CHALMERS
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Investigation and validation of new Technologies to replace existing dishwasher diverters

Master's thesis in Product Development (MPPDE)

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CHALMERS UNIVERSITY OF TECHNOLOGY
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Abstract

There has been constant evolution of the dishwasher since its invention in the 1880s. Over the years there have been major breakthroughs in combination with continuous minor developments. A dominant design is eventually established with strong competition between companies to provide increasingly innovative and better features with each passing day. Over the last decade greater focus has been on water distribution and energy efficiency. The diverter and the associated system is a key contributor towards an efficient and high performing water distribution system. It has been observed that most of the dishwasher manufacturers including ASKO use a similar technology to divert water to the spray arms. This technology has certain flaws but is an effective and non-expensive solution nevertheless.

ASKO has identified the dishwasher diverter as a space to challenge the existing technology and investigate for better solutions with the aim to eventually replace the existing diverter with a better technology. The thesis project is an attempt in this direction to explore potential concepts and technologies to carry out the functions of the existing diverter more efficiently.

The project uses the product development approach divided in multiple stages from ideation to creation of concepts that are validated using prototyping and testing. The report documents the work carried out in each of these stages and then presents potential concepts that can replace existing dishwasher diverters. Finally, the report also provides certain recommendation for future work to the company. The findings of this report can be seen the first step towards developing a new diverter technology.

Lastly, text, development work and processes used are done following an ethical code of conduct. Respective individual work in the form of literature and patents used for the compilation of this report is referred correctly wherever necessary.

Keywords: Dishwasher, Diverter, Product development.

Acknowledgements

I would like to thank each individual associated with this project for their contribution towards the realization of the product and helping me gain an experience which has certainly developed my skills and will most certainly help me in my respective future endeavors.

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Last but not the least, I extend my gratitude towards Chalmers University of Technology and the IMS department for allowing me to carry out this thesis project and providing me with great infrastructure to improve the quality of work produced.

Herschelle Anthony Dsouza, Gothenburg, June 2023

Contents

List of Figures

List of Tables

1
Introduction

This chapter gives a brief description about the problem targeted in the thesis and defines the aim and scope of the thesis work.

1.1 Background

The master thesis project is carried out in the IMS Department of Chalmers in collaboration with ASKO Appliances AB which is a part of the Hisense group. ASKO develops and manufactures home appliances like Dishwashers, Coffee Machines, Ovens, Washing machines, drying cabinets etc. The facility in Lidköping focuses on research and development and acts as a competence center for dishwashers. The thesis is one of the pre-development projects carried out at ASKO for next generations of dishwashers.

Water distribution within dishwashers is becoming increasingly complex. From the beginning, just two rotating arms operated at the same time were used. As the demand for increased cleaning performance and variety of washing baskets have led to use of multiple spray arms and variation in nozzle diameter and performance. Nowadays, they are combined with additional arms, power nozzles, impellers, spraying tubes etc. On the contrary the demand for decreased water usage is strengthened, and it becomes impossible to operate all these at the same time by energy and efficiency standards. Today a simple and inexpensive diverter based on the principle of a rotating disc with holes which is operated by a motor is used by ASKO and most of its competitors.It is used both to direct the water to a specific spraying device and to regulate the water pressure which will be explained in detail in the upcoming sections.

The development of a new system to divert water can give ASKO a competitive edge in the market with a differentiating technology. It can not only improve the functionality and efficiency but also act as a marketing tool and boost sales in the upcoming dishwasher generations. Thus, it becomes an important project for the company to maintain and enhance its position in the premium dishwasher market segment.

1.2 Problem Description

The dishwashers developed by ASKO today consist of a minimum of two and a maximum of three spray nozzles. The general placement of the two main spray arms is one each at the bottom and the top. Some Models have an extra spray arm on the top for a better cleaning performance of the uppermost basket. The water is recycled throughout the wash cycles. The water is collected in the sump and pumped upwards while a filter in between collects the dirt and large suspended particles. The water is pumped into the diverter which diverts the water to the required spray arm regulated by the program of the wash cycle.

The diverter consists of a shaft with a plate having a cutout. It also has two or three outlets which lead to each spray arm nozzles respectively. The shaft is rotated by an asynchronous motor which aligns the cut-out with the desired outlet to supply water to the intended spray arm1.2.

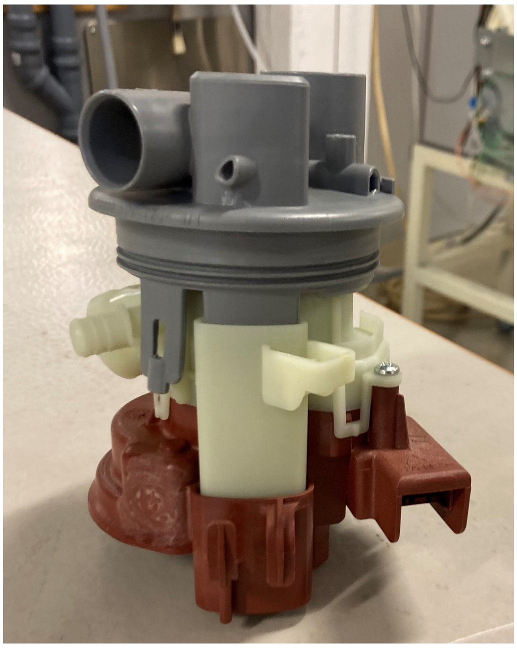

Figure 1.1: Existing Diverter

Figure 1.2: Diverter in Dishwasher

The existing diverter system is cheap and effective but has certain limitations that can be addressed which can result in a more efficient diverter system. The primary issue is that the three spray arms cannot be operated independently, one at a time due to variation in the sump level and the design of the cutout in the rotating plate. This is because the volume of water in the system is different for each spray arm cycle. The upper and top spray arm being connected to the diverter with vertical tubes cause it to have excess volume of water in the system when the lower spray arm is operational as the lower spray arm is directly connected to the diverter. The water level in the sump has to be maintained below the filter to avoid dirt and food particles spreading on the floor of the dishwasher or getting deposited back on the dishes. Currently, this excess water is managed by simultaneously running 2 spray arms with the non-desired spray arm having the flow of excess water. This reduces the control and efficiency.

A secondary issue with the existing rotating disc is that the rotation can be blocked by dirt such as gravel or dirt. This causes malfunction in the diverter, and in extreme cases causes the shaft of the diverter to fail due to large soil particles getting stuck.

Additionally, there is always internal leakage to spray devices as the cut-out plate isn't fixed as it needs to rotate to align itself with the outlet. This causes loss of pressure to desired spray arms thus reducing the cleaning performance of individual spray arms

Lastly, on average the spray arm is switched every 3 minutes in a wash cycle that lasts for approximately 3 hours amounting to realignment 60 times per dishwashing cycle. The current switching mechanism takes approximately one minute to switch as the asynchronous motor used has a rpm of 8. A general trend of low rpm is seen in competitor diverters and is discussed in detail in the upcoming chapter.2.2 The mechanism used is a mechanical ticker that needs to get back to the original position each time a switch is made. This means that about 60 minutes in each washing cycle is lost only in switching between spray arms. A faster switching mechanism will reduce the overall dishwashing cycle time by a significant margin.

Figure 1.3: Outlet Switching Mechanism

1.3 Aim and Scope

The aim of the project is to investigate and identify a new technology for a dishwasher to divert or switch water to different spray nozzles and zones within the dishwasher. A minimum of three outputs are needed where each output needs to be either closed, fully open or partially open independently.

Scope of Thesis Work

- Understanding the existing diverter system used by ASKO and its competitors, its technology and identifying associated problems to overcome.
- Research and literature review of different technologies and applications which perform similar function.
- Ideation and Conceptualization of potential alternatives in accordance with the weighted technical and functional requirements.
- Elimination of inferior concepts.
- Concept Validation through Design-built-test cycles.

1.4 Methods

The project uses a Product development approach at tackling the targeted problems with a product based solution to replace the existing system with a more enhanced system. This approach uses various tools and decision-making matrices during its course.

The first step is to understand the existing diverter system and identify its limitations and drawbacks. A set of requirements, their justification and a way to evaluate them are generated. The entire system is then functionally decomposed and classified by using functional decomposition tools like function tree and system diagram. Alternatives are ideated to fulfill each function by taking experience from existing patents, applications and other relevant products in the market. Parallelly a thorough patent search is also carried out to search for similar existing technologies and inventions related to dishwasher diverters.

In the next stage the conceptualization tool of a morphological matrix is created to combine alternatives to generate complete concepts. The matrix is complimented with creating sketches and system diagrams of concepts for better visualization and understanding. A combination of iterative weighted decision matrices like Pugh and Kesselring are used to eliminate inferior concepts based on requirement specifications developed earlier in the project.

The remaining concepts are converted into prototypes using 3D modelling tools like Solidworks and rapid prototyping techniques like additive manufacturing with each iteration building on the knowledge of the testes and observations of the previous one. The iterations continued successful data and observations obtained are used to validate the concept's feasibility and improved functionality and performance with respect to the existing diver specifications.

The validated concept thus would act as the foundation on which future development would be carried out to convert it to a product that meets the manufacturing, functional and performance standards of dishwasher diverters with the end goal of replacing existing diverter technology used at the company.

2

Market Trends and Competitor Analysis

2.1 Market Trends and Assessment

With increasing customer demands and preferences, understanding the market trends can result in development of products that serve these customer needs. Secondly it also helps companies to identify new potential opportunities and maintain a competitive edge. In an industry with frequent innovations and technical advancements it becomes critical to stay up to date with the latest trends and developments.

Firstly, the dishwasher market is predicted to be poised to grow at a rate of approximately 5 percent in the upcoming years with an average expected growth per year of approximately 757 million dollars a year[1]. On the other hand some other market studies show that the expected global dishwasher market is set to grow at a rate of approximately 8 percent each year until 2027[2]. New markets are emerging in Asia with increase in purchasing power parity of the east.

This industry is constantly driven by product innovation, new features, greater performance and increasing loading capacities. Manufacturers are trying to make their dishwasher smarter by integrating it with automatic and remote control features. ASKO's latest generation of their dishwasher has a liquid auto-dosing feature that eliminates the need to dose liquid detergent before each cycle. Similarly, there is a constant race to launch new dishwashers in the market and to capture as much of the market as possible. Each manufacturer places itself in a different bracket and has a target market segment and aims to increase their share of the targeted market.

2.2 Competitor Identification and Technology Study

As seen in the trends in the appliance industry and especially the dishwasher industry there has been an increase in development of innovative features that improve the product. These features not only give a functional and performance edge over the other dishwashers in the market at that point of time but also act as a marketing push to drive up sales. Thus, it becomes extremely critical for any company to be aware of the latest technologies utilized by competing brands in order to maintain or gain a competitive edge.

In Europe the main competitors of ASKO are Miele, Electrolux and Bosh while in America brands like whirlpool, GE, Subzero Wolf, BSH etc. In order to study the technology and diverters used by competitors, diverters were taken from market models of dishwasher of Electrolux, Bosh and Miele. The diverters were then dismounted and disassembled to understand the overall specification, working principle and components used. This is presented below followed by a summary of observations.

Electrolux

The diverter worked on the principle of a rotating disc with slots which are aligned one at a time to the exit channels of the spray arm. This is a fairly simple design with no possibility of using multiple arms and sending water partially. The motor used is almost identical to the one being used at ASKO with 2.5/3 rotations per minute. This depicts that the switching time of the existing Electrolux machines is also relatively high taking but lower than ASKO as they have just 2 channels instead of 3. The size of the diverter is also smaller than the one used by ASKO.

Figure 2.1: Electrolux Diverter

Figure 2.2: Electrolux Plate cutout.jpg

Bosch

The diver used by Bosch works on the same working principle as Electrolux and ASKO but has multiple outlets and configurations on their disc as shown below. The Bosch machine has a maximum of 3 spray arms but has 5 major slots on their disc. It would suggest a possibility of using 2 spray arms at the same time. The design is more complicated as compared to ASKO and Electrolux but has the same fundamental working principle. The motor however is faster with 4./-8 r per minute suggesting faster switching times between arms.

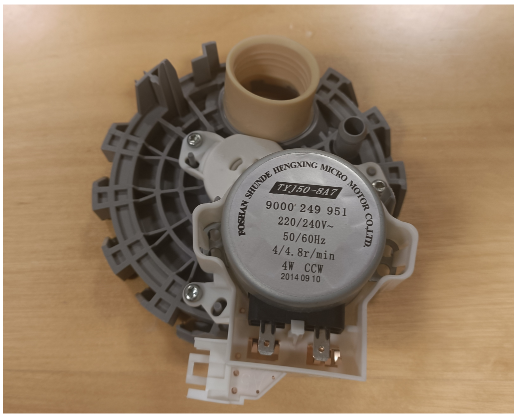

Figure 2.3: Bosch Diverter.jpg

Figure 2.4: Bosch Plate Cutout

Miele

By far one of ASKO's biggest direct competitors in the European market, it becomes extremely important to take a detailed look into their diverters. The diverter housing is larger and consists of the circulation pump, water heating coil and the diverter motor. The diverter motor is 6 rpm faster than Electrolux and ASKO while being comparable to Bosch. The biggest difference is the way the water is diverted to different spray arms. It works more like a pump housing that has slots which can be covered individually using a plastic plate that can be snapped on. This suggests that by covering different combination of slots they can achieve multiple configurations for different models. However, there can be a single configuration for a single machine as once the plates are in place they cannot be changed without manually being dismounted. This leads to the suggestion that the Miele diverter is based on a similar working principle but has a configuration with precise timing and control as no other components or deviations have been found along the path of till the spray arm. The alignment of the rotating slotted chamber is drive by a sector gear that is controlled by a motor. The chamber can rotate in both directions along the length of the geared sector.

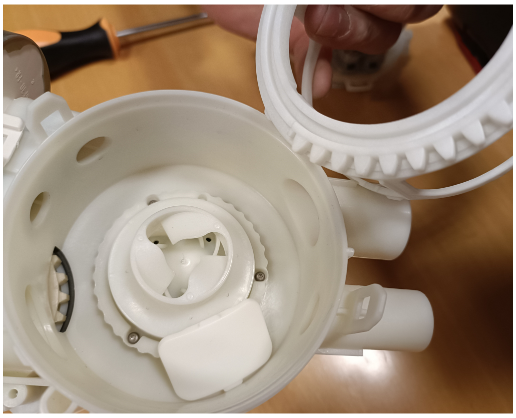

Figure 2.5: Miele Diverter

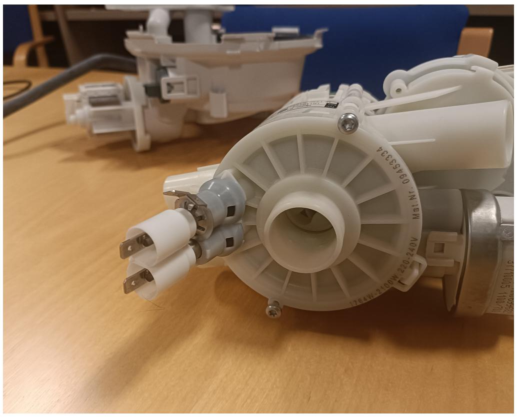

Figure 2.6: Miele Heating unit

3

Requirement Management

3.1 Current Diverter Specification

The existing diverter system consists of 3 parts i.e. the motor and casing, the diverting element and the outlet manifold. The motor utilized is an 4W 220/240V 50/60Hz asynchronous motor with a rpm of 2.5/3. The casing is connected to the diverting element and a mechanical positioning unit. The unit consists of a gear with a mechanical ticker mechanism which resets the starting position before the switch between outlets is done. The motor is connected to a shaft which drives the switching mechanism inside the diverting element.

The diverting element has an inlet hole of 27 mm diameter which receives water from the circulation pump which is connected to the sump where water is collected at the bottom of the dishwashing cabin. The end of the shaft connected to the motor has a plastic plate with a profile slot to divert water to the desired outlet. The slot has 3 positions which direct the majority of the water to one outlet at a time.

The 3 outlets are connected to the lower spray arm, upper spray arm and the top spray arm. The lower spray arm is directly connected to the diverter manifold through an outlet of 25 mm diameter. The other two outlets are 20 mm and 15 mm diameter and are connected to the upper and top spray arms via tubes. When the lower spray arm is switched on the plate with the profile is aligned in such a way that excess water that is otherwise in the tubes leading to the upper and top spray arm flows out of the spray arm at a lower pressure. This is done to avoid the water level rising over the filter thus causing the dirt to splatter on the dishwasher floor, walls or splashing back to the dishes.

Parameters	
Dimensions (mm)	Approximately 150x120x110 mm
Material	Various Plastic Polymers
Weight (g)	
Pressure at inlet	Not Disclosed
Pressure at Outlet (P lower, P upper, Ptop)	7-20
Water Temperature (Operational)	85 degree c
Cost/ piece	Not Disclosed
Water used / cycle	9.7 litres
Motor Specifications	
Type	Synchoronous Motor
Voltage	220/240 V
Watts	4W
Rpm	2.5/3
Manufacturer	Foshan Shunde HengXing
Model	TYJ50-8A7B

Table 3.1: Diverter Technical Specifications

3.2 Requirement Specification

A requirement is a need, target or performance level that needs to be achieved by the product. Requirement specifications help to form a clear understanding of what needs to be developed and how. They are created by collaboration and inputs of different stakeholders associated with the product. They form the basis of the plan created to deliver the desired product or service on time.

In regard to dishwasher diverter technology being developed in this master thesis the requirement specifications are created on the basis of the existing diverter specifications and its limitations that are aimed to address while also taking into consideration some good to have features.

To establish the requirement specifications a detailed study of the technical specifications of the existing diverter is carried out as discussed in the previous subsection. A series of meetings and company visits are also held with ASKO who is the primary stakeholder of the product being developed. This helped to understand the current problems identified by ASKO and varied importance level and need to solve each problem. A set of additional good to have features are also discussed and taken into consideration while formulating the requirement specification sheet.

The requirement specification sheet consists of a list of requirements, the justification explaining the need for that requirement and a way to evaluate the fulfillment of the requirement during product realization and testing. The requirements are classified into 4 categories which are namely Functional requirements, Operational requirements, Reliability requirements and Physical requirements. Each requirement is classified either as a demand or desire and denoted with 'R' or 'D' respectively followed by the serial number in the list.

The key functional requirements include the ability of the diverter to intake water from a single inlet and divert it independently to other outlets with no external leakage and minimum internal leakage. It would also be desirable to have partial diversion of water to multiple outlets and eventually a feature to self clean the chamber of the diverter.

The operational requirements focus primarily on the inlet and out water pressures that need to be maintained during the wash cycles for each spray arm. It also includes the temperature and switching time between spray arms. On the other hand the reliability requirements are formulated to maintain the standards of the ASKO dishwasher components. The physical requirements are focused towards physical integration of the diverter with the existing components inside the dishwasher.The detailed requirement specifications formulated are presented in the table below.

Requirement (Criterion)	Justification	Evaluation
1.Functional Requirement		
R1 Recieve water from source through a single inlet channel	Basic Function of a water diverter in dishwashers	
R2 Divert water to one of multiple spray arm Outlets		Each outlet can be either open or close
R3 No external leakage	Loss in pressure. Possible damage of electronic components.	Visual inspection under operating conditions
D1 Possible to switch water to outlet channels partially	Increased control of wash cycles	Each outlet having 3 modes- Open, Close and partially open
D2 No internal Leakages		Simulation in design phase, Testing in build Phase
D3 Self cleaning of internal volume	Clogging due to dirt and soil	TBD based on the design
2. Operational Requirement		
R1 Maintain required inlet pressure. No pressure loss	Spray arm roation and nozzle spray coverage,	Tests to determine the spray area of each spray arm.
R2 Maintain desired output pressure range at each outlet	force is determined by input and output pressure	No loss in cleaning performance compared to benchmark
R3 Must withshand water termperature of 70 degree celsius	Temperature for effective cleaning (Experimental value)	Equivalent/ Improved cleaning performance compared to benchmark
R4 Maintain adequate sump water level	Filter works only if the sump level is maintained. Can cause recirculation of soil in wash cabin	Volume measurement when each spray arm is used
D1 Low switcing time between spray arms	Time loss due to slow switching	
3. Reliability Requirement		
R1 Product Lifecycle of 20 years	Premium brand with high reliability goals	Long Term Continuous tests. Similar to the ones currently being run at ASKO to test reliability of various components and systems
D1 Limited Moving Parts	Decreases reliability and increases chances of breakdown	
D2 Non reactive material	Dissolved oxygen in water can cause corrosion over time	
4. Physical Requirements		
R1 Must fit within [L*B*H].........(TBD) (Constraint)?	Compact Design	NA
R2 Must be compatible with interface of connecting components.	Limited changes to existing system and component design	NA
D1 Must be lightweight (Quantify Later)	Material and cost Optimization	NA (Possible to compare with benchmark)

Table 3.2: Requirement Specification List

4

Patents Analysis

Patents are an important aspect of New product development as new innovations and inventions are intellectual properties that need to be protected to allow the owner of these rights an opportunity to gain rewards for the work done. They play a key role during the process of developing new concepts as it is important to study prior art and similar existing technologies.

The following table presents a summary of various patents which are similar to the diverter technology in dishwashers. These patents are studied with an aim of understanding different technologies and mechanism used in diverters. Secondly, the patents are also used as an inspiration to generate ideas.

Sr no	Patent Number	Applicant	Inventor	Title
1	EP3510308B1	ILLINOIS TOOL WORKS [US]	KRIEGER JEFFREY J [US]; OLSON JONATHAN H [US]	Clog Resistant Appliance Diverter Valve[3]
2	US11000176B2	MIDEA GROUP CO LTD [CN]	DIGMAN ROBERT M [US]; BOYER JOEL [US]	DISHWASHER WITH ROTATABLE DIVERTER VALVE[4]
3	US10010234B2	WHIRLPOOL CO [US]	LUCIANO JUAN I [US]; RAPPETTE ANTONY M [US]	DIVERTER VALVE AND DISHWASHER WITH DIVERTER VALVE[5]
4	US2020288941A1	FOSHAN SHUNDE , MIDEA WASHING APPLIANCES MFG CO LTD [CN]; MIDEA GROUP CO LTD [CN]	LIU CHAOPENG [CN]; LIU SHANSHAN [CN]	DIVERTER VALVE ASSEMBLY, DISHWASHER, AND HOUSEHOLD APPLIANCE[6]
5	EP2708178B1	Elbi International SpA	Paolo Ravedati; Enzo Brignone; Giovanni Giordano Pasqualino CASO	Diverter valve device, in particular for a washing machine, such as a dishwasher[7]
6	US20180084967A1	Haier US Appliance Solutions Inc	Christopher Brandon Ross; Kyle DurhamDaniel J. Hart	Hydraulically actuated diverter for an appliance[8]
7	US2016213219A1	WHIRLPOOL CO [US]	LUCIANO JUAN I [US]; RAPPETTE ANTONY M [US]; WELCH RODNEY M [US]	Hydraulically-driven dishwasher diverters[9]
8	US2021088147A1	CYCLONAIRE CORP [US]	SCHMID SCOTT MICHAEL [US]; BONICK ZACKARY JAMES [US]	Rotary disc type diverter valve for bulk material handling[10]
9	US2012192903A1	ARMSTRONG JAMES LEE [US]; FROELICHER STEPHEN [US]; BOYER JOEL CHARLES [US]; GEN ELECTRIC [US]	ARMSTRONG JAMES LEE [US]; FROELICHER STEPHEN [US]; BOYER JOEL CHARLES [US]	Water diverter valve and related dishwasher[11]

Table 4.1: Patents-Diverter Technology

5

Functional Analysis

This chapter presents the process of understanding the functions and sub functions performed by the existing diverter today while describing how these functions are related to each other and other dishwasher components and environment. Additionally, new desired functions are derived from the requirement specifications and a combined function tree is made that will form the basis of the ideation phase. Lastly an attempt has also been made to classify all functions based on their importance, priority and interdependency.

5.1 Diverter System Block Diagram

The diverter system in the ASKO dishwasher consists of 5 major components which are the Diverter itself, the sump where all water is collected during wash cycles, the circulation pump, the water heater and lastly the three spray arms which rotate by the pressure of water and spray water on the dishes in the washing basket.

The focus of this thesis is developing to a new diverter. However, that cannot be done by treating the diverter in isolation independent of the system. The entire diverter system must be taken into consideration as a whole and relevant functions of other components impact the diverter functions and performance. For example the function of the sump to 'collect water' serves as an input to the circulation pump whose main function is to 'Pump Water'. The heater is responsible to 'Heat water' for effective cleaning. The function of tubes is to 'transport water' to the spray arm which has the function to 'Spray water' on the dishes. The diverter has the main function to 'divert water' to independent spray arms one at a time. However, each of the functions also have secondary functions that are crucial for maintaining desired operational conditions and performance levels in regard to cleaning, energy efficiency etc.

The diverter system including its components and functions are converted into a block diagram for visual representation of the system and the interrelation of various functions and sub functions. The schematic block diagram of the entire diverter system has been presented below. The illustration below has functions included in boxes like 'Divert water'. The functional decomposition of the system has been discussed in the following section

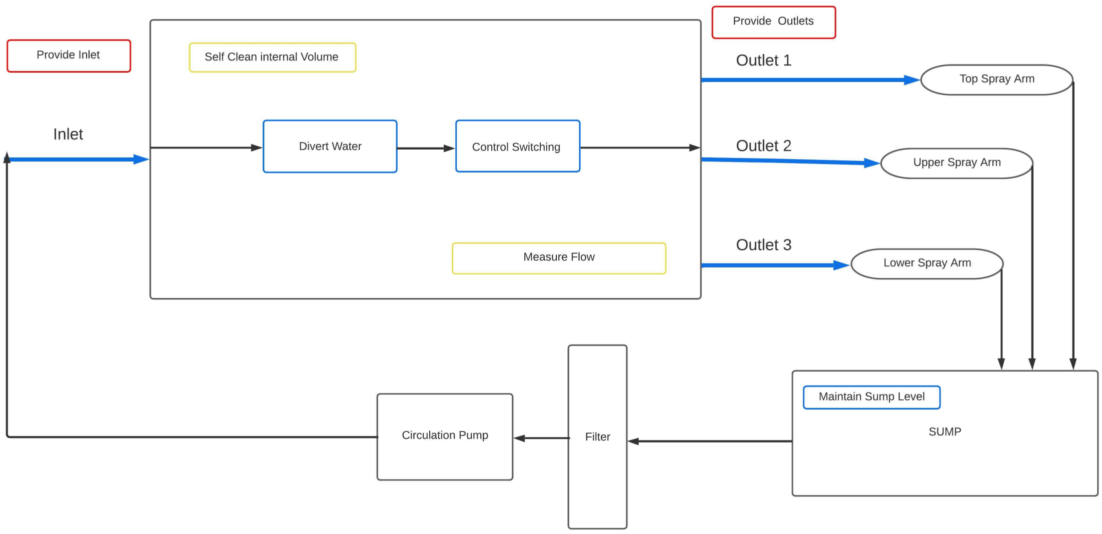

Figure 5.1: Diverter system Block diagram

5.2 Function Tree

The function tree is a tool generally used in the early phase of product development to hieratically decompose the final desired product or service in a set of functions and sub functions. The function is typically written in the form of a verb and noun and can have a brief description. This can be done using either a top-down approach or a bottom up approach.

The main aim of the function tree is to ensure that all functions relevant for the design and development of the product are accounted for in the early stages itself. This reduces the design gaps or oversight that can be caused in complex products with multiple functions and interrelations. The design and conceptualization process is streamlined as the product can be developed in smaller parts rather than the entire product all at once. The functions can be classified, and primary functions can be addressed before other functions. It can also be used a tool for solving problems at a functional level. For example a problem can be solved by introducing a function to target it specifically.

The relevant functions necessary for a diver system and additional functions needed to solve problems were combined and are illustrated below in the function tree diagram. The function tree decomposes the entire water distribution system of which the diverter is a part. It is important to also note that the function of maintaining sump level can be performed independently or can be a function of the diverter as well.

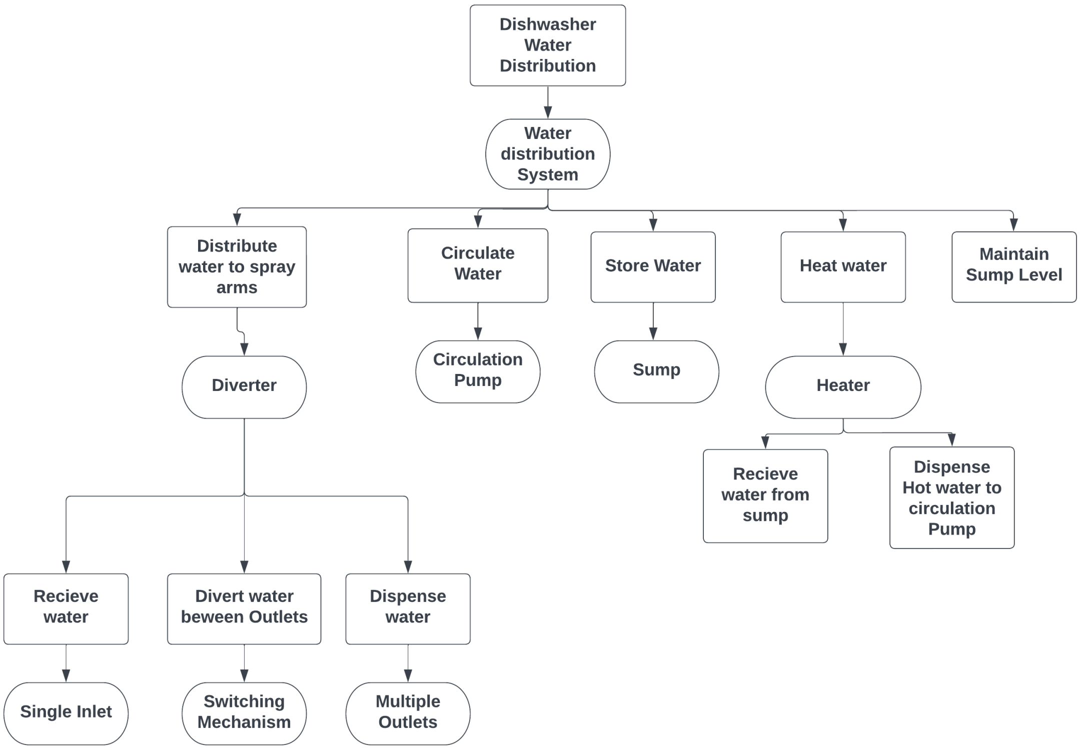

Figure 5.2: Function Tree Diagram

5.3 Classification of functions

There are 8 functions that are found to be important to develop a diverter. They are further classified as primary functions, basic functions and desirable functions. The list is presented below.

- **Primary Functions**
  1. Divert Water
  2. Maintain Sump level
  3. Control Outlet switching
- **Basic Functions**
  1. Provide Single Inlet
  2. Provide Multiple outlets
- **Desirable Functions**
  1. Self clean Internal volume
  2. Measure Flow
  3. Divert water partially

  In the next stage of the development process the solution is focused towards fulfilling the primary and basic functions of the diverter with the view of treating desirable functions as an add-on that can be later incorporated in the design. More details are discussed in the next chapter.

6
Ideation

6.1 Ideation Process and Tools

The overall aim of the ideation process is to generate multiple ways that each function can be fulfilled. The source of the ideas is not restrained or confined to a specific domain. It can be self generated ideas, ideas inspired from existing solutions in the market, different applications in a similar area, previous patents, observations etc. In a product development context this is the stage where the funnel of ideas is widened as much as possible to cover a wide range of solutions without a strong consideration of its feasibility, operational challenges and technicalities.

In this thesis project the strong emphasis of finding ideas is through investigating existing solutions and patents, exploring relevant application areas and taking inspiration from existing products in the market. In order to structure the search for ideas the relevant or potential application areas are identified within each function. It is important to note that as discussed before this is done for primary and basic functions while excluding the desirable functions which are decided to be added on at a later stage. The reason for not considering the desirable functions at this stage is that it would make the overall process more complex and could potentially lead to a solution with a compromise on the key functions of the diverter while trying to incorporate desirable functions. For example a compromise on requirement of internal or external leakage would affect the main functionality of a dishwasher diverter. If the diverter is prone to leakage it cannot be used at all. Thus, the focus is to create a solution that has the primary and basic functions of a diverter covered while the desirable functions are seen as a nice to have feature.

In each application area Keywords are identified and noted that would drive the search in literature, patents and also existing solutions. New keywords are added throughout the process of ideation whenever necessary. These new keywords could be based on the findings and results of the previous keywords or relevant to the ideas generated. A color scheme is used to differentiate between keywords that have generated ideas and the ones which have not. Keywords relevant to the ones that have lead to ideas are then added thus increasing the chance of finding more ideas. The ideas that are generated and then recorded in a table which describes the idea, states its source and also maps it to the keyword that led to the idea. This list is presented and discussed in the following subsection.

The following table enlists the keywords used during the course of the ideation process.

Function 1- Switch/ Divert water

Application Area	Keywords					
Pipes and valves	Diverter valve	Water diverter	Fluid Diverter	Multiple outlet valve	Sliding gate valves	Multi-stage sliding valve
	Solenoid valve with sliding plunger	Directional control valve	Rotary valves	Flow distribution valve	Fluid flow control valve	
	Valve control system	Automatic flow control valves	Fluid regulation system	Globe valve	Diaphgram valve	Butterfly valve
Professional Dishwashers	Winterhalter	Variable pressure dishwasher	Variable pressure washer			
	Miele	Tank System				
	Ge appliances	Dishwasher Variable Pressure Jets				
Liquid Dispensers	Multi liquid dispenser	Dispenser Outlet				
Food manufacturing industry	Plug Diverter	Sanitary valves				
Water treatment	Fluid separation	Water segregation	Water distribution system	Water splitter	Fluid distribution system	
Liquid transfer systems						

Table 6.1: Keywords-Divert Water

Maintain Sump Level

Application Area	Keywords				
Volume and flow	Varying volume chambers	Void volume in flow path	Sump level control	Variable flow rate systems	Flow balancing systems
Surge tanks	Surge tank systems	Surge arresters	Surge relief valves		
Accumlators	Hydraulic accumulators				
Sensors and flow meters	Flow meter	Flow sensor	Water level sensor		
Industrial processes	Fluid transfer systems	Industrial Control valves	Continuous flow systems	Process fluid control systems	
Water treatment	Tank level monitoring systems	Sump pumps	Water distribution systems		

Table 6.2: Keywords-Maintain Sump Level

Function	Application Area	Keywords
Control Outlet switching	**Electromechanical**	**Rotary actuators**
	Screw -Driven	Servo motors
	Belt- driven linear	Stepper motors
	Rack-pinion	Synchoronous motors
	Linear motor	
	Solenoid	
	Linear servo	

Table 6.3: Keywords-Control Outlet Switching

6.2 List of Ideas Generated

Using the keywords multiple ideas are generated to fulfill each application as mentioned before. These ideas are summarized in a sheet with reference to the source of the idea and are presented in the following table.

Function	Serial number	Category/ Application area	Title	Description	Keyword
Divert/Switch Water	1.1	Piping and valves	Plunger connector	Block with multiple outlets and a piston/ plunger which can slide to provide connection	Diverter Valve
	1.2		Gear transmission slot	It is a gear which aligns a single outlet hole to the chamber/ inlet surce. Similar to existing designs	Diverter Valve
	1.3		Hydraulic Connector	Single piston which can simultaneously open one slot while close the other	Diverter Valve
	1.4		Revolving Slot	The slot reloved aroud its axis and aligns the inlet and outlet. It can also cut off the supply betweeen the two.	Diverter Valve
	1.5		Single actuator multiple position	Similar to 1.2 and similar designs but has a motor for axial retation as well as a place that can be moved in lateral direction to engange/disengage the Hole	Diverter Valve
	1.6		Rotating Inlet, Fixed Outlets	Cube with multiple outlets. Inlet can rotate within the cube to supply water to desired outlet	Diverter Valve
	1.7		Rotating Sector in Pipe	A rotating sector that channels the flow of water by blocking the other available outlets using a rotating sector	Water diverter
	1.8		Multiple outlet Valve	Simple 4 way valve with independent open/close knobs	Multiple outlet Valve
	1.9		Sliding gate valve	A gate controls the flow of liquid from one end to another	Sliding gate valve
	1.1		Sliding plate with slots	The sliding plates aligns with a matching slot to enable liquid transfer	Sliding gate valve
	1.11		Sliding carriage with slot and spring	A piston aligns 2 slots based one 2 stroke distances. One plate is fixed while other acts as a carriage	Sliding gate valve
	1.12		Linear sliding gate valve	Uses a ratchet to control flow from orifice at multiple positions	Sliding gate valve
	1.13		Sliding gate valve.2	A gate controls the flow of liquid from one end to another	Sliding gate valve
	1.14		Directional control vavle	A sliding arrangement which connects diferent slots to form a passage	Directional control vavle
	1.15		Multi outlet- gear driven diverter valve	A gear connects the different outlets to the linear sliding inlet.	Multiple outlet valve
	1.16		Multiple solenoid control valvles	Each valve can open and close fully + partially open thus have a lot of different control possibilities	–
Maintain Sump Level	2.1	Volume and flow	Varying volume chambers	Have 3 different chambers associated with each flow path before the diversion	
	2.2	Volume and flow	void volume	have a void volume relating to the excess amount of water in the flow path after the diversion	
	2.3	Dishwaher Sump	Sump re-design?	Redesign the sump to incoporate more water so as to have water level always below the filter	
	2.4	Surge tank	Surge tank	The Surge tank will provide extra water when demand is very high and will suck water when demand is very low	
Control switching time	3.1	NA	Half gear spring loaded	Linear motion - Half gear to shift linearly in one direction and retractable spring to bring it to position one	
	3.2	NA	two way Linear	Linear mmotion in both directions controlled by a rotational or linear actuator	
	3.3	NA	Rotary	Use a motor attached to the rotating mechanism	
	3.4	NA	Linerar- sliding Gear mechanism	A rotary motor with gear meshed to a rack for linear motion	

Table 6.4: List of generated Ideas

For unambiguous organization each of the idea is given a title and a serial number which maps the function number and idea number. For example Idea 1.1 signifies that it belongs to the first function i.e. 'Divert water' and the first idea with the title 'Plunger connector'. Each idea is also briefly described in order to state the basic working principle. For effective file management the source PDFs and documents are saved using the same serial number.

6.3 List of Alternatives

The ideas generated using keyword searches are then used as an inspiration to develop multiple alternatives to fulfill each function. Each alternative is defined with a clear working principle and illustrated with a diagram. The alternatives are used as an input in the morphological matrix which is the primary tool used for concept generation. A detailed explanation of the morphological matrix and how it is used during the course of the thesis is presented in the upcoming chapter.

The different alternatives for each function are explained below in detail. Alternative solutions which have variations they are explained and illustrated as well with naming done using alphabets. A table is also created to present the list of alternatives as a summary. The Table includes the title of each alternative, a short description and the ideas that were taken inspiration from for creating the alternative.

1. **Divert Water**

    1.1 **Sliding plate**

    The alternative solution consists of a sliding plate with holes cut out. One individual hole is for each outlet that is connected to a spray arm. The sliding plate has one open slot that aligns to the desired outlet. When one outlet is active the length of the plate is such that it blocks other outlets. Thus, one outlet is active independently at a time.

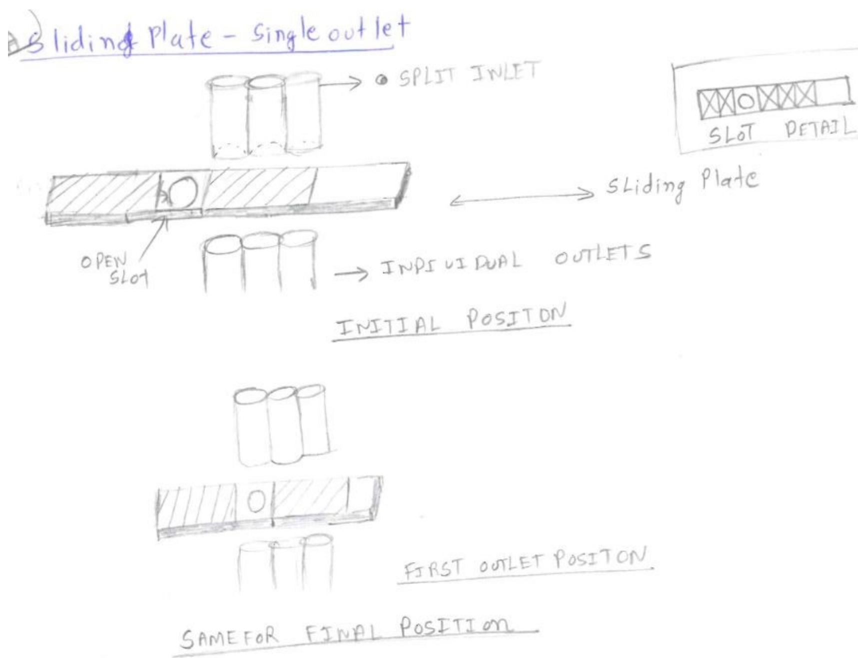

Figure 6.1: Sliding Plate a

This principle can also be used to generate a partial flow in two outlets simultaneously. This can be done by modifying the open slot from circular to elliptical slot such that two outlets share the flow.

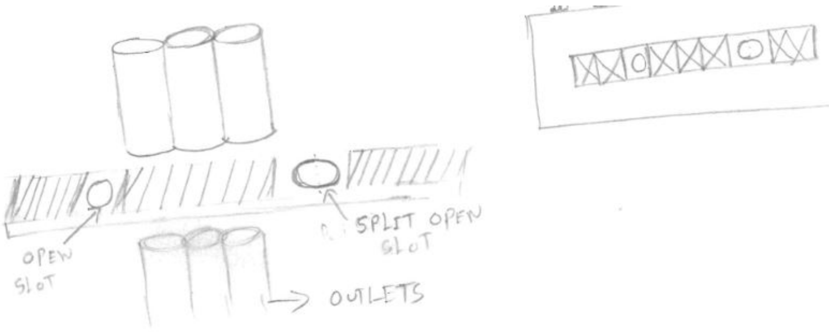

Figure 6.2: Sliding Plate b

Alternatively two diverters with two sliding plates as illustrated below can be used. In this sub solution each diverter will have two outlets. One outlet will remain blocked while the other one will be open. The water flowing from the inlet can directly pass to an outlet or act as an inlet to a second diverter. The second diverter has a sliding plate similar to the first one and guide the water to outlet two or outlet three.

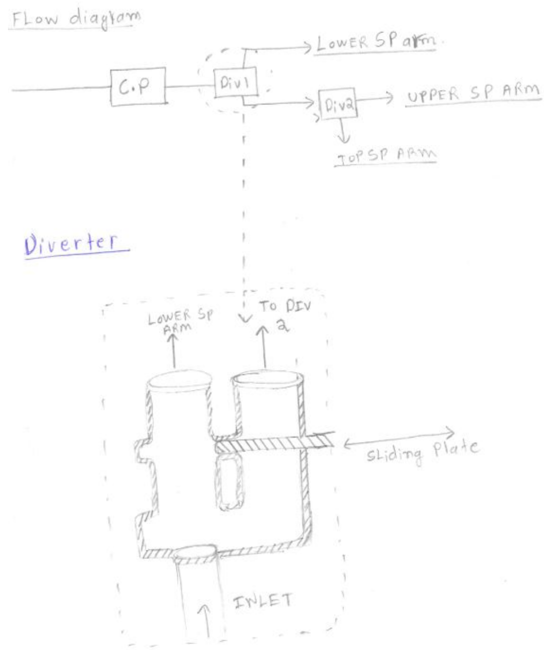

Figure 6.3: Sliding Plate c

1.2 **Rotating inlet, fixed outlet**
This alternative solution consists of a single inlet which is connected to outlet ports which are mutually perpendicular to each other. The inlet rotates aligning itself with the desired outlet. The inlet is connected to the pump using an interface housing a bearing.

A variation of this alternative solution could be adding a fourth outlet which further branches out ad acts as input to two of the three outlets from a separate path. This can provide an opportunity for partial flow.

The illustration below represents the alternative solution.

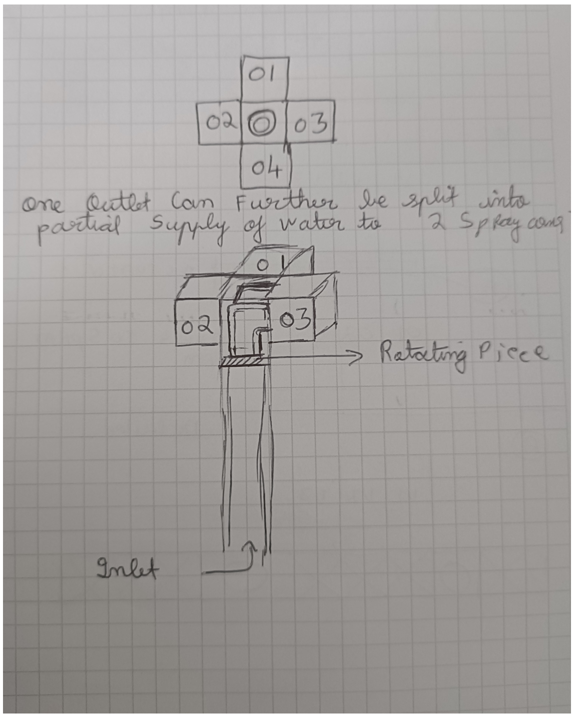

Figure 6.4: Rotating inlet, fixed outlet

1.3 **Sliding inlet fixed outlets**
In this alternative the outlets are in a series and each outlet is connected to the spray arm. The inlet is represented by a flexible hose which move linearly and aligns to the desired outlet. Since the inlet is moving the outlets not in use do not need to be blocked.

Another variation of this concept is using a 4th outlet which can branch out and serve as input to two of the spray arms. Thus providing a potential for partial flow.

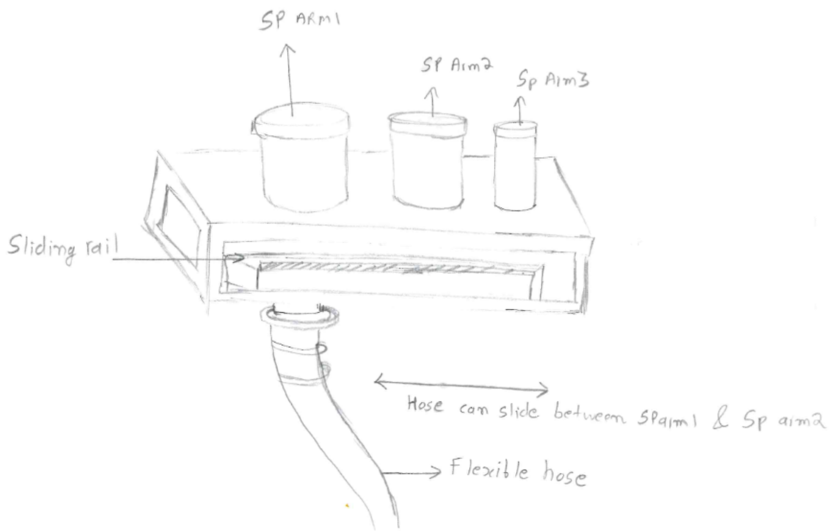

Figure 6.5: Sliding inlet fixed outlet

1.4 **Ball valve**
This alternative solution is inspired from a ball valve which is a spherical ball with a cut-out within to channel the water to different outlets. Multiple outlets can be made with the core idea that the spherical profile of the ball valve will block other outlets when one is active.

1.5 **Multi solenoid**
In this alternative the main idea is to have multiple valves which can open and close to allow independent flow of water. The inlet is split into three channels with the valve connected to each inlet. The Valve is also connected to three individual outlets. The valves have the possibility to vary the flow rate thus giving great control. This makes it possible to have partial flow in each spray arm simultaneously.

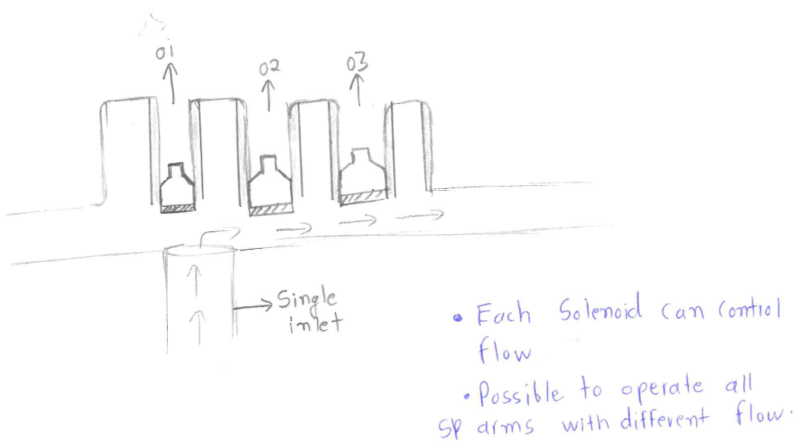

Figure 6.6: Multi solenoid a

Another variation of this idea could be having the three outlets with valves perpendicular to each other. This is similar to the existing configuration of diverter outlets. The advantage that this variation can bring is eliminating the need to split the inlet in three to facilitate three valves. The three valves can be placed on the outlets directly.

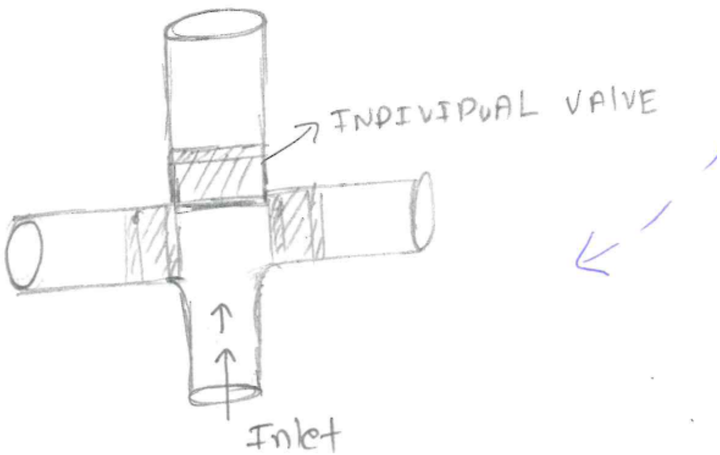

Figure 6.7: Multi solenoid b

1.6 **Split inlet with spool**
The potential solution is inspired by a 3/2 or 5/2 Hydraulic valve where a spool inside channels the water between the inlet and outlet and also between channels. The main idea is utilizing this spool like sliding part within a container with the aim to divert water. The basic idea consists of the inlet split into three and a spool within redirects the water to respective outlets one at a time. The spool can be designed in different ways while keeping the core principle the same.

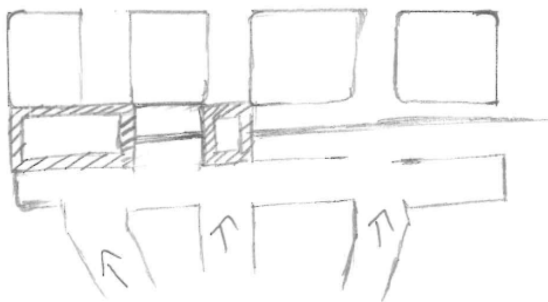

Figure 6.8: Split inlet with spool a

A variation could be to use the perpendicular outlet setup as discussed in the previous idea and have a bridge type spool with a slot in the center to let water pass through directly to one spray arm. The spool can move left or right and direct the water to the outlets on the left or right while the spool blocks the other outlets.

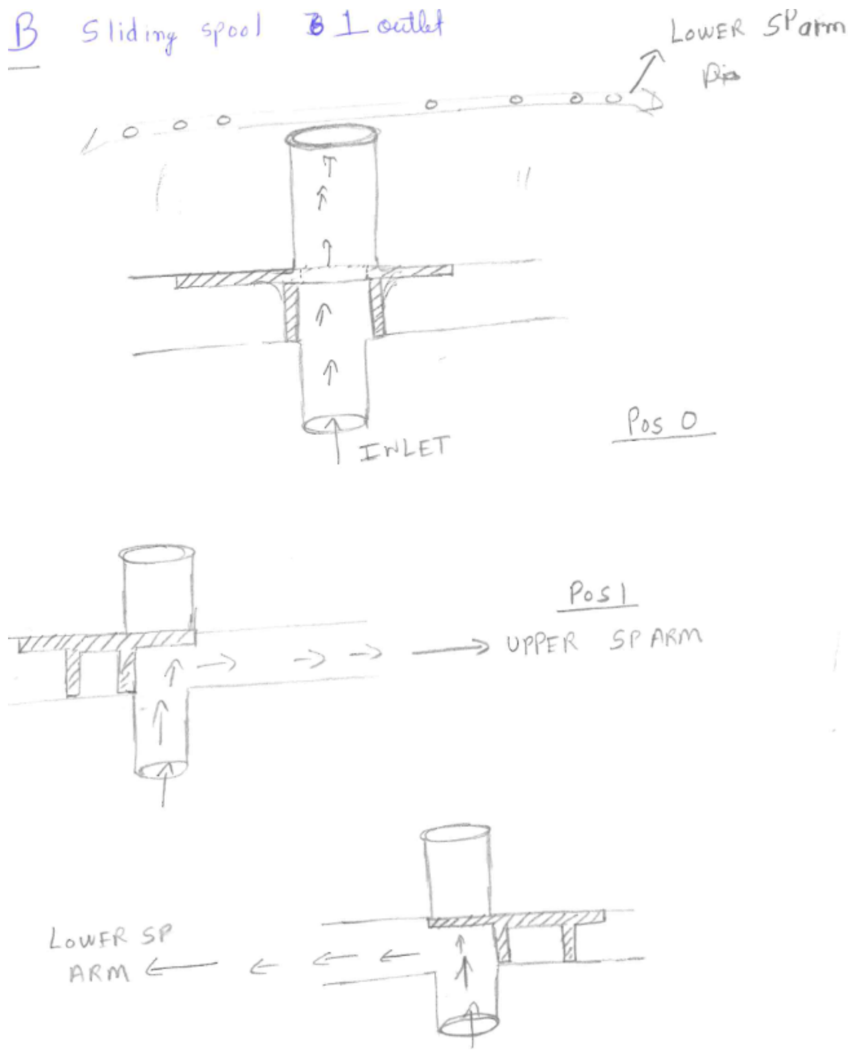

Figure 6.9: Split inlet with spool b

1.7 **Revolving section**
This solution is inspired from a rotating valve to divert water in piping. A section of pipe is between the inlet and outlets. This section is straight and connected to one outlet in the normal position wherein the water flows directly through. The section can revolve and align to the other outlets.

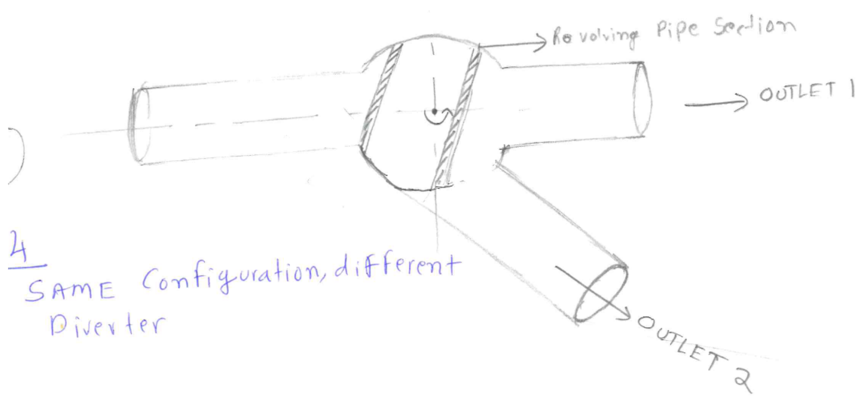

Figure 6.10: Revolving section

1.8 **Sector alignment**
The idea is similar to the previous idea of revolving section. In this idea the revolving section is replaced by a revolving sector that deflects the water. The inlet is not disconnected at any stage like in the previous idea. Multiple sectors can be created to deflect water to the outlets.

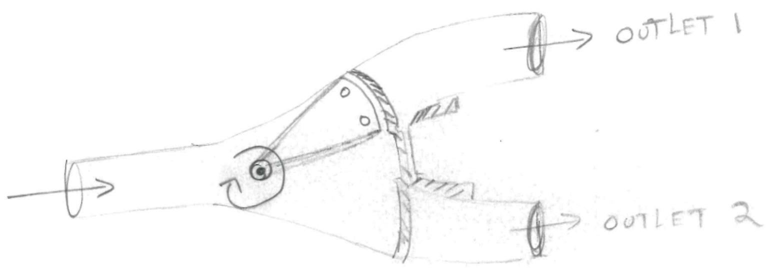

Figure 6.11: Sector alignment

2. **Maintain Sump Level**

2.1 **Varying Volume chamber**

The first idea to maintain sump level is to have different chambers before the inlet of different volumes where each volume corresponds to the difference in water level that has to be maintained. Thus, whenever one flow path is active the volume in that path is adjusted. For example if the top spray arm is active in the current configuration of diverter used by ASKO no volume chamber at the inlet is needed as all the water is utilized in the circulation cycle. However, if the upper or lower spray arm is active the excess water has to be managed. One possible way to do it is using two different volume chamber at the inlet which can hold this excess water when the circulation cycle is running.

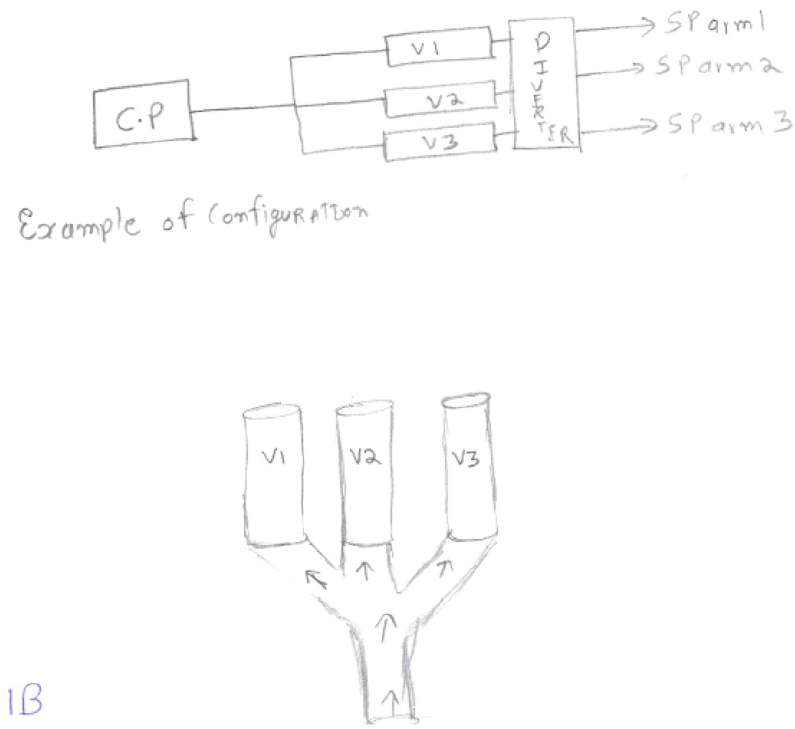

Figure 6.12: Varying Volume chamber

2.2 Varying volume in flow path

The solution presented here is similar to the first one, but the adjustment for excess water is done in the flow path rather than the inlet or outlet of the diverter. This adjustment can be done using a varying void volume, or it can be done using a change is pipe diameters in a way which does not affect the required pressure.

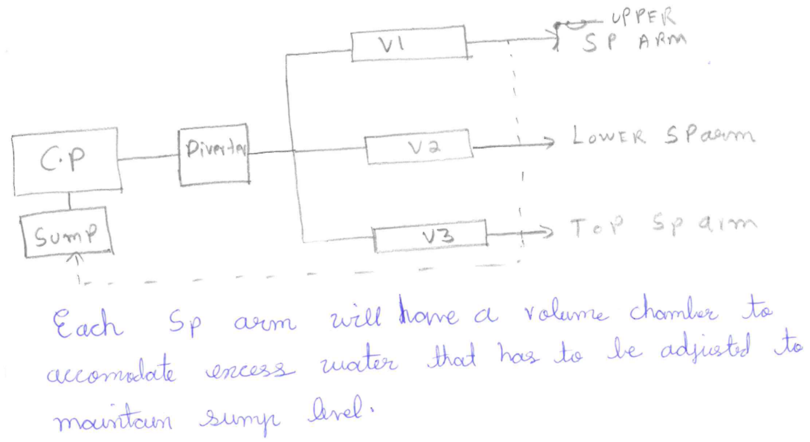

Figure 6.13: Varying volume in flow path

2.3 Sump re-design

The easiest way to solve this problem could be to redesign the sump is such a way that is holds all the water so that the water level does not exceed the filter. This would mean to have a lager sump which is attached to the circulation pump.

2.4 Surge tank

A potential solution could be to have a surge tank which stores the excess water temporarily when the circulation cycles are on. This tank will have inlet on one side on the top while its outlet on the bottom. The tank is positioned below the sump, so water can flow easily to the tank whenever needed and the circulation pump helps pump out water whenever the relevant spray arm circulation cycle is activated.

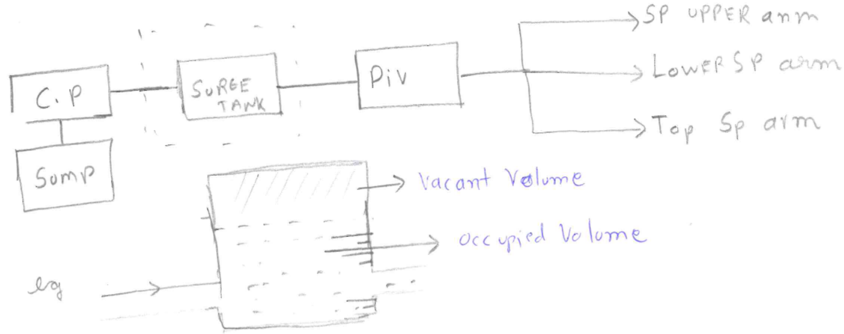

Figure 6.14: Surge tank

3. Control Switching Time

The switching action between individual outlets can be deigned to have the least possible time to reduce overall dishwashing cycles.

3.1 **Half gear spring-loaded**

This idea provides linear translation motion to enable switching between outlets in the diverter. It consists of a spring-loaded rack and a gear with teeth on half of the circumference. The gear rotates and moves the rack linearly in one direction. The end of the rack is connected to the linear switching mechanism in the diverter. Once the last tooth is engaged and the gear rotates further the gear slips off, and the spring retracts the rack to the starting position.

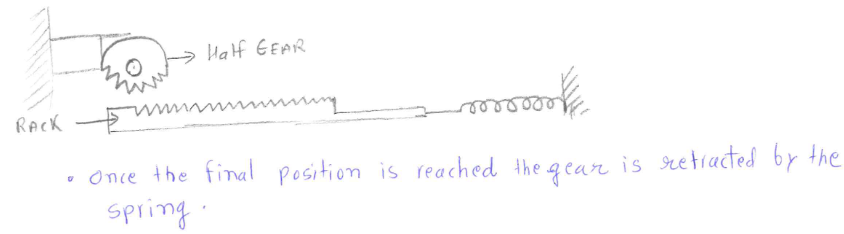

Figure 6.15: Half gear spring-loaded

3.2 **Two-way Linear**

A simple linear actuator that moves in two direction. This can be brought about by various electromechanical actuators.

3.3 **Rotary**

A simple rotary actuator which can be brought about by different types of rotary devices like motors.

Since there are multiple ways to bring about both linear and rotary motion for the switching mechanism a decision is made to categorize the function by two general ideas in terms of type of motion and not the actual mechanism that can bring about this motion. All ideas until this point were based on linear motion or rotary motion for switching between diverter outlets. Thus, the two alternatives that were used as input to the morphological matrix were 'Linear Translation' and 'Rotary Motion'.

The process of generating the morphological matrix is explained in detail in the next chapter.

To summarize this chapter a summary table of all alternative solutions with a brief description is presented below.

Function	No	Alternative solution name	Description	Idea Mapping number
Divert water	1.1	Sliding plate	Sliding plate with holes	1.9,1.10, 1.11,1.12
	1.2	Rotating inlet, fixed outlet	Have 3-4 fixed outlet channels/tubes. Rotate the inlet to align with the desired output channel	1.6,1.8
	1.3	Sliding inlet fixed outlets	Have 3-4 fixed outlets and a sliding inlet with a flexible hose	1.15
	1.4	Ball valve	Have a sphere with an L shaped inner cutout. Rotate the cutout to align to various fixed outlets	1.6.1.8
	1.5	Multi solenoid	Each solenoid can open/close and partially open at various position with numerous flow control options	1.16
	1.6	Split inlet with spool	Inspired from hydraulic direction flow valve	1.14
	1.7	Revolving section	A section of pipe revolves and aligns with outlet	1.4
	1.8	Sector alignment	A rotating sector in Y channel	1.7
Maintain sump Level	2.1	Varying Volume chamber	Have 3 chambers of necessary between the circulation pump and the diverting mechanism	2.1
	2.2	Varying volume in flow path	Have a void volume in each flow path	2.2
	2.3	Sump re design	Redesign the sump to incorporate more water to have water level always below the filter	2.3
	2.4	Surge tank	A chamber in the vertically Upward-Downward direction which can provide extra volume space in the flow path	2.4
	2.5	Sump surge	Modification to the sump or area around it to incorporate a surge tank like structure	2.4
Control switching time	3.1	Half gear spring-loaded	Linear motion - Half gear to shift linearly in one direction and retractable spring to bring it to position one	
	3.2	Two-way Linear	Linear motion in both directions controlled by a rotational or linear actuator	
	3.3	Rotary	Use a motor attached to the rotating mechanism	
	3.4	Linear-sliding Gear mechanism	A rotary motor with gear meshed to a rack for linear motion	1.15

Table 6.5: List of alternatives

7

Concept Generation

In the previous chapter the process of generating alternatives and a list of alternatives are thoroughly discussed. In this chapter these alternatives are combined with each other to form complete conceptual solutions of a dishwasher diverter system. A combination of conceptualization tools and logical reasoning is used in this process with the aim is to create of set of concepts that can be evaluated using a set of criteria.

The first subsection explains the morphological matrix as a tool in product development and then presents the morphological matrices created. In the next subsection the process of synthesizing alternatives and forming concepts is illustrated and finally a list of concepts is presented.

7.1 Morphological Matrix

The morphological matrix is a tool that is used to systematically generate concepts and design solutions. The basic idea is to break down the system in functions and then systematically combine each alternative solution with other alternative solutions in the matrix resulting in one complete solution. The end result of a morphological matrix is to end up with multiple configurations of the alternatives present in the matrix.

The main advantage of this approach is it allows the product developer to explore a large design space in a structured manner. Secondly, it is used to enhance creativity and innovation as combining different alternative solutions can lead to new ideas. It is also a visual tool to communicate ideas and concepts which help for better decision-making.

The morphological matrix for this thesis project has alternative solutions in subsequent columns and the corresponding functions in subsequent rows. The matrix table is presented below.

Sr no	Function	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5	Alternative 6	Alternative 7	Alternative 8	Alternative 9
1	Divert Water	Sliding plate	Sliding inlet fixed outlets	Multi solenoid	Split inlet with spool	Sliding inlet fixed outlets	Ball valve	Rotating inlet, fixed outlet	Revolving section	Sector alignment
2	Maintain Sump Level	Varying Volume chamber	Varying volume in flow path	Sump re design	Surge tank					
3	Control switching	Linear	Rotary							
4	Provide Inlet	Single inlet	Single inlet Split into 3 channels							
5	Provide Outlet	Multiple Individual Outlets								

Table 7.1: Morphological Matrix

On careful analysis it is seen that function number three 'Control Switching' has two alternative solutions which include a linear motion enabling translation in the switching mechanism or a rotary motion. As mentioned in the previous chapter each alternative solution is compatible with either linear motion or rotary motion. Thus combining alternatives to form concepts would lead to many incompatible solutions. To avoid this the morphological matrix is split into two matrices.The first matrix is linear solutions and is given the name 'Morphological Matrix-Linear' while the second one comprises only of rotary solutions and is given the name 'Morphological matrix-Rotary'. These matrices are presented below.

No	Function	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5	Alternative 6	Alternative 7	Alternative 8
	Principle	Sliding plate			Multiple control valves		Sliding spool		Sliding inlet fixed outlets
1	**Divert Water**	Sliding plate-Single Outlet	Sliding plate-Single + Split Outlet	Dual Sliding Diverter	Multi solenoid-Parallel outlet	Multi solenoid-Perpendicular outlet	Sliding Horizontal Spool	T Spool	Sliding inlet fixed outlets
2	**Maintain Sump Level**	Varying Volume chamber	Varying volume in the flow path	Sump re-design	Surge tank				
3	**Control switching**	Linear actuator							
4	**Provide Inlet**	Single inlet	Split Inlet						
5	**Provide Outlet**	Multiple Individual Outlets							

Table 7.2: Morphological Matrix-Linear

No	Function	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5
	Principle	Ball valve		Rotating inlet, fixed outlet	Revolving section	Sector Split
1	**Divert Water**	3 outlets Ball valve	3+ combination outlet ball valve	Rotating inlet, fixed outlet	Revolving section	Sector Split
2	**Maintain Sump Level**	Varying Volume chamber	Varying volume in flow path	Sump re-design	Surge tank	
3	**Control switching**	Rotary actuator				
4	**Provide Inlet**	Single inlet	Single inlet Split into 3 channels			
5	**Provide Outlet**	Multiple Individual Outlets				

Table 7.3: Morphological matrix-Rotary

7.2 List of Concepts

Once the Morphological matrices are created the next step in the process is to synthesize the alternatives to form concepts. It is important during this process to have a well-defined structure and labelling to produce as many as possible relevant concepts without ambiguity. Thus, a standard naming scheme is followed where all concepts are named in accordance to the function and alternative number. The name itself denotes the alternative and the position of the function. For example in the number '1124' the number two denotes the alternative number while the third position denotes the function i.e. 2nd alternative of the third function. Thus, each number is unique and represents a single concept. Since there are two matrices a single Letter before the concept number represents which matrices the concept belongs to. The letter 'L' denotes Linear motion concepts and the letter 'R' denotes rotary motion concepts. For example If the concept is named 'L-1124' it belongs to the Linear group of matrices.

An important thing to note is that during the process of creating concepts the compatibility of alternative solutions with the other solutions is taken into consideration. This is done with the same point of view of avoiding incompatible solutions which created increased complexity to filter out at a later stage. For example the concept L-11111 is not taken into consideration as the alternative 1 for the function 'Divert water' is not compatible with a single inlet but rather would require a split inlet. A similar process is carried out and a list of 35 concepts is created which is presented in the table below.

On further analysis of the morphological matrices some alternatives are found which can carry about more than one function thus making the other alternative solution redundant. In the design and development it is always beneficial if one feature can perform more than one function thus eliminating the need for an additional feature. For instance the alternative of 'varying volume chamber' to maintain sump level and the alternative of 'split inlet' can be combined as the split inlet can itself act as 'Varying volume chamber' if designed accordingly thus eliminating the need to have an extra feature. The concepts which have both these concepts were identified. One of the concepts is carried forward while the remaining redundant concepts are removed. This process is repeated for both linear and rotary concepts and the final list of concepts is created. The following table presents the final set of concepts which are taken forward to the evaluation stage.

Sr. No	Concept number	Comments
1	L-11121	
2	L-12121	Redundant 2 and 4 alt, Can be combined
3	L-14121	Redundant 2 and 4 alt, Can be combined
4	L-21121	
5	L-22121	Redundant 2 and 4 alt, Can be combined
6	L-24121	Redundant 2 and 4 alt, Can be combined
7	L-31111	
8	L-32111	Possible reduntant 2 and 4, investigate
9	L-34111	Possible reduntant 2 and 4, investigate
10	L-41121	
11	L-42121	Redundant 2 and 4 alt, Can be combined
12	L-44121	Redundant 2 and 4 alt, Can be combined
13	L-51121	
14	L-52121	Redundant 2 and 4 alt, Can be combined
15	L-54121	Redundant 2 and 4 alt, Can be combined
16	L-61121	
17	L-62121	Redundant 2 and 4 alt, Can be combined
18	L-64121	Redundant 2 and 4 alt, Can be combined
19	L-72111	
20	L-74111	
21	L-81111	
22	L-82111	
23	L-84111	
24	R-12111	
25	R-14111	
26	R-22111	
27	R-24111	
28	R-32111	Redundant 1 and 2 alt, Can be combined
29	R-34111	Redundant 1 and 2 alt, Can be combined
30	R-41111	
31	R-42111	Redundant 4 and 2, Can be combined
32	R-44111	
33	R-51111	
34	R-52111	Redundant 4 and 2, Can be combined
35	R-54111	

Table 7.4: List of all concepts

Sr No	Concept number
1	L-11121
4	L-21121
7	L-31111
10	L-41121
13	L-51121
16	L-61121
19	L-72111
20	L-74111
21	L-81111
22	L-82111
23	L-84111
24	R-12111
25	R-14111
26	R-22111
27	R-24111
30	R-41111
32	R-44111
33	R-51111
35	R-54111

Table 7.5: Final List of concepts

In order to evaluate concepts it is important to be able to visualize and understand the components of the concept as a system rather than individual alternative solutions. Thus, each concept in the list of final concepts is illustrated using a basic system diagram consisting of the relevant components of the diverter system. These illustrations are then used during the evaluation process for side by side comparison and also to get a better understanding through visual representation. The illustrations are presented in the appendix A.1 and appendix A.2.

8

Concept Evaluation

In this chapter the evaluation process of the concepts to find the best remaining concepts is thoroughly explained. Firstly the criteria for evaluation is defined based on requirements of the diverter set earlier. This set of criteria is then used to evaluate concepts using evaluation tools 'Pugh matrix' and 'Kesselring Matrix'. Lastly, the remaining concepts are presented in detail which are taken forward in the thesis.

8.1 Evaluation Critera

The first step in any evaluation process is to define the criteria which is to be used for the evaluation. It is the most important part of the evaluation process as the criteria drive the selection process and influence the concepts which stand out over the remaining concepts. The criteria provide the basis for evaluation and making informed decisions through objective analysis. Some key advantages of a well-defined criterion include decision transparency, side by side comparative analysis and structured decision-making process.

Requirement specifications are used as the basis to define the criteria. A list of relevant criteria is drawn up. For example for the functional requirement R1 'Receive water from source through a single inlet channel' and R2 'R2 Divert water to one of multiple spray arm Outlets' the relevant criteria selected is limited or no pressure drop. The requirement for no external leakages lead to the criteria of Adequate sealing. Criteria are similarly drawn out for the operational, Physical and reliability requirements. The list of criteria obtained after this process is presented below.

- Pressure Loss
- Sealing
- Partial flow possibility
- Internal Leakage
- No of components
- Design Complexity
- Cost
- Switching Speed
- Size
- Safety
- Reliability
- Number of moving parts

In order to ensure that the most relevant and important criteria are taken into consideration for the selection process, a review of each criterion is done. Based on this review, certain criteria are eliminated.

External sealing is an important criterion which is also the main contributor towards safety as the diverter cannot leak externally into the dishwasher. The leakage is directly linked to the switching mechanism as it only thing which connects the inner and outer part of the diverter. The switching mechanism is to be decided at a later stage. Thus, it is decided to eliminate these criteria at this stage and bring it back into consideration while designing the switching mechanism. Similarly, as switching speed is also determined by the switching mechanism, it can be considered during the selection of switching mechanism.

During the review, it is also decided that the cost and reliability of the system is not important at this stage. The cost can be reduced in the latter stages of development where factors like sourcing, economies of scale etc. are taken into consideration. Including cost in pre-development has the risk to block potentially viable and good solutions purely based on individual component costs. ASKO products are build to be reliable for 20 year life cycle, thus this can be taken care of in the later stage during component selection and build of the product.

Thus, the list of criteria is revised and presented below.

- Pressure Loss
- Partial flow possibility
- Internal Leakage
- No of components
- Design Complexity
- Size

The criteria selected are all important, but they are not equally important for the diverter system. Some criterion have higher weight than other criterion. This is an important factor in the selection process as it influences the selection process greatly. This ensures that the solution that emerges is in accordance with the most critical requirements. Other aspects of the diverter system can be eventually modified, replaced or upgraded to form an even more complete and robust system. The weightage to each of the criteria is assigned by giving higher consideration to functional and operational requirements and in close collaboration with the company. Once the weightage is set, it is used throughout the concept evaluation process, which is explained in the upcoming subsections. The weightage of each of the criteria is given in the table below.

Weighted Criteria	Weight (%)
Pressure Loss (Minimum)	30
Partial flow possibility	15
Internal Leakage	35
No of components	10
Design Complexity	5
Size	5

Table 8.1: Criteria Weightage

During the course of the evaluation various decision matrices and decision-making tools were considered. However. PUGH and Kesselring matrices are considered for this project due to their close relevance and weight based decision-making which is the priority in this thesis.

8.2 Pugh Matrix

The first tool that is used in the evaluation process is the Pugh matrix, which helps to systematically compare concepts using a set of predefined criteria. In this process, a matrix is created with the concepts in columns while the weighted criteria is written in rows along with their multiplication factors based on weighted percentage. For example, a criterion with 20 percent weight is assigned the weight factor of two. Any one concept is selected as the baseline and then compared to each other concept for each criterion. If the other concept is better than the baseline concept on a criteria point, it is given a score of +1. On the contrary, if it is worse as compared to the baseline then it is given a score of -1, while a score of 0 is given if they are equal or a decision cannot be made. This score is multiplied with the weight factor of each criterion, and then the score of each concept is summed. The concepts with significantly weaker scores are eliminated.

The Pugh matrix process is an iterative process of elimination. For the subsequent iteration, the concept with the highest score is taken as a baseline and the process is repeated till an iteration is reached where there is no concept which is higher than the baseline concept. The remaining concepts can be taken forward in the evaluation process. In this thesis project, evaluation process is carried out individually for both linear and rotary concepts in multiple iterations, which are explained below.

Concept L-11121 is taken as the baseline for the linear concepts, while R-12111 is taken as the baseline for rotary concepts. Comparisons are made between the baseline and other concepts for each criterion. For example, for the criterion of pressure loss if the diameter of a pipe is increased, the pressure drop will decrease for a given flow rate, all else being equal. Conversely, if the diameter of a pipe is decreased, the pressure drop will increase for a given flow rate. Thus, the pressure drop in concept L-21121 would be generally higher as the split outlet is splitting the water that should flow through one pipe into two pipes to provide partial flow.

Solutions which have the possibility for partial flow over the baseline are given +1. The internal leakages in concepts are approximated by considering factors like number of different sealing elements, separation between exits, interface between moving elements. For instance, concept L-31111 would have higher chances of leakage as there are two diverters having 2 sealing elements as compared to one sealing element in the baseline concept. In case of components, the number of components (diverter components + other system components) are counted and directly compared.Lastly, the size and design complexity of the system is estimated using the number of components and size and design complexity of each individual component in the system.

The Pugh matrix after the first iteration for both linear and rotary concept are presented below.

Criteria	**Weight**	**Concepts-Linear**																				
	10	11121	21121		31111		41121		51121		61121		72111		74111		81111		82111		84111	
Pressure Loss (Minimum)	3	D	-1	-3	1	3	0	0	0	0	1	3	1	3	1	3	-1	-3	-1	-3	-1	-3
Partial flow possibility	1.5	a	1	1.5	0	0	1	1.5	1	1.5	0	0	0	0	0	0	0	0	0	0	0	0
Internal Leakage	3.5	t	0	0	-1	-3.5	1	3.5	1	3.5	-1	-3.5	1	3.5	1	3.5	-1	-3.5	-1	-3.5	-1	-3.5
No of components	1	u	0	0	-1	-1	-1	-1	-1	-1	0	0	-1	-1	-1	-1	0	0	-1	-1	-1	-1
Design Complexity	0.5	m	0	0	-1	-0.5	-1	-0.5	-1	-0.5	-1	-0.5	0	0	0	0	-1	-0.5	-1	-0.5	-1	-0.5
Size	0.5		-1	-0.5	-1	-0.5	0	0	0	0	0	0	-1	-0.5	1	0.5	0	0	0	0	0	0
Net value	10		-1	*-2*	-3	*-2.5*	0	*3.5*	0	*3.5*	-1	*-1*	0	*5*	2	*6*	-3	*-7*	-4	*-8*	-4	*-8*
Futher development			Yes		Yes		Yes		Yes		Yes		Yes		Yes		No		No		No	

Table 8.2: Pugh Matrix iteration 1-Linear

Criteria	**Weight**	**Concepts-Rotary**															
	10	12111		14111		21111		24111		41111		44111		51111		54111	
Pressure Loss (Minimum)	3	D		0	0	0	0	0	0	1	3	1	3	1	3	1	3
Partial flow possibility	1.5	A		0	0	1	1.5	1	1.5	0	0	0	0	0	0	0	0
Internal Leakage	3.5	T		0	0	0	0	0	0	-1	-3.5	-1	-3.5	-1	-3.5	-1	-3.5
No of components	1	U		-1	-1	0	0	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
Design Complexity	0.5	M		0	0	0	0	0	0	-1	-0.5	-1	-0.5	-1	-0.5	-1	-0.5
Size	0.5			-1	-0.5	0	0	-1	-0.5	-1	-0.5	-1	-0.5	-1	-0.5	-1	-0.5
Net value	10			-2	-1.5	1	*1.5*	-1	0	-3	-2.5	-3	-2.5	-3	-2.5	-3	-2.5
Futher development		Yes		Yes		Yes		Yes		Yes		Yes		Yes		Yes	

Table 8.3: Pugh Matrix iteration 1-Rotary

It is observed that concepts L-81111, L-82111, L-84111 have significantly weaker scores as compared to the base while concept L-74111 has the highest score. Thus, these concepts weaker concepts are eliminated while L-74111 is selected as the baseline for the next iteration of Pugh matrix for the linear concepts. However, for the rotary concepts it is fascinating to observe that four concepts have the same score with no concept having significantly weaker scores. Thus, no eliminations are made at this stage, but the concept R-21111 which has the highest score is considered as the baseline for the next iteration. The second iteration matrix is presented below.

Criteria	**Weight**	**Concepts-Linear**															
	10	11121		21121		31111		41121		51121		61121		72111		74111	
Pressure Loss (Minimum)	3	-1	-3	-1	-3	0	0	-1	-3	-1	-3	0	0	0	0	D	
Partial flow possibility	1.5	0	0	1	1.5	0	0	1	1.5	1	1.5	0	0	0	0	A	
Internal Leakage	3.5	-1	-3.5	-1	-3.5	-1	-3.5	*0*	0	*0*	0	-1	-3.5	0	0	T	
No of components	1	1	1	1	1	-1	-1	1	1	1	1	1	1	-1	-1	U	
Design Complexity	0.5	0	0	0	0	-1	-0.5	-1	-0.5	-1	-0.5	0	0	0	0	M	
Size	0.5	0	0	-1	-0.5	-1	-0.5	-1	-0.5	0	0	-1	-0.5	-1	-0.5		
Net value	10	-1	-5.5	-1	*-4.5*	-4	-5.5	-1	-1.5	0	-1	-1	-3	-2	*-1.5*		
Futher development		No		No		No		Yes		Yes		Yes		Yes		Yes	

Table 8.4: Pugh Matrix iteration 2-Linear

Criteria	**Weight**	**Concepts-Rotary**															
	10	12111		14111		21111		24111		41111		44111		51111		54111	
Pressure Loss (Minimum)	3	0	0	1	3	D		0	0	1	3	1	3	1	3	1	3
Partial flow possibility	1.5	-1	-1.5	-1	-1.5	A		0	0	-1	-1.5	-1	-1.5	-1	-1.5	-1	-1.5
Internal Leakage	3.5	0	0	1	3.5	T		0	0	0	0	0	0	-1	-3.5	-1	-3.5
No of components	1	0	0	1	1	U		-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
Design Complexity	0.5	0	0	1	0.5	M		-1	-0.5	1	0.5	-1	-0.5	-1	-0.5	-1	-0.5
Size	0.5	0	0	1	0.5			-1	-0.5	-1	-0.5	-1	-0.5	-1	-0.5	-1	-0.5
Net value	10	-1	-1.5	4	7	0	0	-3	-2	-1	0.5	-3	-0.5	-4	-4	-4	-4
Futher development		Yes		Yes		Yes		Yes		Yes		Yes		No		No	

Table 8.5: Pugh Matrix iteration 2-Rotary

After the completion of the second iteration for linear concepts, it is seen that L-11121, L-21121 and L-31111 have a score that is each significantly lower than the baseline. Thus, these three concepts are eliminated in this stage. Additionally, none of the concept scored positive points, i.e. points higher than the baseline concept. Thus, no further iterations of Pugh matrix are needed for linear concepts.However, for rotary concepts, R-14111 receives the highest score while concepts R-51111 and R-54111 get the lowest scores. These two concepts are eliminated, and the next iteration for rotary concepts is carried out using the best concept as the reference.

Criteria	**Weight**	**Concepts-Rotary**											
	10	12111		14111		21111		24111		41111		44111	
Pressure Loss (Minimum)	3	0	0	D		-1	-3	-1	-3	1	3	1	3
Partial flow possibility	1.5	0	0	A		1	1.5	1	1.5	0	0	0	0
Internal Leakage	3.5	0	0	T		-1	-3.5	-1	-3.5	-1	-3.5	1	3.5
No of components	1	-1	-1	U		-1	-1	0	0	-1	-1	-1	-1
Design Complexity	0.5	-1	-0.5	M		-1	-0.5	-1	-0.5	-1	-0.5	-1	-0.5
Size	0.5	-1	-0.5			-1	-0.5	0	0	-1	-0.5	-1	-0.5
Net value	10	-3	-2			-4	-7	-2	-5.5	-3	-2.5	-1	4.5
Further development		Yes		Yes		No		No		Yes		Yes	

Table 8.6: Pugh Matrix iteration 3-Rotary

In the third iteration, concept R-21111 and R-24111 are removed as they have the lowest scores which are significant enough for elimination. There is no concept which has a positive score, thus no further iterations are required. The remaining concepts can be taken forward in the evaluation process. A total of 5 linear concepts and 4 rotary concepts are taken into the next stage of the evaluation process.

The final remaining concepts in the Pugh Matrix are presented below

Criteria	**Weight**	**Concepts- Linear**										**Concepts-Rotary**							
	10	41121		51121		61121		72111		74111		12111		14111		41111		44111	
Pressure Loss (Minimum)	3	-1	-3	-1	-3	0	0	0	0	D		0	0	D		1	3	1	3
Partial flow possibility	1.5	1	1.5	1	1.5	0	0	0	0	A		0	0	A		0	0	0	0
Internal Leakage	3.5	*0*	0	*0*	0	-1	-3.5	0	0	T		0	0	T		-1	-3.5	1	3.5
No of components	1	1	1	1	1	1	1	-1	-1	U		-1	-1	U		-1	-1	-1	-1
Design Complexity	0.5	-1	-0.5	-1	-0.5	0	0	0	0	M		-1	-0.5	M		-1	-0.5	-1	-0.5
Size	0.5	-1	-0.5	0	0	-1	-0.5	-1	-0.5			-1	-0.5			-1	-0.5	-1	-0.5
Net value	10	-1	-1.5	0	-1	-1	-3	-2	*-1.5*			-3	-2			-3	-2.5	-1	4.5
Futher development		Yes		Yes		Yes		Yes		Yes		Yes		Yes		Yes		Yes	
Working Principle		Multiple control valves				Sliding spool						Ball valve				Revolving Section			

Table 8.7: Pugh remaining concepts

8.3 Kesselring Matrix

The second tool that is used in the concept evaluation process is the kesselring matrix. It is a weighted matrix which is similar to Pugh matrix but is done only for one iteration. Each concept is assigned a rating out of a maximum rating based on how effectively the concept fulfills the respective criteria. This rated score is then multiplied with the weight assigned to each concept for each criterion. The total score for each concept is then summed. The concepts are then ranked on the basis of the score obtained.

		Ideal		**L-41121**		**L-51121**		**L-61121**		**L-72111**		**L-74111**		**R-12111**		**R-14111**		**R-41111**		**R-44111**	
Criteria	**Weight (x/10)**	**Rating (1-5)**	**Weighted Score**	**Rating (1-5)**	**Weighted Score**	**Rating (1-5)**	**Weighted Score**	**Rating (1-5)**	**Weighted Score**	**Rating (1-5)**	**Weighted Score**	**Rating (1-5)**	**Weighted Score**	**Rating (1-5)**	**Weighted Score**	**Rating (1-5)**	**Weighted Score**	**Rating (1-5)**	**Weighted Score**	**Rating (1-5)**	**Weighted Score**
Pressure Loss (Minimum)	3	5	15	3	9	3	9	4	12	5	15	5	15	2	6	2	6	5	15	5	15
Partial flow possibility	1.5	5	7.5	5	7.5	5	7.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Internal Leakage	3.5	5	17.5	4	14	4	14	3	10.5	5	17.5	5	17.5	3	10.5	3	10.5	4	14	4	14
No of components	1	5	5	4	4	4	4	4	4	3	3	4	4	4	4	4	4	4	4	3	3
Design Complexity	0.5	5	2.5	2	1	2	1	3	1.5	3	1.5	4	2	2	1	3	1.5	3	1.5	3	1.5
Size	0.5	5	2.5	4	2	5	2.5	3	1.5	5	2.5	5	2.5	5	2.5	4	2	3	1.5	3	1.5
	Total		50	37.5		38		29.5		39.5		41		24		24		36		35	
	Rank			4		3		7		2		1		8		9		5		6	
				Multiple control valves						Sliding spool								Revolving Section			
				Principle rank 2						Principle rank 1								Principle rank 3			

Table 8.8: Kesselring Matrix

The results of the matrix show that three concepts have significantly lower scores than the rest of the concepts. These concepts are L-61121,R-12111 and R-14111 which are eliminated. The remaining 6 concepts have scores which are close to each other in pairs. This leads to the observation that these concepts can be grouped as pairs rather than considering them as single entities, as they have the function of divert water in common. For example, the concepts L-41121 and L-51121 have the same main principle of multi-solenoid valves while concepts of L-72111 and L-74111 work on the principle of a sliding spool as explained in the previous chapters. Similarly, the concepts R-41111 and R-44111 also share a common working principle of a revolving section.

Thus, there are 6 concepts working on three different principles that are potential solutions to create a new diverter system for ASKO dishwashers. However, the concepts L-72111 and L-74111 with the highest scores of 41 and 39.5 respectively are taken forward towards the design and validation phase of the product development thesis. In case this concept does not lead to a viable and functional diverter, other concepts can be considered. There is also a possibility to combine features of the remaining or eliminated concepts if needed, backed with enough validation.

9

Concept Validation and Prototyping

In the previous chapter potential concepts that can be developed into a diverter system are identified and presented. In this chapter the concepts are designed, tested and validated for functionality. The first part of the chapter discusses the tools and the techniques used during the course of concept validation. In the subsequent subsections the testing setup is explained along with detailed iteration wise concept evolution from a basic idea to a functional prototype.

9.1 Prototyping Tools and Techniques

The concept validation and prototyping is mainly done using a combination of fabrication and additive manufacturing techniques. The test setup is build using existing dishwasher components modified for the specific use case in this project and will be explained in detail in the next subsection. The prototyping is mainly done using plastic additive manufacturing by using fused deposition modelling method. The printer used throughout is 'Original Prusa i3 MK3S+' available at different labs at the Chalmers facilities. The material of plastic filament used is PETG. The main design tool used is the CAD software' Solidworks 2022 student' while the 'PrusaSlicer 2.5.2' is used as the 3D printing pre-processing and build setup software.

9.2 Test Setup

The testing setup is build by modifying the existing dishwasher specifically to test the diverter concepts in development. All other components of the dishwasher except the diverter system are taken away. It only consists of the base of the dishwashing cabinet which has the sump at the bottom in the center covered by a filter. The cabinet is such that all water sprayed on the dishes flows and collects directly into the sump. The sump is connected to the circulation pump and water heater. A hose is connected from the circulation pump of which one end acts as an outlet to the circulation pump and the other end is the input to the diverter. The water flowing from the diverter in actual case flows to the spray arms. However, in this test case three tubes are connected to the three outlets on the diverter and the water is directly let into the dishwashing cabinet.

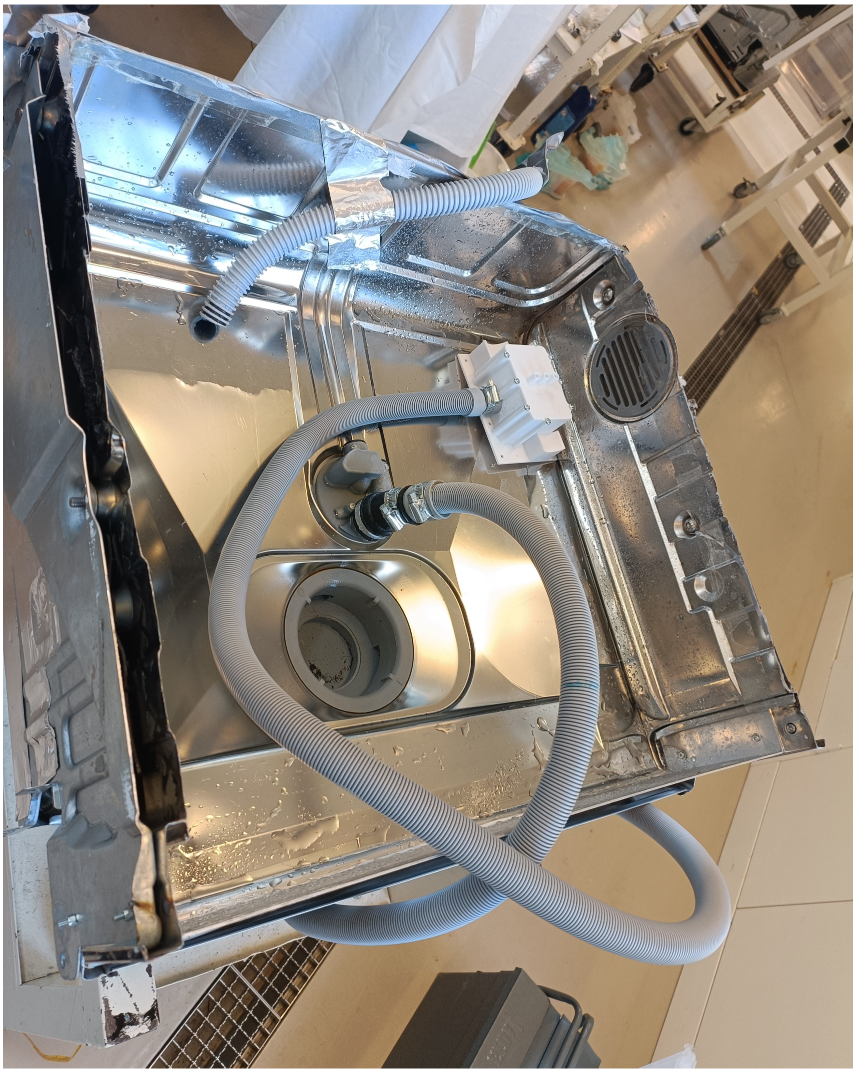

Figure 9.1: Testing setup

The diverter prototype is built in multiple iterations. Each of the iterations is explained in the upcoming section.

9.3 Concept Development Iterations

The concepts that are decided to take forward into prototyping and testing are L-72111 and L-74111. Both these concepts work on the principle of a sliding spool which directs water towards the desired outlet. Initially a simple test to observe the movement of the spool inside a rectangular pipe and a circular pipe is carried out. This is done by designing and 3D printing two basic pipe forms and their spool. When the spool is in the center of the pipe the slot in the spool aligns with one outlet, thus allowing a flow of water to one spray arm. When the spool moves to the right or the left the water is directed to either of the other two outlets. Two pipes are designed in 3D CAD and the printed parts are presented below.

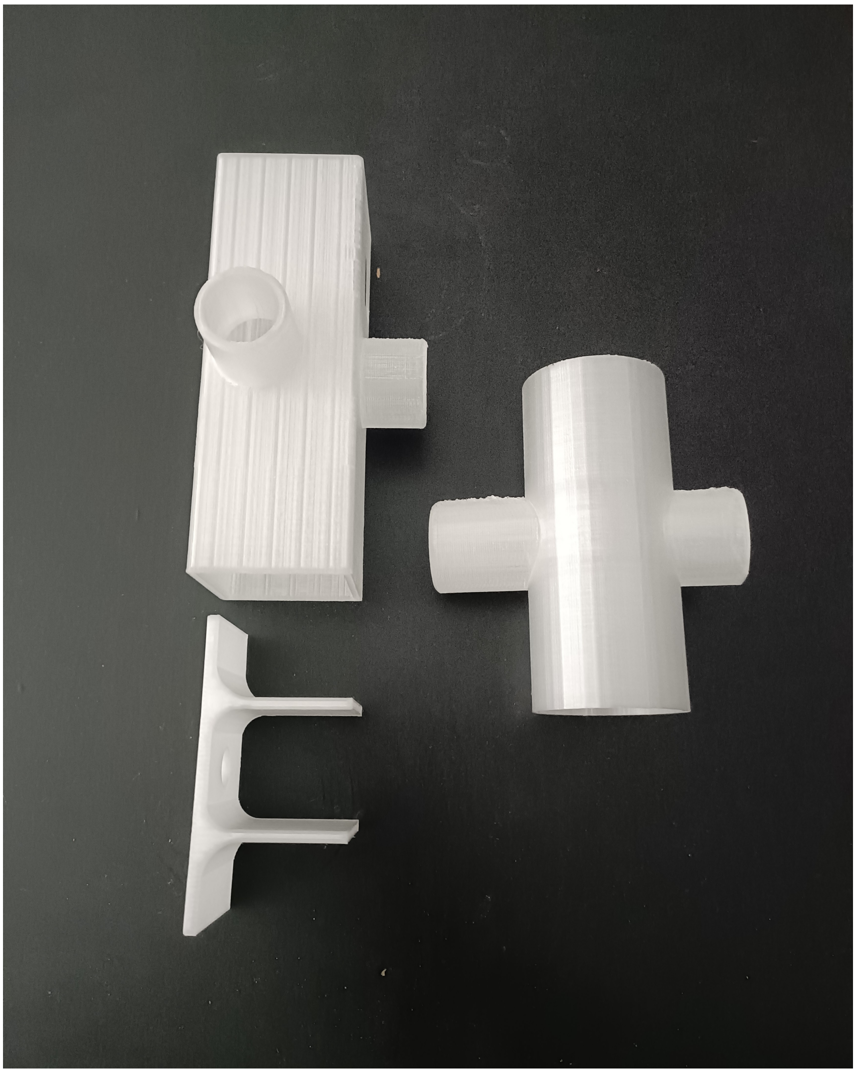

Figure 9.2: Pipe forms with Sliding spool

A basic form and fit test was done on the spool to check the sliding motion. It is observed that a significant amount of surface area is in contact with the walls of the pipe especially the top of the spool which need extra surface area to block the central hole when either left or right outlet is active. Thus, it is necessary to reduce the surface area as much as possible especially on the side walls as it can increase leakage. This means that spool in its current form cannot be used further. Different other concepts are then visited to look for potential features that can be combined with the sliding spool concept. One such idea was to use a sliding plate as in alternative 1.1 6.3. This concept is then developed in iterations which are explained below.

The iteration number is given by the name of the concept followed by the version number, This concept is named as 'Outlets in column' with the short form of OC followed by version number. Each iteration is presented in the form of a brief description followed by three subsections which are Tests, Results and observations and design changes.

9.3.1 Iteration 1 - OC 1.0

The main goal in this iteration is to create a design which incorporates the slider mechanism and to find the hole arrangement adequate to transfer water from the inlet to three outlets one at a time. The design uses the volume dimensions of the existing dishwasher as a reference with the aim to create the entire design within this bounding box. A container is made with three outlets in a column. The diameters of these outlets are in accordance with the diameters of the three individual outlets on the existing dishwasher. The container has one side open with another plate designed separately to seal it off. The container also has a slot for the slider which can move along the length of the container. The slider has three holes at a diagonal which align to the three holes on the container.

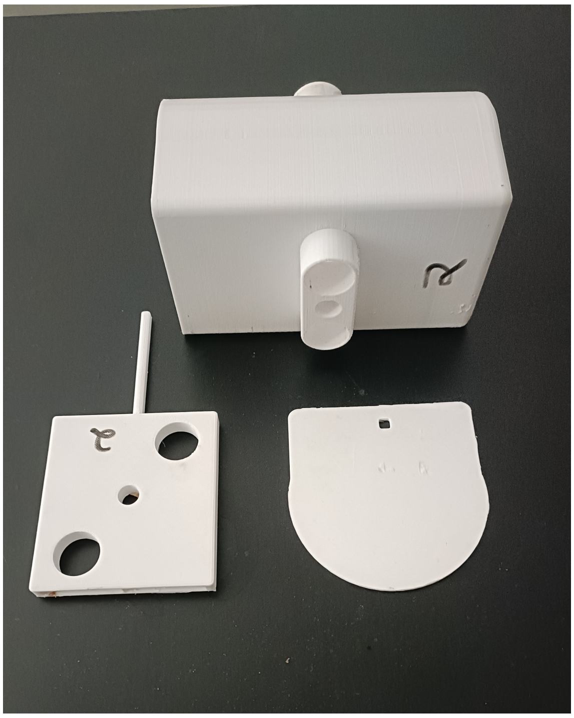

Figure 9.3: Iteration 1

Test : The sliding motion of slider in the slot. Hole alignment where only one outlet is active while the other two are blocked. Check the fit of the hose with the inlet of the container printed.

Result and Observations : The slider slides smoothly in the slot with 0.25 mm clearance on either side as well as the top. The hole alignment works well when the slider is moved left or right from the central position. The hose fits well inside the inlet tube.

Design Changes : Extremely large volume as the volume matches the bounding box of the existing ASKO diverter. Thus, a volume reduction is necessary to make the design compact and avoid pressure losses. Standardize all three of the outlet holes with equal diameter for design simplicity in the early stages. Design the inlet hole diameter to make the hose fit on top of the inlet pipe to make clamping possible under high pressure of the circulation pump.

9.3.2 Iteration 2 - OC 2.0

In this iteration the changes determined in the previous iteration are made. The container size is reduced to a rectangular box with outer dimensions of 75 x 50 x 34. The inlet pipe outer diameter is changed to 16 to fit the hose inlet diameter. All outlets holes are made with diameter 8 mm in accordance with the inner diameter of the hose that is to be used in order to clamp the hose on the pipe securely. Additionally, a seat is provided on the slider holes to incorporate a rubber sealing with an aim to minimize leakage between adjacent outlets. A lid containing the three outlets in a straight line is designed on the top having an interface to match with the container. In addition, a sealing is seat is also provided to seal the lid with a foam sealing string.

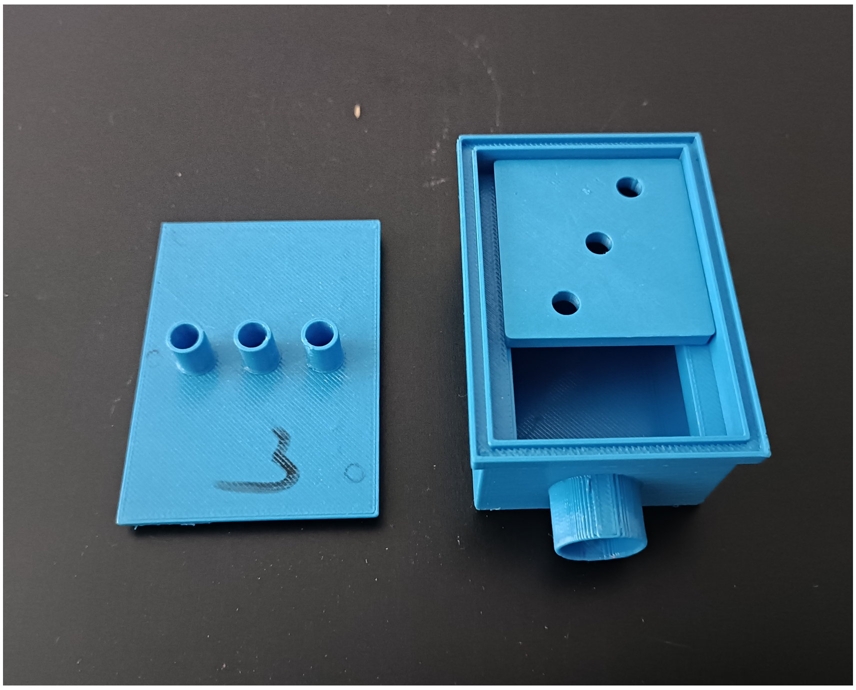

Figure 9.4: Iteration 2

Test : Sliding motion of slider in the smaller container design. Check fitment of both inlet and outlet hoses in accordance to the design changes. Check fitment of the lid with the container. Test fitment of sealing string in the seat provided. Test small rubber sealing on the slider by connecting the container to a normal water tap.

Result and Observations : The slider slides smoothly in the slot while the hole alignment works well when the slider is moved either side from the central position. The hose fits slightly loose as it is made of rubber and a slightly higher outer diameter for the inlet pipe is needed while the same applies to the three outlet pipes. The rubber sealing displaces itself from the slider seat as there is no wall on one side. The lid fits well with the container however the seat for sealing the container is too narrow.

Design Changes : Increase the outer diameter of inlet pipe and three outlet pipes attached to the container and the lid respectively. Increase the width of the sealing seat. Provide a wall on both sides for sealing on all outlets. Add screw hole on the lid and screw tubes on the container to ensure a secure fit between the lid and the container and avoid leakage.

9.3.3 Iteration 3 - OC 3.0

In this iteration more modifications are made based on the previous iteration. The inlet and outlet pipe diameters are increased by 0.5 mm each to 8.5 mm and 16.5 mm respectively. The width of the external sealing seat is increased to 2 mm from 1 mm in the previous iteration.No changes are done to the slider for this iteration. Screw hole and tubes are designed for the screw PTKL 3,5x12 FZB T10.

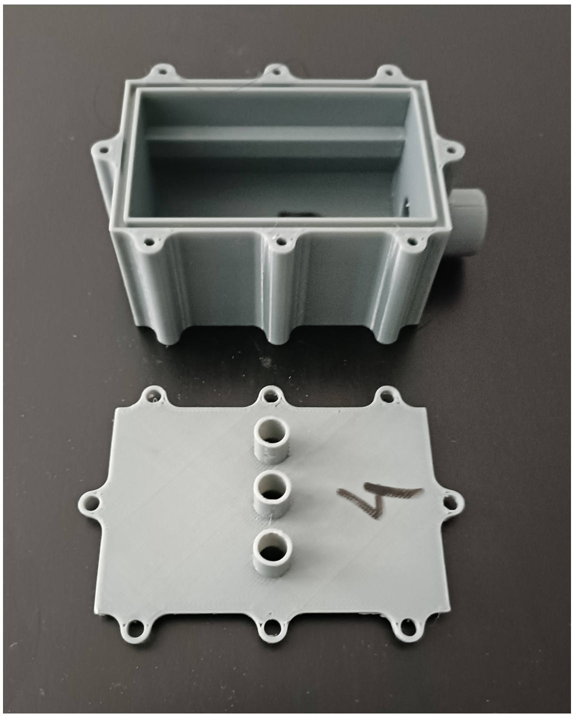

Figure 9.5: Iteration 3

Test : Test the screw fit. Check the external sealing fit. Check the hose fit for inlet and outlets.

Result and Observations : The screw fits well in the screw tube with proper clamping. However, gaps are noticed between lid and container due to uneven removal of support material. The hose fits perfectly on both the inlet and the outlet. The external sealing between lid and container still doesn't fit the container seat.

Design Changes : Incorporate design changes for outlet sealing seats and increase width or external sealing. Explore options for moving the slider along the slot.

9.3.4 Iteration 4 - OC 4.0

In the previous iterations the container, lid and placement of holes and pipes is defined. It is necessary to determine and integrate the mechanism to bring about translation motion of the slider along the slot. The most widely used alternative is a simple linear actuator that is connected to the slider. The only significant disadvantage of this solution is the external sealing ability of the diverter. Since the slider mechanism is submerged with water during operation the actuator would have to be separated from the container with sealing in between. It is quite challenging to ensure a reliable and tight seal on a moving mechanism. Thus, different other ideas are explored further with an attempt to create a completely sealed diverter.

A breakthrough comes with the idea to use electromagnets to drive the slider without actual contact between the actuating mechanism and the slider. The idea is to use a ferric material or a permanent magnet inside the slider which can be controller by electromagnets from the outside. The initial plan is to have two electromagnets on either side of the slider and have two slots within the slider where the ferric material or permanent magnet is concealed. The slider will be positioned in the center of the container aligned with the central outlet as a normal position. Turning on power to one of the magnets will create a magnetic field which will attract the magnet in the slider, thus moving the slider towards one end of the container. In this position one hole will be aligned with one outlet while the other two will be blocked. Springs are to be set in place to maintain the slider in the central position and also retract the slider to the central position when the electromagnet is turned off. There is also a possibility to use one electromagnet and reversing the polarity to cause repulsion towards the far outlet and attraction towards the near outlet.

Before this concept is tried a pre iteration was made for testing changes to both the internal and external sealing separately without the container. A slider is designed with a male and female interface with cavity in between. This is to test the possibility of having a permanent magnet within the slider. A sealing seat with walls is also made to try the sealing fit. The printed parts are presented below. The external sealing fits but would eventually need a higher curvature on the edges to smoothly accommodate the foam string, The rubber sealing on the slider also fits within the seat much better than before. The printed also shows that slider can be made in two parts with the possibility to add ferric material in the cavity.

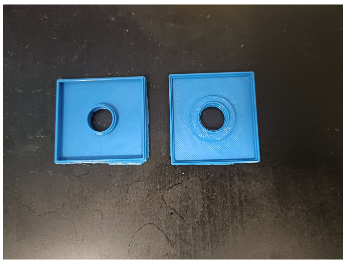

Figure 9.6: Slider with Cavity

The container, lid and slider are designed according to the electromagnet concept. Seats are provided for internal sealing based on results of the pre iteration. Seats are provided on the slider as well as the container inner wall for the springs. The rest of the design is the same as the previous iteration with no changes done to parameters that are already set. Springs of different lengths and stiffness along with two electromagnets with lifting strength of 25 N are ordered. An iron bar is cut and placed inside the slider. The images of printed parts are presented below.

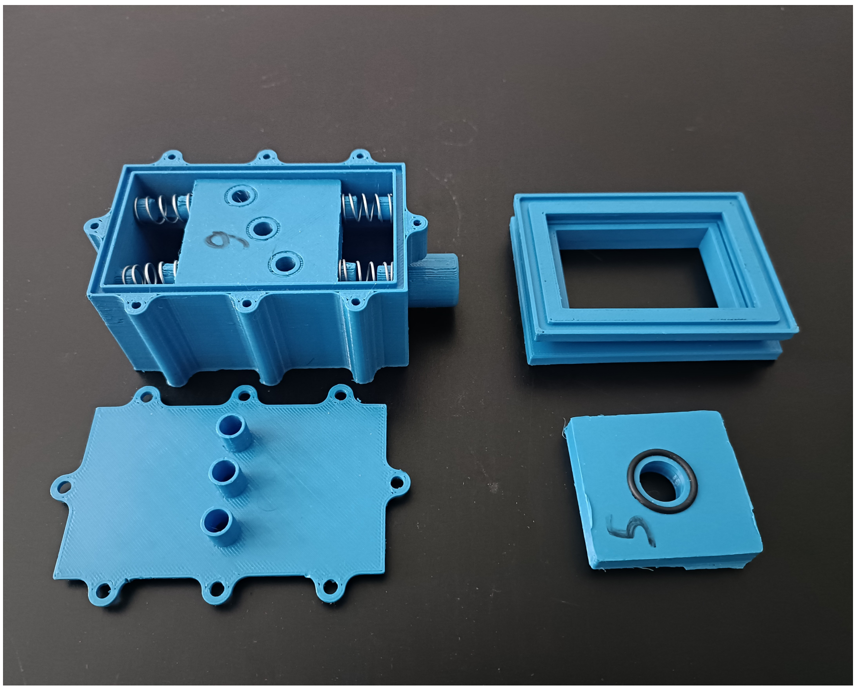

Figure 9.7: Iteration 4.1

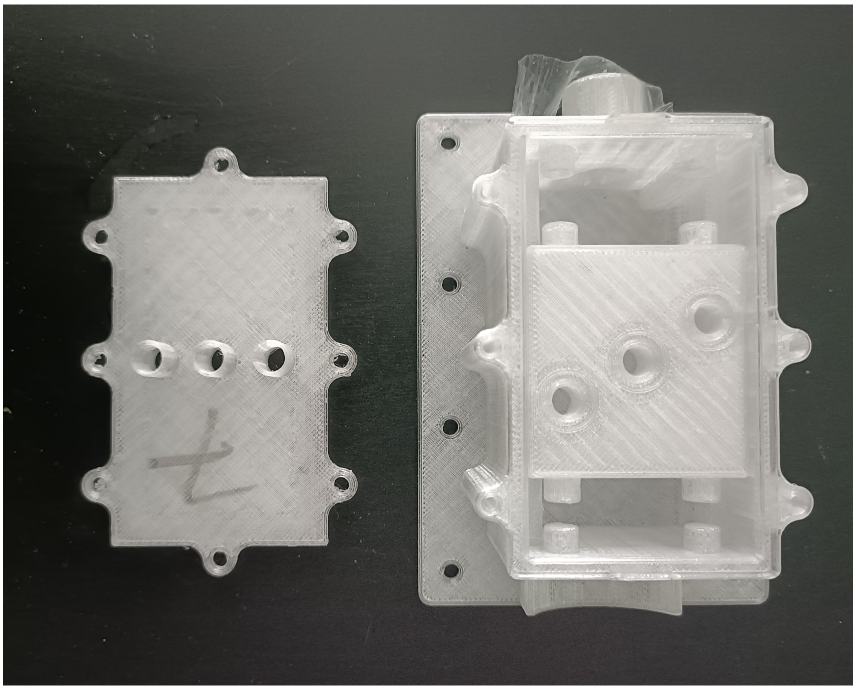

Figure 9.8: Iteration 4.2

Test : Test external sealing. Try different springs to check both fit on seat and compression strength. Test the slider movement with the electromagnet.

Result and Observations : The external sealing fits well in the width and depth of the sealing slot but needs a grater curvature on the edges. The electromagnets are not powerful enough to attract the slider due to the large distance between the magnet and the slider. The screw tubes on the sides were removed to reduce the distance between the magnets and slider. This brings a small change in the attractive pull, but the strength is not enough to flush the slider against the container wall which is needed for hole alignment. It is also observed that when a permanent magnet was placed on the face of the slider, the gap is small enough for the electromagnet to attract the slider towards itself.

Design Changes : Increase curvature of external sealing seat. Reduce the distance between the slider and the walls by making the design more compact. Remove diagonally opposite springs and add screw tubes to that side. Make a housing inside the slider for the permanent magnets.

9.3.5 Iteration 5 - OC 5.0

In this iteration the external sealing seat has a curvature of 5 mm. Two seats are provided on either side for the electromagnets. The permanent magnets are located inside the slider. Additionally, a plate is provided at on which the diverter prototype can be fastened while operation under pump with high pressure.

Test : External sealing fit between lid and container with screw and running water from the motor. Internal leakage test without inner sealing. Slider movement test using electromagnets.

Result and Observations : The external sealing fits with some leakage under running water from the circulation pump. The sealing foam does not compress completely to ensure a leakproof container. The slider does not move with the electromagnets in either direction.

Design Changes : Go back to iteration four and redesign the slider where the permanent magnet is in front of the slider with a 3-5 mm gap between the wall and the magnet. Design a housing for the permanent magnet which is integrated with the two parts of the slider. Provide internal sealing seats for rubber sealing with dimensions 8.1 x 1.6 mm.

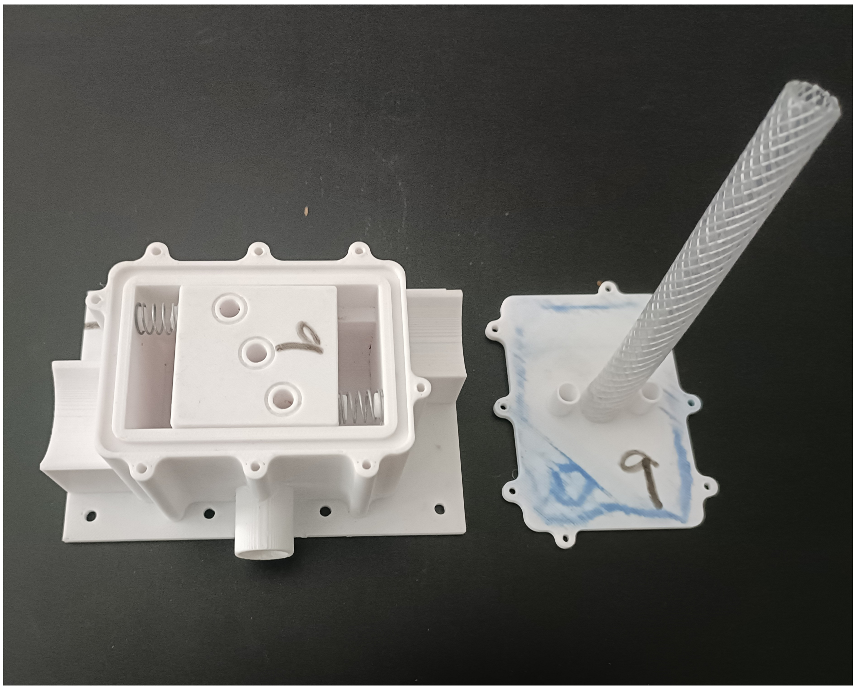

Figure 9.9: Iteration 5

9.3.6 Iteration 6 - OC 6.0

In this iteration the permanent magnets are designed in a way to be diagonally opposite to each other on the opposite side of the spring. Thus, the electromagnet can be placed in line with the magnet and does not interfere with the spring. The internal sealing seat is modified in accordance to a new rubber sealing of dimensions 8.1 x 1.6 mm. All other aspects of the design are unchanged.

Test : Test the movement of slider using electromagnets. Ribs are added to the lid to increase stiffness and reduce flexing. Test the external and internal leakage with the circulation pump active.

Result and Observations :The slider movements needed minute adjustments. There are no external leakages and thus the sealing parameters are finalized. The inner sealing has to be developed and tested further.

Design Changes : Centering of electromagnet mounts is required. The distance between magnet seat and wall of the container has to be reduced to accommodate spring length available. Addition of rib to the lid. Print slider without support material for inner sealing seats.

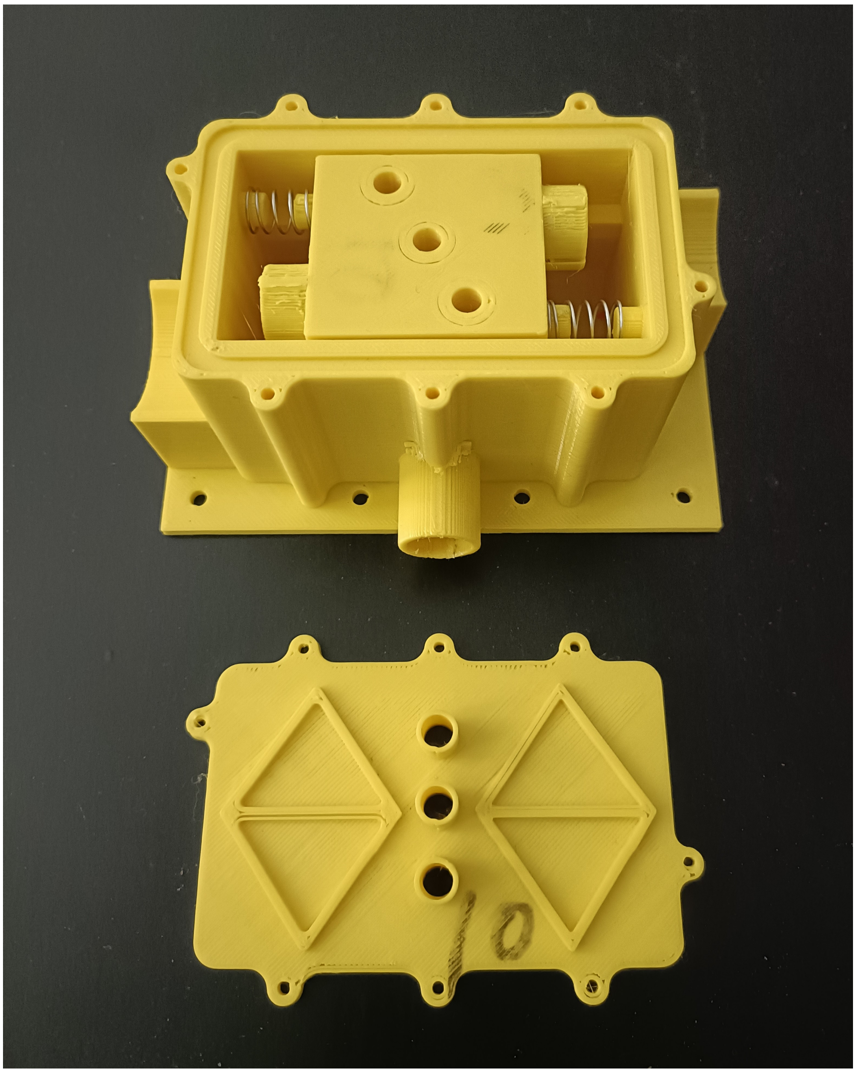

Figure 9.10: Iteration 6

9.3.7 Iteration 7 - OC 7.0

This is the final iteration carried out in this development process where a working prototype has been achieved. Further developments are needed to improve the sensitivity of electromagnet, inner sealing ability to reduce leakages. Thus, the concept has enough evidence to be validated subject to additional work in the mentioned aspects. The specifications of the components used and the dimensions of the final part are not presented at this stage as they are still a work in progress. However, associated Cad designs and the components themselves are presented to the company to carry on further development.

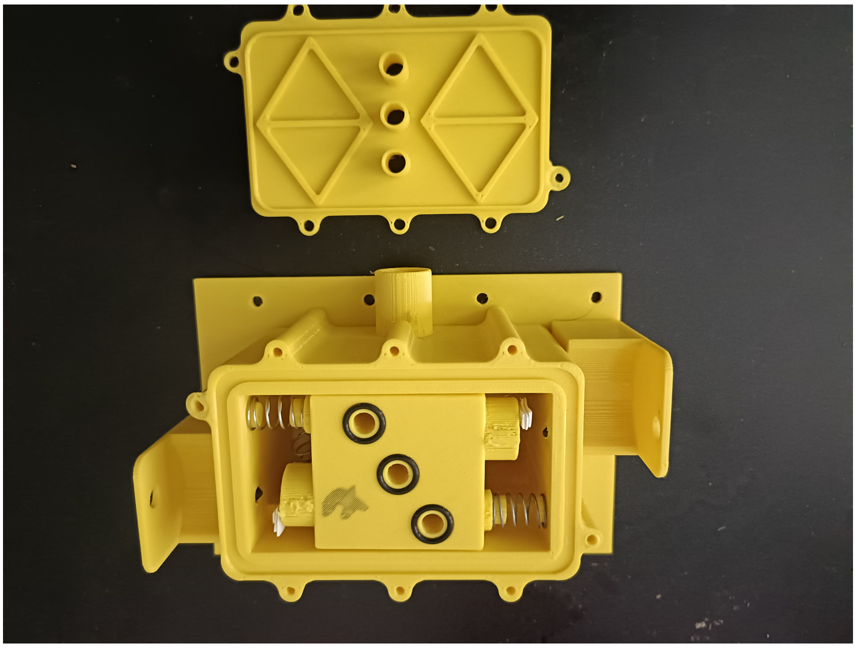

Figure 9.11: Final Iteration

10
Disucssion

The purpose of the thesis is to explore and investigate different technologies and develop potential solutions to replace existing diverters in dishwashers. The primary objective of this report is to present the developed concepts and the process followed in doing so. Six concepts based on three different working principles have been shortlisted as potential solutions after the concept evaluation stage out of which one concept combined with features of other concepts has been developed in a series of iterations.

Firstly several product development tools and matrices are used in the thesis. The tools being theoretical in nature, assumption and modifications have been done to fit the project and the nature of results desired. For example the Pugh matrix has been used in a weighted format to account for differences in importance of criteria in the desired solution. This is a good learning experience to be able to apply different tools learned in the course of the masters program.

A key observation is that all potential solutions fall in one of two categories which are concepts driven by linear motion or concepts driven by rotary motion. The existing diverter solution uses rotary motion while the proposed solution uses linear motion. It is interesting to note that there is a lot of flexibility with respect to how this motion is brought about. In the proposed solution a new concept in dishwashers is used where the property of magnetism is the key driver of the diverter mechanism. However, a simple linear actuator could also be used as a cost-effective and reliable solution but would require greater amount of design, build and test cycles to achieve complete sealing to meet both functional and safety requirements. In this project only the concept using magnetism has been developed to a level where the results are enough to validate the feasibility of the concept. With more time and resources more work could have been done to explore other ways of bringing about the linear motion.

As mentioned before one concept based on one working principle has been developed and tested, however there are other potential concepts which can be explored based on desired features. For example the concept with multiple solenoids would be suitable if there is need for a system with greater control and partial flow. Significant progress is made on developing one concept in the available time frame, however more work could be done on other potential solutions.

The diverter alone is one part of the entire water distribution system. The other key parts include the sump, the circulation pump and the spray arms. Maintaining sump level is another important feature the thesis work has tried to address, however only a conceptual solution could be provided. The solution proposes to design a tank which is to be placed below the sump to store excess water when the top and upper spray arms are active. In this regard no prototyping or design work is carried out due to lack of time and complexity to create space in the existing dishwasher.

A significant number of iterations are carried out in the validation and testing phase of the project. However, a few iterations were done only due to dimensional changes rather than testing the functionality. If these iterations could be avoided or reduced more iterations could be carried out. The best advantage of using 3D printing is that it gives immense design freedom to try out different things and make changes immediately. However, the printing time associated with 3D printing coupled with high demand for printers at the university means iterations cannot be planned frequently. This it was important to be resourceful and try to test as many things as possible in each iteration.

No prior work has been done with regard to development of dishwasher diverters using a new technology at ASKO. Thus, the thesis work is a starting point for development work in this direction. ASKO can use the report to look at different potential solutions and ideas to inspire their own development work as well as continue to work with the proposed concept.

Recommendations for the company

- With regard to the proposed concept the further iterations should be aimed at reducing internal leakage by integrating the sealing in a better way on the slider. Secondly, the control using electromagnets or magnets can be increased by improving the design and changing the specifications of components used.

- The company can look into magnetism as a property to drive different other applications especially those applications that need good sealing or need to be waterproof.

11
Conclusion

In this thesis several potential concepts for dishwasher diverters are theoretically developed, evaluated and eliminated. The most promising concept is developed further in a series of six iterations using design and prototyping driven by feedback received through testing. The current version of the concept is proposed to the company with recommendations to carry on future work to develop a complete solution that can be integrated in future generations of dishwashers.

The current prototype meets the functional requirements of the product. However, the operational and reliability requirements of pressure and other parameters need to be developed over time by using existing component and tubing dimensions.

Thus, it is recommended that the company continue future development work while using this report as a basis for validation of feasibility of the proposed concept with the ultimate aim to develop a launch ready version of the dishwasher with a state-of-the-art diverter which brings both efficiency and has the potential to increase brand value.

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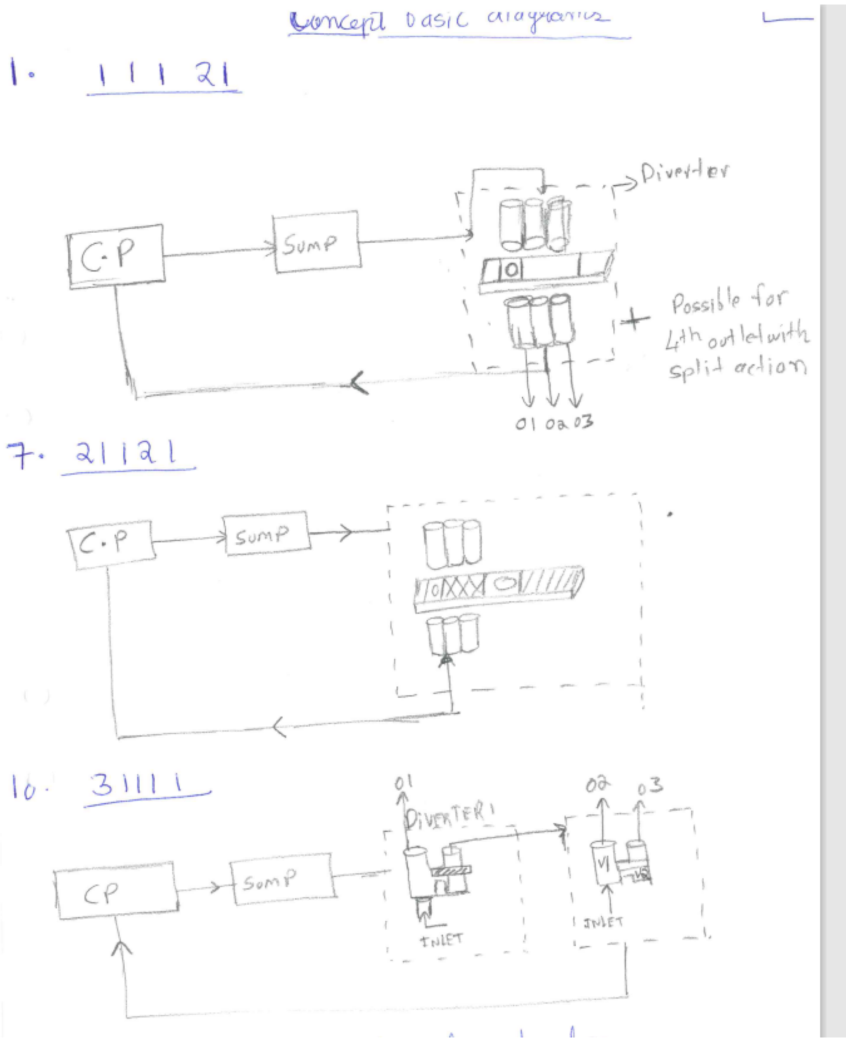
A

Appendix A

A.1 Linear Concepts



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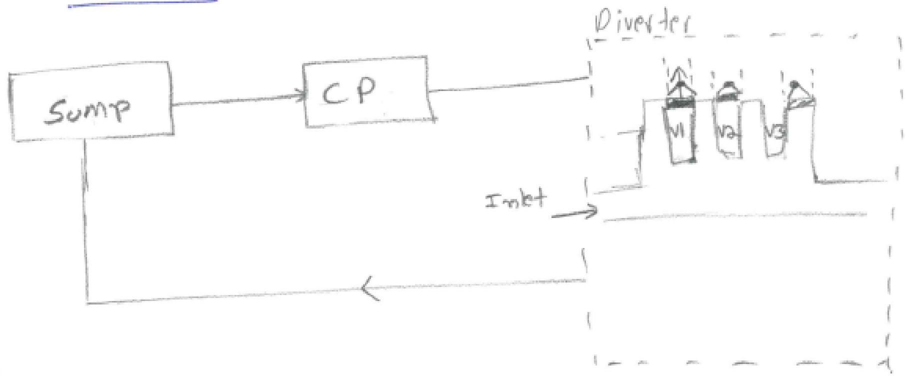
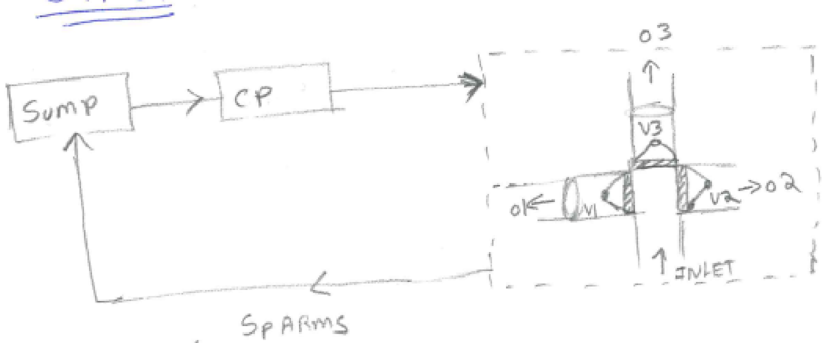


- V1, V2, V3 are varying volume chambers
- [symbol] represents So solenoids for flow control

16. 51121 ✓



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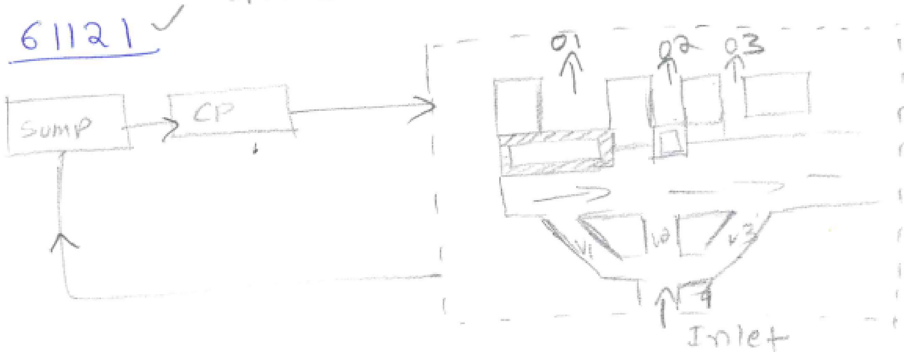
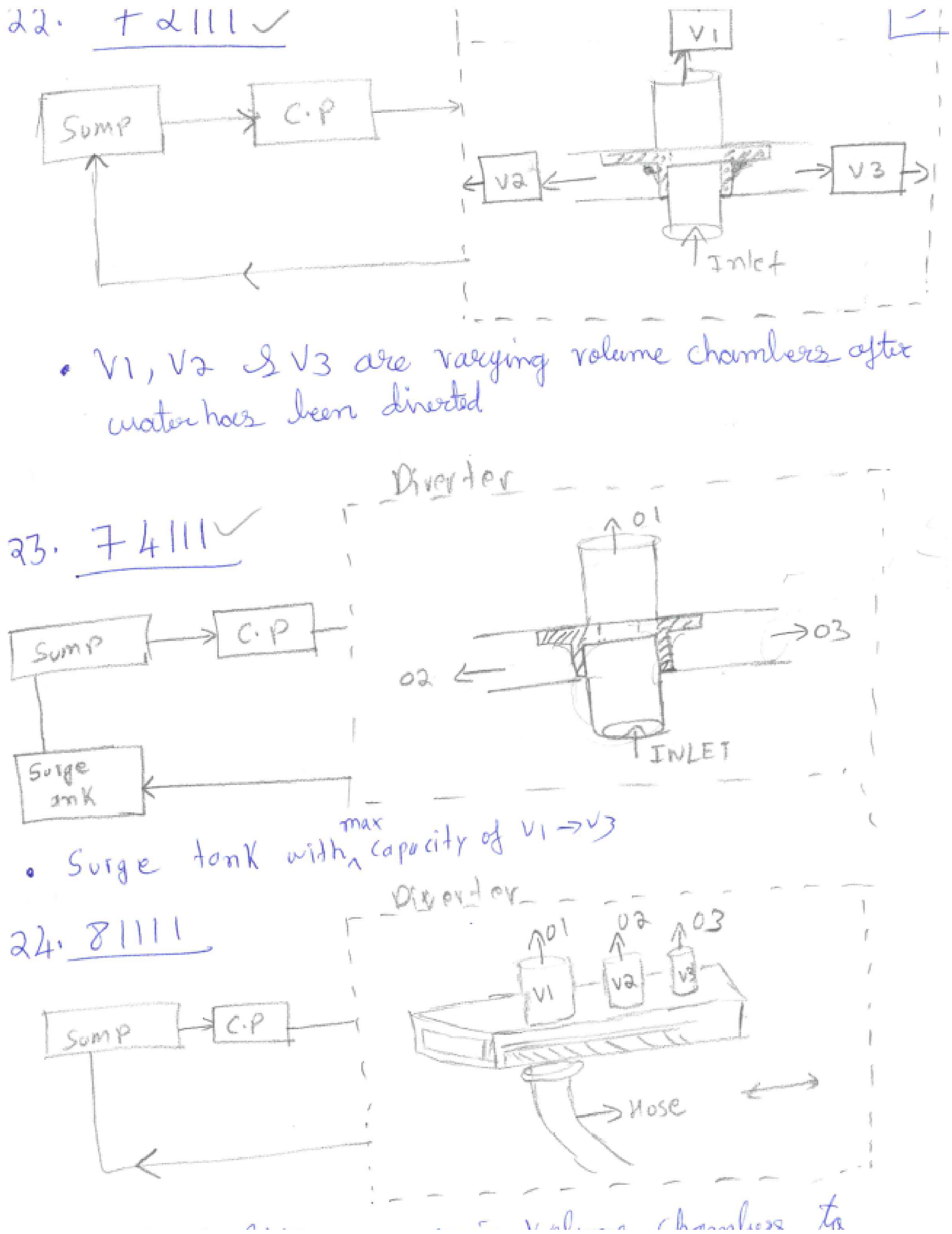
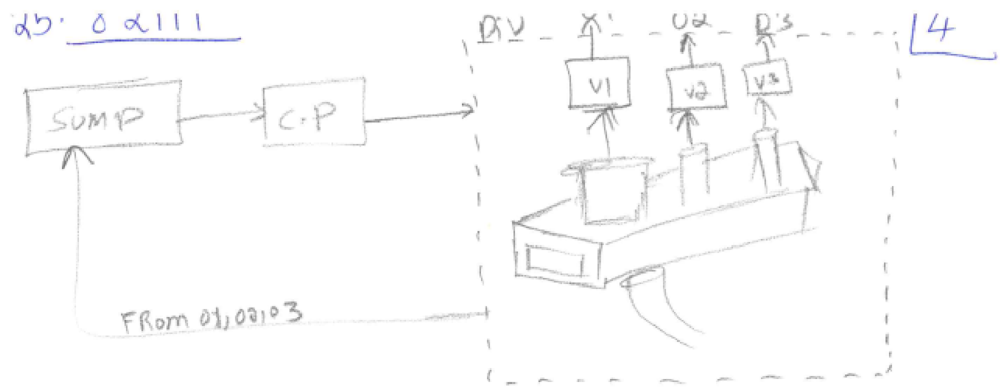
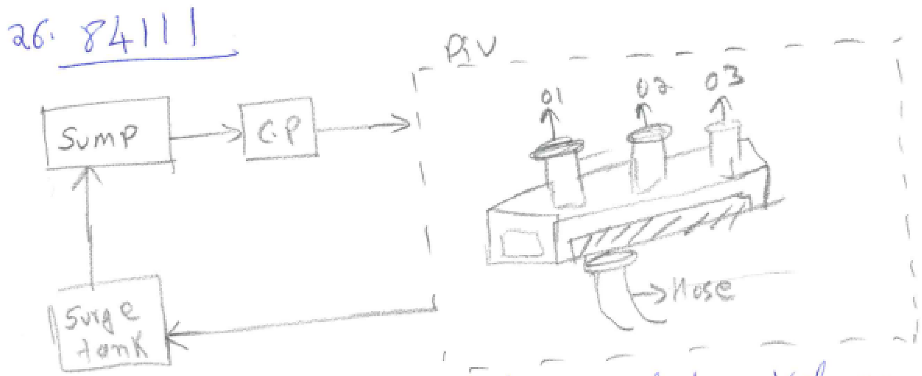


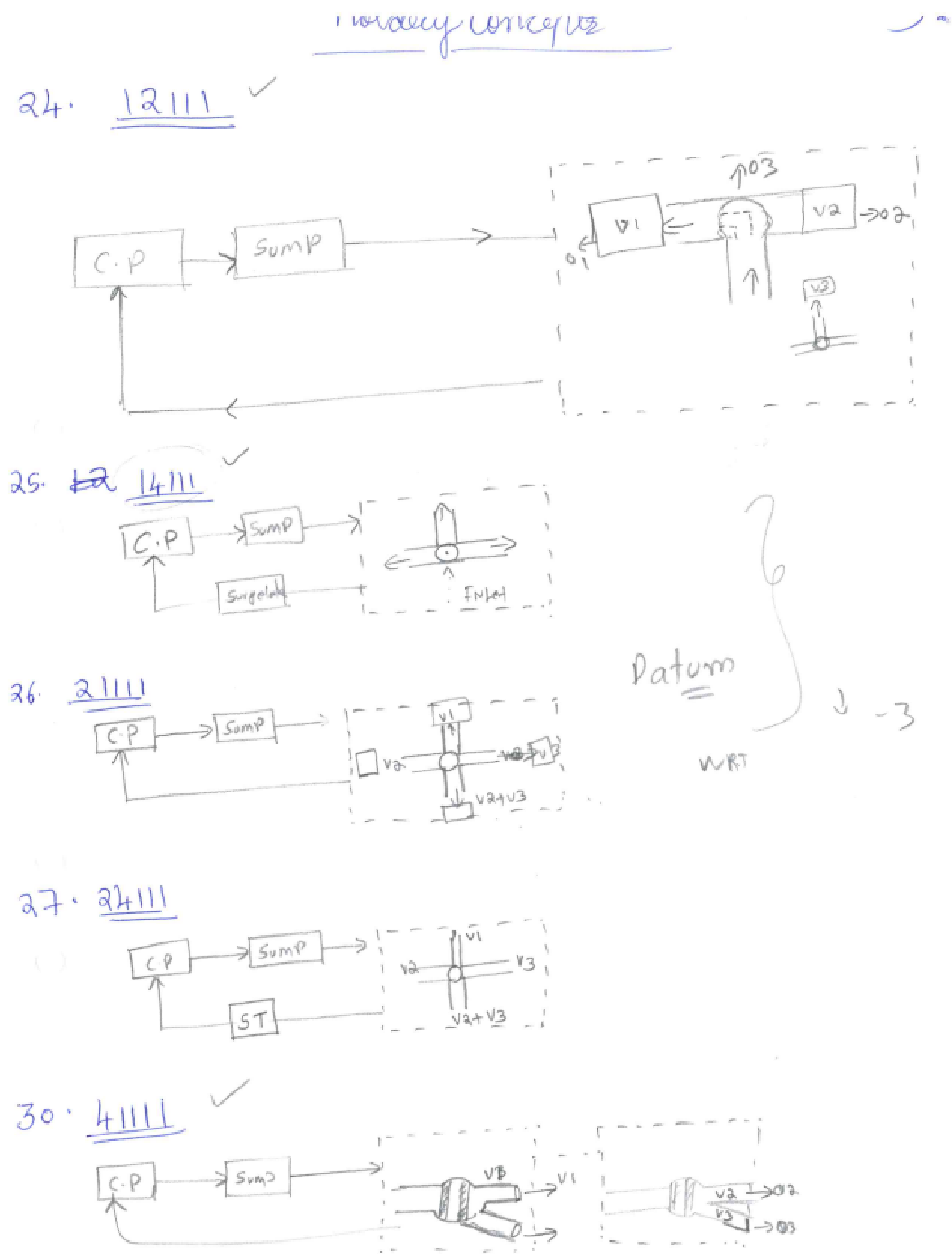

22. 7 2111
Sump
C.P
V1
V2
V3
Inlet
V1, V2 & V3 are varying volume chambers after water has been diverted
Diverter
23. 7 4111
Sump
C.P
Surge tank
O1
O2
O3
INLET
Surge tank with max capacity of V1 → V3
Diverter
24. 81111
Sump
C.P
O1
O2
O3
V1
V2
V3
Hose





- Surge tank accomodates V1 to V3 Volume levels

A.2 Rotary Concepts



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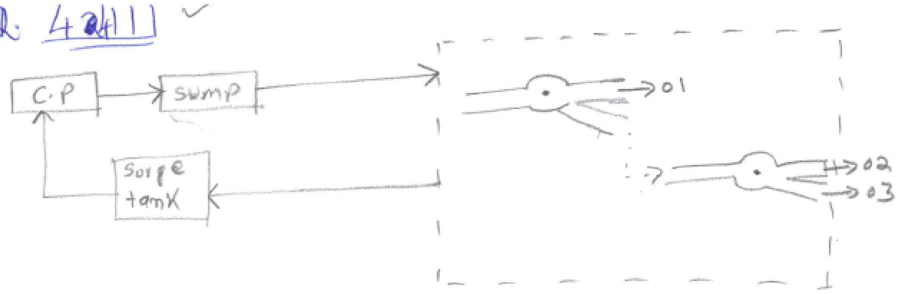

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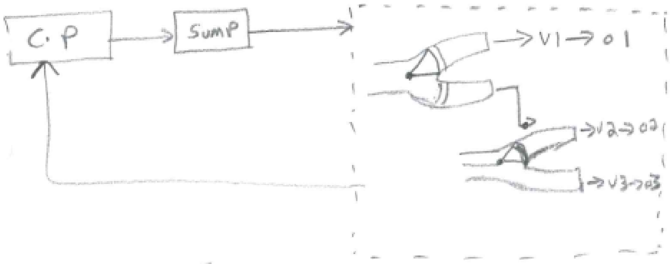

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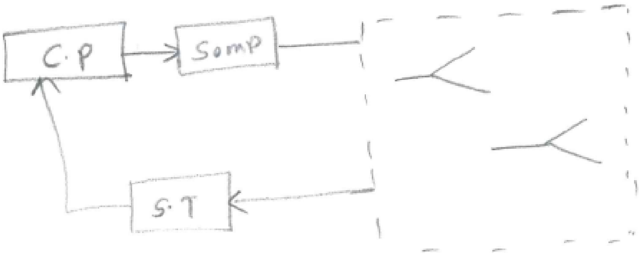

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