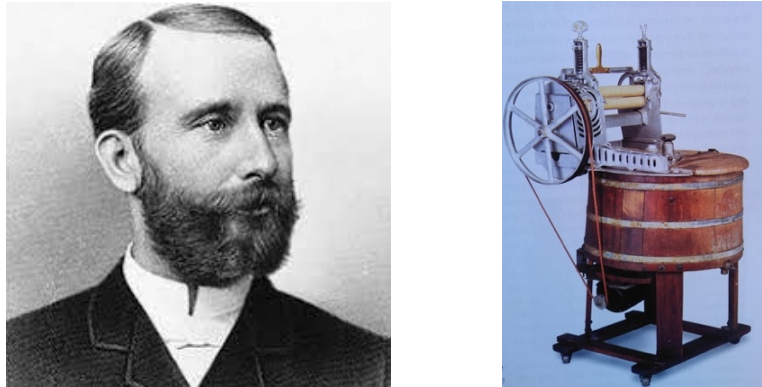


Figure 2.2: The Mighty Thor by Alva J. Fisher

Washing machines have been manufactured since the late 1800s. This simple technology was developed by a number of inventors. Alva J. Fisher created this domestic appliance, which was a drum-shaped device with a galvanised tub and an electric motor. The Mighty Thor, developed by Alva Fisher (1862–1957), was the first motorised electrical washing machine invented by the Hurley Machine Company of Chicago, Illinois, in 1908. The modern-day electric washing machine that we have come to know first became popular in the 1930s-1950s.

2.3) ADVANTAGES AND DISADVANTAGES

Washing machine has its own advantages over the other modes of washing. They are discussed as below:

- The loading inlet is located on top, making it relatively easy for the customer to load the clothes without having to bend.
- Some of Top-Loading laundry machines even enable adding further laundry clothes once after the initiation of the wash cycle is done.
- Top-loading washers needs low maintenance, and may not need a regular cycle to clean door seals and bellows and are less expensive than their alternatives usually.

Although there are many advantages of washing machine, there are certain limitations as well as discussed below:

- Top-loading washers, in contrast, are not believed to be as effective at cleaning.

- Top-loading machines are typically noisier than other varieties due to a higher use of mechanical transmission.
- After the spin cycle, there may be more water in the wet load, which could lengthen the drying process.

2.4) DISCOVERY

In the past, individuals would scrape their clothing with sand or beat it against rocks to remove dirt, then wash it in local streams. The washing machine is one such appliance. Jacob Christian Schaffer (father of WM) created the washing machine and published a design in Germany in 1767. The scrub board was invented to simplify washing clothing thirty years after Schaffer's washing machine in 1797.

James King, an American, obtained the first drum-equipped washing machine patent in 1851, although it was still powered by hand. Hamilton Smith received a patent for the rotational washing machine in 1858. In 1874, Indiana resident William Blackstone created and built a birthday gift for his wife. The first washing machines were created especially for domestic usage.

The Hurley Machine Company of Chicago, Illinois, introduced the Thor washing machine, designed by Alva J. Fisher, as the industry's first electric-powered washer in 1908. The Thor was a galvanised tub, electric-powered washing machine in the drum style. On August 9th, 1910, a patent was granted.

The first agitator washing machine was created in 1920 by Beatty Brothers of Fergus, Ontario. Earlier Beatty machines had nickel- or nickel-chromium-plated ribbed copper tubs. Maytag was the first company in the US to use agitator technology.

The first electric automated washing machine intended for home use was created in 1923 by a firm by the name of Bendix Home Appliances. A device that can wash, rinse, and dry water from clothes in one step is developed in the 1930s by John W. Chamberlain of Bendix Aviation Corporation.

The washing machine's next advancement was the addition of a timing device, which enabled the washer to be programmed to run for a predetermined amount of time during a wash cycle. The user no longer had to keep an eye on its behaviour all the time. Earlier versions of Whirlpool Corporation created the very first top-loading automated washing machines in 1947.

Early in the 1950s, a large number of American manufacturers began offering washers with a spin-dry feature in place of the wringer, which removed buttons and led to accidents involving hands and hair. A washing machine featuring five push buttons to control the washing temperature, rinse temperature, agitation speed, and spin speed was introduced in 1957 by General Electric (GE).

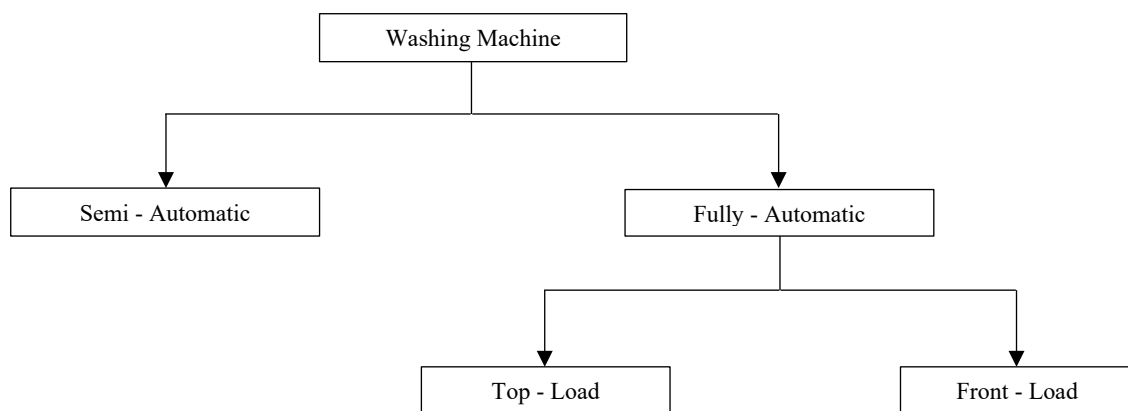
2.5) PRINCIPLE OF WASHING MACHINE

The main principles behind the working of a washing machine are centrifugation. The two main forces used are the centrifugal and centripetal forces.

All washing machines use three different sources of energy, mechanical, thermal and chemical energy. Thus, mechanical energy is imparted to the clothes load by the rotation of the agitator in the top loaders, or by the tumbling action of the drum, in the front loaders. The temperature of the wash bath supplies thermal energy, while the detergent and other laundry chemicals supply chemical action. The timer controls each and every part of the washing cycle. The timer controls various other switches in order to control several other functions. This is also the one that decides on the correct amount of electricity to be sent to each section of the machine at the right time.

2.6) TYPES OF WASHING MACHINES

By function, there are two sorts of washing machines:



❖ Semi-automatic washing machine (SAWM)

In semi-automatic machines the controls aren't fully automatic and manual intervention is needed. These are high loading twin tub machines where the washer and therefore the appliance are separate units. So, the task of loading and unloading some of additional times. These are preferred wherever running water isn't offered.



Figure 2.3 : Semi-automatic washing machine

❖ **Fully automatic washing machine (FAWM)**

On the other hand, a fully automatic washing machine can be either top or front loading, requires no manual involvement other than to drop the laundry in, turn on the machine, and allow time for it to complete washing and drying. A specific continuous water supply from a valve is necessary for fully automatic machinery. One tub serves as the container for the entire operation. After placing the clothing in the tub with the water and detergent, the wash cycle is tailored to meet the needs. The washing machine performs the jobs of washing, rising, and drying, and when it is through with each, it beeps to inform users.

On the basis of how clothing are fed into machine, washing machines are further categorised. Top-loaded and front-loaded machines are two categories based on this:

1. Top loaded machine: Top-loading machines employ two vertically drum with an impeller to move back and forth while pulling the clothing in the centre down. They are then propelled back up onto the basket's outside edge by the centre. The interior drum is mobile and perforated to allow water to drain. The water is kept in the outer drum. Compared to front loaders, top loaders use a lot more water.



Figure 2.4 : Top - loading and Front - loading washing machine

Even during a power failure, top loaders make it simple to remove the clothes without bending. These machines need standard detergents for washing.

Even after the cycle has started, more clothing can be added. The ease of loading and unloading increases with drum size.

2. Front loaded machine: Compared to traditional machines, front-loading washing machines use less water and energy. The tumble wash motion is used to wash clothes in all front-loading washers. Typically, front loaders cost more. However, these use less water and dries clothes much more quickly than top-loading machines, which lowers energy usage. Front loaders can't be opened in the middle of the wash cycle. This kind of loader uses detergents that produce less lather, and if the supply is cut off, the water in the drum prevents the door from opening.

2.7) NOMENCLATURE OF WASHING MACHINES

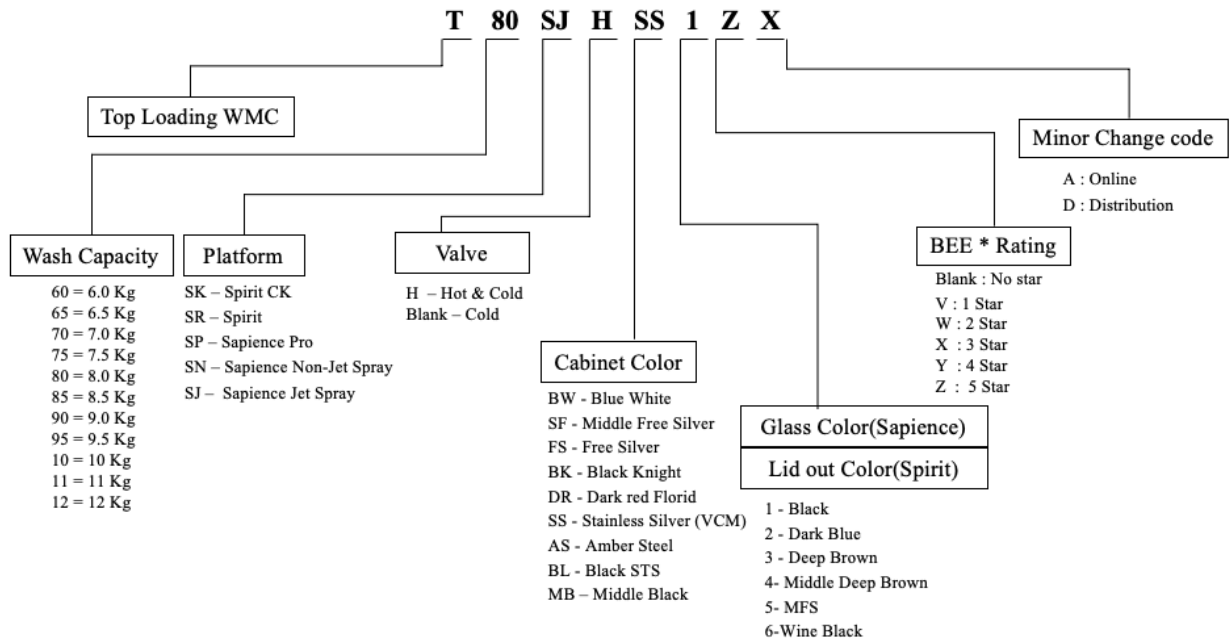


Figure 2.5: Top-load Model Nomenclature

CHAPTER 3

WASHING MACHINE - TECHNICAL ASPECTS

3.1) WASHING PRINCIPLE OF WASHING MACHINE

3.1.1) How Does It Work?

Clothing and different linens are placed within the top-load or front-load washing machine, some detergent is added, and it begins to work. They need direct access to a water system, that brings water into the detergent-filled drum. Once the clothing has been agitated or bounced through the detergent water, the dirt, soil, or stains will then be removed. The washer enters a spin cycle, removing all water from the clothing. Once more, water fills tub, removal out any leftover detergent. However, by spinning at a high speed, it spins out the wetness and leaves the clothes dry. The functional diagram of a washing machine is shown in figure 3.1 below.

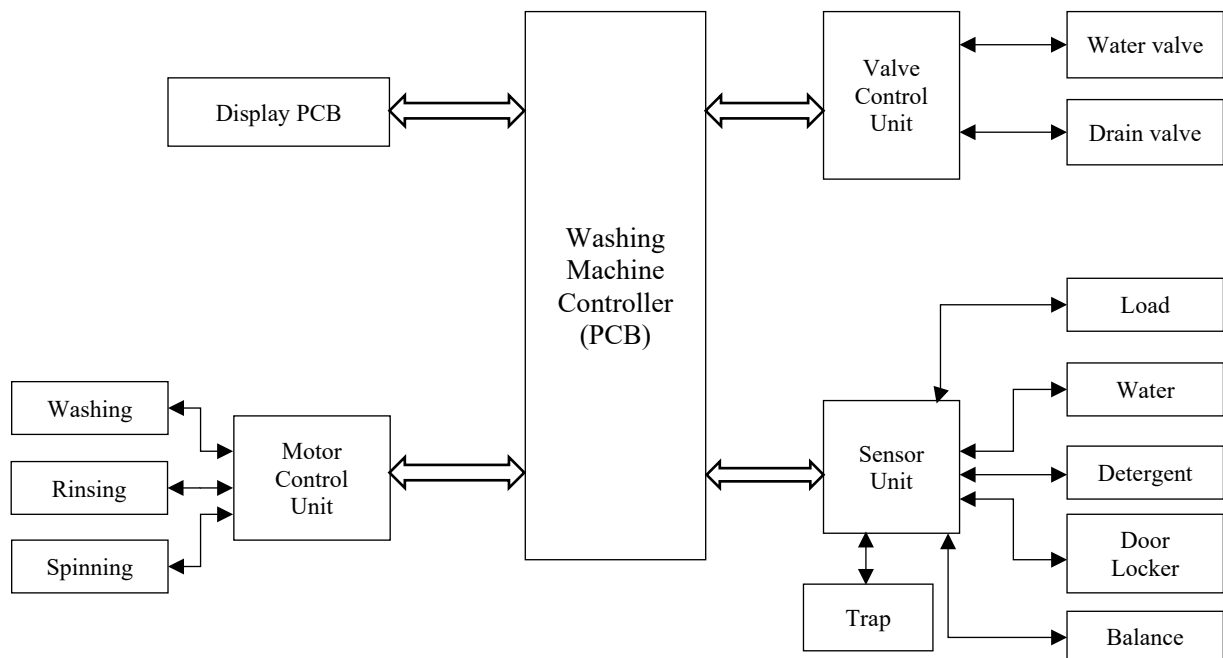


Figure 3.1: Block diagram of automatic washing machine

1. Valve control unit: The water injector valve as well as drain valve are both under control of this unit. It includes all of the instructions for inlet water valve, including when to open and when to close it.
2. Sensor unit: The sensor unit contains all the data from the sensors that are used in washing machines, such as the load sensing sensor that determines how much load is inside the tub and then fills it with water.

3. Motor control unit: This unit manages how the motor operates. It contains all the details about the motor's rotation, including when the motor rotates clockwise and when it rotates counter clockwise. Additionally, it specifies when the motor will turn on and off for each of the three scenarios—washing, rinsing, and spinning.

4. Display unit: The display unit is made out of a PCB having LEDs to show when a process is finished, when an issue arises while washing, when buttons are set or reset, etc. The numeric value display and the error message display both use a seven-segment display.

3.1.2) Working program of washing machine

- Washing Program:** The washing machine must first determine whether water is accessible for washing. It moves on to detergent box after confirming the water supply. The process then resumes with filling the drum with water for a certain amount of time before closing the water valve. To carry out the wash process, the machine's drum must however rotate. For this reason, the motor will start which in turn moves the washing drum, and stops after predefined timeframe and once washing process is done the water is drained out. The following flowchart in figure 3.2 provides a clear picture of the above steps.

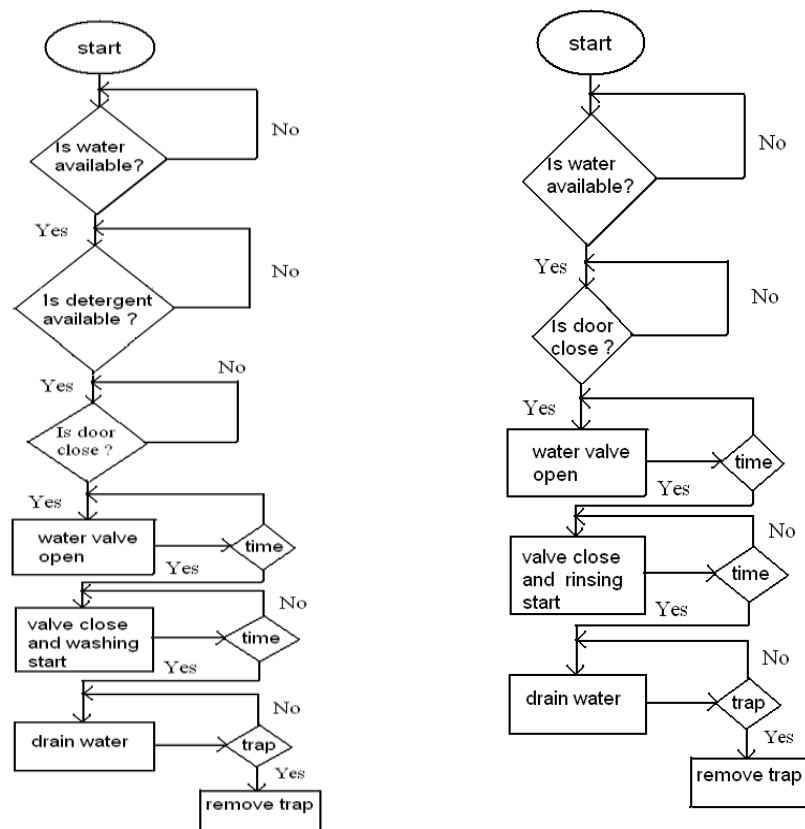


Figure 3.2: Flowchart of washing and rinsing process

- **Rinsing Program:** Checking whether there is water available for rinsing is necessary before starting the rinse process again. It is necessary to verify that the machine's door is securely closed. The water valve closes as the next step in the operation after the drum has been filled with water for a set time period. The motor rotates the drum, and stops after specific time. Once the rinse method is completed the water is drained out.
- **Spinning Program:** Once the rinsing is complete, the door must be closed in order to begin the drying process. To perform the spinning process, the machine's drum should rotate. At the same time, a drain valve is opened, allowing water to drain out through the drain pipe. The process ends once the clothes have dried thoroughly. Higher spins speed, the drier the clothes at the end of the laundry cycle and therefore the shorter the drying time. Once the water drains out fully from the laundry the buzzer beep to point that drying method is completed. Therefore, entire laundry process is completed.

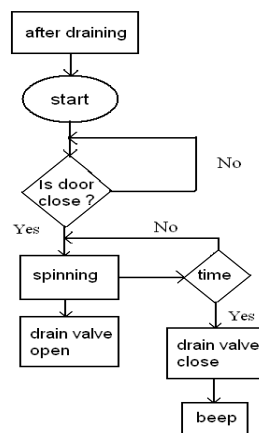


Figure 3.3: Flowchart of spinning process

3.1.3) Efficiency of Washing

In washing machine, the electrical energy is converted in kinetic energy then the mechanical energy is converted into heat energy. Washing machines are majorly of three types – Fully automatic (Front or Top load) and semi-automatic washing machine. Bureau of energy efficiency (BEE) has made it mandatory for most of the home appliances to display a star label on top of each model with star rating and wattage information. Higher the rating higher the energy efficiency and lower the rating more energy consumption.

Washing machine in India come with rating of 300W to 3000 Watt. Semi-automatic washing machine can vary it 300 W to 400 W rating. Top loading WM is slightly higher from 350 W to 500 W. Front-load is usually between 2000 and 2500 W.

Table 1 predicts that how much power a top-loader consumes per kg per cycle.

Table 2 predicts star rating label criteria of a front-loader consumes per kg per cycle.

Star Rating	E per cycle kWh/Kg/cycle	Star Rating	E per cycle kWh/Kg/cycle
1-star	$0.0171 < E \leq 0.0185$	1-star	$0.16 < E \leq 0.18$
2-star	$0.0158 < E \leq 0.0171$	2-star	$0.14 < E \leq 0.16$
3-star	$0.0145 < E \leq 0.0158$	3-star	$0.11 < E \leq 0.14$
4-star	$0.0132 < E \leq 0.0145$	4-star	$0.09 < E \leq 0.11$
5-star	$E \leq 0.0132$	5-star	$E \leq 0.09$

Table 3 predicting the Minimum Requirement for Top and Front Loader:

Requirement	Front Loader	Top Loader
Wash Efficiency	$\geq 95 \%$	$\geq 80 \%$
Rinse Efficiency	≤ 2.25	≤ 2.25
Spin (Water extraction)	$\leq 75 \%$	$\leq 75 \%$
Water Consumption	$\leq 9 \text{ l/kg/cycle}$	$\leq 23 \text{ l/kg/cycle}$

Washing machine power consumption depends on 2 major elements one is that motor that spins drum and second is that heating equipment that gives hot water combine for cleansing.

Out of those the heating element consumes an oversized quantity of power (70%) and therefore the rest motor, pump, PCB display consumes considerably less power (30%).

3.2) DESIGN OF A WASHING MACHINE

The most important parts of washing machine are inner and outer drum. Besides two drums, there are lots of components. The washing machine mainly comprises of three assemblies: Top Cover Assembly, Cabinet assembly and Tub assembly

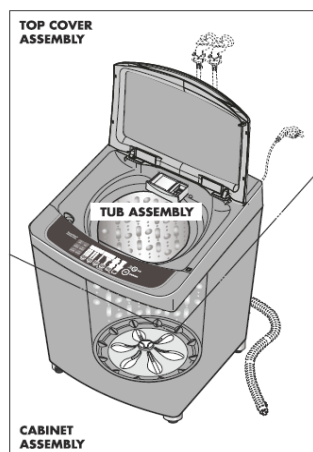


Figure 3.4: Design of Washing Machine

3.2.1) Top Cover Assembly

The top cover assembly of the washing machine contains the top cover (forms bottom for the top cover assembly). It contains the PCB and the program devices for the operative washing machine. Lid (an entry for the clothes to the washer tub). PCB and the interface devices area unit taken from the electronics & electrical companies and is fitted into top cover with assistance of spring lock. Glass and Glass support (the glass support is created by thermoforming method. Glass is made up of sintering soda lime and is tempered glass). Detergent Case (the detergent feeder is employed to feed the detergent).

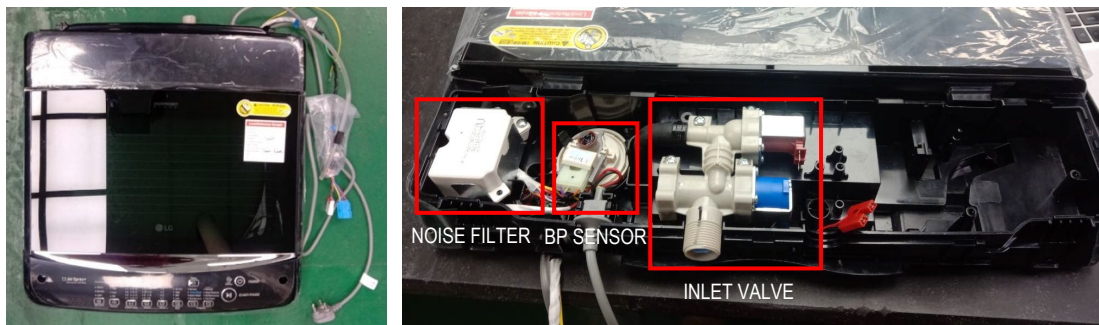


Figure 3.4.1 : Top Cover Assembly of Top-load WM

The other components of top cover assembly from front panel side includes Door lock, Printed Circuit board (PCB), Control plate & back panel side are Inlet valve, noise filter, BP Sensor.

1. PCB

Printed circuit board (PCB) is the base of the washing machine. PCB controls all the functioning in the washing machine. In PCB different components are present. It consists of the layout/path and connectivity to the electronic components such as ICs, resistors, capacitors, diodes, transistor, transformer, etc.

The automatic working of the washing machine is controlled by the PCB in which the microcontroller/ any other IC and sends it through the path to perform required function. Different functions of washing machine may use the different paths in the PCB for its functioning. An epoxy coating is added to the surface of PCB to protect from dust and rusting. There are two sides of the PCB: Mains and display. The main PCB generally contains the components and display side PCB contains all the tact switches and LED which shows the display.

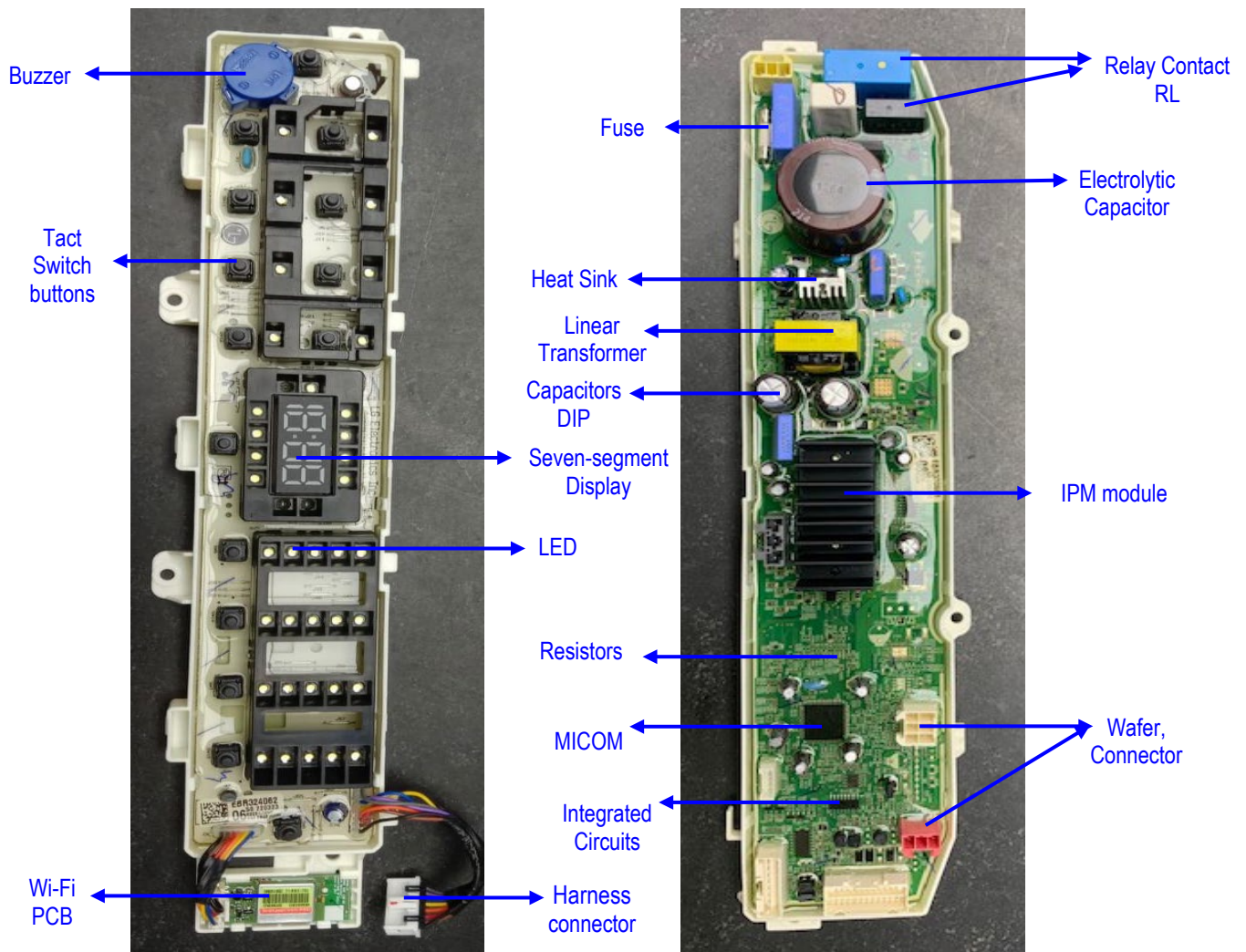


Figure 3.4.2: Display and Load/Main side PCB

2. Control Plate

The control display plate is pasted on the front panel of the top cover where all the controls are displayed like power, start/pause, water selector, rinse, spin and different wash modes.

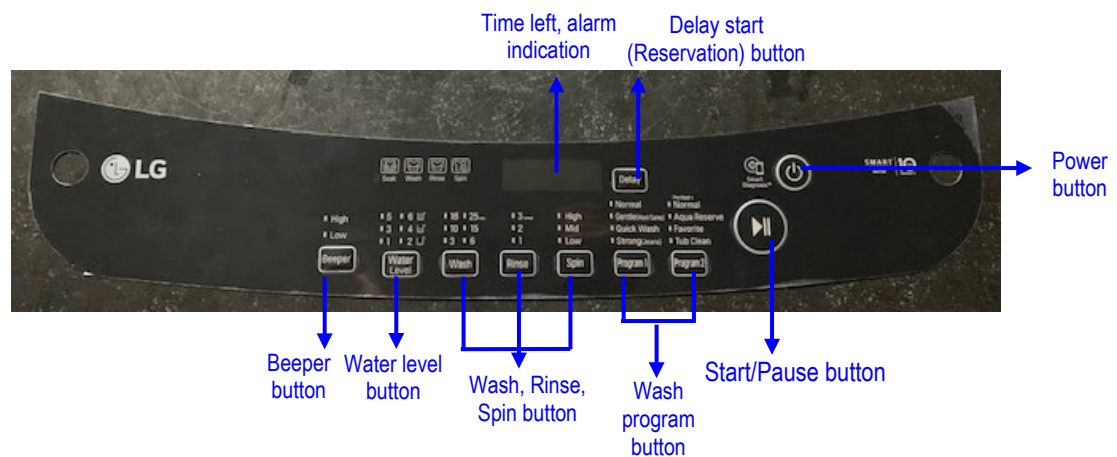


Figure 3.4.3: Control Plate

3. INLET VALVE

The component that connects the two water hoses to the washing machine and regulates the intake of both hot and cold water is known as the water inlet valve. The hot and cold-water hoses are connected to water inlet valve's two threaded ports at rear of the machine. A solenoid valve in each port opens and closes the supply of hot and cold water.

A very small, low amperage control voltage is used to energize electromagnetic coils in solenoid. The electromagnets pull a metal piece out of way, acting as an opening valve to allow water flow in the washing machine. A spring is sometimes put in place to keep the valve normally closed, and valve only moves to overcome spring when a solenoid is energised. Instead of employing a spring to keep valve in a generally closed position, some machines use the water pressure to push against a lever, which creates a tight seal and shuts off water flow. A fine mesh filter screen is located within each of input valve's ports and is responsible for keeping sand, minerals and other waste from entering your system.

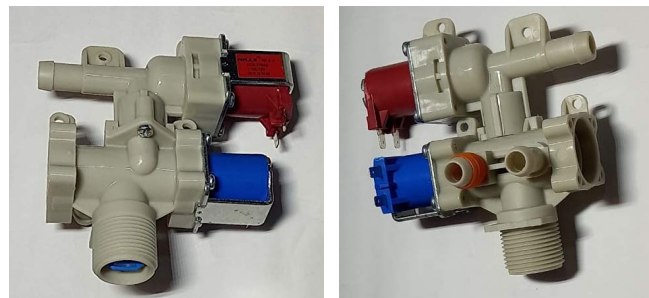


Figure 3.4.4: Water Inlet Valve

4. BP SENSOR

This is a device designed to monitor a process and provide an output when a set pressure (set point) is reached. The process pressure is applied to a diaphragm or piston to generate a force that is compared to that of a pre-compressed range in a pressure switch.

When the pressure in the hose reaches a predetermined level, the pressure switch is programmed to switch power from the washer's fill valve and direct it to the timer, stopping the flow of water and starting the washer's first cycle. The air in the pressure tube becomes pressured when the tub fills with water because it has no way to escape. The pressure causes the diaphragm to move upward, alerting the pressure switch to the rising water level. It's an extended, hollow plastic tube that holds air. The sensor's internal ball is nickel-plated. As water fills the tub, it conjointly goes into the tube, pushing air toward the tube's high.

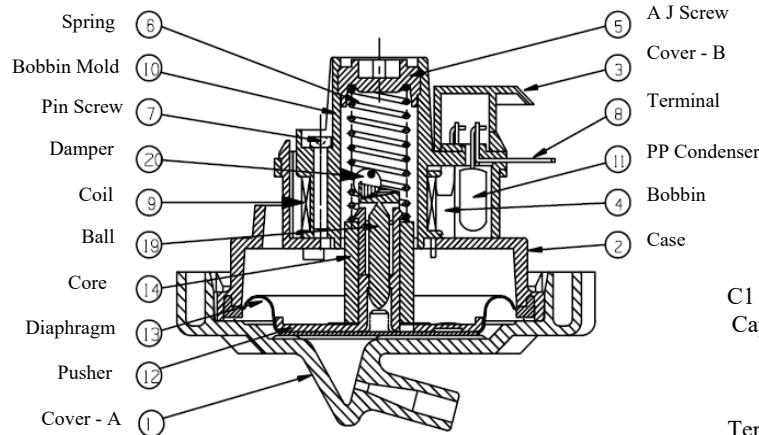


Figure 3.4.5: Cut Section of BP Sensor



Ball Pressure Sensor

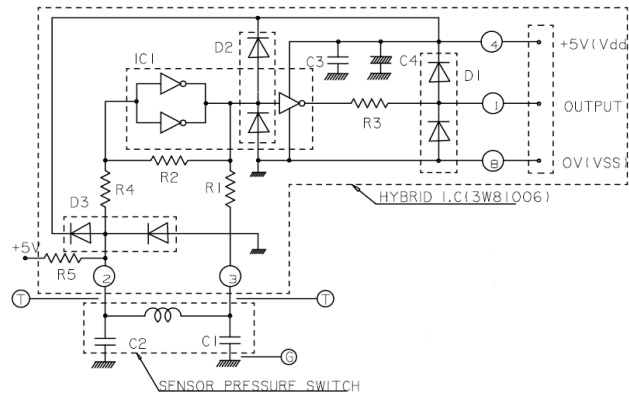
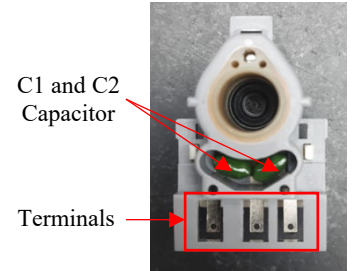


Figure 3.4.6: Circuit for measuring level

The above shown circuit diagram (fig. 3.4.6) is for ball pressure sensor used for measuring level. Rated voltage of the switch is 5V DC. In the above circuit IC1 is the CMOS inverter which operate with very little power loss and at relatively high speed. There are five resistor which are connected in the circuit; where $R1 = 3.3K\Omega$, $R2 = 100K\Omega$, $R3 = 150\Omega$, $R4 = 560\Omega$ and $R5 = 12K\Omega$. Four capacitors C1, C2, C3 and C4 of the value $0.022\mu F$, $0.022\mu F$, $0.01\mu F$ and $33\mu F$ respectively. C4 is the 10V $33\mu F$ electrolysis condenser. D1, D2 and D3 are the switching diodes. For measuring of the level, a hybrid I.C. and sensor pressure switch circuit are connected to each other.

6. Noise filter

The noise filters for home appliances minimizes the influence on products by suppressing and blocking the electromagnetic waves generated during the operation of the appliances. The noise filter is used in washing machines.

Noise filters and reactors block and reduce the harmful electromagnetic waves from the power generation facilities and help to maintain its best performance in response to various environmental changes. By applying components, such as coils, capacitors, resistors, fuses, and connection terminals to the PCB board, a product that removes noise.

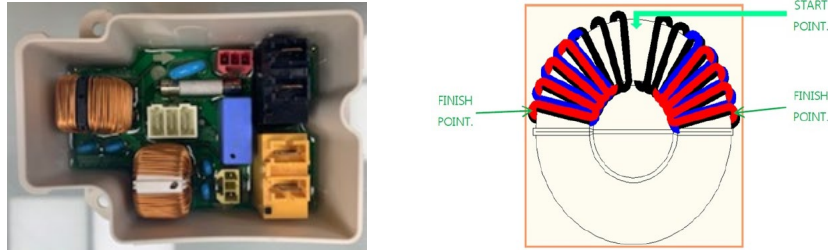


Figure 3.4.7: Noise Filter

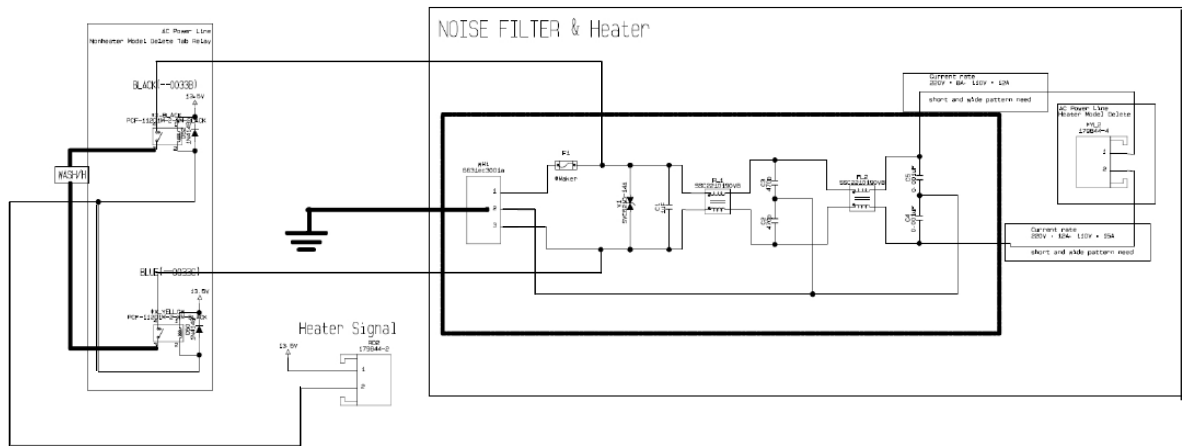


Figure 3.4.8: Internal circuit of noise filter

In the above figure 3.4.8 circuit diagram, FL1 and FL2 are the line filter assembly. V1 is the varistor (SVC 621 D-14A) which safeguards circuits from excessive voltage surges. Across varistor there is film capacitor C1 with value $1.0\mu\text{F}$, AC 275V. Others capacitors are connected across line filter assembly. These are the ceramic capacitors C2 and C3 connected with FL1 with a specification 470pF, AC 250V each and C4 and C5 to FL2 having value 1000pF, AC 250 V each. WH1 is the 3P input wafer, YL2 is 2P AC power yellow wafer and RD2 is the 2P heater signal red wafer. Wafer is typically used to transfer signals or power from one place to another within unit. In noise filter there are three wafer connectors white (3P) for input yellow (2P) for AC power and red (2P) for heater signal. F1 is the fuse of 250V/15A in circuit for electrical safety of device that operates to supply overcurrent protection of an circuit. Fuse is an essential part of the circuit that has metal wire or strip that melts once an excessive amount of current flows through it, thereby stopping or interrupting the supply.

D50 and D52 (1N4148) are the two rapid switching, high-speed, small-sized diodes. X Yellow and X Black are the 1-pole contact power relay with DC coil, PCF series. It has coil voltage of 12VDC, rated current 20 amperes and contact voltage 250VAC.

Noise filter can withstand voltage of line to GND, AC 1500 V for 1 minute and 1800 V AC for 1 second. The inductance of the FL1 is 40.0mH + 25% at 1 kHz with resonant frequency of 120~220 kHz at 25°C. Rated current of filter is 5A peak current with a rated voltage of AC 250V at 50/60 Hz. The insulation resistance of noise filter should be 500V DC from Line to GND for 1 minute at 300MΩ or more. Coil Terminal must be parallel with each other and must be vertical at center of coil. Varistor should not touch the fuse.

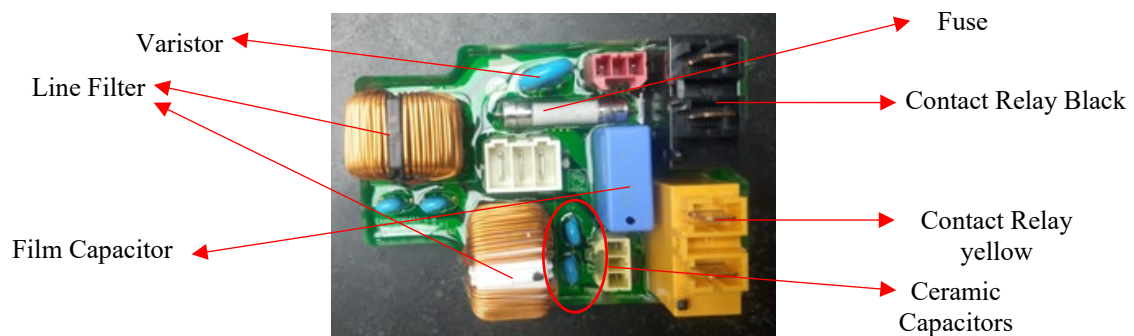


Figure 3.4.9: PCB of noise filter

3.2.2) Cabinet Assembly

The Cabinet Assembly (Fig. 3.5), on which all the other components are supported, serves as the washing machine's framework. The following components make up it:

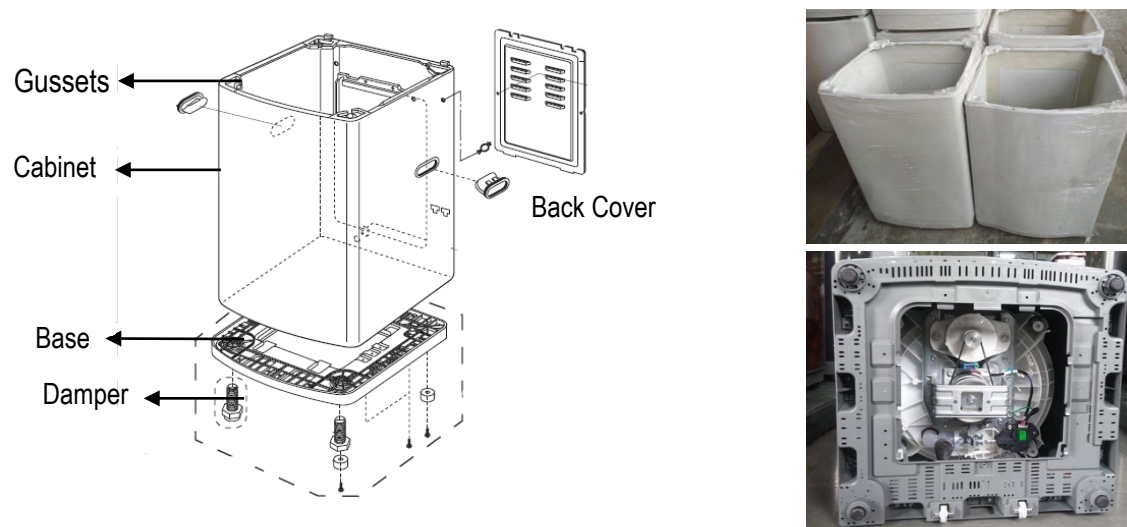


Figure 3.5: Cabinet assembly exploded view

The main structure of the cabinet assembly is the cabinet. It is created by the process of bending sheet metal, and the materials used might vary depending on the colour and model design. PCM coated galvanized steel sheet is used for washing machine. Generally, the material used is SGCC material steel sheet. These sheets not only comply with ROHS requirements but also are rated as top-class in quality and performance. Base is the part that holds the cabinet and other components of the washing machine. It is usually made up of resin PP RM60 material. It is manufactured by injection molding.

3.2.3) Tub Assembly

In reality, washing machines have two tubs. The inner drum, which rotates inside the washer and has holes drilled into it to let water in and out, is where the laundry is loaded. The outer tub supports the inner drum and holds the water inside, preventing leakage into the other parts of the machine.

1. Outer Tub Assembly

This assembly includes the shaft, bearings & shaft seal in the bottom of the tub as an assembly.

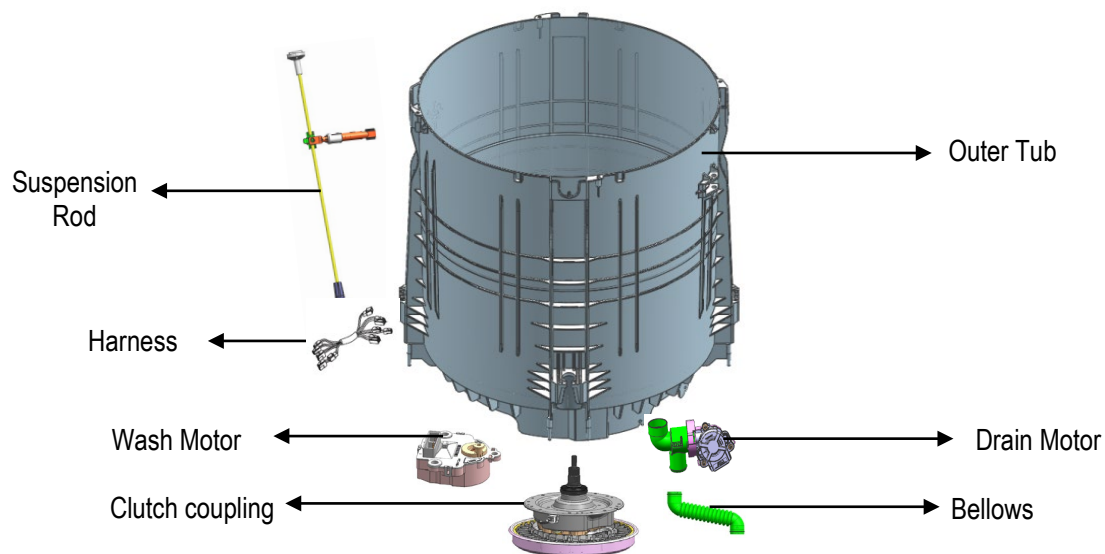


Figure 3.6: Outer Tub assembly

- Outer Tub:** The outer tub on top-load washing machines is made out of hard plastic or metal, is stationary, and is supported by rods and springs, or sits on a base frame tub support. The washer's pressure tube is attached to side of outer tub and the drive motor, pulleys, and pumps are usually mounted to its bottom, The outer tub supports inner tub, allowing it to spin freely.

- **Suspension Rods:** Suspension rods in washing machine helps to keep the machine stable by supporting the tub. These connect the outer tub to the base frame and help to keep the tub from swaying during the spin cycle. The moving system is supported by a stationary support structure, which is typically the washer's outer cabinet or frame. To stop the moving system from occasionally travelling too far, the motion must be dampened, especially during spin.
- **BLDC Motor:** A brushless DC direct drive motor for a washer has a stator with a frame, a core inside, and a number of core teeth that extend outward from frame with coils wound on them. The rotor is mounted around core teeth and rotates when power is applied to the stator.

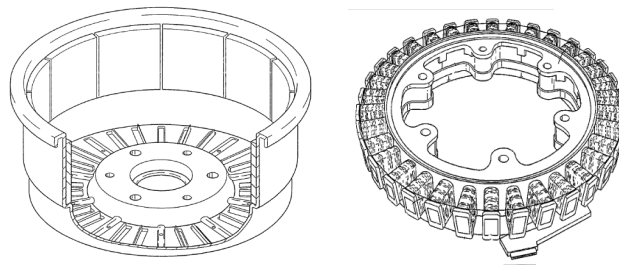


Figure 3.6.1: Rotor and Stator of BLDC motor

The BLDC motor has a rotor encircling the stator and a coil wrapped on it for generating spinning energy when power is applied to the stator. A drum shaft is used to transmit the driving force from a motor to the drum. The drum shaft has bearings at both the front and back, and the bearings are supported by a bearing housing that is located in the middle of the tub's back wall. Perspective views of the stator and rotor are shown in Figure 3.6.1.

The stator has an annular frame, many core teeth that protrude outward from the frame, and coils wound on each of the teeth. The rotor or armature has permanent magnets connected to the inner of the drum shaft.

The other type of motor is DC brushless motor (Fig. 3.6.2) is Non-Direct Drive (NDD) which was installed in the traditional washing machines. The below illustrated motor has 310 VDC, 2.5 A, 2700 motor RPM with constant power of 150 W. The number of pole/slots of the motor is 8 pole/12 slot. The nominal voltage is 220 V and maximum permissible current in drive circuit is 3 A. When the motor is used at low temperature or overcurrent the maximum value of current (Demagnetizing current) depending on the condition effect the rotor magnet. The motor receives PWM voltage from inverter circuit. The stator produces a rotating magnetic field from the three-phase coil and the magnet rotor rotates.

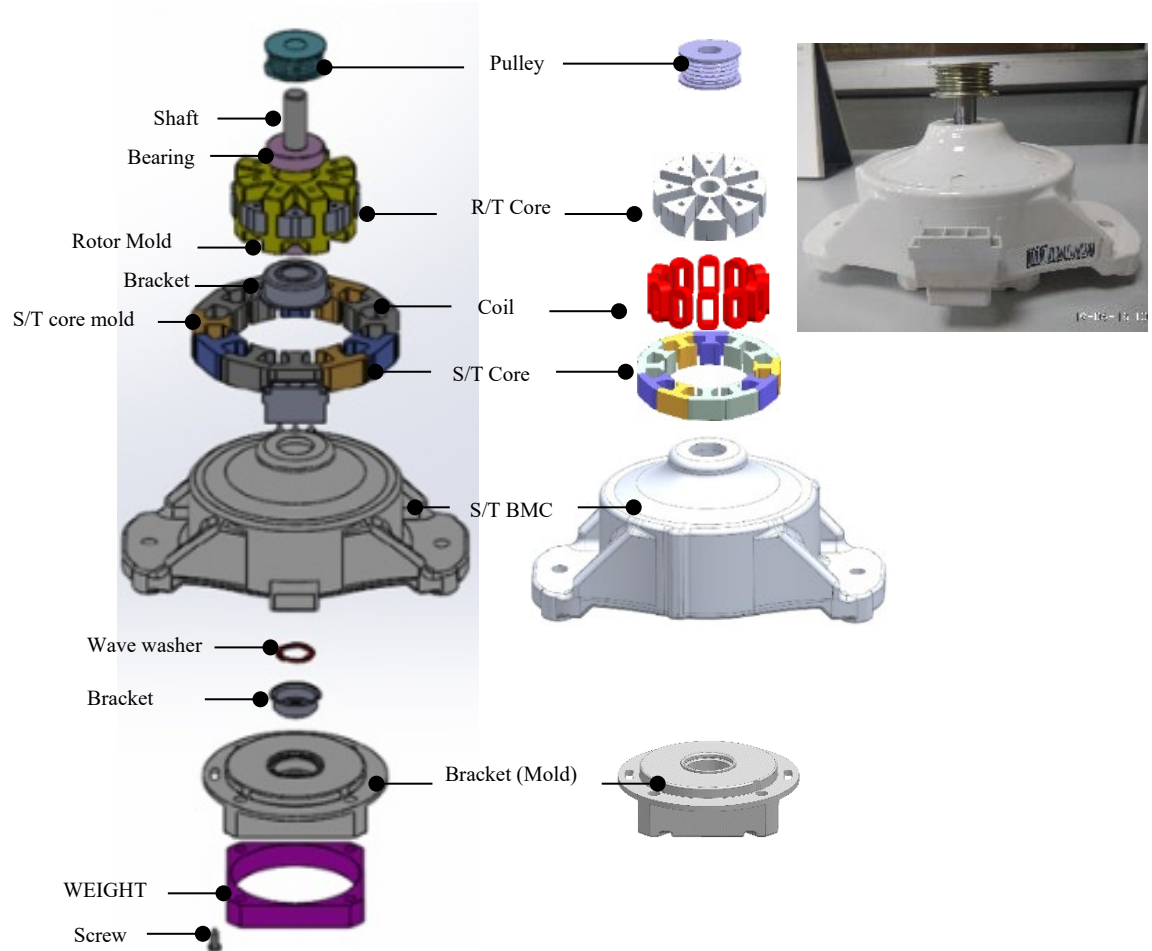


Figure 3.6.2: BLDC Motor Structure

- Drain Motor:** The function of the drain motor in the fully automatic washing machine is the same as the drain electromagnet, but the structure is different. When the drain electromagnet is energized and attracted, the AC drain motor does not have the contact impact sound and electromagnetic sound of the armature and the iron core, and the sound is small during operation. A small synchronous motor, a gearbox with various speeds, a string for traction, and a stroke switch comprise the drainage motor. When draining, the computer board (or programmable controller) supplies power to the miniature synchronous motor of the drainage motor. The synchronous motor rotates, and the low-speed rotation changes the steel wire entangled in the rotary drainage motor, and the steel wire rope pulls the connecting arm, which pulls the drain valve plug to overcome the elastic force of the valve spring to drain at the same time pull the clutch brake arm, and the stroke switch acts when the wire is wound.

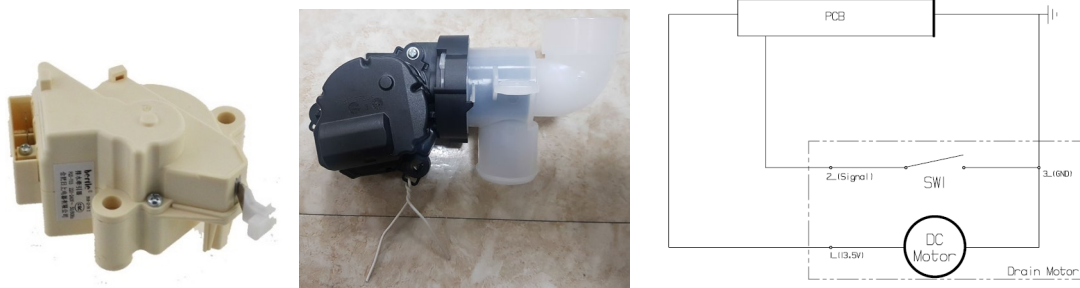


Figure 3.6.3: AC Drain Motor and DC Drain Motor

Another type of drain motor used in washing machines are the DC drain motors with voltage 13.5 V, 0.285 A current and 4.5 W power. The components of the DC drain motor include lever, cover 1-2, plate, custom terminal 1-2-3, parallel pin, contact-arm, DC motor, machine screw, worm gear, gear, gear shaft, case, spring, straight shaft, bellows and PV case. 13.5 V DC at normal and humidity in atmosphere, current consumption should be less than 65 mA at no load. The operational time and return time of drain motor should be less than 6 seconds.

- **Clutch Coupling / Housing bearing:** The principle of the washing machine clutch, the deceleration clutch is also called the reducer. It is the major part of the pulsator transmission mechanism in a regular washing machine. Its purpose is to reduce the motor's speed and increase the torque in order to get the pulsator to work.



Figure 3.6.4: (A) Clutch coupling housing assembly, (B) Clutch Gear box assembly

The above figure 3.6.4 illustrates the Clutch coupling housing bearing for direct drive washer and the other is clutch gear box that is used in belt driven washers. Direct drive washing machines perform better than belt-drive washers. In addition, they lack belts and the other parts that most commonly wear down and break on belt-drive washers. Direct drive washers are also quieter, more reliable, and more energy-efficient than their belt-drive counterparts. In a belt-drive washer, a motor turns the washer's tub via a belt drive, a mechanical system that uses a pair of pulleys connected to a central shaft with a flexible band or belt. The belt drive transfers power to the motor so it can rotate the tub.

- **Harness:** In order to ensure correct operation, the wiring harness in a washer is used and it transmits an electrical current from the motor to PCB and other components. The numerous wires and cables can be better protected from damaging impacts of vibrations, abrasions, or dampness by being bound together into a cable harness. Installation time is shortened and procedure is simple to standardize because there is only one wiring to install. The ends of the wires are cut off to reveal the metal (or core), which is then outfitted with any ends or connector housings that are required.



Fig 3.6.5: Harness

2. Inner Tub Assembly

The inner tub assembly of the washing machine contains inner tub, pulsator, magic/lint filter.

- **Inner tub:** A steel sheet is retained in basket that is inside the tub (fig. 3.7). Alternating holes in steel sheet and the basket allow drained water to pass through. The laundry basket is filled with clothes to be washed.

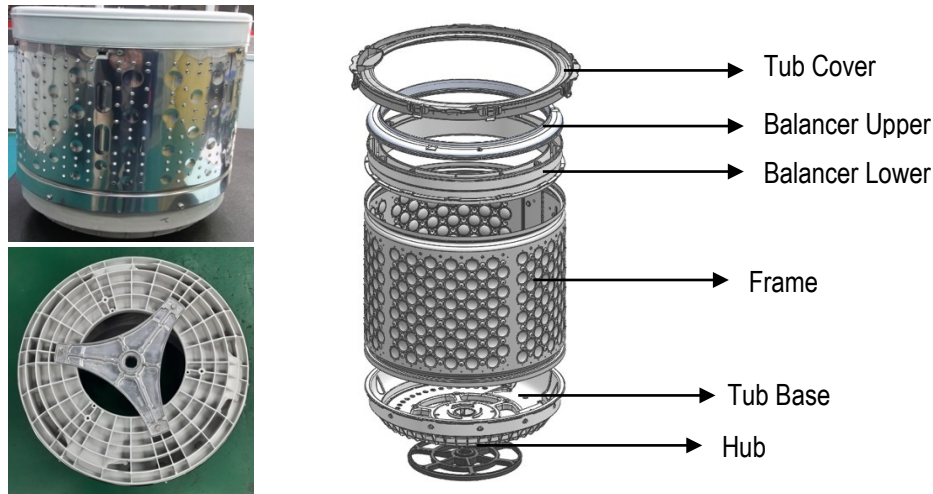


Figure 3.7: Exploded view of inner tub

The balancing ring or basket cover is fitted over the basket. The washer is steadied by the balancing ring, a substantial weight. A metal ring has been fused into the plastic's outer layer to give it strength. After being wrapped into a drum shape, the tub is automatically produced, and the side is welded. The major function of the hub or tripod is to transmit torque between the shaft and the cylinder, making it the most crucial structural element of a washer. The material used for the production of this part is ALDC 3 natural without CED coating through a method known as die-casting, which involves injecting hot metal at high pressure and speed into a perforated metal die.

- Pulsator assembly:** This is located in the middle of the drum is a wheel that moves the water. This allows your clothes to rub against each other to get them clean. The method uses friction between the clothes to get them clean. The pulsator assembly includes pulsator washing, pulsator cap and bush installed in the center of the pulsator.

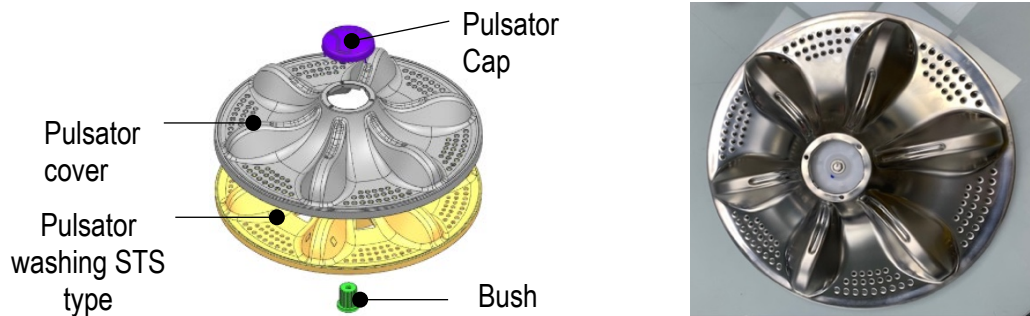


Figure 3.8: Sectional view of Pulsator

3.3) Conventional WM and Inverter WM

When laundry is placed into a fully automatic washer, its sensors will measure the weight of the items. The washing machine's microprocessors use this data to calculate how much time and water are required for that cycle of laundry. The motor speed will remain constant whether a batch of 3kg or 7kg is loaded onto a machine that is designed to handle 7kg. Thus, a great deal of energy will be lost. Although it will save some energy to wash a 3 kg load in a 7 kg washing machine, the cleaning outcomes won't be as good. Inverters can be useful in this situation. Considering weight of the load, an inverter washer may adjust the engine speed to the best possible level. In doing so, the washing machine will be able to consume the minimal energy without compromising how well it cleans. As shown in the diagram 3.9 below, the inverter model is much more effective than the non-inverter.

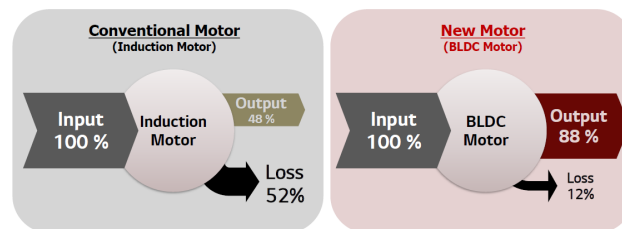


Figure 3.9: Comparison of Conventional and BLDC motor

Smart inverter washing machine has better washing performance with energy saving and smart motion. By using this technique upto 36% energy saving can be done on 7.5 Kg load washing machine.

Saving energy by smart inverter control helps optimal power input to eliminate unnecessary operation minimizing energy loss.

The conventional washing machine takes energy 104.38 Wh and inverter-controlled washing machine uses of 66.77 Wh. Energy saving with better performance is reliable and durable with Lodecibel quiet system. This exclusive soft start regulator system reduces the noise made during the beginning and end of the cycle. No brushes means that washing machine works with less noise, less vibration and with long life span through the Lodecibel quiet system. Noise level VDE result is observed 44.7 dB and allows nearly 10 years of warranty of motor.

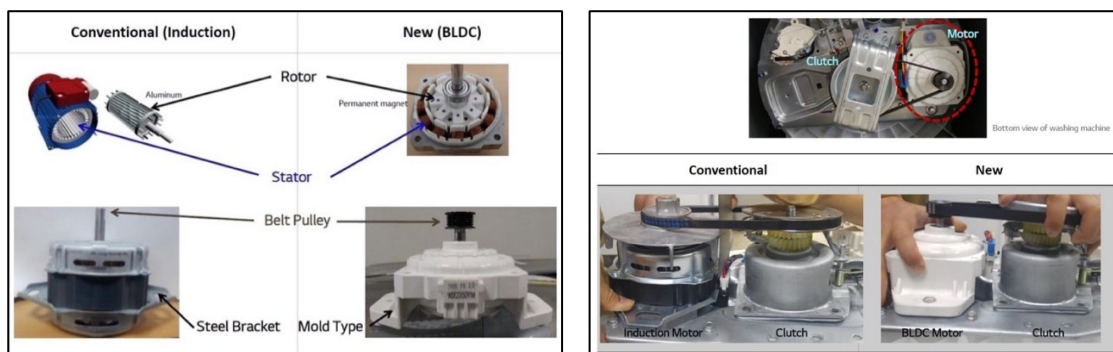


Figure 3.10 : Conventional Motor V/s BLDC Motor

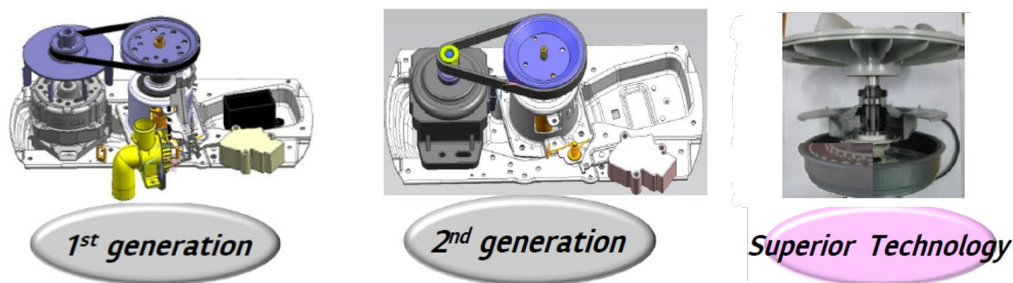


Figure 3.11: Development of Motor type

The above figure 3.11 illustrates the development of motor with the generation of the washing machine. First generation was the single-phase induction motor which was attached with pulley system to the clutch to operate the washing machine. Second generation of motor includes the BLDC motor attached to clutch via belt. The superior technology used nowadays in the washing machines are inverter with direct drive motor (DDM).

3.4.1) Brief Schematic Diagram of WM PCB

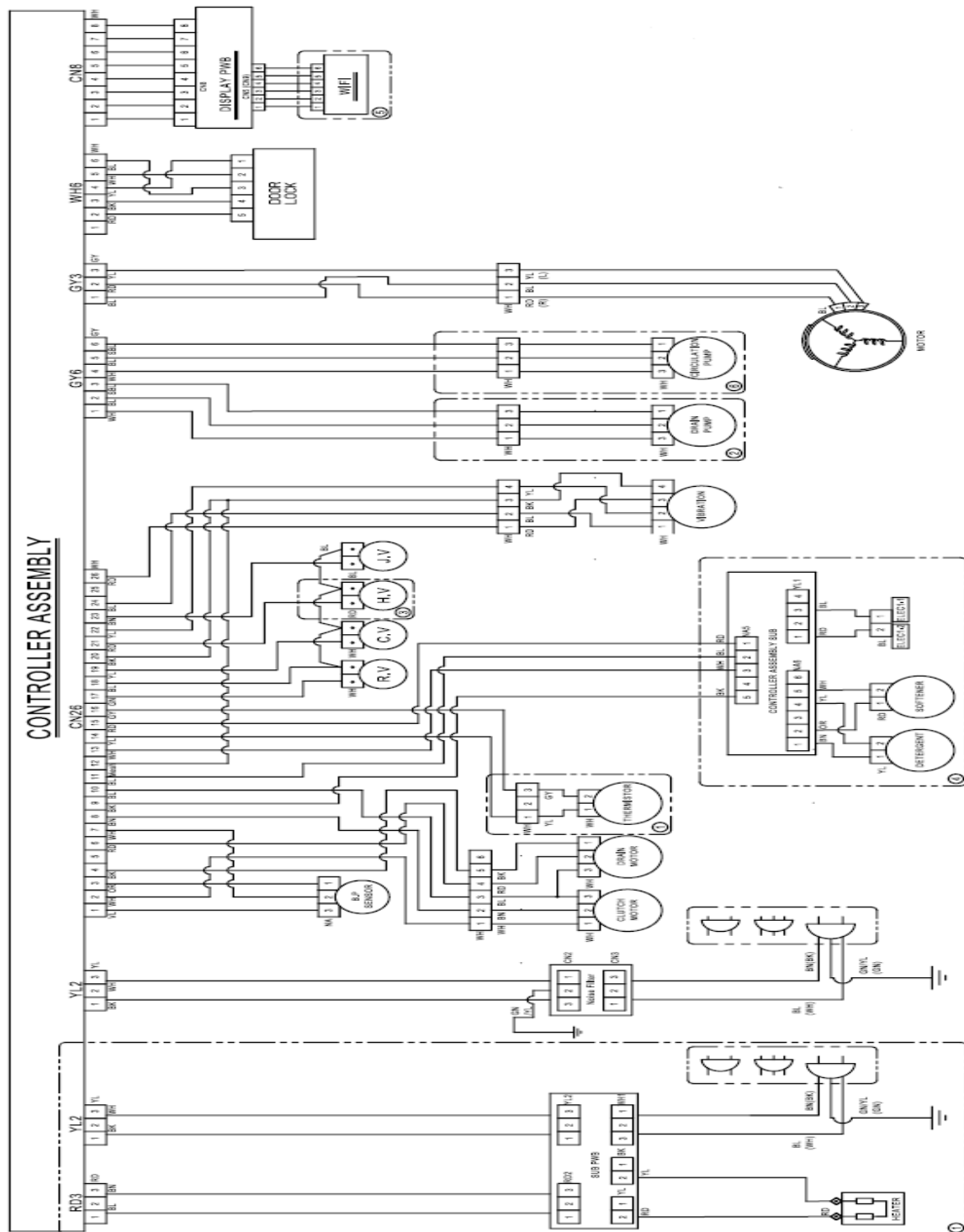


Figure 3.12: Circuit Diagram of PCB

Terminology used in the wiring diagram of the washing machine is as follows:

- CN26 component connector terminals are connected with BP sensor, clutch motor, drain motor, thermistor, sub controller assembly along with the rinse valve, cold valve, hot valve, jet valve.
- CN8 component is the connector of the main PCBA with the display PCB attached with the Wi-Fi PCB (optional).
- WH6 is the door locker switch port which work with the synchronization of the door of the washing machine and displays errors accordingly.
- GY3 connects the BLDC motor to the PCB to sense the speed of the water.
- For heater model RD3 and YL2 connects the heater for functioning whereas YL2 is for the GND.

i. Selecting Washing different options and time:

- The microcontroller has different auto-wash function stored into its memory.
- The time one sets is visible in the seven-segment display on the control panel of washing machine.
- Each indicating light is turned ON to indicate the level.

ii. When touching the start button with the normal / quick/ strong/ pre-wash normal wash selected:

- This program is used for washing normal clothes, this mode automatically selects the most appropriate conditions and completes the sequence in one operation.
- The built-in sensor detects the size of the load and ideal wash power & wash, rinse and spin times are set accordingly.
- Switch ON the power, add the laundry, select the normal wash program and close the lid. The washing machine will itself take the default memory feed in the microcontroller and will complete the operation.

3.4.2) Circuit Block Diagram and signal flow of WM PCB

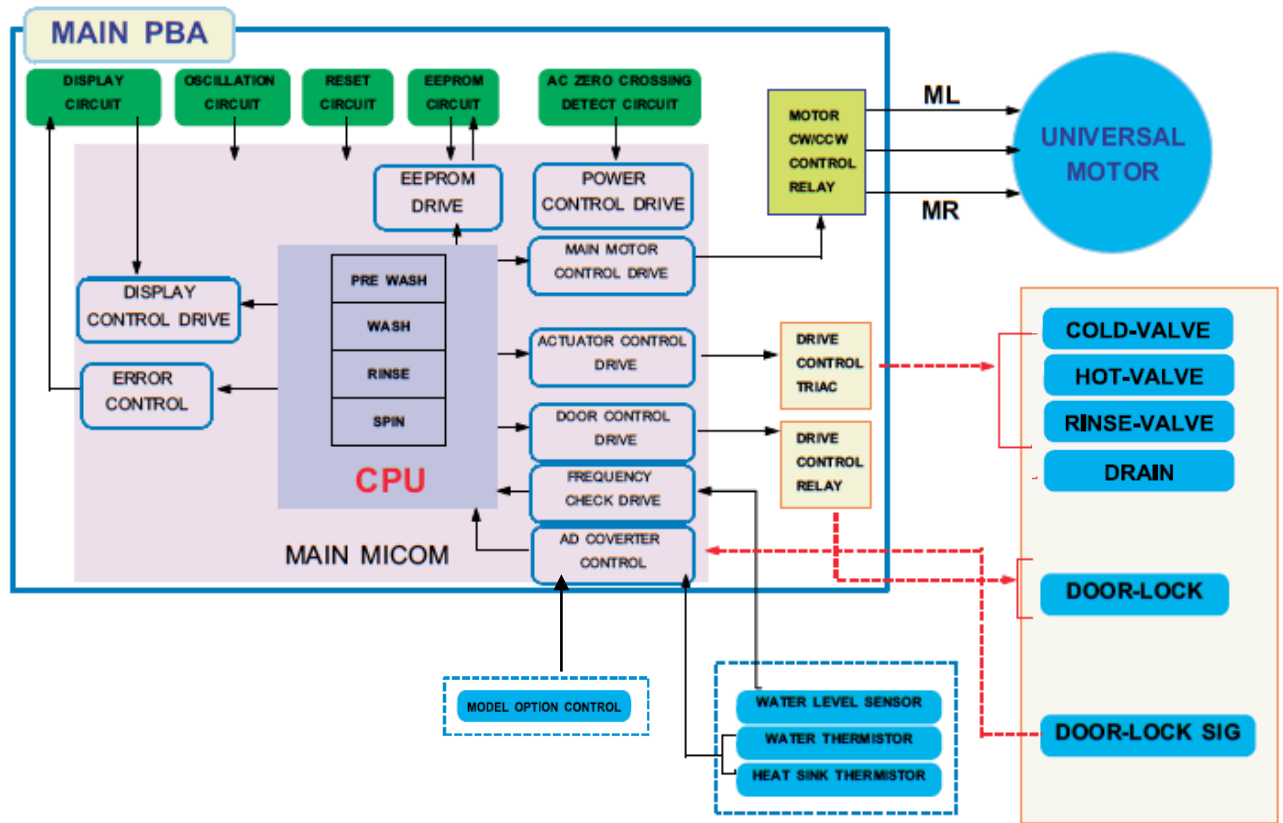


Figure 3.13: Block Diagram of Washing Machine PCB

3.4.3) PCB Microcontroller Module

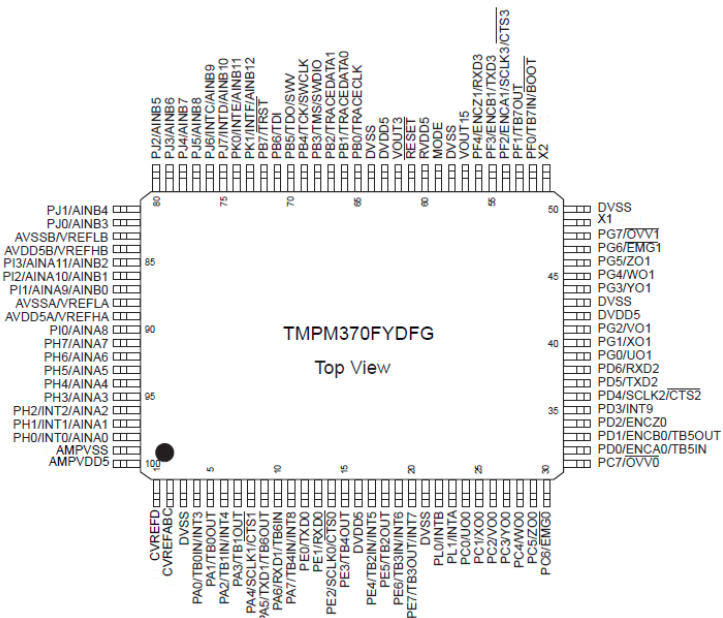


Figure 3.14: Pin layout of MICOM

3.4.4) Connector & Relay Terminals Description

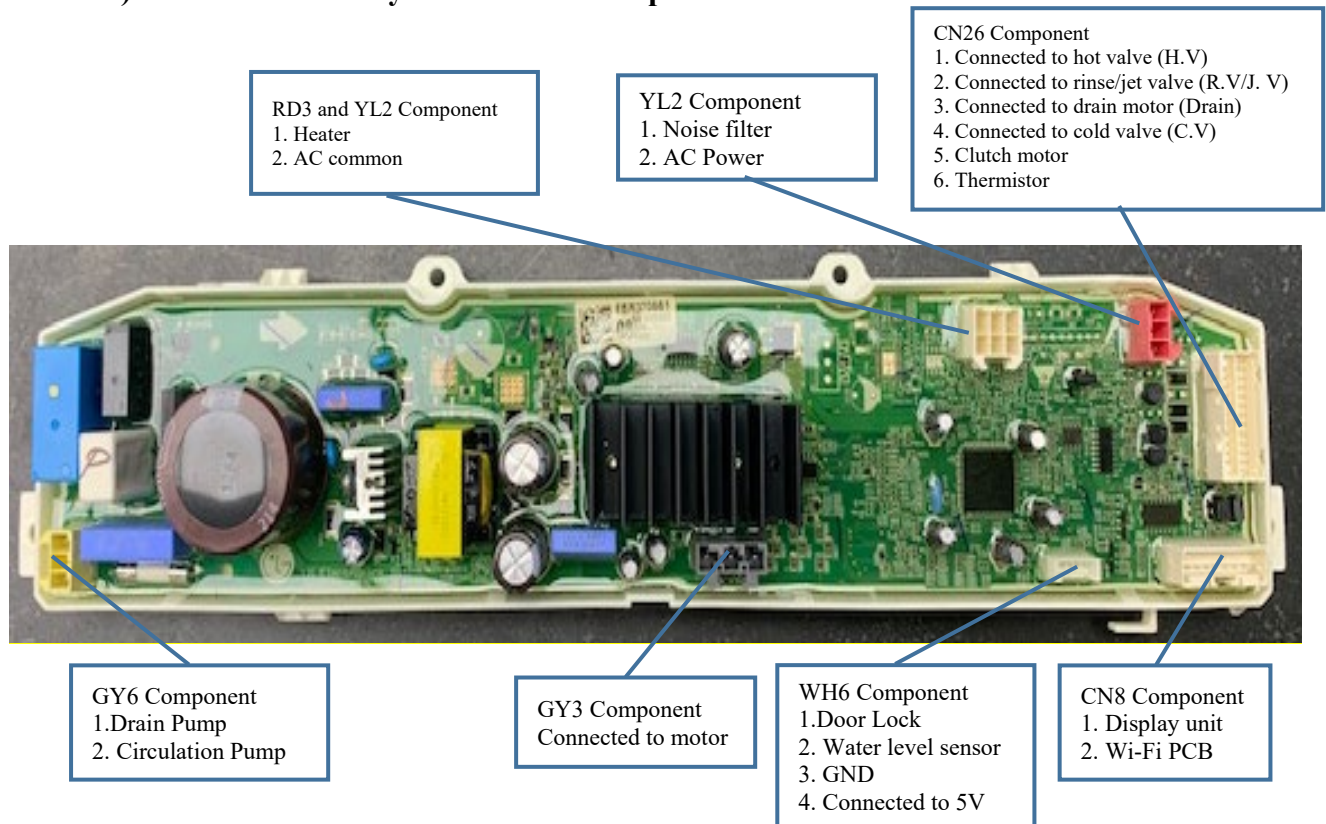


Figure 3.15 : PCB Connector Terminals

- ❖ Inverter Circuit: Controls the speed and frequency of the motor.
- ❖ Display PCB assembly: Displays the function of the operation.
- ❖ Power Relay: Supplies/disconnects power when the power is turned on/off.
- ❖ Valve Driving System: Controls the operation (On/Off) of the valve.
- ❖ Water level sensing system: controls the level of water in the tub while washing.

CHAPTER 4

PROJECT 1: WM – PCB COMPONENT SPECIFICATION AND SAFETY OPTIMIZATION FOR VI & FIELD FAILURE RATE REDUCTION

AIM: To Localize the PCB Manufacturing, Assembly process, optimizing the Fabrication and Assembly of Washing machine PCB, to optimize the SMPS IC specification of the top load washing machine in all models; capacitor specification optimization of the Sapience 10.0 Kg 23” inch jet spray model and to perform all necessary tests for ensuring the smooth operation of the WM with best class efficiency.

4.1) ABOUT THE PROJECT

Earlier, PCBs are manufactured and assembled in China. In order to make Value Innovation of the component, LG is now getting their PCBs manufactured and assembled in India by ILJIN electronics India Limited in Greater Noida. ILJIN is the PCB supplier from Korea which is acquired by Amber group in India. In order to reduce the defects, the epoxy coating of the PCB under fabrication process is improved and also SMPS IC spec is being upgraded to provide more safety to the circuit. Also the capacitor specification is changed to prevent it from bursting. In this project, I worked on performing all the tests that are carried out in R&D and QA which are required to approve the new localized PCB and on understanding concepts of PCB manufacturing and assembling by visiting PCB Fabrication plant at ILJIN electronics.

Washing machine Model PCB:

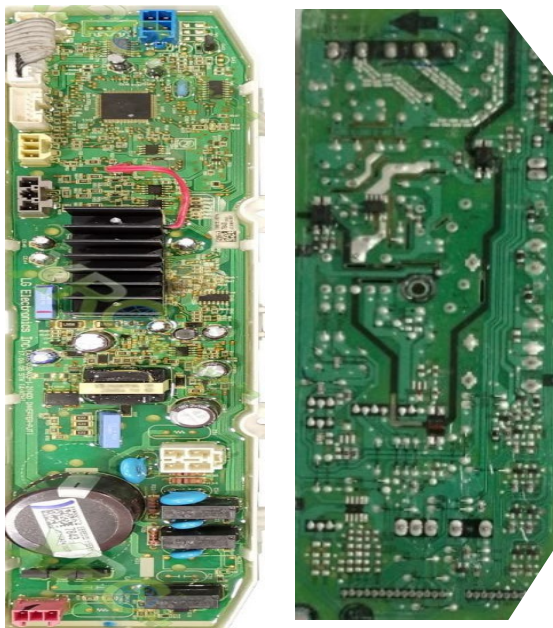


Figure 4.1: 1. PCB Front side with Pin through hole components

2. PCB Back side with Surface Mount Components

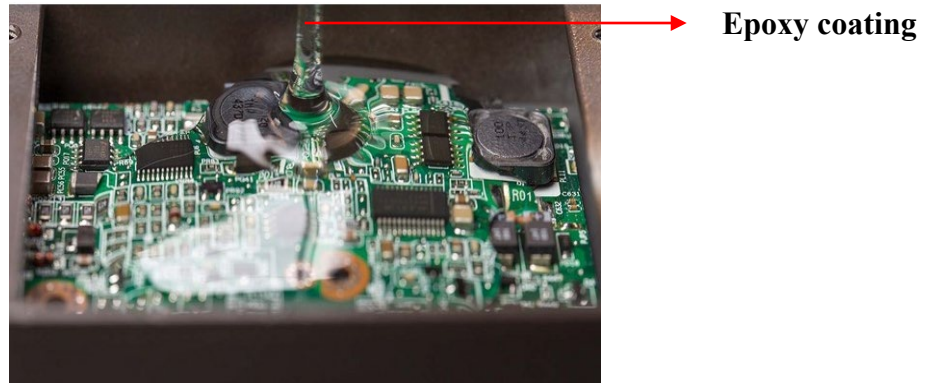


Figure 4.2: Epoxy coating



Figure 4.3: SMPS IC and DC link capacitor

Need for Localization:

- To reduce the overall cost of PCBs and their transportation time.
- To reduce the Inventory time of PCBs.

Epoxy Coating on PCBs:

Waterproofing method of a printed circuit board (hereinafter, abbreviated as PCB), and more particularly, to a waterproofing method using urethane varnish, epoxy resin, polyurethane. The washing machine is an electronic product closely related to water, and the place where it is installed is also mainly humid. Therefore, the PCB used in the washing machine (where PCB refers to assembled parts) should be completely waterproofed.

Therefore, as a method of waterproofing the PCB for electrical and electronic products close to water, such as a washing machine, urethane varnish, silicone rubber, hot melt type adhesive, epoxy resin, etc. are used.

First, in case of using varnish system, since thickness of waterproofing coating is about 40-100 μ . Although it is possible, bottom side of lead wire is sharp, and end of lead wire is sharp, so it is difficult to apply varnish, and even if it is applied, there is a bond that is easily peeled off. Thirdly, hot melt type adhesive has a problem of deteriorating electronic components because it needs to apply heat above 70-80 °C when PCB is bonded. Fourth, epoxy resin system is hard to break under impact due to its high hardness and also generates heat during drying. As a result, there was a defect in deteriorating electronic components.

SMPS IC:

SMPS is an electronic power supply system that makes use of a switching regulator to transfer electrical power effectively. It can increase or decrease the output voltage to maintain a constant output regardless of changes in load. switched-mode power supply (SMPS) converts power using switching devices that are turned on and off at high frequencies, and storage components such as inductors or capacitors to supply power when the switching device is in its non-conduction state.

Capacitor: A DC link electrolytic capacitor is placed in parallel with the input to minimize the effects of voltage variations as the load changes. The DC link capacitor also provides a low-impedance path for ripple currents generated by power switching circuits.

4.2) PCB Manufacturing:

Comprehending the concepts of PCB Manufacturing would help us analyse failures in field PCBs and also to make the better value innovation of the PCB. The process of Construction of our board design is known as PCB Manufacturing.

Manufacturing: Two-step process are involved in manufacturing. One is bare board fabrication and the other is PCB Assembling. Here in Fabrication process, the virtual circuit board is converted into real one. Whereas, in PCB assembling process, Electronic components are mounted onto their respective slots on bare boards.

4.2.1) Fabrication process of PCB board:

In this procedure, the virtual circuit board design is transformed into a real physical structure depending upon the specifications given in the design package. This physical structure is obtained by performing following techniques:

Image transfer: In this step, the desired PCB layout is imaged on to the Copper clad laminates. The film which depicts the traces and pads of the board's design is imaged on to the copper laminate with a photo resist layer while exposing it to a high intensity ultraviolet light source coming through the film.

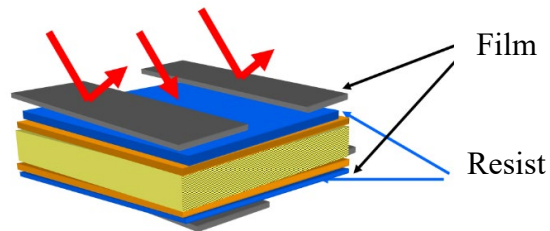


Figure 4.4: Photo resist film

Etching: The etching is nothing but eliminating extra copper from inner layers to disclose traces on pads. This step is used to create copper traces on the PCB by removing excess copper from the copper laminate, only leaving the required circuit on it.

Layer Alignment and Optical Inspection: To ensure all the layers are lined up, these have to undergo alignment punches. Using Optical punch machine, registration holes are punched to align the inner layers to the outer ones.

Layer-up and Bond: In this process, all the layers are stacked up. The layer-up and bonding are the two steps involved in this process. The outer layer is made of panes of fibre glass, epoxy resin is used to pre-impregnate the layers.

Drilling: In this step small holes are drilled into the layered board. These Small holes plated with metal are used to conduct electrical signals, power, and ground through the board layers.

Plating and Copper Deposition: After the drilling, the layer stacked up board comes for plating process. In this process, the drilled hole is filled with a copper in order to provide a path for the electricity. The copper is deposited in the previously drilled holes.

Final Etching: Unwanted copper deposit remains formed during plating process undergo removal. Whereas, the desired copper is protected by tin during this stage. Excess copper is removed by chemical solution applied on the panel. Valued copper is protected by tin deposits on the panel thereby establishing conducting paths and all connections precisely.

Solder Mask Application: In this process, transparent material called as epoxy which acts as a solder mask, will apply on the boards. This material protects board from dust and moisture.

Silkscreen: The panel is provided with an ink-jet writing on its top and bottom surface. These writings are used to indicate all the important information like PCB components, logos, symbols and other vital markings related to the PCB.



Figure 4.5 : Markings on PCB after silk screen print

4.2.2) PCB ASSEMBLY:

In PCB Assembling process, the electronics components required by the circuit will be mounted onto the bare board. The copper traces on the board will provide the electrical connection between components. The basic technologies used in the PCB assembling process which are as follows:

- **Through-Hole Mount Technology:**

This type of technology is used for mounting electronic components on to the PCB. As components inserted through holes that are drilled on bare boards, they are called as “through-hole components”. Using molten metal solder, the component leads are attached to the pads on other side of the bare board with wave or reflow soldering equipment. These Electronic components are mounted either radially or axially depending upon the space constraints.

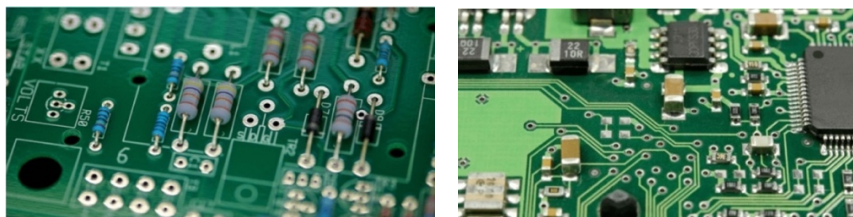


Figure 4.6 : THD mounting and Surface mount components

- **Surface Mounting Technology:**

This type of technology is used for mounting electronic components known as Surface Mount components which are directly mounted on the surface of the bare boards with solder. Surface Mount component (SMT) is tinier than PTH component because Surface mount components have smaller leads than PTH components.

4.3) DMAIC Six Sigma Approach

To increase efficiency and improve quality of performance, many top firms are utilising lean tools and approaches. Utilizing Six Sigma is one of the popular performance improvement strategies. Six Sigma initiatives are geared towards the reduction of inefficiency and non-valuable added activities (NVA) and optimising customer satisfaction. On the shop floor, economic benefits and improved quality could be realised using the DMAIC Six Sigma methodology. The phases of the DMAIC technique are define, measure, analyse, improve, and control. The Six Sigma DMAIC method is an incremental improvement system for processes that are currently performing below expectations. Although the DMAIC model approach is a structured problem-solving tool, the technique is now prominent for even more various tasks, including improving quality, productivity improvements, reducing costs, and other pursuits in operations management. In addition to manufacturing, other types of operations such as services, healthcare, and others also use this method.

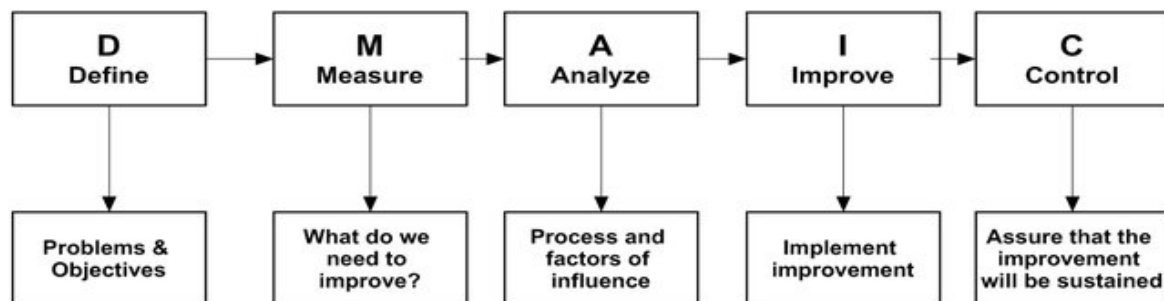


Figure 4.7 : Six sigma DMAIC methodology

Design Improvisation:

There are three improvements done in order to reduce the failures in the PCB as stated below:

- 1) SMPS IC upgradation 650 V → 800 V and is without heat sink.
- 2) Electrolytic DC Link capacitor changed from MEC CON 450 V, 220 μ F → SAMHWA 460V, 220 μ F.

4.4) SMPC IC optimization in PCB of all models of washing machine:

Define Phase (Identify the problem):

This one was decided to make improvements to the printed circuit board that has the most defects in washing machines. The project's primary objective was to minimize FFR the lowest as suspected in 2022 is 0.21%, FFR is improved from 2020 is 7%↓ and in 2021 is 16% ↓ from the previous years.

Tool: Top Loading Washing Machine PCB dead

Manufacturer: SANKEN ELECTRIC CO., LTD

Bad origin: Field

Issues: PCB dead/burst or no work at high voltage areas; SMPS IC defect.

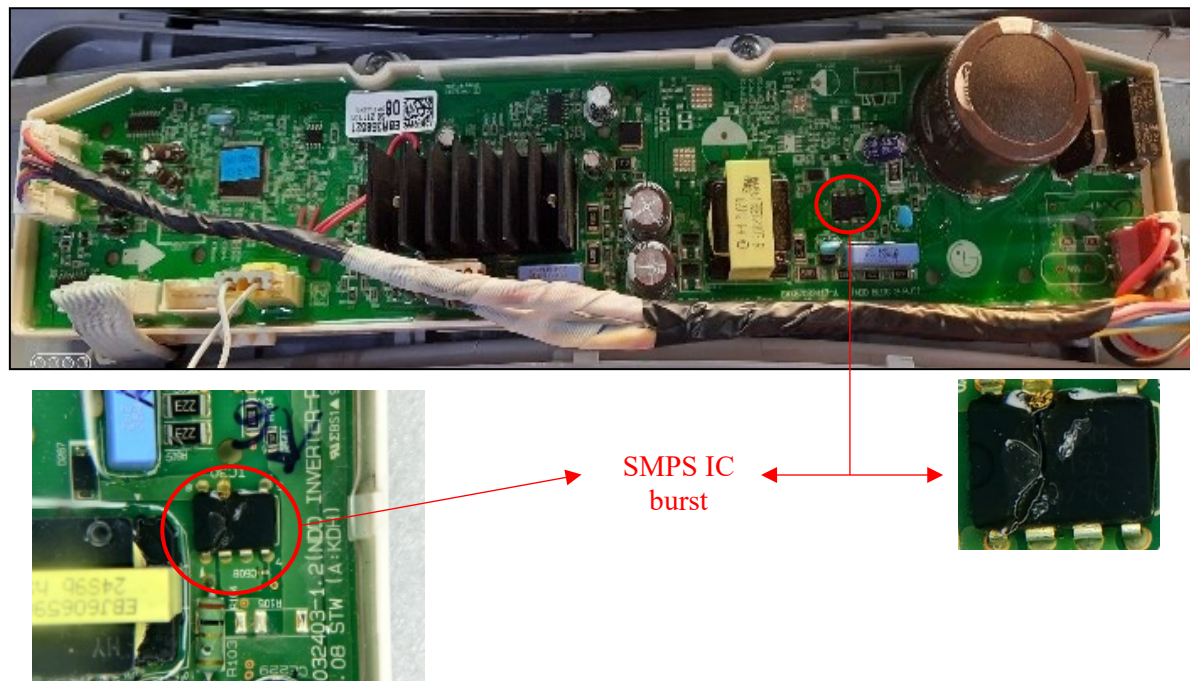


Figure 4.8: SMPS IC Burst Main PCB Side

SMPS IC: The switched-mode power supply (SMPS) transforms electricity by using switching components that are switched on and off at higher frequency, as well as storage elements like inductor and capacitor to supply power whenever the switching component is in its non-conduction state. A MOSFET as well as a current mode PWM controller IC are both included in SMPS Power ICs, which are used in switching power supplies. By automatically transitioning between burst-oscillation under low load situations and PWM operation during normal operation, the minimal standby power is achieved.

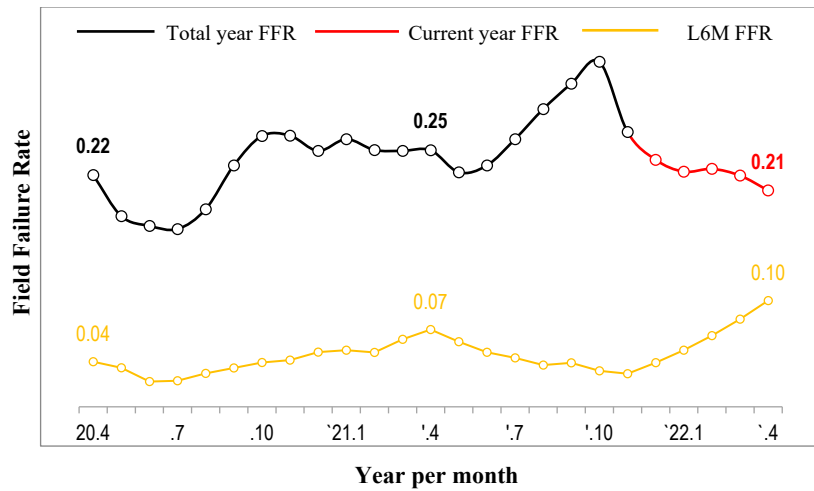


Figure 4.9: FFR Trend

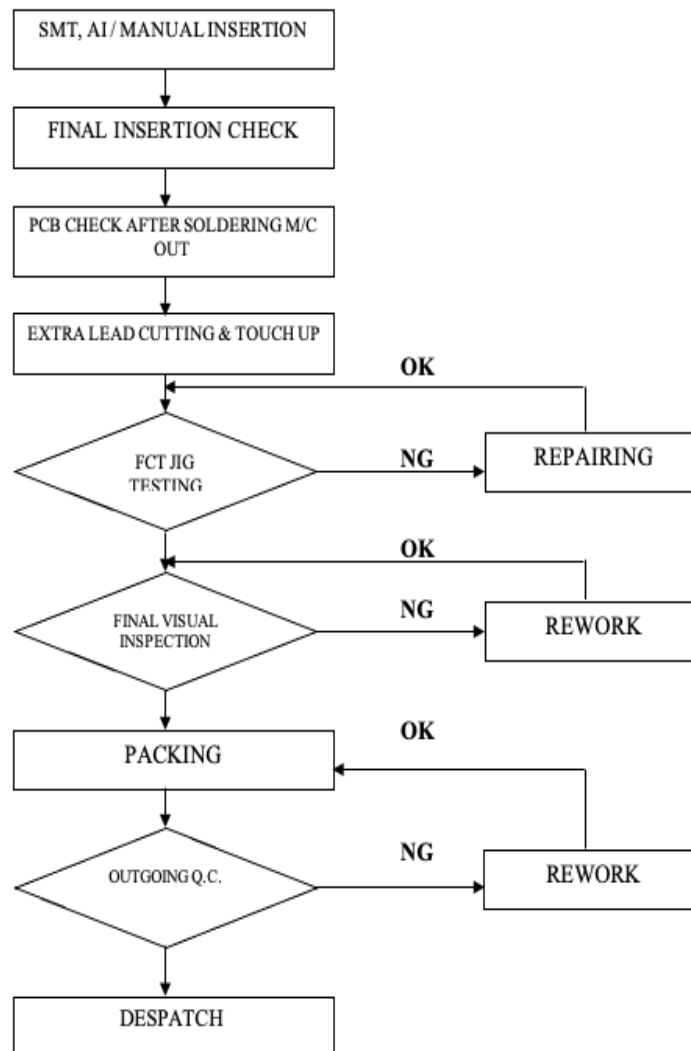


Figure 4.10: PCB manufacturing process flow diagram

Measure Phase:

By using Visual Inspection Report, this phase analyses the PCB manufacturing process's performance during the previous months. Figure 4.11 displays the overall trend chart that was created.

Field Return	Total	Portion
Total	126	100%
Dead/ Burnt	45	36%
NDF	59	47%
LED Issue (Driver IC)	6	5%
Others	16	13%

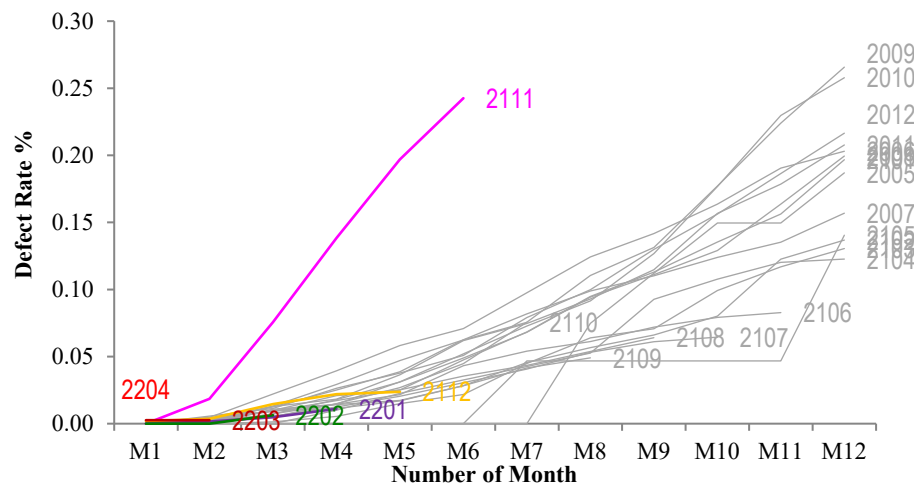


Figure 4.11: Graph of Overall Open defect

Analyse Phase:

Before the primary MOSFET controller IC with Drain-to-Source Breakdown Voltage V_{DS} is 650 V, On Resistance $R_{DS(ON)}$ of 2.8Ω , Average Switching Frequency 67 kHz with maximum switching current 7.0 A. Now the new SMPS IC is used 2 chip structure MOSFET controller which has Drain-to-Source Breakdown Voltage 800 V, On Resistance $R_{DS(ON)}$ of 1.7Ω (reduced thermal resistance compared to previous SMPS is advantageous), Average Switching Frequency 100 kHz (improved efficiency) and Drain Peak Current 5.8 A (trans saturation is 5A and OCP is 3.4 max.). By the use of the 800 V SMPS 8-pin IC will lead to the following advantages such as:

- 1) Better protection in normal operation.
- 2) Better surge protection.
- 3) Automatic Standby Function No Load Power Consumption < 15 mW.
- 4) Enhancing circuit effectiveness (The circuit efficiency is increased by a small amount because the step output control can keep VRM of auxiliary rectification diodes low).
- 5) Overvoltage Protection, Overload Protection, and Overcurrent Protection .

AS IS



TO BE



Figure 4.12: Before and After SMPS IC

NEW SMPS IC DESCRIPTION:

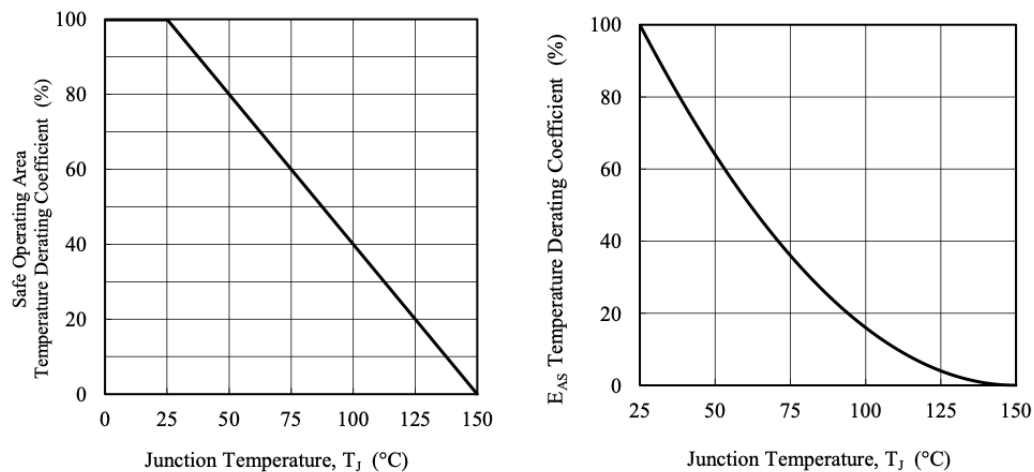


Figure 4.13: Temperature curve and Avalanche energy curve

Structure of New SMPS IC:

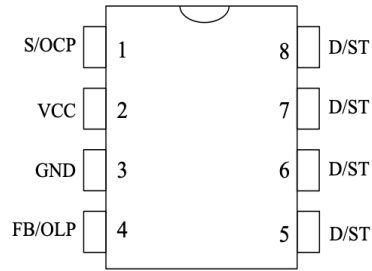


Figure 4.14: Pin Configuration of 800 V SMPS IC

1. S/OCP: Overcurrent Protection (OCP) signal input and power MOSFET source.
2. VCC: Input of overvoltage protection signal & power supply voltage for control component.
3. GND: Ground
4. FB/OLP: inputs for the overload protection signal and the consistent voltage control signal.
5. D/ST: Start-up current input and drain for power MOSFETs. To improve thermal dissipation, the PCB connections D/ST pins must be as diverse as possible.

A clamp snubber circuit made of capacitor-resistor-diode (CRD) pairing should be added on primary winding P in applications where power supply is designed so that V_{DS} experiences high transient surge voltages. Alternatively, damper snubber circuit made of capacitor (C) or resistor-capacitor (RC) integration should be incorporated between D/ST pin and S/OCP pin.

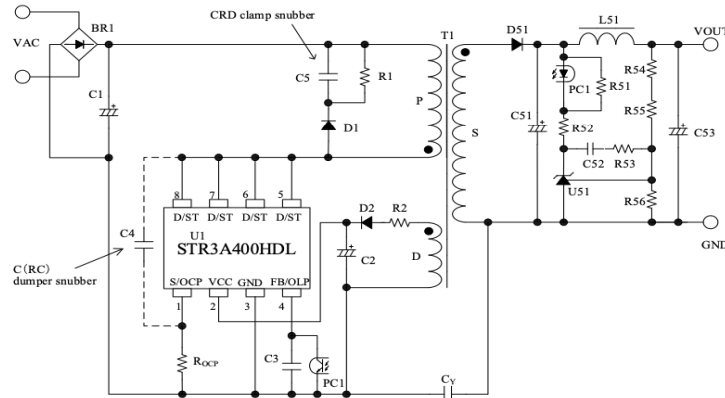


Figure 4.15: Connecting SMPS IC in the PCB

The IC uses the current-mode control techniques to control the power supply output at a constant voltage, which improves response time and ensures steady operation. At the feedback control, the slope correction is internally added to the FB/OLP pin output to produce the goal voltage, or VSC. By using an internal FB comparator, the IC contrasts the voltage of a current detecting resistor, VROCP, with the target level, VSC, and adjusts the maximum level of VROCP such that it approaches VSC.

Bare Board of the PCB:

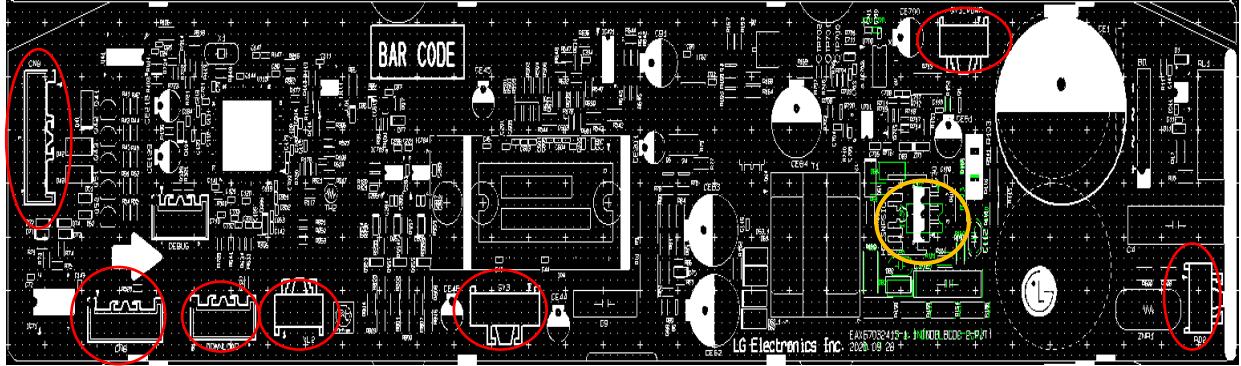


Figure 4.16: PCB board

- **Testing:**

Table 4: Different test performed on PCB with new SMPS IC

No.	Test Type	Test items	Detail	SMPS IC (800 V)
1	Power PCBA certification process	Abnormal Voltage test	2 kV, DC o/p 800 V or less, Varistor current 5A or less	670 V, 0.70 A
				668 V, 0.90 A
				668 V, 0.90 A
				668 V, 0.90 A
2	Electrical Characteristics	Power consumption test	230 V / 50 Hz	Test results OK
3		Drive characteristics test	8.0 Kg load weight 0 V - 50 Hz to 165 V - 50 Hz	Machine (All Electrical/ Electronic Parts) is 150V, No issue observed, Test Result OK.
4		Variable voltage test	165 V, 265 V, 300 V; 50 Hz	No Abnormality Observed till 265V, Machine Operation OK at 300V
5		Spike test	450 V & 470 V / 50 Hz	No issue observed after software improvement LE error observed at 140 V only. M/c OK at 150 V 216 Spike at 450V & 470 V, No issue observed

6	Basic characteristic	Load sensing Test	244 V / 50 Hz	Overall Sensing Rate is 100 % Display Time OK as per Design Standard	
			230 V / 50 Hz		
			216 V / 50 Hz		
7		Spin-drying unbalance test	Marble Front incline, Ceramic Tile Flat floor, Terrazzo Back incline (8.0 Kg of 80%, 6.4 Kg practical load), (8.0 Kg of 50%, 4.0 Kg practical load), (8.0 Kg of 30%, 2.4 Kg practical load)	2 mm 4 mm 2 mm	
				0 mm 0 mm 0 mm	
				0 mm 0 mm 0 mm	
8		Reliability	THB (Thermal Humidity Bias) test	Apply the rated voltage to a thermo-hygrostat with a temp. of 85±5°C and a relative humidity of 85±5%. After applying and leaving it for 500 hours continuously, at room temperature and humidity. After leaving for 2 hours, test the operation.	No abnormality observed
9			Thermal Shock test	[Indoor] 300 consecutive cycles of -40°C, 30min leave, 85°C, 30min leave [Outdoor] 300 consecutive cycles of -45°C 30 minutes, 125°C 30 minutes Repeat for 300 cycles	No abnormality observed
10			HALT test	Cold step	-30 deg. C > -40 deg. C
				Hot step	130 deg. C > 140 deg. C
	Rapid thermal transition			Test good	
	Random vibration			Test good	
	Combined environment			Test good	
11	Normal	ICT/FCT	ICT	Pass	
			FCT	Pass	
12	ECO	XRF	No Toxic substances	OK	

- **Power-PCBA Abnormal voltage test:**

Purpose of the test: Evaluating the tolerance of power AC/DC conversion part due to abnormal overvoltage / noise following power disturbance and repeated inflow of lightning in countries with unstable power sources such as India.

Test method:

- Abnormal voltage waveform applied by connecting PCBA to Abnormal Simulator
- Abnormal waveform: Triangle wave (Shape), 400 μ s (Peak Duration)
- After selecting the relevant waveform in the UPC program installed in the Simulator PC, proceed with the test

Test conditions: Test quantity taken Power PCBA 4EA; Applied Abnormal Voltage: 2.0kV; Number of applied cycles: 20 cycles. Application method: Normal voltage for 9 seconds, Abnormal voltage for 1 second per cycle

Judgment Criteria: After the test is completed, there should be no damage to parts and no abnormalities in appearance. (However, in the case of DC Cap. Swelling, the electrical performance spec is determined after sending to the parts maker). DC Output Measurement Voltage: 800V or less; Varistor measurement current: 5A or less. After the abnormal test, there should be no abnormal operation after verifying the SET Status connection function.

Observations:

Table 5: Power-PCBA Abnormal voltage test results

PCB number	DC Cap Type	DC-voltage (Max) when 20C is applied	VAR current (A) when 20C is applied	Special features after 20 Cycles
Samhwa HW 500V/ 220uF India	HW/Samhwa	670	0.70	DC Cap very hot and micro-inflated Var no current flow
Samhwa HW 500V/ 220uF India	HW/Samhwa	668	0.90	DC Cap very hot and micro-inflated Var no current flow
Samhwa HW 500V/ 220uF India	HW/Samhwa	668	0.90	DC Cap very hot and micro-inflated Var no current flow
Samhwa HW 500V/ 220uF India	HW/Samhwa	668	0.90	DC Cap very hot and micro-inflated Var no current flow

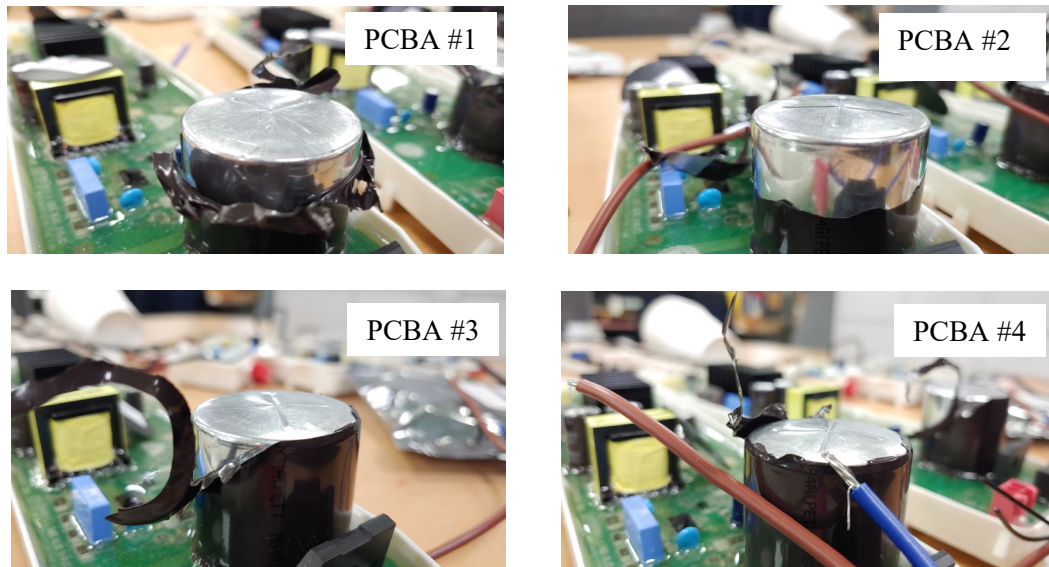


Figure 4.17: Electrolytic Cap Swelling

- **Power Consumption Test**

Purpose of the test: Verification of power consumption fluctuations due to SMPS change

Test method:

- Apply rated voltage & rated frequency after input the test load
- Operation 1 Cycle by default (Std) Course
- Check Power Consumption for Each Pattern
- While spinning, check rpm when maximum rpm's power consume is fixed at same level.

Judgement Criteria: Worst data of average by sample must be within Product Standard; Wash

Power < 230W+15, Spin Power < 140W+15% and Standby power consumption < 0.5W

Observations:

Table 6: Power Consumption Test Results

Rate Test	Division			STD (RMS)	#1	#2	#3	Avg	Judgment	
230V 50Hz	Washing	Max	W	Ref.	398.00	389.00	401.00	396.00	-	
			A	Ref.	2.88	2.84	3.05	2.92	-	
		Running	W	264.5	76.96	79.70	77.07	77.91	OK	
			A	1.84	0.72	0.73	0.72	0.72	OK	
	Spinning	Max	W	Ref.	129.00	109.00	127.00	121.67	-	
			A	Ref.	1.22	1.11	1.20	1.18	-	
		Running	W	161	66.41	55.35	62.36	61.37	OK	
			A	1.15	0.76	0.62	0.72	0.70	OK	
	Standby (Off Mode)			W	< 0.5	0.3	0.3	0.3	0.3	OK
	Total W Hr			W Hr		59.42	56.85	58.79	58.35	

- **Drive Characteristic Test**

Test purpose: Verification of change in manoeuvring characteristics as per SMPS change.

Test method:

1. Test condition specified in normal temperature test; DC Water supply valve's water Pressure should be 5kg.f/cm². warm water valve should supply warm water with temperature of 65±5°C. Every load should be in ON mode.

2. Raise C.V.C. F's power gradually from 0 V and check starting voltage of each electronic parts. Within range of measured starting voltages, check starting voltage of every electronic part by directly apply voltages. Record minimum starting voltage by directly apply voltages.

Judgement Criteria: Should start with less than 85% of voltage rating.

Observations: Minimum Staring Voltage: Motor: 150V, Drain motor: 100V, Inlet Valve: 80 V, PCB: 80V. PCB Display Starts at 80V. The spin starting RPM at 75% rated voltage: (Sample 1 - 740 RPM & Sample 2 - 740RPM).

Table 7 : Results Drive Characteristics Test

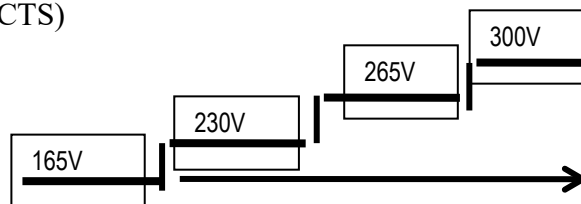
Check point	Clutch Pulley RPM (Spec- Min 660 rpm)		Drain Motor (Drain Operation OK)		Inlet Valve (Water Supply on at 2.5 kgf/cm ²)		PCB (Display On)		Result		
	Voltage	Sample1	Sample2	Sample1	Sample2	Sample1	Sample2	Sample1		Sample2	
Load Weight (8.0Kg)	165	740	740	On	On	On	On	On	On	Machine Operation OK at 150 V	
	160	740	740	On	On	On	On	On	On		
	150	740	740	On	On	On	On	On	On		
	140	LE ERROR		On	On	On	On	On	On	All Parts not Functioning till 140V	
	130	LE ERROR		On	On	On	On	On	On		
	120	LE ERROR		On	On	On	On	On	On		
	110	LE ERROR		On	On	On	On	On	On		
	100	LE ERROR		On	On	On	On	On	On		
	90	LE ERROR		On	On	On	On	On	On		
	80	LE ERROR		On	On	On	On	On	On		
	70	Off		Off	Off	Off	Off	Off	Off		PCB Display not On till 70V
	60	LE ERROR		Off	Off	Off	Off	Off	Off		
	50	LE ERROR		Off	Off	Off	Off	Off	Off		
	40	LE ERROR		Off	Off	Off	Off	Off	Off		
	30	LE ERROR		Off	Off	Off	Off	Off	Off		
	20	LE ERROR		Off	Off	Off	Off	Off	Off		
	10	LE ERROR		Off	Off	Off	Off	Off	Off		
	0	LE ERROR		Off	Off	Off	Off	Off	Off		

- **Variable Voltage Test**

Test purpose: Electrical characteristic verification according to SMPS change.

Test method:

- Put Test cloth in the machine uniformly on the (Periphery of the drum of rated capacity)
- Run machine at -25% rated voltage for 3 cycles, (Rated 03 Cycle, +15% voltage 3 cycles)
- After that run 03 cycle at 300V (ICTS)



Judgement Criteria:

Low Voltage : No Locking for > 5 Sec & no TP Operation during 3 cycles. High Voltage: No TP Operation for 3 cycles Operation. Machine Movement < 35 mm (3 Cycles)

Observations:

No Abnormality Observed till 265V, Machine Operation OK at 300V

Table 8 : Results of Leakage Current, Withstand Voltage & IR Test

Test Parameter	Sample -1	Sample-2	Result
HV	No Breakdown	No Breakdown	OK
IR	7.0 G Ω	6.53 G Ω	OK
Leakage Current	0.096	0.088	OK
M/C Movement	07 mm	10 mm	OK

- **Spike Test (ICTS)**

Test purpose: Electrical stability verification according to SMPS change.

Test method: Run Machine at 165 V for 1 Hr, 220V for 4 Hrs & 300V for 1 Hr. before conducting Spike Test. Run the machine with 220V for 5 Min and apply a spike of 450V for 1 Sec, repeat this 216 times i.e., apply 216 spikes at 5 Min interval.

Judgment criteria: No abnormality Required & all Electrical Parts should work OK. No malfunctioning required.

Observations: No issue observed after Software improvement. LE Error observed at 140 V only. Machine OK at 150 V (Refer Drive Characteristics Test). 216 Spike at 450V/50Hz & 216 Spike at 470V/50Hz.

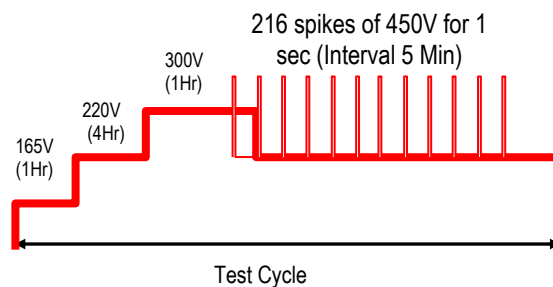


Figure 4.18: Spike Tester

- **ICT / FCT:**

As an illustration of white box testing, in-circuit testing (ICT) involves examining populated printed circuit boards (PCBs) with an electrical probe to look for sparks, opens, resistance, capacitance, as well as other fundamental values that indicate whether assembly was correctly built. It can be carried out either using a fixtureless in-circuit test configuration or a "bed of nails" inspection fixture and specialized testing tools. A bed-of-nails tester is a typical tool for in-circuit testing. This fixture made up of variety of "pogo pins," which are spring-loaded pins. The pins on printed circuit board can be utilized as sample points for in-circuit testing when they establish electrical contact with spots on board whenever printed circuit board is connected with and forced down onto bed-of-nails tester. Bed-of-nails testers do have benefit of allowing multiple tests to be run simultaneously, but they also put lot of strain on the PCB.

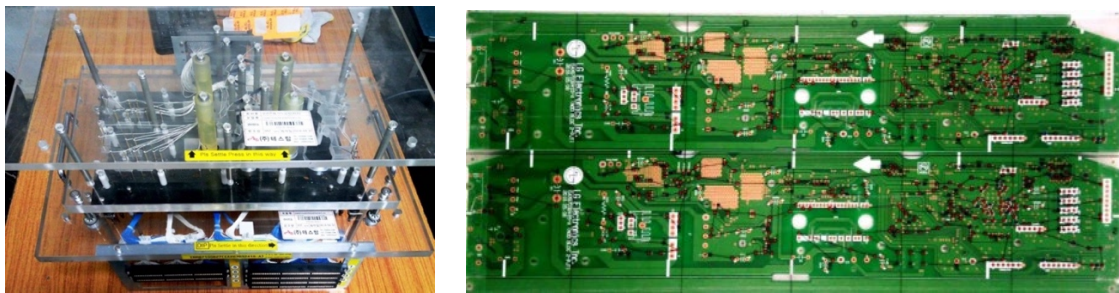


Figure 4.19: ICT Fixture and Map pin



Figure 4.20: ICT Monitor pass rate and ICT Pass rate

FCT Fixture:

FCT is a functional test fixture, mainly for testing function of the product. Its main test object is PCBA circuit board. PCBA needs to test its various performances through different fixtures. The FCT test fixture is mainly for PCBA. After the power is turned on, tests are performed on components like voltages, current, energy, power factor, frequencies, duty cycle, brightness, and color as well as FLASH and EEPROM programming, character and speech recognition, pressure and temperature measurement, motion control, and power-on tests.

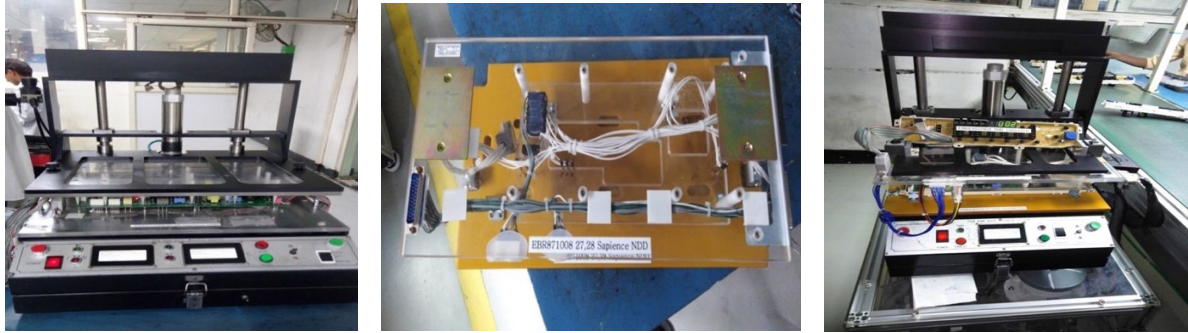


Figure 4.21: FCT Fixture, Auto FCT (Line) and Final Final FCT Fixture

Results: New SMPS IC withstands voltage of 800 V has passed all the above performed tests, and will replace 650 V SMPS IC with heat sink in all top load washing machine models.

Improvement phase:

Detection enhancement (ILO): In Supplier Quality Assurance department, the following improvements have been done:

Part Reliability Sample Size Increased

Spike Test: $N = 3 \rightarrow N = 5$, Thermal Shock Test: $N = 3 \rightarrow N = 5$, THB Test: $N = 3 \rightarrow N = 5$.

Line quality check the below points are added for enhancement of the PCB:

100% function check: DE Error, PCB dead and Wiring Issues Inspection & Monitoring add.

Process Improvement:

1. Supplier are using panel for switch testing.

Impact- Switch hard and not work issue resolved in all models.

2. Added a system with software to check the PCB assembly is Passed by ICT and FCT.

Impact- Without function testing, PCBA not pass from Line.

3. Now added a system at LQC stage at WMC line for checking repair count and checking 100% repair count at LQC stage.

Control Phase:

We must make sure that the effective action plan is implemented completely throughout this period. To ensure that gains are maintained, controls must be set up to monitor the system. OPL is a straightforward practical tool used to train employees in a firm to help elevate the standard of the delivered goods and services. The primary goal of OPL is to ensure that all operators and shifts perform at a consistent level of quality. To serve as a manual for the operators, detailed working procedures will be provided. This is essential since it will get rid of certain bad manufacturing processes and add some new steps or procedures.

Operators who are more acquainted to the previous process steps may take some time to completely understand the new modifications. A control strategy was also offered to use statistical methods to track the performance over time. This is done to keep an eye on the new process's stability.

4.5) SAMWHA Electrolytic Capacitor optimization in PCB of Sapience 10.0 Kg 23 inch Jet Spray BEE 5 Star non pump DC drain motor Top Loading Washing Machine:

Define Phase: The PCB has the highest number of defect in washing machine and hence it was chosen for improvement as PCB is the brain of the washing machine. Another aim of the project is to optimize the core part of the PCB which is electrolytic capacitor to reduce the FFR to the lowest as suspected in 2022 is 0.21%, the FFR is improved from 2020 is 7% ↓ and in 2021 is 16% ↓ from the previous years.

Tool: Top Loading BLDC

Manufacturer: MEC CON

Bad Origin: Field

Failure phenomenon: DC Link Capacitor Swelling, no power due to PCB component burnout and no Water Inlet (Diode D42 SMT Process Defect)

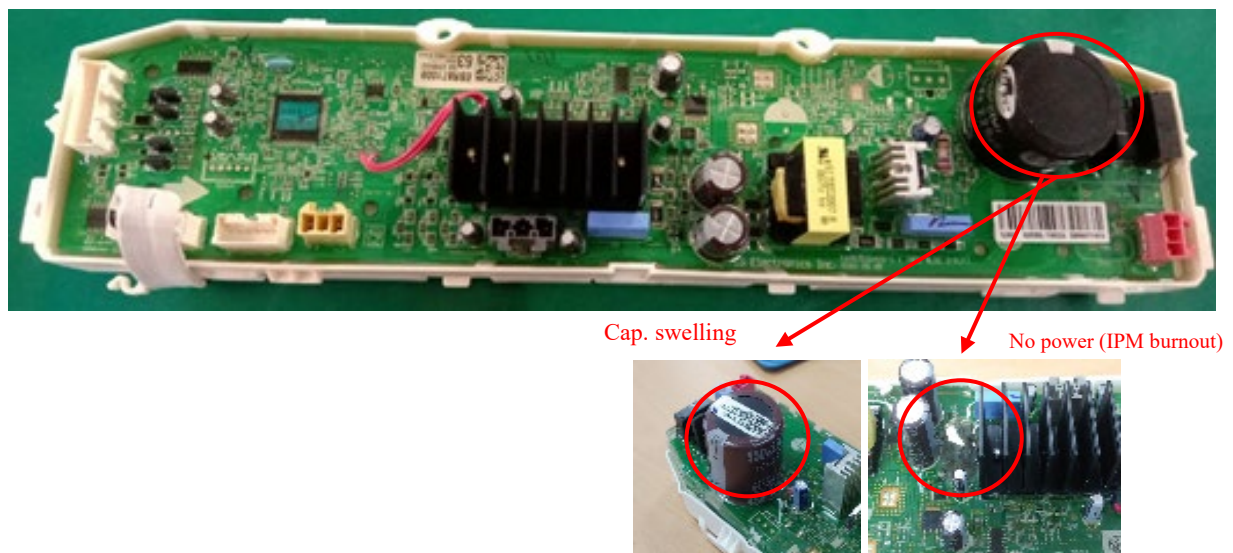


Figure 4.22: DC Link Capacitor Burst

Analysis of the mechanism of occurrence:

- 1) IPM burnout (check overvoltage burnout type)
- 2) DC Link Capacitor + Foil joint corrosion check (Foil precipitation and increased erosion causes etching of the tap surface and monorail and disconnection is not caused by external foreign matter (salt)).



Figure 4.23: Disassembled photo of field defect capacitor

Causes:

- Assembly Capacitor due to process delay
Reproduction of defects before assembly (humidity 65~75%, room temperature condition) left unattended and load applied.
- Capacitor Foil joint open → IPM burnout
Condition: Capacitor Foiled Defective joint sample → Cycle verification (DC Link voltage measurement). Reproducibility: Moisture content of 9% or more Confirmation of reproduction of the same shape as the defect under the conditions.

Table 9: Comparison between electrolytic capacitors

Item	MEC 450V	Samhwa 460V	Samhwa 500V
Rated Voltage	450VDC	460VDC	500VDC
Surge Voltage	500VDC	500VDC	550VDC
Capacitance	220 μ F	220 μ F	220 μ F
Leakage Current	1980 μ A	944 μ A	995 μ A
Dissipation Factor	0.2	0.2	0.2
Rated Ripple Current	1.12 A(rms)	1.3 A (rms)	1.26 A (rms)
Temperature Range	-25~ +105°C	-25~ +105°C	-25~ +105°C
Load Life	3000 hr	3000 hr	3000 hr
Foil pressure	690 V	690 V	780 V
Insulation voltage of electrolyte	900 V	850 V	850 V
Chemical voltage of electrolyte	530 V	510 V	510 V

Action to be taken: Improving and measures to prevent recurrence (Samhwa Securing supply and demand → Carrying out quantity changes).

Measure Phase:

L6M Field Return	Total	Portion
Total	49	100%
Dead/ Burnt	23	47%
NDF	15	31%
LED Issue (Driver IC)	2	4%
Others	8	16%

The issue occurred generally in overvoltage area; first issue was found out on 6 May 2021 after bad catch in May recovery analysis; defect confirmation was done by June 2021. Total production quantity was 201,472 units (total mass production of MEC was 720K pieces) out of which 395 units was poor quantity with the defect rate of 1960 PPM.

Country	India	Vietnam	Indonesia	Total
Target quantity	338,012	3,616	13,801	355,429
Estimated Cap. error	203 cases	75 cases	91 cases	369 cases

Analyse Phase:

According to the test requirements, an evaluation is done on a number of PCBs that contain the new electrolytic capacitor. The procedure involves post-processing, dried film lamination, exposure, develop, and IPQC. We can determine the polluted processes from this evaluation. Visual inspection and IPQC are used in the procedure (In-Process- Quality-Control).

Table 10 shows the results of the evaluation of SAMWHA 460 V electrolytic capacitor.

No.	Test Type	Test items	Detail	Capacitor (460 V)
1	Product Reliability	High temp wash continuous test (2,000 Cycle)	Load 10 Kg, water level 10 Load 10 Kg, water level 9 Load 6 Kg, water level 7	OK (100%)
2		Normal Temp. PGM Continue (Load Sensing Defective)	1-7 water level continuous run 30C per water level	Target cycle 30, capacitance 188 μ F No issue observed.
3		Low Temp. Spin Continue (2,000 Cycle)	Load 0.8 kg (Lower UB)	Test results OK, Capacitance after test is 187 μ F.

4	Electrical Characteristics	Temperature rise (IEC) test	AL Capacitor Temperature rise should be < 85°C	Temp Rise OK. Max. Temp. observed 49.3 °C.
5		withstand voltage test	Operate 2 Cycles at Rated Voltage/ rated Frequency	Temp Rise OK. Max. Temp. observed 48.7 °C.
6		Spike Test	Run Machine at 165 V for 1 Hr, 230V, 50Hz for 4 Hrs & 300V for 1 Hr and with 220~230V, 50Hz for 5 min and apply a Spike of 470V for 1 sec, every 5 Min,	HV no breakdown; OK
				IR = 1000 MΩ; OK
				Leakage current = 0.185, 0.168; OK
				Test result OK. Testing continues till 648 Spikes no issue observed
				Minor Swelling observed on capacitor

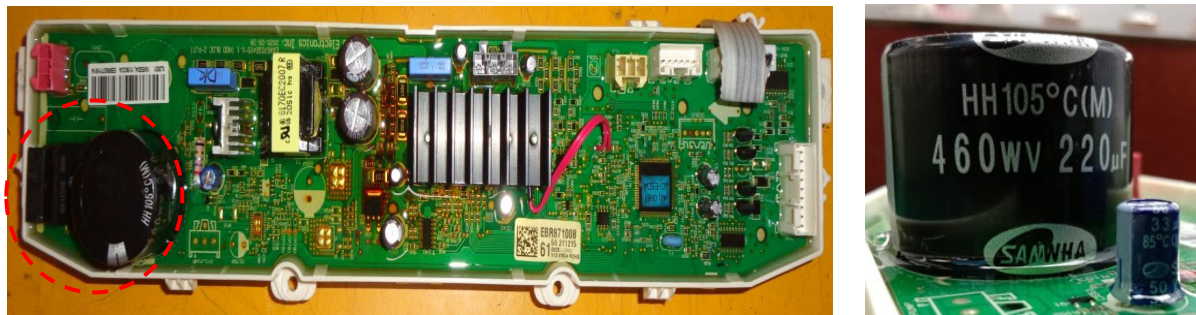


Figure 4.24: Samwha 460 V, 220 μF Capacitor

- **Temperature Rise Test (IEC)**

Purpose of test: PCBA FFR Improvement: DC Link Capacitor Improvement: Samwha 460V.

Test method:

1. Measure initial coil resistance of the motor windings.
2. Load 10.0 kg clothes in the machine 2.
3. Operate 3 consecutive cycles with 4 min pause between each Cycle.
4. Measure the Final Resistance of the windings after 3rd cycle completion.
5. Check Temp. Rise as per Standard for Motor & other Electrical parts.

Test Condition: Wash capacity 10.0 Kg, rated voltage 230 V, 50 Hz, test load as per BEE load, room temp $20 \pm 5^\circ\text{C}$ with water temp 35°C applied on 3 samples.

Judgement Criteria: AL Capacitor Temperature rise should be < 85°C (Direct Method, Thermocouple).

Observations:

Table 11: Temperature rise test results

S. No.	Component Name	Thermo Couple Temp Spec (°)	Temp Rise (°C) observations (DC Link Capacitor Improvement : Samwha 460V)												Max Temp	Results
			206.8V (220V-6%)						244V (230V+6%)							
			Sample#1		Sample#2		Sample#3		Sample#1		Sample#2		Sample#3			
			Initial	After	Initial	After	Initial	After	Initial	After	Initial	After	Initial	After		
1	Noise Filter	<85	23.2	31.2	23.0	37.9	22.9	32.5	22.5	30.5	22.7	35.5	22.3	30.9	37.9	OK
2	Capacitor CE1	<85	23.3	45.7	22.9	47.3	23.4	49.3	23.1	45.9	24.1	45.6	23.0	47.0	49.3	OK
3	IPM3	<95	23.3	68.5	23.1	71.6	23.3	76.2	23.3	71.2	23.4	72.8	22.9	74.9	76.2	OK
4	IPM4	<95	23.3	68.1	22.8	72.0	23.5	77.7	23.0	70.2	23.2	73.1	23.0	76.3	77.7	OK
5	SMPS Trans.	<85	22.0	77.5	23.1	54.3	23.2	54.9	23.2	53.4	23.7	54.0	23.1	53.5	77.5	OK
6	B-Diode1	<90	23.5	62.8	23.0	65.8	23.3	69.0	23.0	60.7	24.0	61.3	22.9	62.2	69.0	OK
7	Capacitor CE62	<95	23.3	58.3	23.0	66.0	23.5	62.9	23.1	58.8	23.6	59.5	23.1	60.5	66.0	OK
8	Box Capacitor	<90	23.2	66.3	23.1	65.9	23.4	66.8	23.0	60.6	23.3	64.0	22.9	65.4	66.8	OK
9	Ambient	23±2	22.7	22.7	22.7	22.7	22.7	22.7	22.7	23.1	22.7	23.1	22.7	23.1	23.1	OK

Table 12: Temperature Rise values at 244V and 207V

Sample	Run	Wire	R1	R2	t1	t2	Temp Rise
			Ω	Ω	C	C	Degree
1	Spin3	B-R	13.9	16.3	22.7	22.9	42.57
		B-Y	13.9	16.2	22.7	22.9	40.79
		R-Y	13.8	16.2	22.7	22.9	42.88
2	Spin3	B-R	14	16	22.7	22.9	35.19
		B-Y	13.9	16.3	22.7	22.9	42.57
		R-Y	13.9	16	22.7	22.9	37.22
3	Spin3	B-R	14	17	22.7	22.9	52.88
		B-Y	14	16.8	22.7	22.9	49.34
		R-Y	13.9	16.6	22.7	22.9	47.91

Sample	Run	Wire	R1	R2	t1	t2	Temp Rise
			Ω	Ω	C	C	Degree
1	Spin3	B-R	13.8	15.5	22.9	23.6	29.84
		B-Y	13.8	15.3	22.9	23.6	26.25
		R-Y	13.6	15.6	22.9	23.6	35.76
2	Spin3	B-R	14	15.5	22.9	23.6	25.86
		B-Y	13.8	15.4	22.9	23.6	28.04
		R-Y	13.9	15.8	22.9	23.6	33.19
3	Spin3	B-R	13.9	16.8	22.9	23.6	51.02
		B-Y	14	16.6	22.9	23.6	45.34
		R-Y	13.9	16.5	22.9	23.6	45.67

Table 13: Capacitance measured after test

Test Sample	Capacitance After test
1	222 μF
2	223 μF
3	222 μF

Temp Rise OK. Maximum Temp Rise observed 52.88°C.

- Withstanding Voltage Test**

Purpose of test: To demonstrate that the PCB can resist transient voltage spikes caused by switching, surges, and other related events while operating safely at its rated voltage.

Test method: Operate 2 Cycles at Rated Voltage/ rated Frequency. Keep Test Samples at Room Temp. for 1 hr. After that, operate 1 cycle at 125% of rated Voltage. (Normal Course) & Check Leakage Current, HV/ IR.



Figure 4.25: Test setup of withstand voltage test

Judgement Criteria: Leakage current < 0.45 mA, IR $\geq 10 \text{ M } \Omega$, HV - No break down at 1,500V/1Min, 5 mA) & Double insulation panel: Must withstand 3,750V / 1 min No Coil Short & Heating of Components.

Observations:

Table 14: Results of Voltage Withstand Test

Test Parameter	Sample -1	Sample-2	Result
HV	No Breakdown	No Breakdown	OK
IR	1000 M Ω	1000 M Ω	OK
Leakage Current	0.185	0.168	OK

- Spike Test (ICTS)**

Purpose of test: To determine the behaviour of a software application when it receives extreme variations in traffic that receives a sudden and extreme increase or decrease in load.

Test method: Run Machine at 165 V for 1 Hr, 230V, 50Hz for 4 Hrs & 300V for 1 Hr before conducting Spike Test. Run machine 220~230V, 50Hz for 5 min & apply Spike of 470V for 1 sec, every 5 Min. Repeat cycles for 216 times. Check during Spike Test & After Spike Test.

Judgement criteria: No abnormality Required & all Electrical Parts should work OK and No Malfunctioning required.

Observations:

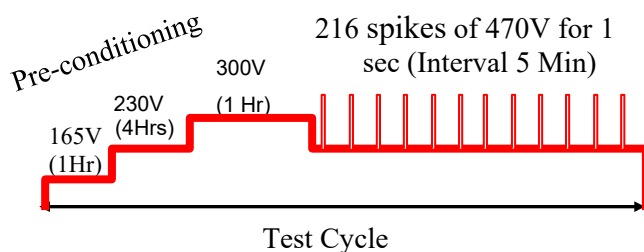




Figure 4.26: Test setup for Spike Tester

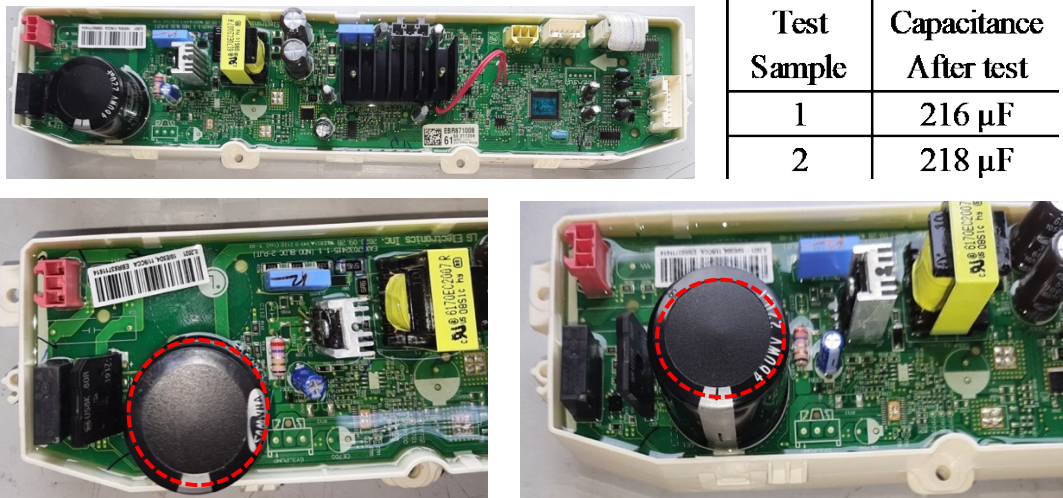


Figure 4.27: Results of Spike Test

Test result OK. Testing continues till 648 Spikes no issue observed. (Minor Swelling observed on the capacitor).

Improvement Phase:

Samhwa Electrolytic Capacitor withstand voltage 460V, Aging Voltage 520V selected. Samhwa 460V & Aging 520V has higher abnormal resistance than the existing MEC 450V.

- Samhwa Aging 520V has higher abnormal resistance.
- Samhwa 460V Electrolytic Cap Spike Test Criteria OK.

Samhwa Electrolytic Capacitor Aging Voltage 520V Prior Review Spec Selection.

1) Overvoltage Area Abnormal Test

Test method: 2.0kV Abnormal overvoltage application (20 Cycles).

Judgment criteria: After completion of the test, there should be no damage to parts or abnormalities in appearance (however, in the case of DC cap swelling, the electric performance spec. DC Output measurement voltage 800V or less. After the abnormal test, there should be no abnormal operation after verifying the set state connection function.

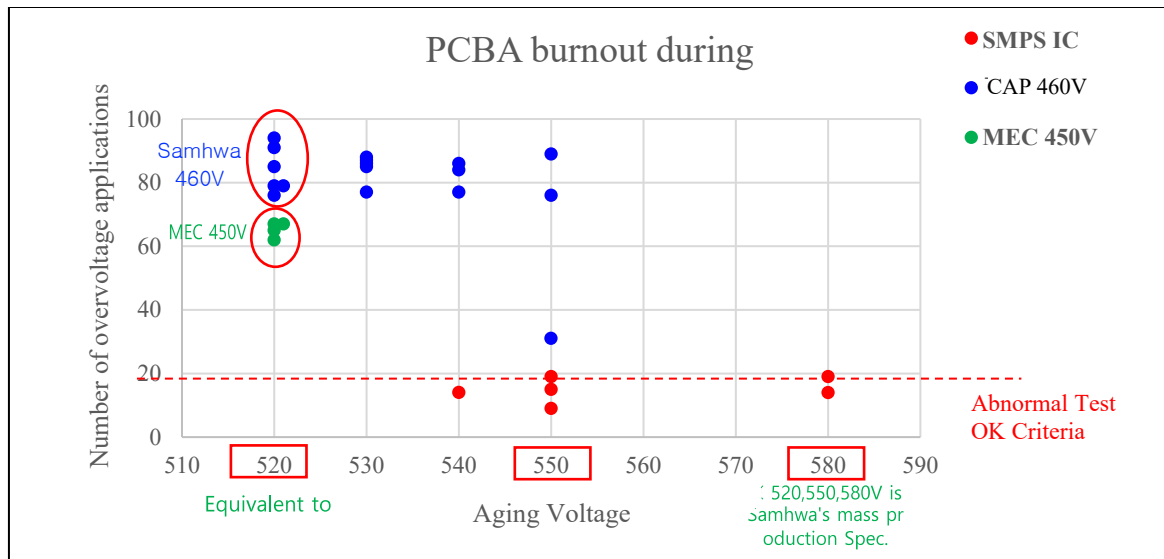


Figure 4.28: Aging voltage of both capacitors

- Abnormal Test Pass Criteria 20 Cycles - 520V satisfied (6/6), 530V satisfied (4/4), 540V burnout (1/4), 550V burnout (3/6), 580V burnout (3/3).
- As a result of the limit test, Aging Voltage 520V Spec operates normally for the longest time (average 80 times accreditation).

Formation voltage: An insulating film of aluminium oxide (Al_2O_3) is applied to the surface of the aluminium foil. Means the voltage applied to form. The formation voltage is the capacitor base voltage. It creates performance, and the higher the formation voltage, the more the Foil is used, the more the capacitor voltage / lifespan.

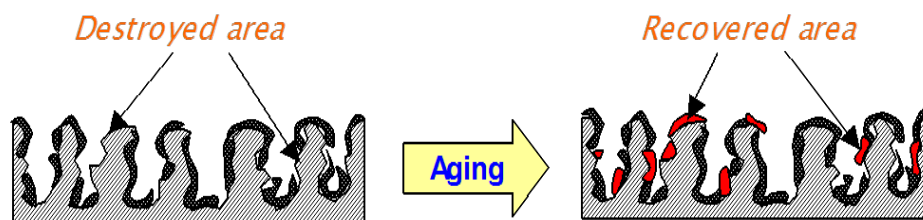


Figure 4.29: Aging Process

Aging: The process of regenerating the surface of the defective aluminum foil.

Withstanding Voltage is determined through the aging process

Application ratio: 10% (Feb) → 50% (Mar) → 90% (Apr)

Some lot defects occurred in 2020 due to MEC condenser process production.

MEC Condenser → Changed to Samhwa Condenser

Other defect improvement activities:

- Beeper No/Low sound (Structure improves to prevent F/Panel interference with Buzzer as Slot & Rib are added).
- DB Diode artwork improved.
- Noise Filter Spec upgraded.

Control Phase:

We need to make sure that the productive action plan is implemented fully throughout this period. To ensure that gains are maintained, controls must be set up to monitor the system. The one-point lesson (OPL) or awareness note was developed during this time. OPL is a straightforward proved to be useful to train employees in a firm to help elevate the standard of the delivered goods and services. The primary goal of OPL is to ensure that all operators and shifts perform at a consistent level of quality. To serve as a manual for the operators, detailed working procedures will be provided. This is essential since it will get rid of certain bad manufacturing processes and add some new steps or procedures. Operators who are more familiar to the previous process steps may take some time to completely understand the new adjustments. A control strategy was also offered to use statistical methods to track the performance over time. This is maintained to protect a watch on the new process's stability.

CHAPTER 5

PROJECT 2: WM – LE ERROR CODE DETECTION AND ANALYSIS FOR THE FIELD FAILURE RATE REDUCTION (FFR)

AIM: To optimize the BLDC motor, multiple Harness and the PCB in manufacturing, assembly process, optimizing the fabrication and assembly of washing machine to resolve the LE error code of the top load washing machine in NDD models; and to perform all necessary tests for ensuring the smooth operation of the WM with best class efficiency to decrease the field failure rate .

4.1) ABOUT THE PROJECT

First, the BLDC motor and PCBs used in washing machine was manufactured and assembled in Thailand and China. For the purpose of Value Innovation of the 21” and 23” sapience model of washing machine, LG is now getting their BLDC motor manufactured and assembled in India by NIDEC India Private Limited. In order to reduce the LE error code defects, BLDC motor structure is improved by adding rib on body of motor, improvement in handling process and prevention of rusting is being upgraded to provide more safety to the part. Also the multiple harness issues found on production line because operator generally insert the thimble manually which causes the issue and disconnection occurs so to improve this inspection is to be done 100% by the supplier and SQA to check the connectors by various methods of testing as defined in the standard. PCB is found dead related to the above problems in matter of process improvement is done on production line. In this project, I deals on performing all the tests that are carried out in R&D and QA which are required to approve the new process improvements and structural transformation and on understanding the concepts by visiting manufacturing and assembling at Fabrication plant of NIDEC.

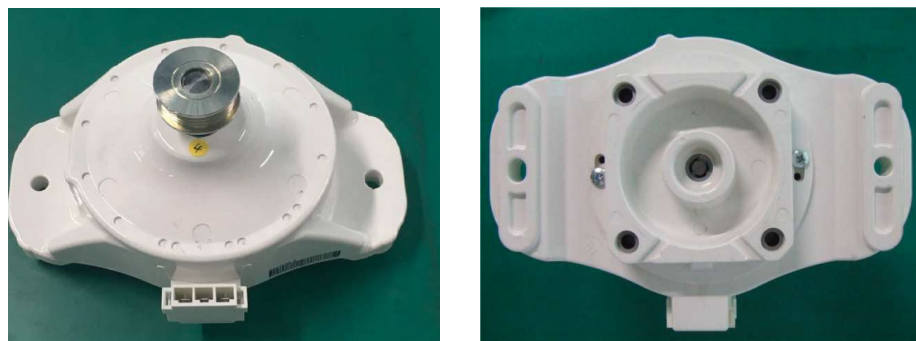


Fig 5.1: BLDC Motor Front side and Back side

4.2) LE Error Code

Whether a front or top loading washing machine is equipped with an error-monitoring system. The washer's display shows an LE error code, which denotes a dead or locked motor or engine, or the connection between the wash motor and washing machine is lost, other reasons can be the harness connector thimble out or PCB dead. It can be a more serious issue. Sometimes the LE error code is displayed simply because the washer is overloaded and the motor stops being able to operate. Additionally, it could happen if anything foreign gets caught between the washing plate and the inside basket, like a coin, a button, or a clip.

However, in more severe cases it indicates a failed rotor position sensor, a broken motor, or damaged sensor or motor wires. If the LE code on washing machine is accompanied by loud “clanking” noises then there is need to check the rotor on the unit.

If the thermal overload protection circuitry in the washer's motor has tripped, the LE code may also appear. This feature is intended to stop the washer's engine from overheating and harming it permanently.

4.3) LE Error code description by DMAIC

Define Phase:

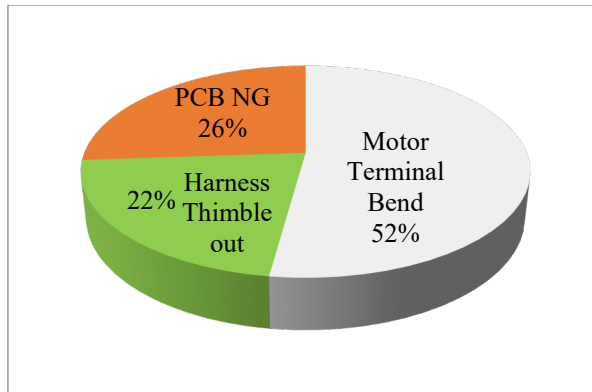
The BLDC motor and related components that has the highest number of defect in washing machine. The aim of the project was to reduce the FFR the lowest as suspected in 2022 is 0.06%, the FFR is improved from 2020 is 9% ↓ and in 2021 is 12% ↓ from the previous years. The first issue of LE error due to PCB dead found on 09.05.2022. The number of defects was 2 pieces out from the total of 384 pieces. Defect PPM is 2604 and major action need to be taken regarding the process improvement and awareness to line operators.

Tool: 21” and 23” Sapience Top Loading Washing Machine

Manufacturer: NIDEC India Private Limited

Bad origin: Field

Issues: Motor Terminal Bend (52%), PCB NG (26%) and Harness Thimble out (22%).



- Reported PPM of BLDC motor: 330
- Target PPM of BLDC motor: 99



Figure 5.2: LE Error Code on Washing Machine Display

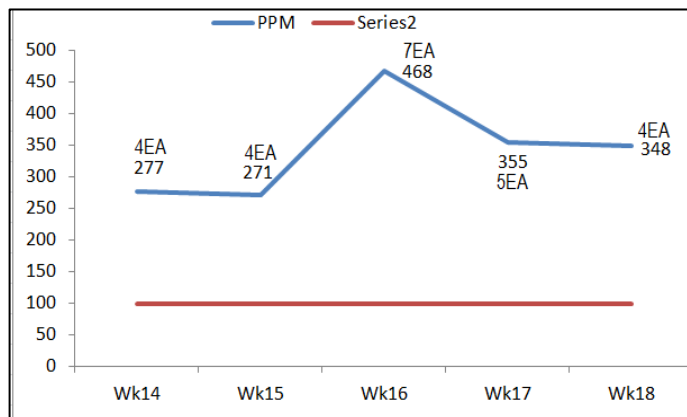


Figure 5.3: LE error code Defect Trend

Major Causes of LE Error:

- 1) Motor Terminal Bend: 52%
- 2) PCB NG: 26%
- 3) Harness Thimble Out: 22%



Figure 5.4: Motor Terminal Pin bend

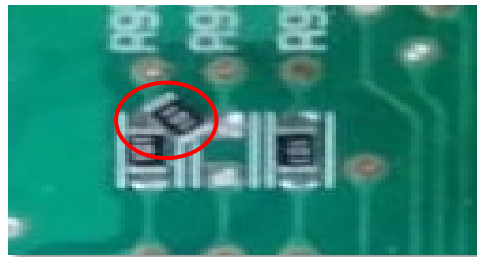


Figure 5.5: Resistance found shifting in PCB

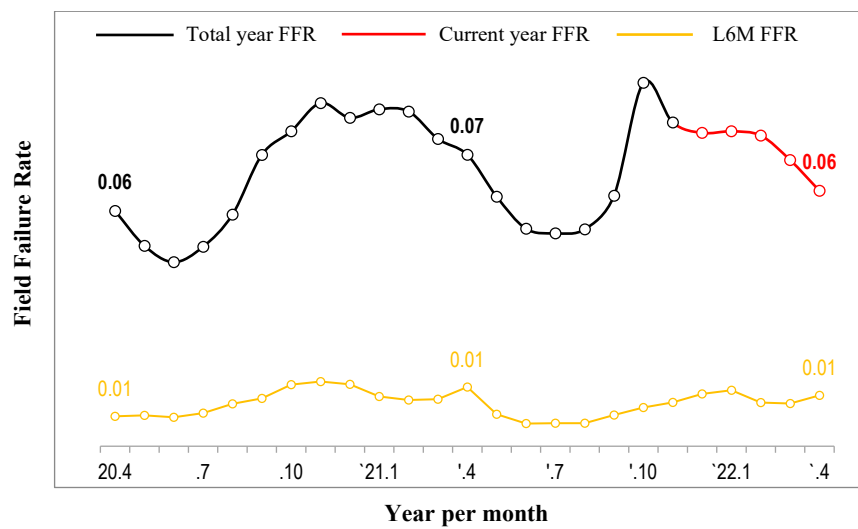


Figure 5.6: FFR Trend

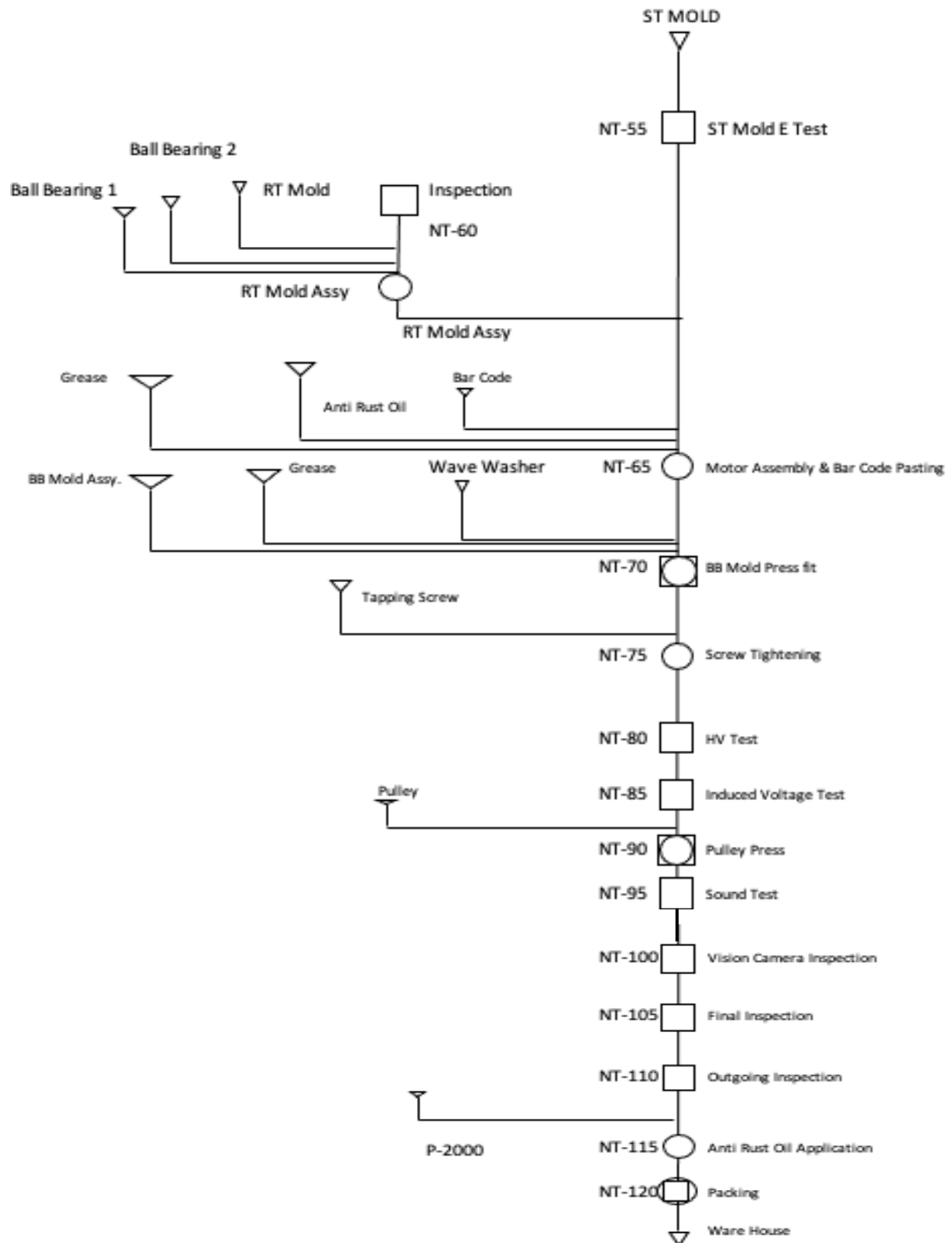


Figure 5.7: Process flow for fabricating BLDC motors

Measure Phase:

Through using Visual Inspection Report, this phase analyses how the BLDC motor's flaws have performed during the previous months. Figure 5.8 displays the trend over time chart for the LE error.

Field Return	SVC	Portion
Total	25	100%
LE Error	2	8%
Dead	6	24%
Noise	11	44%
Motor Jack damage	1	4%
NDF	5	20%

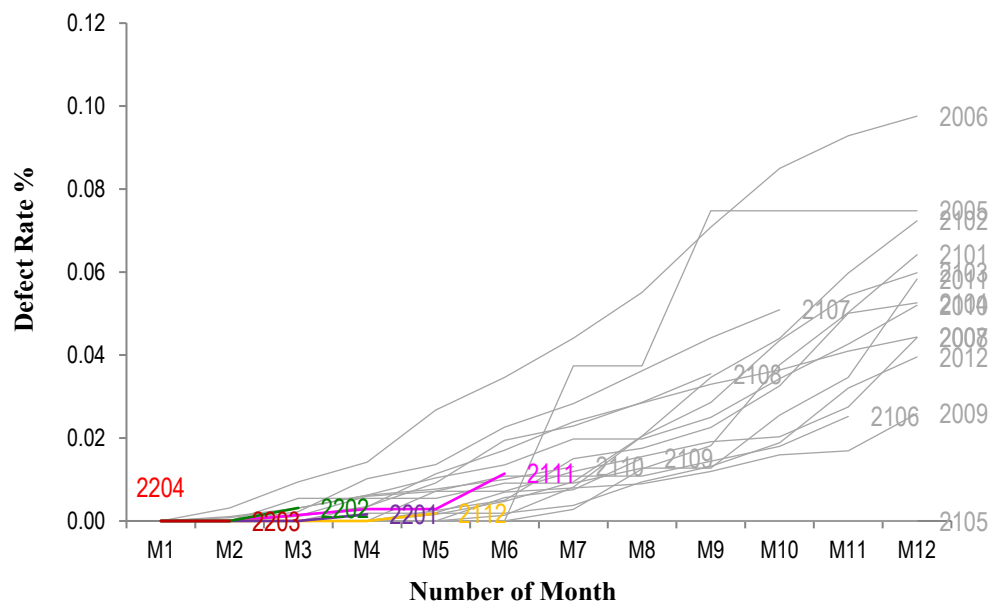


Figure 5.8: Graph of Overall Open defect

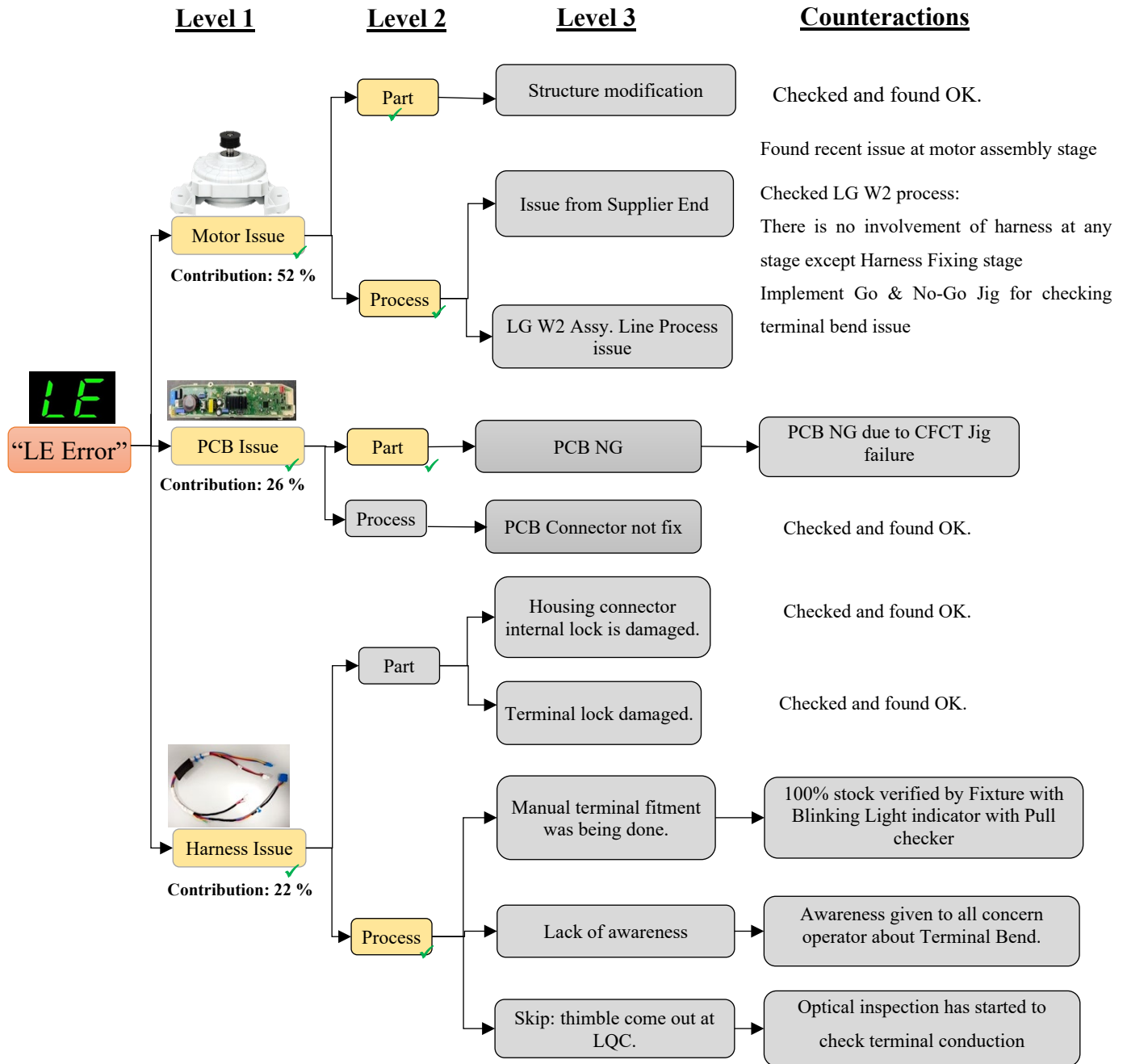
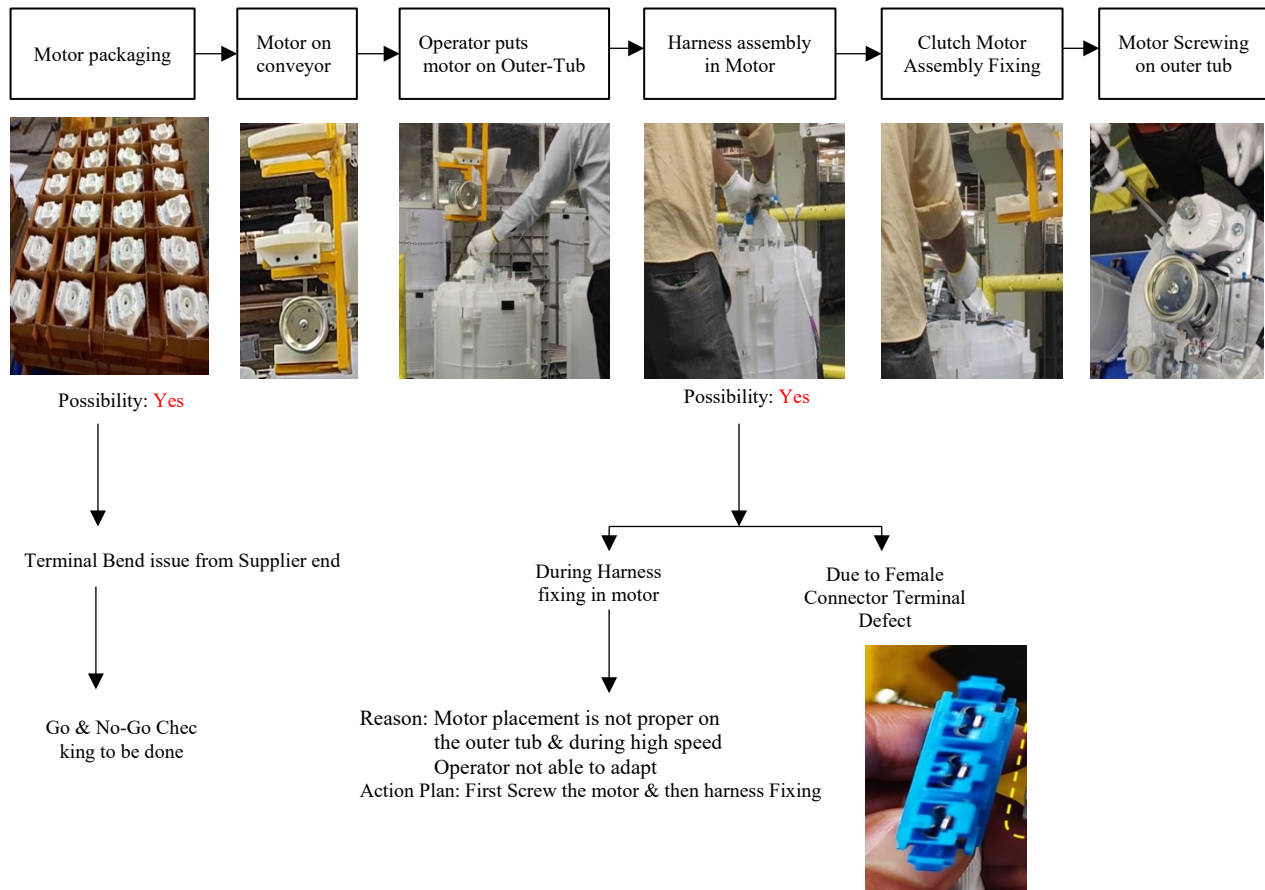


Figure 5.9: Logic Tree for LE Error code

Factor affecting the LE error (52%) by BLDC motor:

- Checking method Not adequate
- Outer Tub Assy. Line Process Issue
- Operator Body Fatigue

Possibility of Motor Terminal Bend Issue:



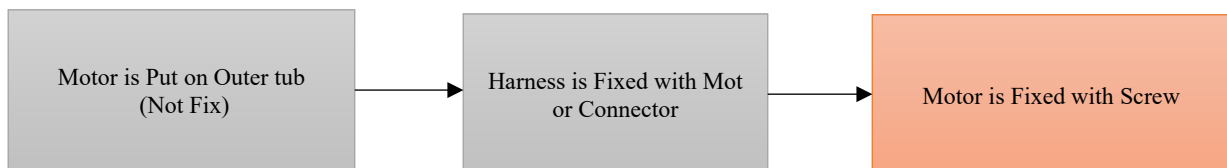
Process Analysis of LGEIL W2 Assy. Line:

- Outer Tub Assy. Line Process Issue

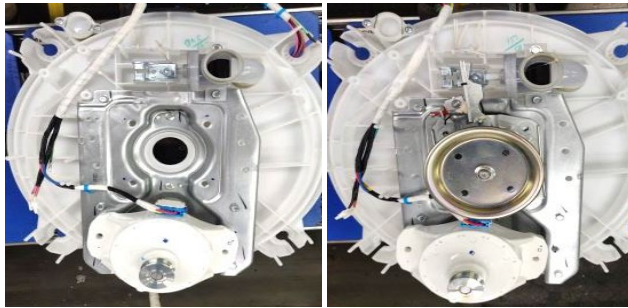
First Step : Motor is Put in Outer tub (Not Fix)

Second step : Motor harness Connector is Fixed.

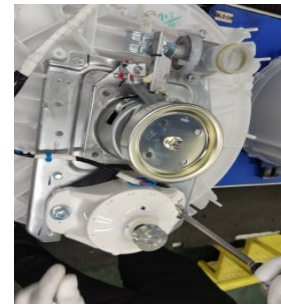
Third Step : Fixed the Motor with Screw



Stage 1 : Harness Fix + Place Clutch Assembly



Stage 2 : Motor Fix



Process Analysis of Nidec (Supplier):

Checking method : Vision Camera will Observed the Alignment of Terminal Pins With reference of Pocket Width.

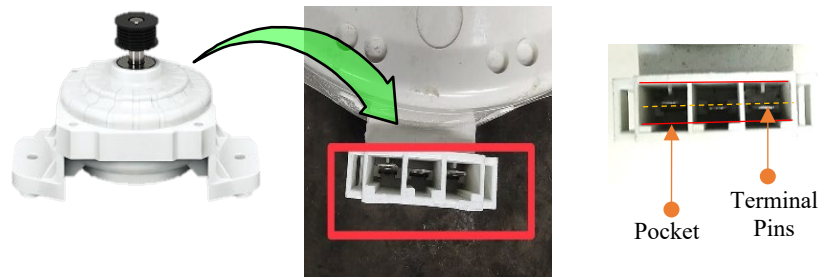


Figure 5.10: Motor checking method of the pocket and terminal pins

Rust & Noise

- Noise due to rust on bearing
- Rust occur due to moisture entry into motor
- Rust occur due to moisture condensing (Humid Environment)



Figure 5.11: Rust on motor pulley

① Water Entry from Top (Shaft Rust, Rotor OK)

- Water Tracing mark observe (Show in figure)
- Water accumulate at BB holder near Shaft and entry in motor due to capillary action in running condition

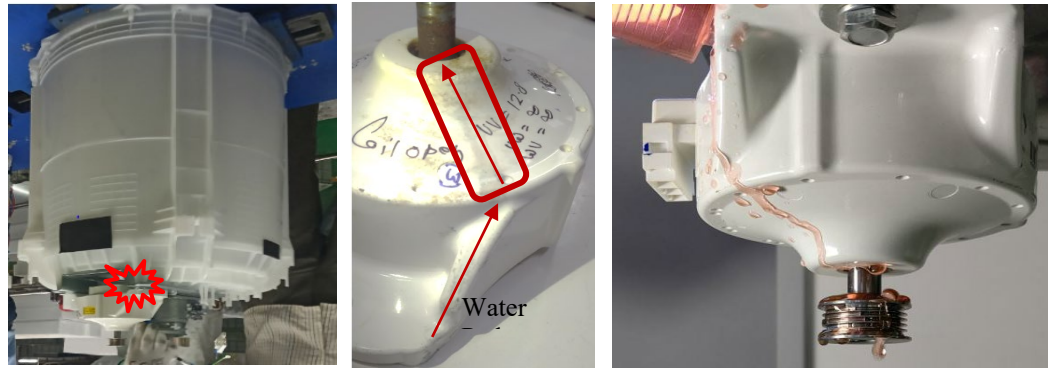


Figure 5.12: Entry and accumulation of water in BLDC motor

② Water Entry from bottom (Shaft OK, Rotor : Rust)

- Simulation Testing performed (Water Color test : 24Hrs)
- No Water Entry from Bottom Side was found.



Figure 5.13: BLDC motor shaft, rusted rotor and water at bottom of motor

Factor affecting the LE error (22%) by harness thimble out:

- Manual Terminal Fitment
- Housing Lock not Fixed.
- Terminal bend in Crimping Process

Manual terminal Insertion : No check point & Fixture available at Sub assembly, which observed the thimble out issue.

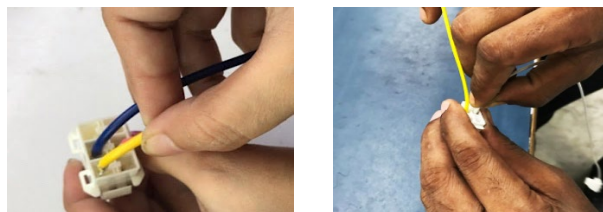


Figure 5.14: Manual Terminal Insertion

Housing Lock is not Fix : Housing body was not fixed with female spade Connector due which Thimble Is Out.



Figure 5.15: Housing Lock is not Fix

- Due terminal bend and after applying the excessive force during matting the housing, bend terminal got back out. During the process Terminals are getting bend from the top side.

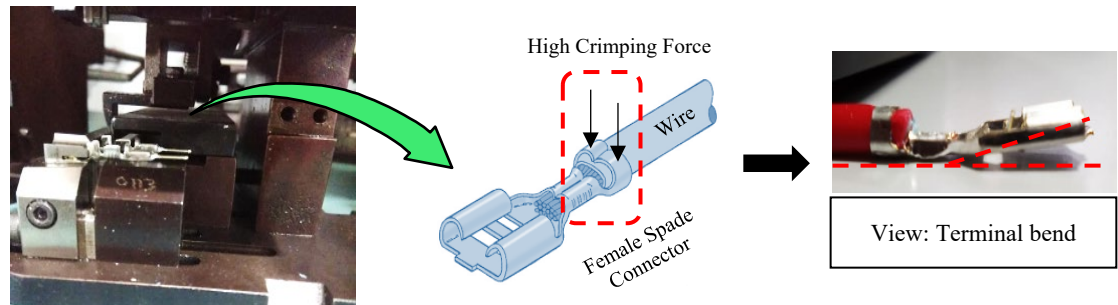
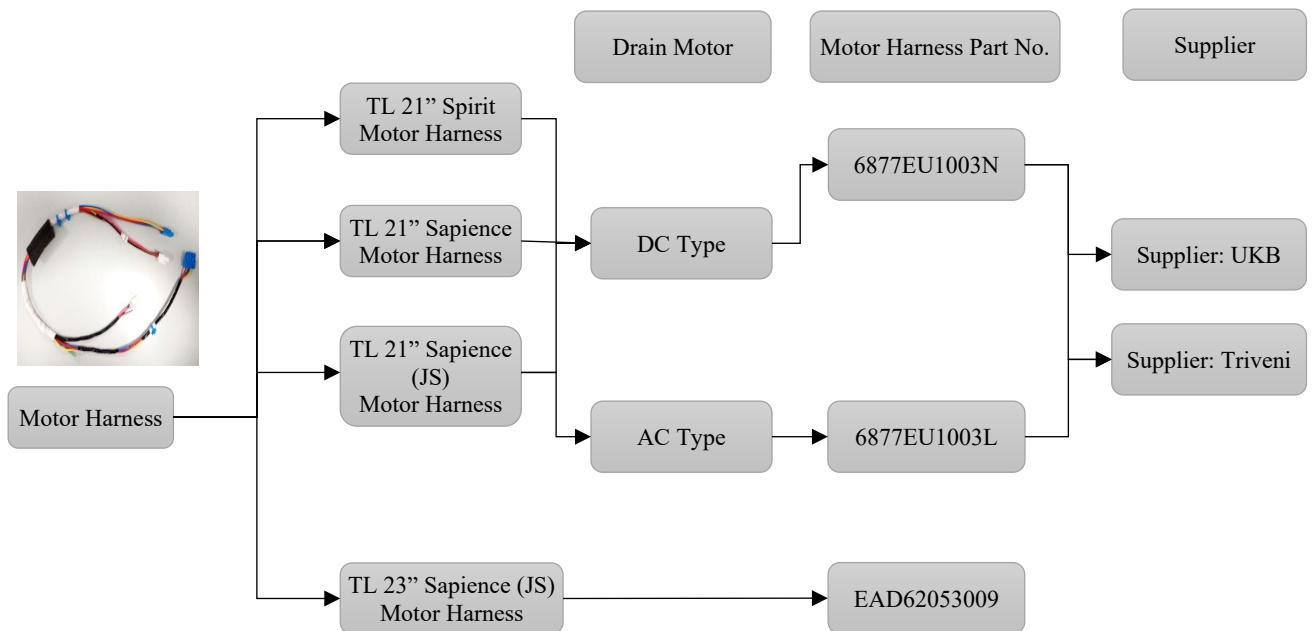


Figure 5.16: Terminal bend

Major contribution of terminal bend issue is found out at UKB Harness supplier.



Factor affecting the LE error (26%) by PCB:

- Visually PCB Found not OK – Resistance R952 found shifting (Not detected by jig because motor's belt was loose due to belt crack).
- PWS Results: Found OK. Find below link for reference.
- Solder Profile and Soldering temperature – Found OK as per standard
- CFCT Testing Jig Validation: Total CFCT Jigs- 9 nos., Found OK Jigs – 8 nos., Found NG Jig – 1 (Jig was found NG as belt is loose due to cracking in belt).
- During component refilling feeder not teach. Due to that reason component was shifted from its location. That resulted in R952 location component shifting.

There can be any causes of the PCB dead. There were numerous potential reasons why R952 could have shifted on the PCB, and Figure 5.20 is fishbone schematic describes them all.

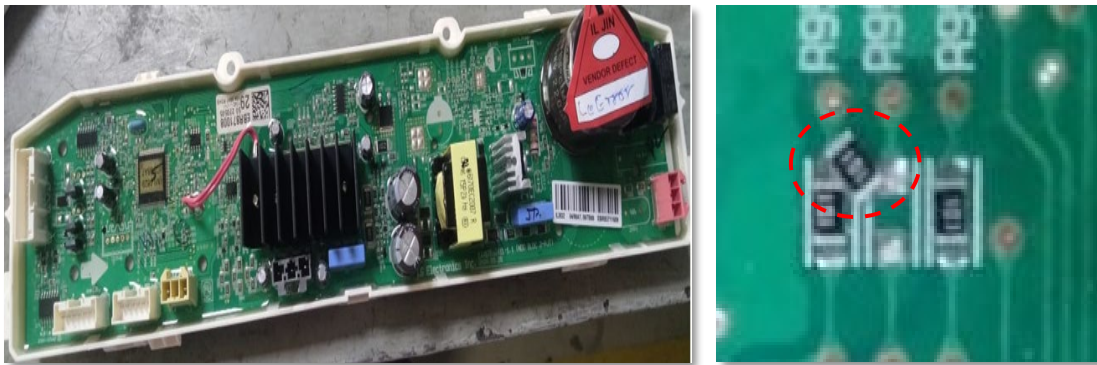


Figure 5.17: R952 shifting in the PCB



Figure 5.18: Motor V-Belt damaged

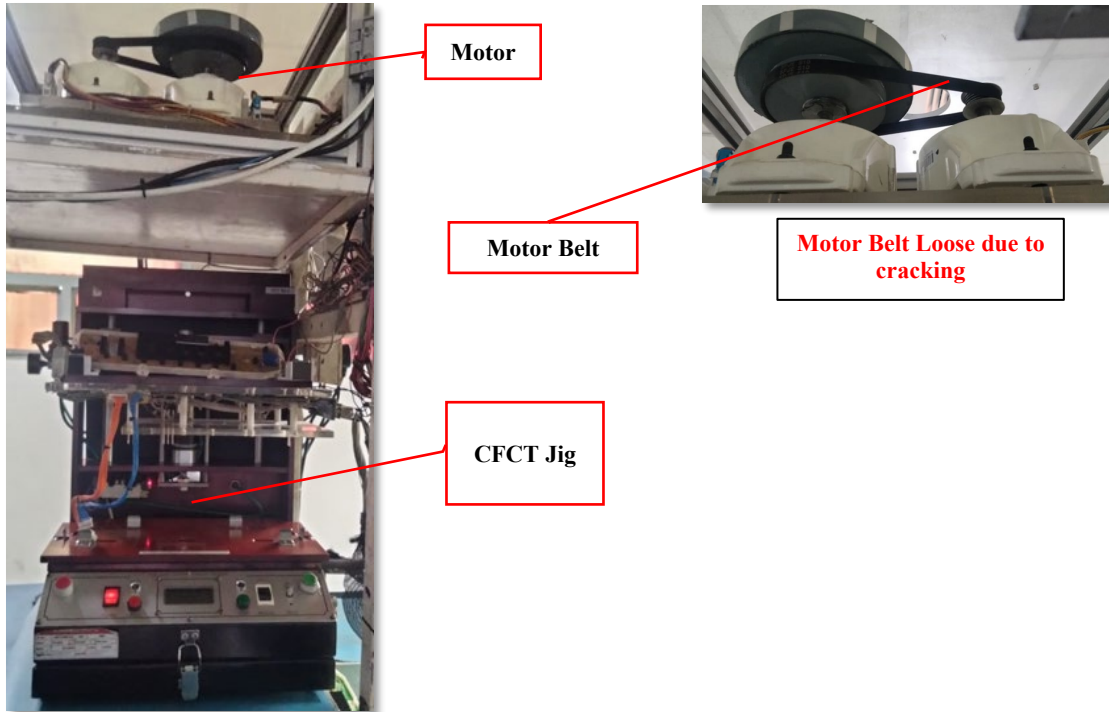


Figure 5.19: CFCT Testing Jig

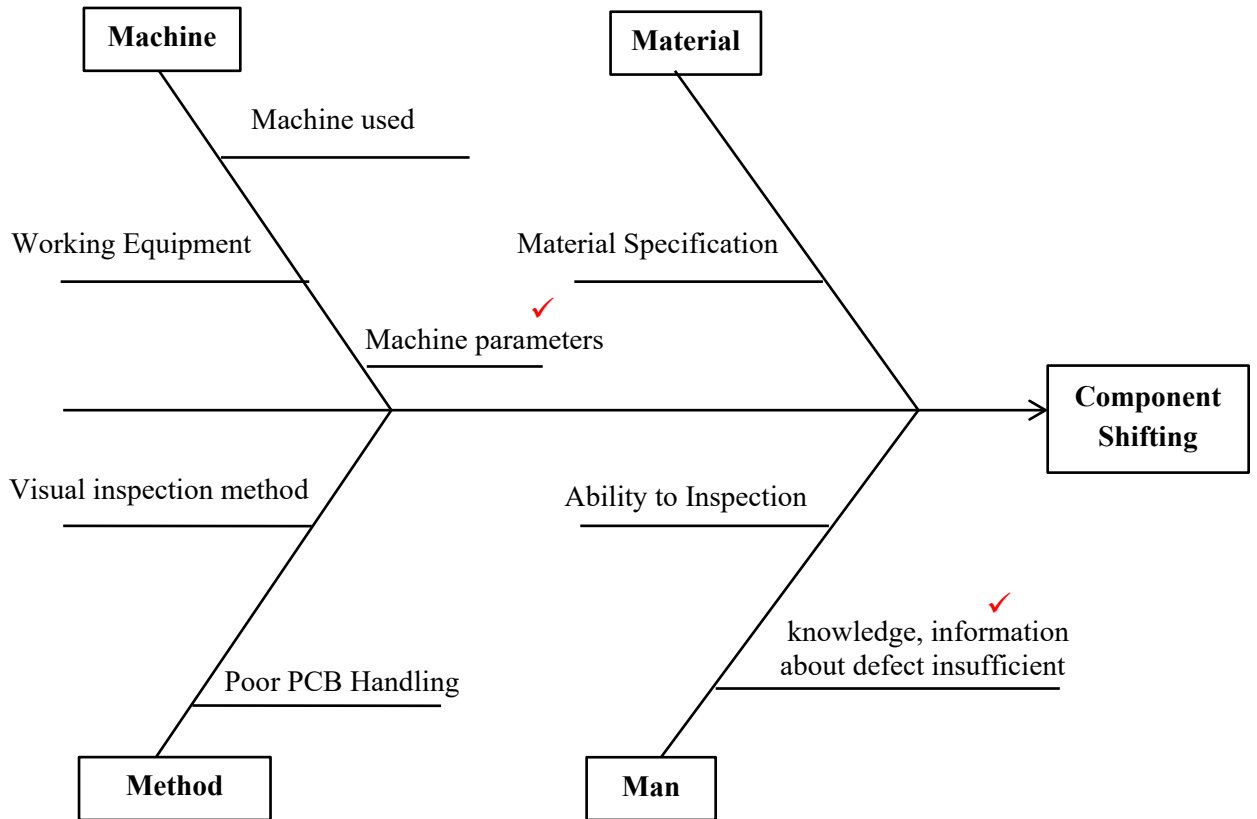


Figure 5.20: The fishbone diagram for the causes of resister shifting

Analyse Phase:

As per the analysis the major modifications are done in BLDC motor as shown below:

- For Rust and Noise (Structure modification to avoid moisture entry)

- ① Add Rib on the body to avoid water entry near shaft

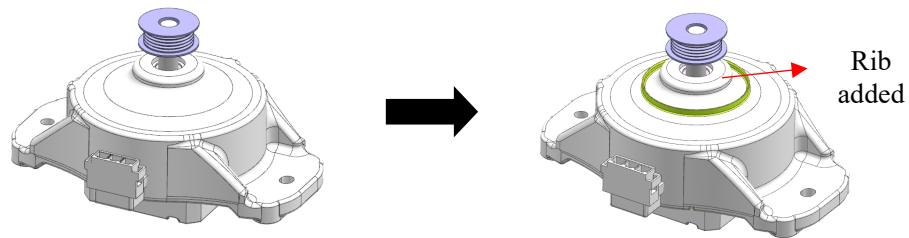


Figure 5.21: Rib added to avoid moisture entry

- ② Apply Rubber sealed bearing

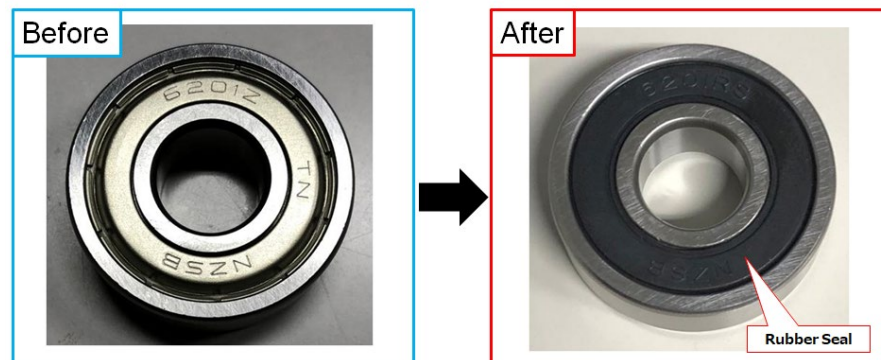


Figure 5.22: Rubber seal added

- ③ Add Water Path with drain Passage (Rotor Rust, Shaft OK)

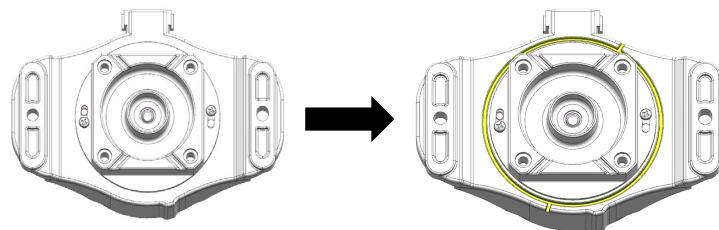


Figure 5.23: Water path added

- Stator Press Fit circular shape modification:

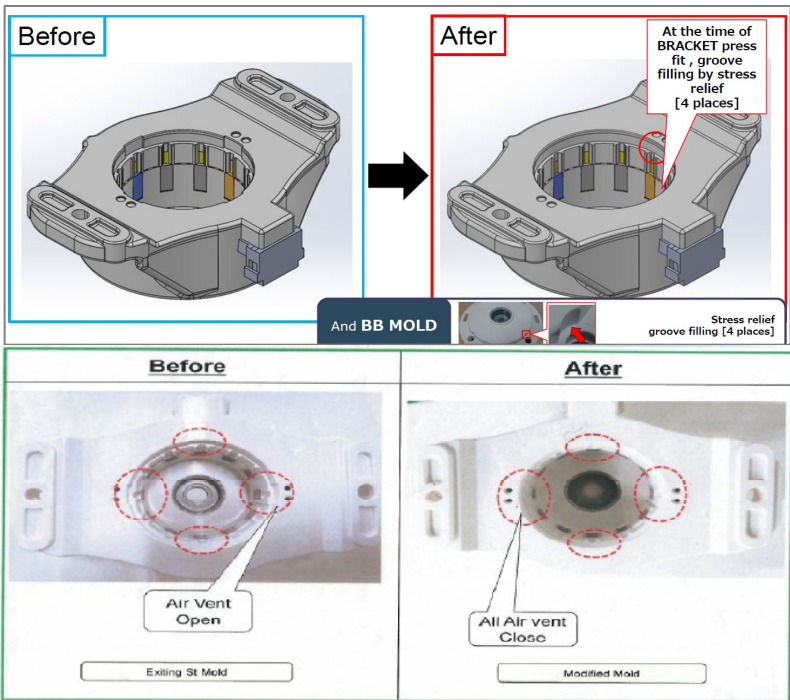


Figure 5.24: Stator Press Fit Circular Shape

- Weight holding Hole Filling:

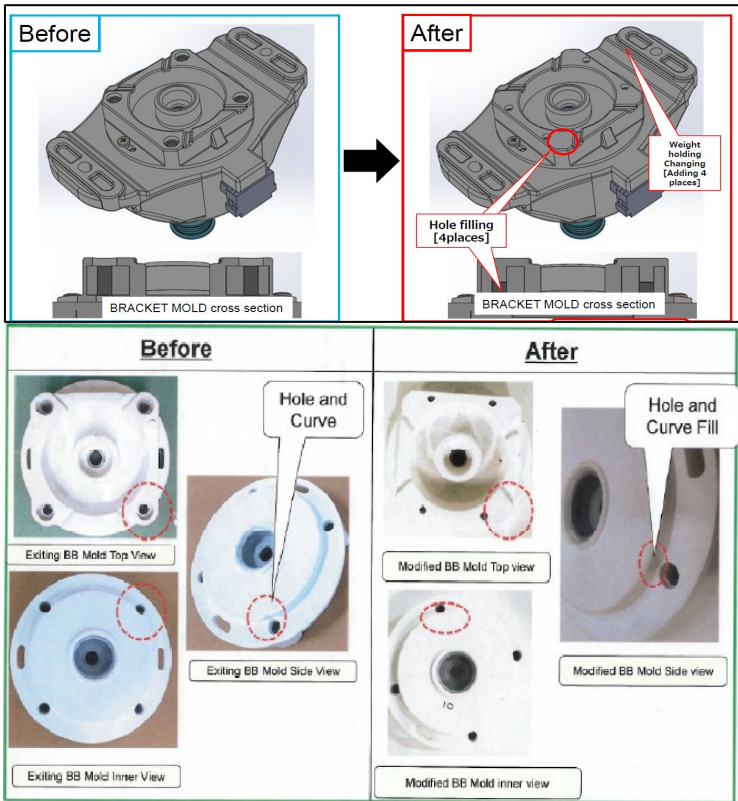


Figure 5.25: Bracket Hole Close

4.4) Testing:

Table 15: Different test performed on BLDC with new structure changes

No.	Test	Test Conditions	Specifications	Results
1	Voltage Endurance	Should withstand without abnormality in performance when there is application of AC 1500V For 1Min or AC 1800V for 1 second	Leakage Current < 5 mA	0.16 mA, 0.18 mA, 0.19 mA Found OK
2	Insulation Resistance	when insulation is measured between Terminal and non-charge metal Part by using megohmmeter of DC 500V.	IR Should not be less than 100MΩ.	> 50 G Ohm OK
3	Temperature Rise Test	Program cycle is run Under Rated saturation condition at rated Frequency and 1.06 times of rated voltage.	Motor Winding Temp. Rise should be < 105 °C (Resistance Method)	Maximum Temp. rise is 28.20 °C at 244 V.
4	Moisture Resistance insulation Performance Test	Keep the samples at temperature of 40±3°C and relative humidity of 95±2% for 48 Hrs	HV / IR Should be OK	HV 0.16, 0.18, 0.16, 0.17, 0.15 mA IR > 50 G ohm
5	Noise/Vibration Test	Measured at a distance of 0.5m from pulley end Vibration: this shall be 15μm when Measured at outside surface center	Noise < 45 dB Vibration < 15μm when measured at outside surface center.	< 45 dB: 38, 39, 37, 38, 39 < 15μm: 0.015, 0.012, 0.012, 0.011, 0.014
6	Brine Spray Test	Leave samples for 7 cycles, where 1 cycle composed of 8Hr of 5% Saline water & Interruption of 16 hr Under amb. condition of 40°C & 95% RH.	Insulation Resistance and Electrical Propertied (HV / IR / Resistance / Motor Jam).	25°C: 13.2, 12.9, 13.0, 13.0, 13.3 ohm 75°C: 15.8, 16.0, 15.9, 15.8, 15.8 ohm
7	Thermal Shock test	Leaving the samples for 120 Cycles	There must be no crack and deformity.	Test results OK

8	Over voltage withstand test	Run the motor for 1 Cycle operation under condition of set. Installation at 120% of rated voltage	HV / IR should be OK	HV: 0.20, 0.19, 0.20, 0.20, 0.18 mA IR > 50 G ohm
9	Durability test in Part	Assemble the Part into the Jig and Perform the below Test 2.7Sec ON / 0.5Sec OFF for 650Hrs	HV / IR Should be OK No wiring Burn	No winding burn out. HV / IR test found OK No Bearing breakage & no abnormal noise found.
10	RPM Check	Check RPM of the part	Should be 2700 RPM	Found OK

Results:

New BLDC motor modified due to water and moisture entry has passed all the above performed tests.

Improvement phase:

Detection enhancement (ILO): 1. Line quality check, below points are added for enhancement of BLDC Motor: 100% Inspection for belt fixing at tub outer assembly line (Loose, Position alignment with clutch).

2. Housing body is fixed with female spade Connector, and Softly Pull it 2 times, due which Thimble is Not Out.

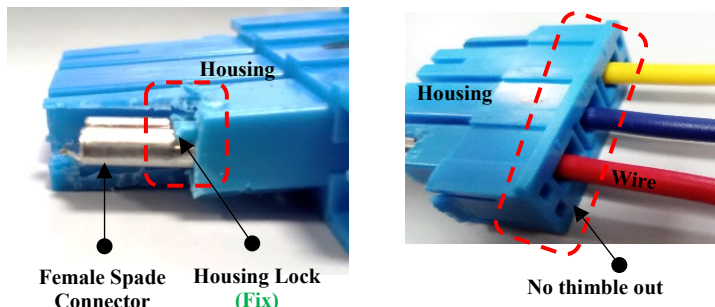


Figure 5.26: Harness connector fixing

3. Check and changed the motor belt of every CFCT motor.
4. Verified current available stock at supplier end. (Result 0/ 192 Nos).
5. CFCT: Jig validation defined process once in every week through NG samples.
6. OQC: After getting feedback for issue, OQC increased testing sample double for next 5 lot.
7. Training about component teaching & AOI operator for defect control.
8. After refilling spool, operator have to check feeder teaching.

Process Improvement:

1. BLDC Motor: Thimble bend issue check point at tub outer assembly line.

- Outer Tub Pallet Modify (To prevent touching on Motor)
- Repair Area Outer Tub Assy Pallet modify (To prevent touching on Motor)
- Outer Tub Assy. Process Modification (First Step: Motor is Put in Outer tub (Not Fix), Second step: Fixed the Motor with Screw, Third Step: Fix the Motor harness Connector After the Motor screw fix)

Laser Vision Camera apply for Motor Pin Check (100%)

- Laser vision applied at input stage of motor area.
- Laser vision applied at input stage of motor area, along with drain motor in single area setup.

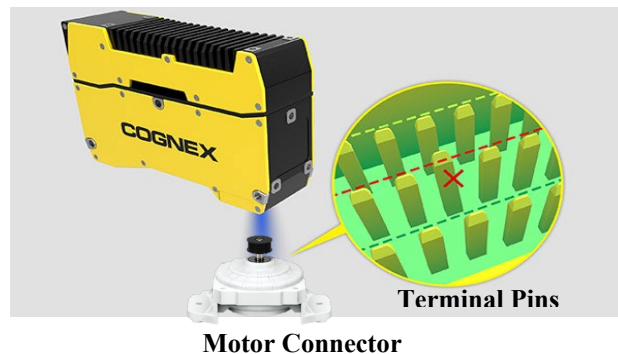


Figure 5.27: Laser Vision Camera apply for Motor Pin Checking

2. Harness : Check point & fixture available at sub assembly, which observed the thimble out issue observed by red light blinking.

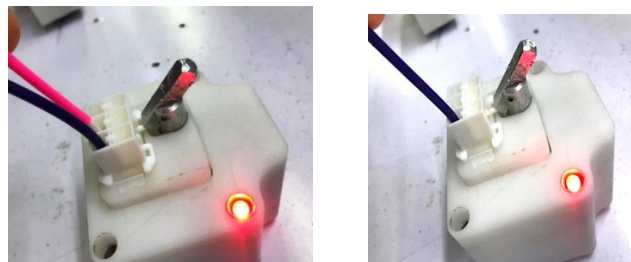


Figure 5.28: Thimble checking fixture

- Crimping Force need to control & monitor, after the crimping process but before insert in housing.



Figure 5.29: Terminal Straight

3. PCB

- Belt checking and changing frequency defined and check point added in jig validation sheet.
- NG sample are made for CFCT jig validation and also defined verification frequency for jig validation.

Design Improvement

Structure modifies to avoid moisture entry:

1. Applied Rib on the body to avoid water entry near shaft.
2. Rubber sealed bearing added.
3. Water Path with drain Passage added.
4. Stator Press Fit circular shape modified.
5. Weight holding Hole Filling done in the BB mold.
6. Motor AAR (NDF) 23% → 3%

Control Phase:

We must make sure that the effective action plan is implemented completely throughout this period. To ensure that gains are maintained, controls must be set up to monitor the system. OPL is a straightforward designed to be operated used to train employees in a firm to help elevate the standard of the delivered goods and services. The primary goal is to ensure that all operators produce work of a similar level. To serve as a manual for the operators, detailed working procedures will be provided. This is essential since it will get rid of certain bad manufacturing processes and add some new steps or procedures. A control strategy was also offered to use statistical methods to track the performance over time.

CONCLUSIONS

Laundry washing is an everyday household activity that will change in the near future due to emerging mega-global trends. Companies all over the world have been working on new laundry trends and technological breakthroughs in order to demonstrate their leadership in this industry. They are concentrating on products that perform better in areas such as smart digital technology and washing efficiency, as well as promoting healthy laundry habits. Because innovations must aim for total social change, they must be organised in such a way that they generate value. To be successful organizational innovations must gain power and support in the society. Our main focus on customer, need, want and demand by providing a good valuable product with less amount of failure rates. By this the product life cycle grows on the maturity stages and maintain dignitary role for competitor companies.

Considering all the above mentioned factors the improvements was done in washing machine for achieving value innovation, cost improvements, UPH on production lines, reduction in 4M and decreasing field failure rate to the lowest for the best class efficiency of product. Introduction of new SMPS IC in PCB is without heat sink with withstand voltage of 800 V shows the integrity in the PCB by providing working wash efficiency without any burnout and failure conditions and is suitable for overvoltage areas. By changing the electrolytic capacitor maker and voltage from MEC CON 450V to SAMWHA 460 V in PCB the performance of the machine shows more fruitful results without any deforming by applying more aluminium oxide (Al_2O_3) on surface of the aluminium foil of capacitor.

A significantly different project describes the LE error code causes, issues and process and part improvement done in the BLDC motor (52%), PCB (26%) and harness (22%) which are the main causes of this error. BLDC motor structure was modified to prevent it from moisture, noise, water entry and rusting. PCB inspection and process handling was improved. Harness connector fixing with housing body detection enhancement at ILO.

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