CHALMERS

Dishwasher improvement at ASKO

Developing a simplified test method to determine the influence of spray arm speed and pressure

Master of Science Thesis in Product Development

PETER TSOUKNIDAS
XIANG ZHANG

Department of Product and Production Development
Division of Product Development
CHALMERS UNIVERSITY OF TECHNOLOGY
Göteborg, Sweden, 2010

MASTER OF SCIENCE THESIS IN PRODUCT DEVELOPMENT

DISHWASHER IMPROVEMENT AT ASKO
Developing a simplified test method to determine the influence of spray arm speed and pressure

PETER TSOUKNIDAS
XIANG ZHANG

Department of Product and Production Development

Division of Product Development
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden, 2010

Dishwasher improvement at ASKO
Developing a simplified test method to determine the influence of spray arm speed and pressure
PETER T. TSOUKNIDAS
XIANG ZHANG

Examiner: Lars Almefelt, Chalmers University of Technology
Supervisor: Marcel Michaelis, Chalmers University of Technology
Industrial supervisor: Patrik Ivarsson, ASKO Appliances AB

Department of Product and Production Development
Chalmers University of Technology
SE-412 96 Göteborg
Sweden
Telephone + 46 (0)31-772 1000

Cover:
[Standardized test method used at ASKO to measure performance,
Page no. 12 for further reading in the report.]

Chalmers Reproservice
Göteborg, Sweden 2010

FOREWORD

This master's thesis was conducted at the request of ASKO Appliances AB. The expected outcome was considered to be of such value to the company that a non-disclosure agreement was established to protect proprietary information. Therefore, some information has been masked in the public version of the report. This includes the exact experiment levels and values, which have been replaced by relative terms in order for the reader to be able to follow the working process, as well as some specific details regarding the construction of the test method.

ABSTRACT

This thesis report describes how a dishwasher was modified and used as a test rig together with a new test method to find the relation between cleaning performance and the rotation speed of the spray arms as well as the water pressure. All tests were conducted using an ASKO D5900 dishwasher.

First off, the tests were planned in detail. To ensure that the tests would be reliable and not overly redundant proper Design of Experiments methods were used. A simplified test method was developed that would be easier and faster to use than the standard tests currently used by dishwasher developers.

When the test rig was to be built several concepts for changing rotation speed and water pressure were generated through brainstorming sessions and the use of morphological matrices based on system design thinking. Kesselring matrices were used during the final selection. The selected concepts were further developed to suit an actual implementation in the dishwasher.

The test rig was built and used to implement the cleaning performance test. Several pre-tests were conducted to evaluate the test method and data analysis method. The first test was implemented and showed a trend of relation between cleaning performance and rotation speed and pressure. Performance increased as the rotation speed decreased and the pressure increased, but due to large deviations the results were not found to be reliable. The deviation of the results was too large to be conclusive by statistical standards. This was the reason for a second test implementation where influencing variables like time and temperature were more accurately controlled. Stable results were acquired during the second test, which supported the results from the first test. The prototype was then tested using European standard dishwasher test methods to determine the external validity of the test method at ASKOs facilities in Vara. Sound tests were also conducted. Finally, some tests were done at a higher pressure level using a stronger pump in order to see if the trend was continuing at even higher pressure levels.

The test results showed that performance increases with higher water pressure and lower rotation speed. The cost of higher pressure is an increasing sound level. The test method proved to be reliable.

Keywords: dishwasher, improvement, pressure, rotation speed, DOE, test method.

TABLE OF CONTENTS

TABLE OF FIGURES

INDEX OF TABLES

1 – INTRODUCTION

Dishwashers are used for cleaning dishes and other eating utensils in restaurants and private residences. A dishwasher is a complex cleaning system that integrates many components both mechanical and electrical. Dishwasher manufacturers are continuously improving their products to satisfy consumer demands. Characteristics that consumers find attractive in a dishwasher are high cleaning performance, low sound level, short cleaning time and low energy consumption among others[1].

1.1 Background

ASKO Appliances AB is a Swedish company located in Vara. They develop and manufacture household appliances such as refrigerators, washing machine and dishwashers of high quality and high performance. ASKO strives to be a leader in dishwasher technology and they are constantly working on improving their products[1]. A lot of effort is put into improving the washing performance. The main parameters influencing the dishwasher performance are: use of detergents/chemicals, water temperature, washing time and mechanical impact on the dishes[1]. The parameters and their relative importance can be seen in Figure 1.1.

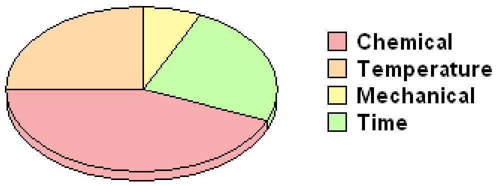


Figure 1.1: Factors influencing dishwasher performance

Keeping an environmental friendly profile has a high priority at ASKO. Decreasing water and energy consumption is beneficial since it lowers the usage costs for the customer and makes the product more environmental friendly.

1.2 Project purpose and goal

The cleaning performance is the most important competitive factor. One way of influencing the performance is by making changes in the mechanical impact on the dishes (as can be seen in Figure 1.1). The two main factors influencing the mechanical impact on the dishes are the rotation speed of the spray arms and the water pressure in the spray arms. Structured tests to determine how these factors influence the performance have not been done at ASKO. The rule of thumb, generally adopted at the company, is that higher pressure and lower rotation speed increase the performance.

[1] *Patrik Ivarsson, ASKO Appliances AB*

ASKO would like to confirm their theories regarding these factors.

This project was to focus on exploring the effect of mechanical impact on dishes, more specifically how the rotation speed and water pressure in the dishwasher spray arms influence the washing performance. The two parameters are naturally coupled since the spray arm is driven by the water pressure alone. The goal of the project was to explore the interrelation between these parameters through testing. A simplified test method to measure dishwasher performance was to be developed to be used at Chalmers while conducting the tests. Methods for altering rotation speed and pressure were to be developed and implemented. All variables that could have an influence on the washing performance were to be documented. Sound measurements were to be made in order to see how changes in pressure and speed would influence the overall sound level of the machine. The results were to be such that they could be used at ASKO to improve their products.

1.3 Scope and limitations

The experiment was limited to one specific dishwasher model, the ASKO D5900. The focus was on improving the performance through mechanical impact on the dishes; none of the other influencing factors seen in Figure 1.1 should be altered. The only parameters that were to be altered were the spray arm rotation speed and the water pressure. Sound level measurements were to be conducted within the limitations of the laboratory environment.

2 – PRODUCT AND EXPERIMENT DEVELOPMENT

In the following, a description of development methods used to develop the test rig and designing the experiment are provided.

2.1 Design of Experiments

This section gives a brief overview of the field of Design of Experiments (DOE). The methods described can be used in experiments ranging from very simple to highly complex.

2.1.1 Planning the experiment

In order to be reliable an experiment needs to be both well planned and well documented. Good planning also saves time and resources. The basic theory when designing an experiment is to follow these steps (Weber & Skillings, 2000):

Clarify the goal

Why is the experiment conducted? What is the phenomenon of interest? This needs to be clearly defined before any further work can be done.

Select dependent variables

Dependent variables, or response variables, are the main variables of interest. These are affected by the independent variables. The effect of the independent variables on the dependent ones is what is studied in the experiment, so one could say that the dependent variables are the 'result variables'.

Identify independent variables

Independent variables are all variables that affect the system and the dependent variables. These need to be found and evaluated. One or more of these will be used to induce an effect on the dependent variables. They are called the controlled variables. The controlled variables are varied in such a manner as to enable studies of their effect on the dependent variables.

Other variables must be evaluated as to decide if they are to be kept constant or, if their influence on the dependent variables is insignificant enough to be disregarded, to be left uncontrolled. In some cases it can be difficult to identify all independent variables. Some might not be found when planning the experiment and thus be left uncontrolled. This will affect the validity of the experiment negatively. It is important to continuously document all variables in order to be able to determine unexpected influences and identify sources of error during the analysis.

Some claim that there should be only one controlled independent variable so as to isolate the effects of this as much as possible (Shuttleworth, 2008). On the one hand, this makes it easier to determine the results, and simplifies the test procedure. On the other hand, there might be interactions between independent variables that cannot be found if they are studied separately in different experiments. A so-called factorial experiment (see section 2.1.3 Factorial experiment) might then be preferable where an arbitrary number of controlled independent variables are allowed (Wikipedia, *Design of Experiments*). Isolating independent variables, thus missing the interaction between them which occur in the actual process studied, can lead to lower external validity. The decision of which variables to control, keep constant and leave uncontrolled is of highest importance to the outcome of the experiment.

Set levels

Each independent variable should have predefined levels between which they are to be varied. These are experiment-specific and should be derived from the experiment goal.

Test design

Selecting how the independent variables should be varied is also an important issue. There are a lot of different methods that have been developed to optimize the testing to get as good results as possible with as few tests as possible. Some of the most common ones are presented in section 2.1.3.

The experiment can then be conducted and the result analyzed. The result of the experiment is an indication or description of the causal link between the independent and dependent variables.

2.1.2 Validity

It is important to address the question about experiment validity. Is the test efficiently isolating the phenomenon studied? Is it a good representation of the real-life phenomenon?

Validity is usually divided into internal and external validity. Internal validity is a measurement of how well the experiment isolates the variables of interest and makes it possible to determine cause and effect. External validity concerns how well the experiment generalizes, i.e. if the test results correspond to the real-life phenomenon (Shuttleworth, 2008). External validity should not be confused with ecological validity. Ecological validity is a measurement for how well the experiment resembles the real-life situation (Wikipedia, *Ecological validity*). Ecological validity is not considered to affect the external or internal experiment validity.

When designing an experiment one wants a certain level of validity, but in many cases it is difficult to get both high internal validity and high external validity. One might increase the level of internal validity by keeping some independent variables constant which are not controlled in real-life, but in doing so you decrease the external validity. This is an effect the test designer should keep in mind when designing the experiment.

2.1.3 Regarding the design selection

When conducting an experiment the choice of design is important. One wants to do as few tests as possible, but still get statistically reliable results. This section describes some of the most common test setups.

Factorial experiment

A factorial experiment (also referred to as a full factorial experiment or fully-crossed experiment (Wikipedia, *Factorial experiment*)) is an experiment of one or more variables which vary in an equal number of steps (called levels) from a minimum to a maximum. The tests are performed with every possible combination of these levels of variables (Milton & Arnold, 2006). An experiment with four variables which each can have two different values would be called a 2^4 factorial experiment. To complete this experiment one would have to do 16 tests. The general form is L^V, where L is the number of levels and V the number of variables that are to be altered.

Fractional factorial design

Using a factorial design of an experiment often results in a very large number of experiments. This might not be time- or cost-efficient. One method to handle this problem is to use a fractional factorial design. The idea is to only conduct a part of all experiments of a factorial experiment (Milton & Arnold, 2006). The experimenter could choose which parts of the complete matrix of test combinations to perform based on a priori knowledge, or reduce the number of variables by merging two or more variables into one (Wikipedia, *Fractional factorial experiment*). The selection of which variables to merge should be done with the importance of the different variables in mind. Variables of high importance should not be merged (Milton & Arnold, 2006). A factorial design of, for example, 2^7 can by this method be reduced to, for instance, 2^5, thus reducing the number of tests from 128 to 32.

When using a fractional factorial design, there is a risk of the effects of variables becoming indistinguishable from one another if the variable selection is not done properly (Milton & Arnold, 2006).

Central composite design

Central composite design can be used instead of a full factorial design. The difference is the placement of testing points, as can be seen in Figure 2.1, where three levels are used. Figure 2.1 a, b and c describe different placement of the testing points around the variable span of interest. This design method is beneficial since it reduces the number of variable combination testing points (Wikipedia, *Central composite design*). In the case of three levels it reduces the number of points from 9 to 8 (compared to a full factorial design).

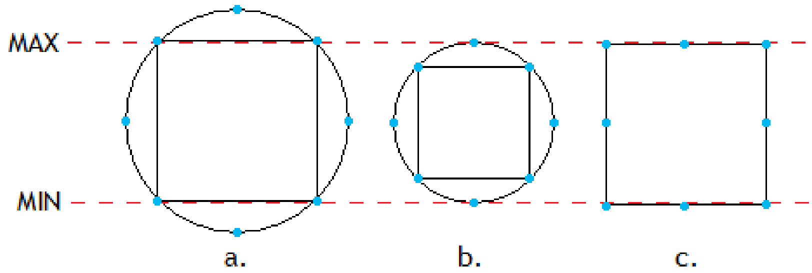


Figure 2.1: Example of central composite designs

Response surface

A response surface is a graphical way of presenting the response influenced by two or more variables (Montgomery, 2005). In Figure 2.2 is an example of two variables and their response plotted as a response surface.

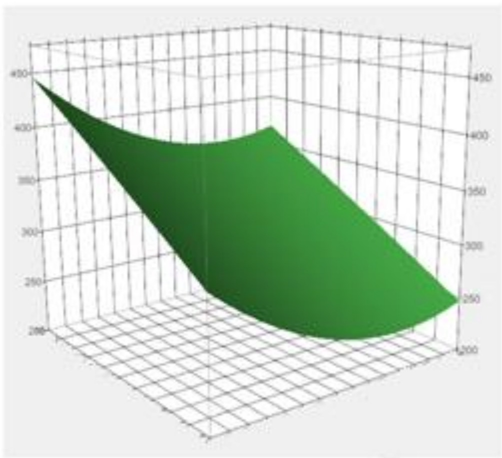


Figure 2.2: Example of response surface plot

The plot can be used to find a maximum (or minimum) in a relatively quick way with few experiments. The more levels used in the experiment, the more accurate the response surface becomes. If too few levels are used, there is a risk of missing a local minimum or maximum and thereby getting inaccurate results.

There is a mathematical method for finding the maximum (or minimum) which could be used to reduce the number of experiments. The method is called the *method of steepest ascent (steepest descent)* and is carried through by plotting the response for an experiment of two variables, and then finding the direction of steepest ascent. The limits for the experiment are then moved in that direction and the procedure is repeated. This will eventually lead to a point where no direction can be determined, which will be assumed to be the maximum (or minimum) (Montgomery, 2005). This method is suitable for tests where one has very accurate response data.

Another way of presenting a response surface is as a contour plot (displayed in Figure

2.3). It is used to present a function or a curve based on two variables as a number of lines at which the response is at an equal value level. These lines are called isolines (Courant, Robbins & Stewart, 1996). Generally, there is a set particular value between each contour line (Wikipedia, *Contour line*). That means if the lines are close together the magnitude of the change is large: the variation is steep. Whereas a sparse line shows that the change is slight.

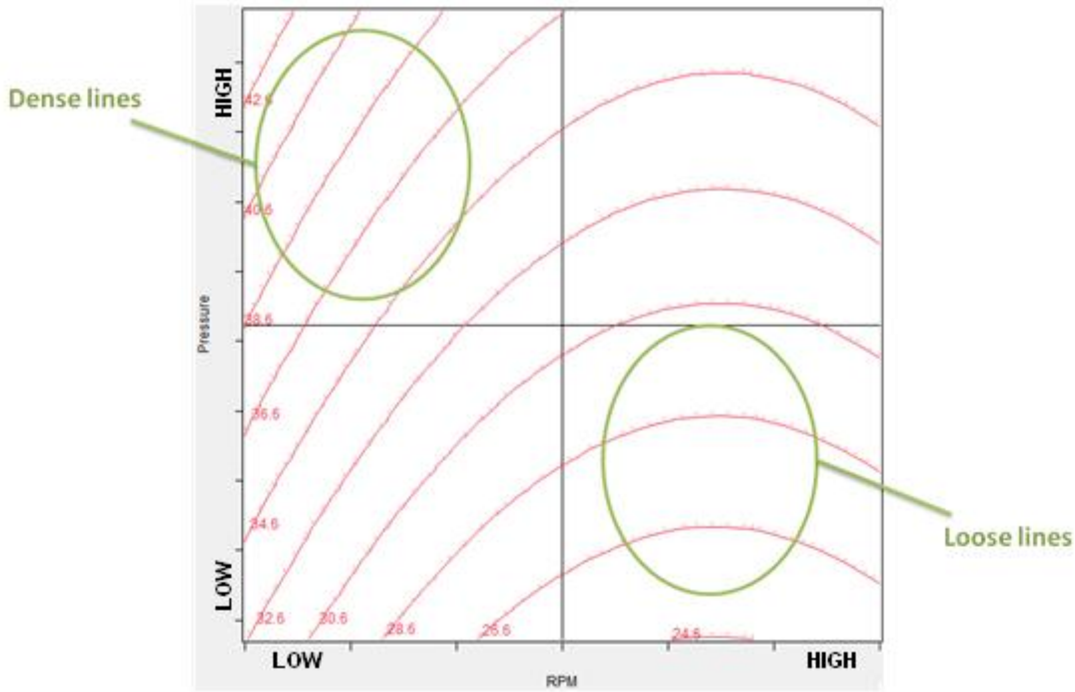


Figure 2.3: *Example of response surface plotted as contour lines*

2.2 Product Development methods

In this section some methods for product development and decision support methods that were used while developing the test method and test rig are described.

2.2.1 System design

System design starts with requirements definition and division into different subsystems. The division into subsystems makes project workflow more practical, efficient, flexible and secure. For each subsystem every component should be defined that contains units, interfaces, time and cost. The design should follow top-down hierarchy as shown in Figure 2.4 Thereby the independent interfaces can be tested (Stevens et al., 1998).

All the components are integrated after they have passed the testing in the subsystem integration process. This is an opposite design direction, as shown in Figure 2.4. All the subsystem should be assembled together as a new system.

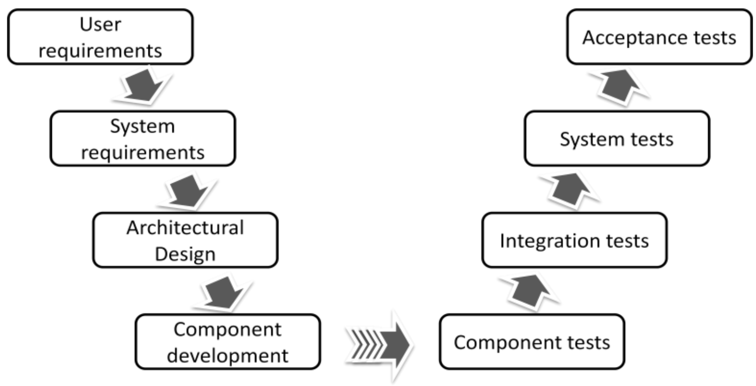


Figure 2.4: *Basic system design workflow according to Stevens et al.*

2.2.2 Product development procedure

When designing a new system, product development methodology should be implemented. This section describes product development methodology as written by Ulrich and Eppinger, 2008. Product development methods are commonly used tools for concept development, system level design and components design. The process can be seen in Figure 2.5.

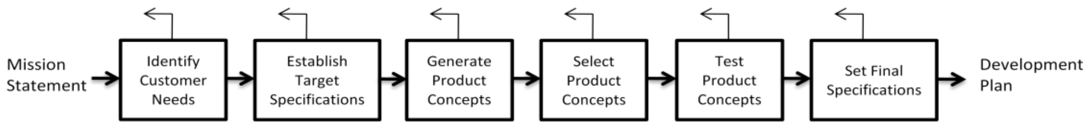


Figure 2.5: *Product development procedure according to Ulrich & Eppinger*

Problems can be formulated by the experimenter or collected from customers and users (Ulrich & Eppinger, 2008) (University of Leeds, *Problem Identification*).

The problems are then reformulated as target specifications which are to represent goals and aspirations for the project of solutions for the problems defined. The target specifications can be derived from the developers themselves, users or from regulations.

The concept generation process begins with a set of needs and target specifications and results in a set of concepts from which a final selection will be made. A good concept generation leaves the team with confidence that the full space of alternatives has been explored. In this phase, the use of morphological matrices and brainstorming, which are based on external and internal searching, are helpful when generating the initial concepts.

The next step is concept selection. In this phase the Kesselring matrix could be used to evaluate the concepts. Some concepts might be combined together to generate a new and improved concept. Finally, a winning concept is selected.

The target specifications will then be revised to become final specifications after a product concept has been chosen.

2.2.3 Morphological matrix

In the product design process the morphological matrix is a very common design method to hinge ideas when one has an glimpse of “what you wish to do” and “how you might go about doing it” (Fargnoli, Rovida & Troisi, 2006). It can be used to combine different part-solutions into a complete solution.

The form of a matrix is comprised by a single left-hand column and several right columns. The left-hand column is used in listing the parameter essential to design as shown in Figure 2.6. To the right of each element in the column is a row containing the possible ways of achieving that particular parameter. Illustrations can be used in the matrix to get direct impression.

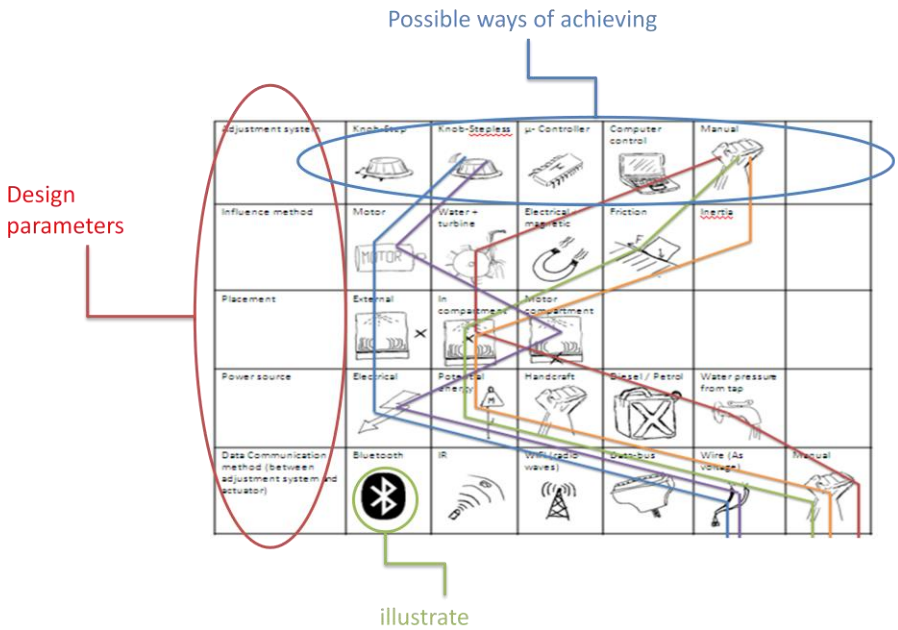


Figure 2.6: *Example of a morphological matrix*

2.2.4 Brainstorming

Brainstorming is a popular creativity tool (Baiduzhidao, *Brainstorming*) that helps designers generate creative solutions to a problem (Ulrich & Eppinger, 2008). It is particularly useful when the designers want to develop new ways of looking at things. In a brainstorming group, it helps designers to utilize the diverse experience of all group members to solve the problem (Mindtools, *Brainstorming*).

Individual brainstorming can sometimes be more effective than brainstorming in a group since it often results in ideas of better quality (Mindtools, *Brainstorming*).

2.2.5 Kesselring matrix

The Kesselring matrix is a design tool which connects each specification with different concepts. The Kesselring matrix is applied to evaluate different concepts in a form. To use the matrix for this purpose, designers have to carefully establish the specification and assign the weight value in the left-hand column. To the right of each element in the column is a row containing the weight value of specific concepts as, Figure 2.7 shows. If every element has received its relevant weight value, the designer can get the final scores by summing up all elements in the same column.

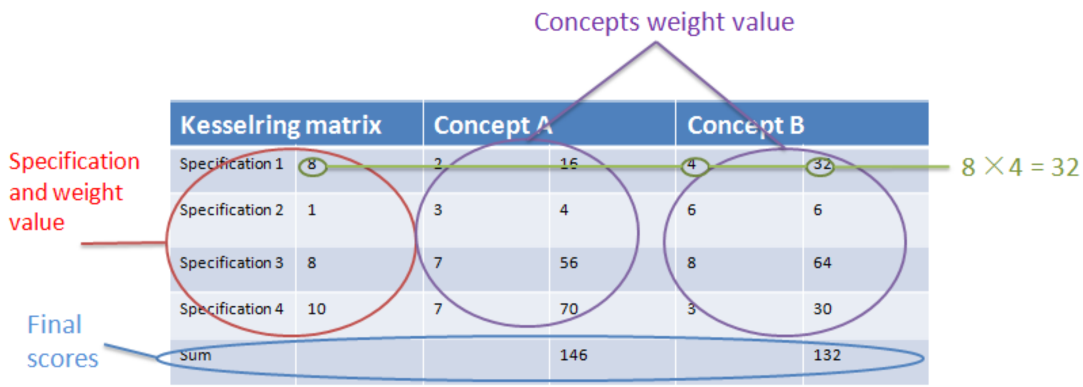


Figure 2.7: *Example of Kesselring matrix*

3 – TEST RIG AND EXPERIMENT DEVELOPMENT

The entire project was divided into subsystems and subtasks in order for it to be easier to develop and find optimal solutions for each part. After system functional tests, the new dishwasher system could be used in the dishwasher cleaning performance test. The main subsystems and subtasks are:

- Designing the experiment
- Creating a simplified test method
- Test rig construction
    - Rotational speed actuator
    - Rotational speed sensor
    - Pressure actuator
    - Pressure sensor
- Test environment documentation

These subsystems and subtasks were developed independently but with the coming integration in mind.

3.1 Designing the experiment

The goal of the experiment was to explore the influence of the rotation speed of the spray-arms and the water pressure on the dishwasher cleaning performance. The purpose was to answer the following question: Can a higher cleaning performance be achieved by changing the water pressure or the spray-arm rotation speed?

The cleaning performance was selected to be the dependant variable. This was the obvious choice considering the goal of the experiment. How this was measured is described in section 3.2. The experiment goal also gives that the controlled independent variables were to be the water pressure in the spray-arms, and the rotation speed of these. It was decided that both variables should be controlled in the same experiment, since it was thought that this would increase the external validity. All other independent variables, such as temperature and humidity, were kept constant and closely monitored (see Chapter 3.2 Development of simplified test method).

The levels of interest in the experiment were set, according to instructions from ASKO, from low rotation speed to high rotation speed with very low pressure to very high pressure. This is a span set around the original machine settings.

It was decided to use a modified form of factorial design with 3 levels as depicted in Figure 3.1. (This was later changed, see 3.3.4 Water pressure actuator)

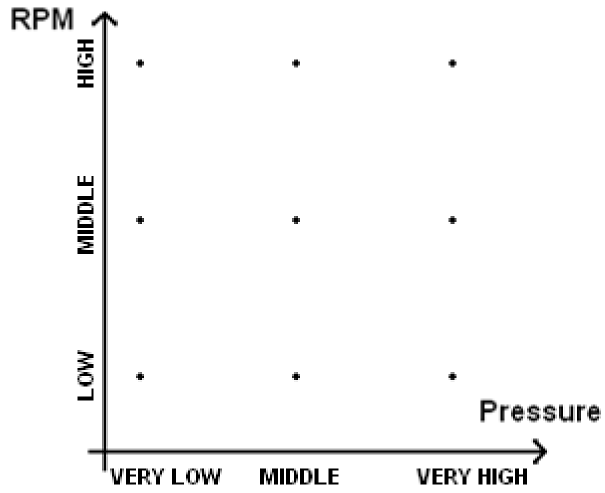


Figure 3.1: *Preliminary levels of experiment*

The tests were made in arbitrary order. The results were then analyzed using JMP Statistical Discovery Software v. 8.0 (JMP) which automatically calculates accuracy in different factor spans and presents the result in a 3D response surface plot.

The response surface steepest ascent method was not applicable in the experiment because of the relatively low accuracy. It was decided that it was more important to get a larger general picture of the interrelations of the rotational speed and pressure than being able to pinpoint the exact maximum. It was also decided to do all testing points since not enough dependable a priori knowledge was available to be able to exclude any points (as in a fractional factorial design).

3.2 Development of Simplified test method

The standardized test methods used at ASKO (and at other appliances developers) to measure the dishwasher cleaning performance are intricate and strictly defined. Specified amounts of foodstuff are placed on different types of plates and glasses. They are then subjected to heating and drying in microwave ovens before they are placed in the dishwasher. The dishes are washed using a specific detergent and a specific program, and are then examined and graded by an expert. Performing the planned experiment using these methods requires more time and resources than what was available for the master's project. Therefore, a simplified test method was developed to be used at the lab facility at Chalmers. The purpose of the simplified test method was to save time and resources and still deliver an accurate and reliable test result. The test method had to be able to detect changes in input and indicate this with notable changes in output, but not so large changes so that the output becomes saturated.

A table of requirements was set up listing all the needs of a functional test in a structured way. These were graded in order to verify which parameters were most important. The entire target specification can be found in Appendix A. The target specifications was reviewed and consulted several times during the development of the simplified test method.

3.2.1 Design parameters

By dividing the simplified test method into its main components or functions the design parameters available for alteration were revealed. A performance indicator that would be able to reflect results of changing water pressure and rotational speed of the cleansing arms was determined to be dependent on several parameters. Through empirical studies and tests the influence of the different parameters on the final result could be determined. Solutions for how to practically alter these parameters were then acquired through research and brainstorming sessions. These were then put in a morphological matrix in order to be able see the alternatives in a structured and easy way and make a selection (see Appendix B). The final selections are presented below.

Indicator

The indicator is the object that is placed in the dishwasher with the soiling agent applied to it. The spontaneous choice of indicator was glasses, dishes or other kitchenware, which would have a high degree of ecological validity. Custom made indicators with different shapes, materials and textures were considered as well. The simplicity and high ecological validity of regular plates were the main reasons to why white plates with a diameter of 25 cm were chosen. These are standard plates used in the standardized tests at ASKO (Artzberg, European standard plates). They are easy to come by, naturally fit in the dishwasher and provide an easy way of applying a soiling agent as well as placing them in the machine in a consequent way. Both European standard plates and Australian standard plates were tested, but the European proved to have the right surface properties. Cutlery and other kitchenware of more complex forms were disregarded to keep the test as simple as possible. Plates were thought to be a satisfying representative for all kitchenware used in a dishwasher.

Soiling agent

The soiling agent is the substance placed on the indicator plate. It should be resistant enough not to be removed completely in the washing process, but not as tough as not to be removed at all. A lot of research in this project was made to find either food or synthetic paint that would fit the requirements of the test. Table 3.1 displays the different substances that were regarded and the factors influencing their applicability. Through preliminary simplified washing tests and research the decision was made to use paint from artistic markers, applied using the marker itself.

Table 3.1: Substances tested for usability in simplified test

Substance	Reasoning	Result
Egg	+ High ecological validity - Difficult to apply and measure accurately - Difficult to analyze - Relatively costly to use in large quantities - Not tough enough without treatment (heating)	Not selected
Balsamic vinegar glace	+ High ecological validity - Time-consuming to apply - Difficult to analyze	Not selected
UV-pen	+ Quick and easy to apply + Easy to standardize + Relatively cheap + UV-light could be used to detect even the tiniest spots - Not tough enough to withstand washing - Low ecological validity	Not selected
Spray-paint	+ Quick to apply + Easy to standardize + Relatively cheap - Too tough to get off during washing - Difficult to apply - Low ecological validity	Not selected
Permanent markers	+ Quick and easy to apply + Easy to standardize + Relatively cheap - Too tough to get off during washing - Low ecological validity	Not selected
Artistic markers	+ Quick and easy to apply + Easy to standardize + Relatively cheap - Low ecological validity	**Selected for tests**

Another factor of interest is the application method. Given the decision of using markers painting was seen to be the most obvious choice. The painting process was made as standardized as possible. Templates were made to cover the plates while painting. Some different patterns and sizes were tested, which can be seen in Figure 3.2. The pattern depicted in Figure 3.2a. was tried on the small plates in the upper basket and figure 3.2b. and 3.2c. were tested on the larger plates in the lower basket.

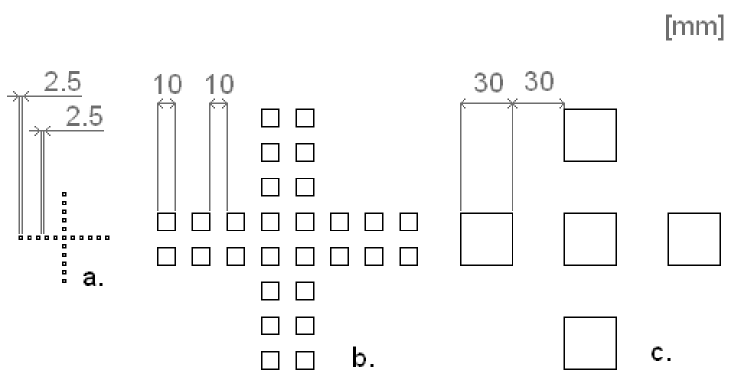


Figure 3.2: Painting patterns tested on plates

The final choice of pattern, a simple square, can be seen in Figure 3.3. 3.3a. depicts the pattern for the large plates and 3.3b. for the small ones. This pattern was decided to be the best choice since it would cover a larger area of the plate, making differences in the surface less important. It would also be easier and faster to analyze the result using the computer vision method (see Analysis method below).

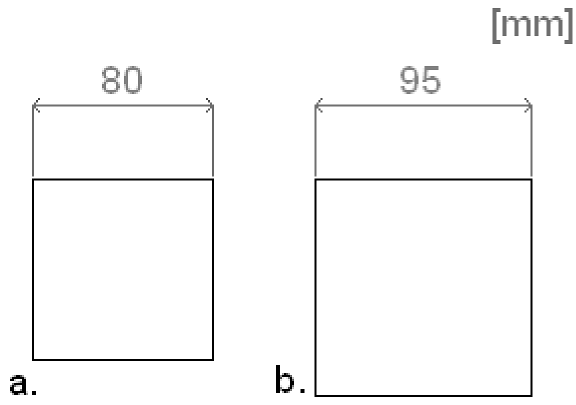


Figure 3.3: *Final painting pattern*

The templates were made from thick building plastics and masking tape, as can be seen in Figure 3.4.

During the initial tests it was noticed that variances in the plate surface influenced the result a lot. Plates that were more worn were harder to clean than less worn ones. Observations were also made of differences on the same plate. Therefore it was decided to use the same area of the plates every time. To ensure that the same area was painted every time permanent markings were made (see Figure 3.4) within which the indicator paint was applied. The masking tape had to be replaced approximately every 10^{th} test run since its adhesive ability decreased due to the repeated painting. The permanent markings had to be repainted roughly every 8^{th} test run.

Figure 3.4: *Painting of test plates*

There is also the influence of the preparation method. The soiling agent could be prepared for instance by drying, heating, burning or freezing (see morphological matrix in Appendix B). This would affect the properties of different soling agents, especially foodstuff[2].

Using the markers, heating the paint using a hairdryer resulted in the paint being much harder to remove. This method of regulating the adhesiveness of the paint was very difficult to standardize, and was therefore rejected. Another method that would be applicable was letting the paint dry for different amounts of time. Tests were made in order to determine if the amount of time the paint was allowed to dry had an effect on the result. Paint was allowed to dry for 10, 5, 2 and 1 minutes before the machine was started. No differences in the result could be observed by visual inspection, but further investigations were needed. A more structured test was done using the computer vision analysis method (see Analysis method below) and the standard test setup (see Chapter 3.5 Experiment Execution). The plates were cleaned with detergent using the Quickwash-program, then rinsed clean from detergent using the Quickwash-program again, without detergent. The tests differed in the amount of time the paint was allowed to dry. With 20 minutes drying time 83% of the paint was removed, and with no drying time 92% was removed. Apparently, the waiting time was an important independent variable, so this was kept constant throughout the experiment.

Dishwasher environment

When considering the dishwasher environment, ecological validity was thought to have a substantial influence on the external validity. Placement, spray angles and such would most likely affect the result. Therefore, the placement of the plates was set as can be seen in Figure 3.5.

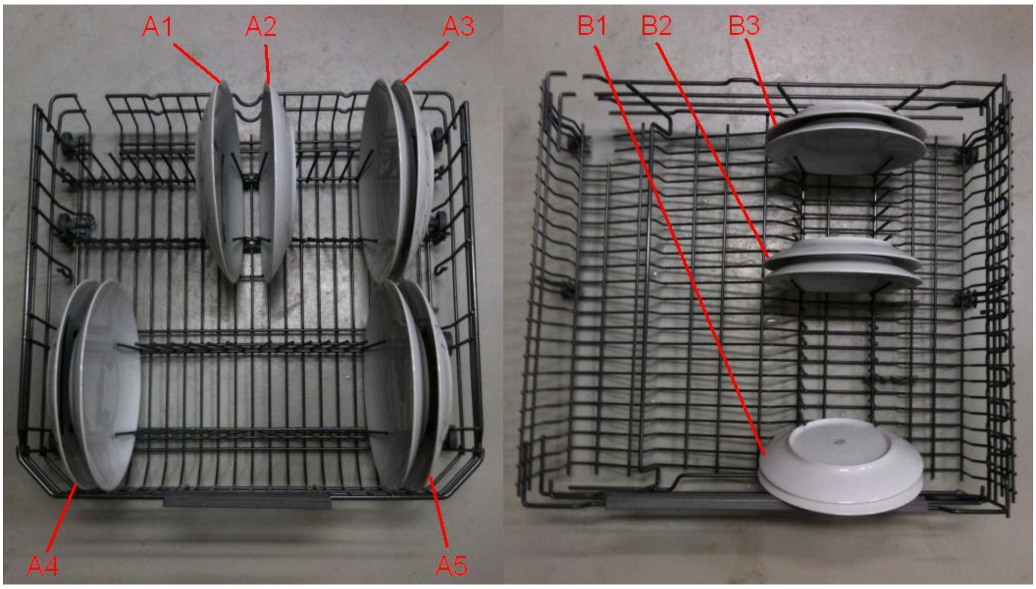


Figure 3.5: *Plate placement in lower (left) and upper (right) baskets*

[2] *Patrik Ivarsson, ASKO Appliances AB*

It was decided to place plates A3, A4, A5, B1, B2 and B3 behind another plate to better mimic the real life situation of a fully loaded dishwasher. The placement was not altered during the experiment; all plates had their specific placement. The rest of the machine was left empty. It was properly cleaned several times before the experiment commenced. The filters were cleaned at a regular basis (once per day, approx. every fifth test run).

The detergent used to clean the plates between each test run was Sun Professional Maskindisk (Supplier: DiverseyLever). ASKO standard testing detergent (Ref. detergent Type B, Batch: GSMB 177-280, 07.12.2009) was tested but it was not capable of removing the paint.

Program

The program used during the experiment was the Quickwash program which takes about 12 minutes to run. It first takes in water heating it up to 30 degrees C while spraying the dishes. It then empties this water. After this it takes in water (without heating it) and sprays the dishes for a couple of minutes and empties the water again. This is done twice. (see flowchart in Figure 3.6)

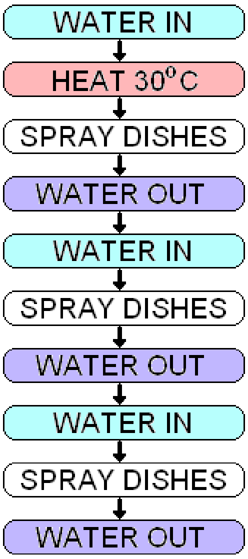


Figure 3.6: *Program flowchart*

The Quickwash program time varies somewhat depending on differences in input water temperature. This was considered to be a part of the inherit system behavior and to contribute to a higher ecological validity, even though this would leave the time variable uncontrolled.

Analysis method

Different methods for analyzing the result were tested. One method that was tested was visual inspection by an analyst, where the analyst estimates how large a percentage of the marked area was cleaned during the test. The indicator plate was inspected spot by spot, where each of the 28 painted squares in the grid (as can be seen in Figure 3.2b.) was graded between 0 and 1 in steps of 0.05. The grades for all squares were added and then divided by 28 to acquire a relative score. After some initial tests it was apparent that the grading could vary somewhat each time the analyst estimated an indicator plate. The grading also varied depending on different analysts. The accuracy of the analysis method was approximated to ± 10%.

To get better accuracy, tests were made with a computer analyzing the indicator plates. This was done by photographing the plates with a digital camera from a set angle and in a specific lighting, and by importing the data to a computer. A digital single-lens reflex (DSLR) camera was used to take all photos of the plates (see Table 3.2). The cameras capability was sufficient for the test. All camera settings were kept constant during the tests. A tripod was used to hold the camera, keeping it stable and at the right distance, which was approximately 1.5 meters between lens and plate surface.

Table 3.2: *Camera specifications*

Camera Model	Canon 400D
Lens Model	Sigma 24-70mm 1:2.8 EXDG
Program	Manual
Focus	AI focus 70mm
Shutter speed, aperture and ISO	1/40 second, F6.3, iso400
Distance between lens and plate surface	1.5 meter

The photos were imported to a computer and photo editing software (GIMP 2.6.8) was then used to manually cut out the painted area. In order to find the edges of the painted area they were marked with a permanent marker that was not removed during the test. These permanent markings also guaranteed that the same area of the plate was used every time, thus eliminating the problem with the surface of the plates influencing the results (see Soiling agent).

A threshold-filter was then applied to the cropped image (can be seen in Figure 3.7). The filter sets the color to either black or white depending on the threshold level, pixel by pixel. The threshold was set manually by visually inspecting the result and selecting a best fit. These manual tasks were recognized as a source of inaccuracy. In order to determine how much these influenced the result a series of tests were made. Two analysts got a set of five images of plates which they were to analyze three times each and then compare the results. The average standard deviation was less than 1 %.

Figure 3.7: *Indicator plate before and after threshold filter was applied*

The black-and-white image resulting from the threshold filter was then saved as a raw data file. In a raw data file the image data is stored pixel by pixel in three bytes, one for each color ingredient, red, green and blue. A 5 by 5 pixel image would thus result in a 75 byte large raw-file. This differs somewhat between software, but this is how GIMP stores the data. MATLAB was then used to import the data as a text string and count the number of white and black pixels and deliver the result in the form of a percentage of white. The whole process is depicted in Figure 3.8.

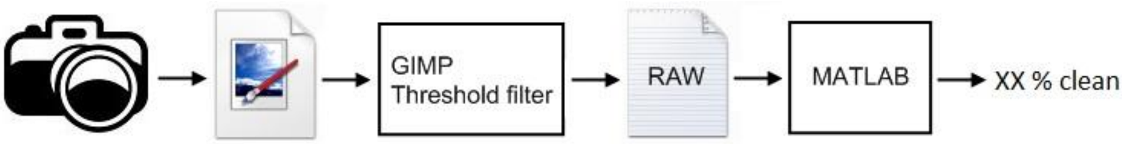


Figure 3.8: *Description of analysis method*

3.3 Development of test rig

The following part describes how the test rig was developed and how product development methods were used.

3.3.1 Development procedure

The development process was done in accordance with the methods described in section 2.2.

Problem identification

In the beginning of the project the goals were identified and most of the information and needs were retrieved from ASKO Appliance AB. The following tasks were identified:

- Rotational speed adjustment
- Water pressure adjustment

Then the tasks were considered based on system design principles described in 2.2.1, thus the tasks were divided into subtasks or subsystems.

- Rotation speed actuator
- Rotation speed sensor
- Water pressure actuator
- Water pressure sensor

From the literature study and company visits, important values were derived: less energy consumption, little water usage, low sound level and so forth. Furthermore, there were some other important values that should be dealt with during the whole project, such as safety.

In addition, the project workflow should be considered as well to determine every step in the project to avoid extra steps or missing some steps, the workflow is easy to follow and useful for estimating the workload.

Target requirement specifications
Most of the requirements for the adjustment of water pressure and rotation speed were from ASKO and other safety requirements from Chalmers. But whatever the origin they were set in a way so that they were possible to validate and verify.

In order to achieve the goal, some parameters of dishwasher which had the largest potential in adjusting pressure and rotation speed within the timeframe and did not hinder other functions, were put in focus. Some of the parameters of dishwasher were excluded early, because of their strong effect on whole washing system or other problems.

Concept generation and screening
The brainstorming and morphological matrix methods were used when generating the initial concepts (see Appendix B). To be able to select the best concepts a Kesselring matrix was used. The requirements were listed and rated on a scale from 1 to 10 on their relative importance to the overall goal, from trivial factors to highly prioritized factors. Concepts were then rated on how they fulfilled the requirements, also on a scale from 1 to 10. This rating was based on engineering analysis and logical evaluation. The two best concepts for each subsystem were selected for further development. Some of the key requirements were explored further for each concept. For details on the selection see Appendix C.

Selection of final concept
The final selection was made based on further studies of the primarily chosen concepts. This was done by re-looping the Kesselring matrix and adjusting the values according to the latest findings. Integrating with ASKO's requirements on the solution, the final requirement specifications were accomplished which included weighting depending on their significance. The different requirements have to the greatest possible extent been

connected to metrics.

Final specifications and system construction
The final specifications were made specific enough to be usable during the part selection and detailed construction. In the final stage the prototype was built based on the final specifications.

3.3.2 Rotation speed actuator

Established target specification for rotation actuator:

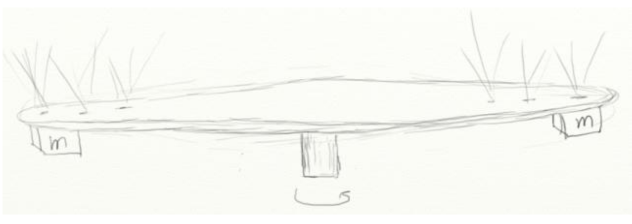
FR1	Possible to achieve target value
FR2	Quick to prepare for use
FR3	Measure velocity with high accuracy
FR4	Not affect other parameter
FR5	Affect other function as little as possible
FR6	Robust enough to withstand washing procedure
FR7	Durable
FR8	Be able to work in different temperatures
FR9	Be water proof
FR10	Physically possible to produce prototype within time frame
FR11	Low cost
FR12	Be safe to use
D1	Should be easy to set the value
D2	Modify the dishwasher as little as possible

Initial concepts
Several design parameters were set in the left columns in the morphological matrix, such as adjustment system and influence method. Then, more possible methods were filled in the matrix form. All the details are shown in Appendix B. The following concepts were generated:

Concept: Frictioner
Friction is created between the rotating spray-arm and some part attached to the machine base, which causes the rotation to decrease. The friction could be regulated by increasing the force applied to the spray-arm.

Figure 3.9: *Concept Frictioner*

Concept: HeavyArm



Weights are added to the tips of the spray-arm in order to make it rotate slower. The weights can be varied to attain different speeds.

Figure 3.10: *Concept HeavyArm*

Concept: Turbine

Air-pressure is used in a completely separated and closed system to propel turbine-like propellers that are directly connected to the spray-arms. The pressure in the system can be regulated by using a potentiometer.

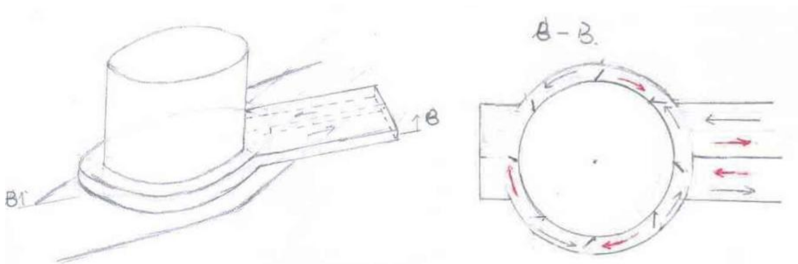


Figure 3.11: *Concept Turbine*

Concept: ExMotor

An external electrical motor is used to regulate the speed. The motor is connected to an axis inside or outside the machine which is connected to the spray-arms through timing belts. The motor is regulated either by using a potentiometer or pulse width modulation through a microcontroller.

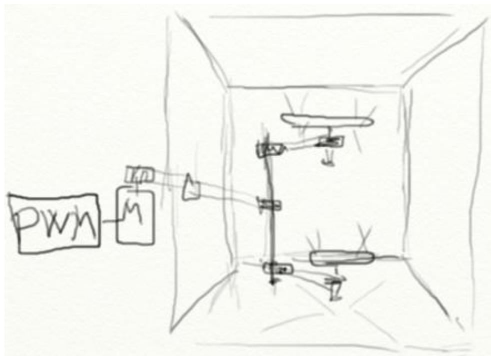


Figure 3.12: *Concept ExMotor*

Concept: InMotor

A waterproof motor is placed in the machine in direct connection to the spray-arm axis. A hole is cut out in the bottom in order for it to fit. The motor is regulated by using a potentiometer.

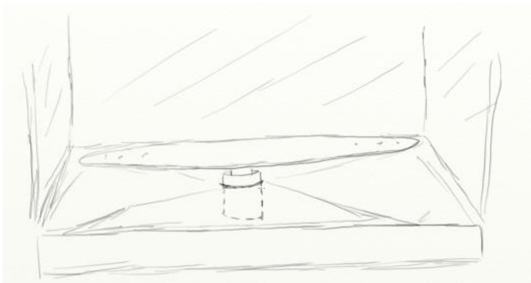


Figure 3.13: *Concept InMotor*

Concept selection

A Kesselring matrix was used in selecting the concepts for further development; all details are shown in Appendix C. The winning concepts were the "External motor" and "Turbine" as can be seen in Table 3.3. Although the "Heavy arm" concept got a higher score, it was disregarded due to its inability to increase the rotation speed.

Table 3.3: *Rotation actuator Kesselring matrix results*

Concepts	Frictioner	Ex-motor	In-Motor	Turbine	Heavy arm
Scores	564	715	603	614	643

Concept: Turbine

Air-pressure is used in a completely separated and closed system to propel turbine-like propellers that are directly connected to the spray-arms. The system is connected to an existing air pressure source and a mechanical valve is added to be able to regulate the air flow. Positive air flow would make the blades rotate faster and negative air flow would slow them down. The positive or negative air flow could be controlled by switching inlet.

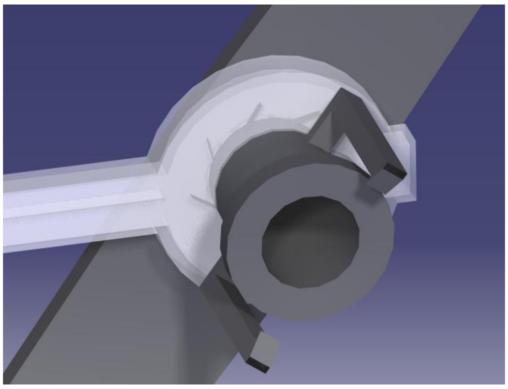


Figure 3.14: *Concept Turbine*

Construction time: This system would be quite difficult to construct and take several days in the prototype lab.

Modification level: A lot of space would be required by the air system, which could influence the spray pattern in the machine. It might also lead to larger modifications in the basket system and the indicator plate placement.

Robustness: It is hard to estimate how such a complex system would hold out during the experiment.

Usability: It would probably be quite easy to set the desired levels of speed, and all desired levels could be set.

Cost: A rough estimation of the cost of the parts that could not be acquired in-house is 500 SEK.

Concept: ExMotor

The concept has been divided into three versions of the original idea, depending on the different placement of the axis. The basic idea is still the same with an external motor that can be used to set the wanted speed. The motor is controlled using a potentiometer to regulate the effect of the motor.

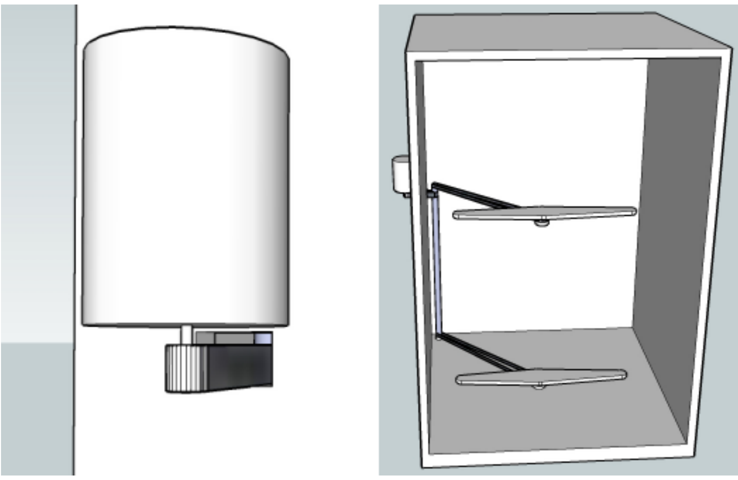


Figure 3.15: *Concept Internal axis version 1*

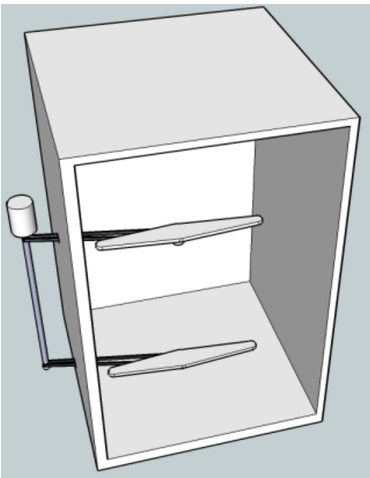


Figure 3.16: *Concept external axis*

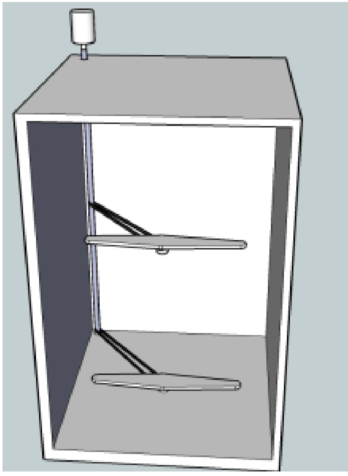


Figure 3.17: *Concept Internal axis version 2*

Construction time: Approximately 3 days

Modification level: It would probably not influence the performance of the dishwasher. It would lead to some modifications of the basket system.

Robustness: If it is made from stainless components it would be robust.

Usability: It would probably be quite easy to set the desired levels of speed, and all desired levels could be set.

Cost: Motor ~300 SEK + timing belt and pulleys ~600 SEK + bearings ~150
= ~1050 SEK

Final selection

The “Internal axis version 2” was selected for the rotation actuator subsystem. This was considered the best mainly because of its less complex construction and robustness. A hole in the top of the machine would leak less water than a hole in the machine wall. It would also be easier to connect the motor to the axis as specified in the “Internal axis version 2” compared to the other two “ExMotor” derived concepts.

Detailed construction - ExMotor

One drawback of the construction was that both spray arms would be rotated in the same direction. This was accepted as a loss of ecological validity in favor of the simplicity of the construction.

A hole was drilled into the top of the dishwasher in the back left corner. A construction made of wood and a 1 mm steel plate (as can be seen in Figure 3.20) was fastened on top of the hole. This allowed for an easy connection between the motor and the axis. A steel axis with a diameter of 8 mm was used, which was supported by two bearings, one in the upper wooden holder (Figure 3.18) and one in the lower wooden holder (Figure 3.19). The lower wooden holder was fastened to the back of the machine using a bent steel plate.

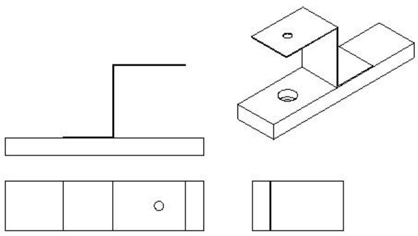


Figure 3.18: *Upper bearing holder and motor holder*

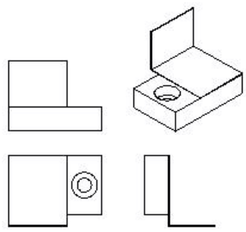


Figure 3.19: *Lower bearing holder*

The bearings had an inner diameter of 8 mm and an outer diameter of 22 mm. They were slightly lowered into tapered holes in the wooden holders to keep in place. The bearings took up the radial loads. The axial load caused by the weight of the axis and the timing belt pulleys was handled by the motor, which had a maximum limit of 5 N of axial load.

Two T5/18-2 (Pitch: 5mm, Number of teeth: 18, Flanges: 2) timing belt pulleys were fastened on the axis at the height of the spray arms. These were connected to larger T5/36-2 pulleys, which had been fastened on the spray arms, by a 5 mm wide timing belt. This gave the pulley system a gear ratio of 2:1. The pulleys were made 10 mm thick in order to fit around the spray arm holders without hindering the rotation. The construction can be seen in Figure 3.20.

Figure 3.20: *Timing belt and pulleys mounted in machine*

When selecting a motor it was decided that a DC-motor was the best choice since the rotation speed could then easily be regulated by changing the input voltage. To select a motor that could be regulated within the desired rotation speed range with sufficient torque, some rough calculations were made. The motor would have to be strong enough to rotate the spray arms even at the highest water pressure level. The torque induced by the water pressure was measured using a force gauge. This was fastened by a thread at a distance of 0.2 meter from the spray arm center. The gauge indicated that the force was less than 2 N on both the upper and lower spray arm. This gives that the torque needed to counter both spray arms would be 2 * 2 * 0.2 = 0.8 Nm. Since the gear ratio was 2:1 only half the torque would be needed, 0.4 Nm. This was considered the maximum torque needed, not including extra torque needed to counter the friction.

The spray arm rotation speed needed was *masked* rpm. Since the gear ration between the timing belt pulleys was 2:1 the motor would have to be able to rotate at least twice the highest speed, i.e. *masked* rpm.

The motor selected was a Micro Motors s.r.l. model HL149, with a maximum torque of 0.15 Nm, a gear ratio of 43.3:1 and a rotation speed of 55 rpm at 24 V DC.
The motor was fitted atop of the axis. This can be seen in Figure 3.20.

3.3.3 Rotation speed sensor

Established target specification for rotation sensor:

FR1	Be able to measure rotational speed
FR2	Quick to prepare for use
FR3	Measure velocity with high accuracy
FR4	Not affect other parameter
FR5	Affect other function as little as possible
FR6	Robust enough to withstand washing procedure
FR7	Durable
FR8	Be able to work in different temperatures
FR9	Be water proof
FR10	Physically possible to produce prototype within time frame
FR11	Low cost
FR12	Be safe to use
FR13	Easy to replace
D1	Should be easy to get the value
D2	Modify the dishwasher as little as possible

Initial concepts:

Several design parameters were set in the left columns in the morphological matrix, such as measuring method, placement and so forth. Then more possible methods were filled in the matrix form. All the details are shown in Appendix B. Finally some concepts have been generated as shown below:

Concept: Click-Counter

A device is constructed that has a feather-recoiling lever sticking out of its side. The lever is activated each time a small outshoot on the spray-arm axis passes it.

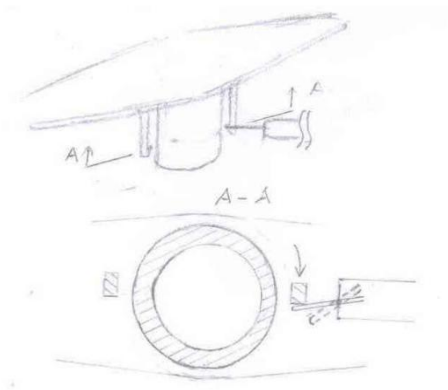


Figure 3.21: *Concept click-Counter*

Concept: Bike Computer

A regular bike computer is attached to the rotating axis of the spray-arm. The output from the sensor is recalculated to get the rpm value.

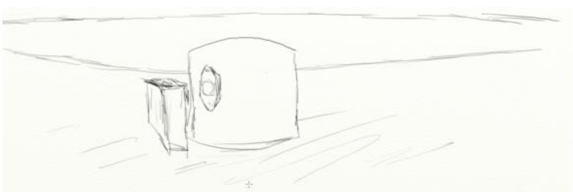


Figure 3.22: *Concept Bike computer*

Concept: Listen

A person is trained to hear the rotation of the washer arm while the machine is running. A timer is used and the number of laps is counted during a specific time-span.

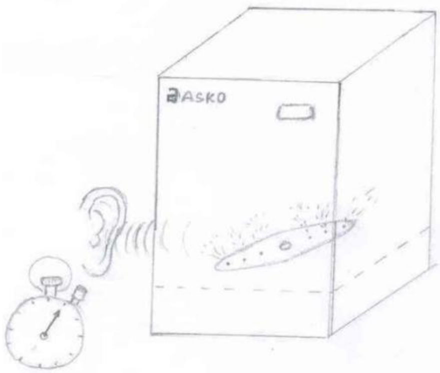


Figure 3.23: *Concept Listen*

Concept: Lookie lookie

A replacement hatch is made from plexiglas through which a person can see the spray arms rotate and count the number of laps during a specific time-span.

Concept: Light

A black line is painted along one side of the spray-arm axis. A light-sensitive sensor is used to detect if the painted section is placed in front of it. A microcontroller is used to acquire data from the sensor and count the number of laps.

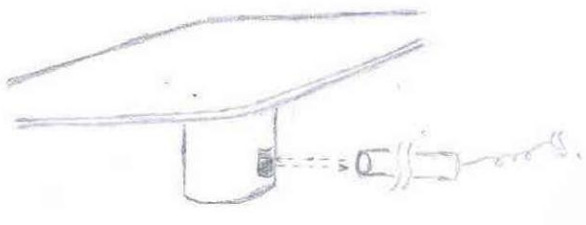


Figure 3.24: *Concept Light*

Concept selection

Kesselring matrix was used to select the concepts for further development, all details can be found in Appendix C. As can be seen in Table 3.4 the concepts “Bike computer” and “Listen” were selected.

Table 3.4: *Rotation sensor Kesselring matrix results*

Concepts	Click counter	Bike computer	Listen	Light sensor	Lookie
Scores	657	822	907	730	814

Concept: Listen

By placing the ear against the machine you can hear the water splashing on the walls of the dishwasher and count the laps. A watch is used to time a set number of laps. The rotation speed can then be calculated using the following formula:

$$\omega = \frac{n}{t}$$

ω: Rotation speed of spray arm [rpm]
n: Number of laps
t: Time [minutes]

Construction time: No construction time.

Modification level: No modification needed.

Robustness: Quite robust.

Usability: Very simple to use, but it might take a few minutes to set the desired speed level.

Cost: 0 SEK

Concept: Bike Computer

A regular wireless bike computer is used to transmit the speed to a receiver outside the dishwasher. The value indicated by the computer could be multiplied with a constant to obtain the actual rotation speed.

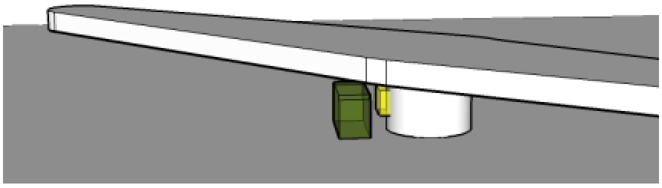


Figure 3.25: *Concept Bike Computer*

Construction time: This device could be set up in less than an hour.

Modification level: The sensor could be placed so that it doesn't influence the system at all.

Robustness: The device was made to withstand outdoor use, so it should be quite robust.

Usability: Very simple to use.

Cost: ~150 SEK

Final selection

The "Bike computer" concept was selected as the best solution for the rotation speed sensor, mainly because it would be much easier and quicker to acquire the measurement.

Detailed construction – Bike Computer

A bike computer (Velleman Model: BC15S) was used to measure the rotation speed. It was attached to the axis on the outside of the machine, thus elimination the risk of getting damaged by water, as can be seen in Figure 3.26.

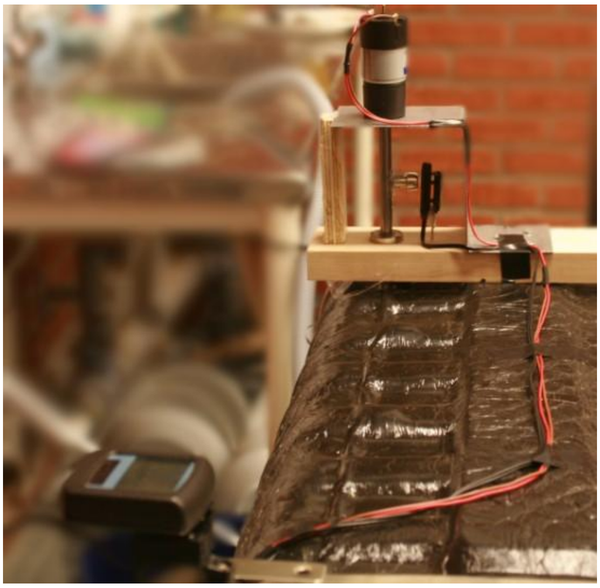


Figure 3.26: *Bike computer mounted*

3.3.4 Water pressure actuator

Established target specification for water pressure actuator:

FR1	Possible to achieve target value
FR2	Quick to prepare for use
FR3	Measure velocity with high accuracy
FR4	Not affect other parameter
FR5	Affect other functions as little as possible
FR6	Robust enough to withstand washing procedure
FR7	Durable
FR8	Be able to work in different temperatures
FR9	Be water proof
FR10	Physically possible to produce prototype within time frame
FR11	Low cost
FR12	Be safe to use
D1	Should be easy to set the value
D2	Modify the dishwasher as little as possible

Initial concepts:

Several design parameters were set in the left columns in the morphological matrix, such as power source and data communication method. Then more possible methods were filled in the matrix form. All the details are shown in Appendix B. Some concepts have been generated as follows:

Concept: PowerMotor

To be able to increase the water pressure the motor is replaced with a more powerful one. Due to its size it may not fit underneath the dishwasher and could be placed behind instead.

Concept: Restrictor

The water is partly blocked by a metal restrictor plate with a small hole in it. By varying the size of the hole, different pressures can be acquired.

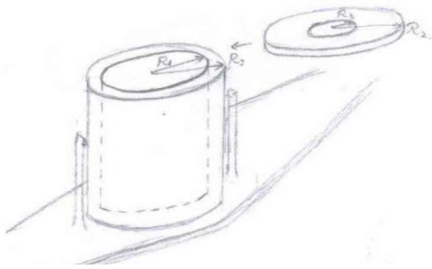


Figure 3.27: *Concept Restrictor*

Concept: ArmVolume

Different sets of sprayer arms are constructed with different inner volume. The volume is regulated to get different pressure.

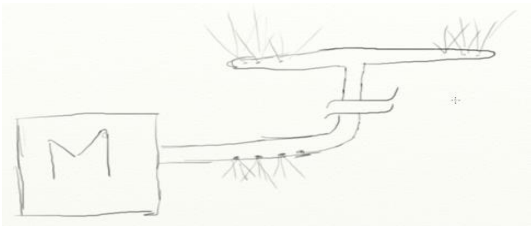


Figure 3.28: *Concept Holy*

Concept: Holy

Holes are made in the pipe that leads to the spray arm in order to decrease the pressure.

Concepts selection

A Kesselring matrix was used to select the concepts for further development; all details are shown in Appendix C. The “power motor” and the “Restrictor” were selected, as can be seen in Table 3.5.

Table 3.5: *Water pressure actuator Kesselring matrix results*

Concepts	Power motor	Restrictor	Arm volume	Holy
Scores	755	709	595	566

Concept: PowerMotor

The original motor should be replaced with a more powerful one which can be controlled to run at different power levels.

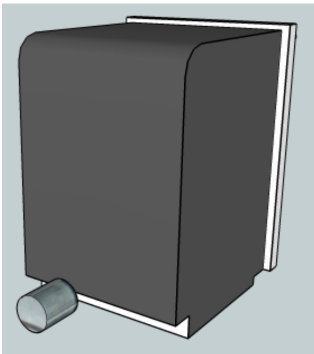


Figure 3.29: *Concept PowerMotor*

Construction time: Help would probably be needed from specialists at ASKO which would take some time to organize and would be costly for ASKO.

Modification level: The larger motor would not fit in the regular compartment and would have to be placed behind the dishwasher. This could possibly increase the sound level of the machine.

Robustness: Since the motor is a standard part made specifically for a dishwasher it *would probably be quite robust.*

Usability: It would be easy to regulate the desired pressure level, and it could be set to any level in the span of interest.

Cost: Parts could be obtained from ASKO. No external costs.

Concept: Restrictor

Thin circular plates with different sized holes should be manufactured. These are to be placed between the spray arm water input and the water pipe. The hole partly shuts off the water supply, thus decreasing the pressure in the water exiting the spray arm.

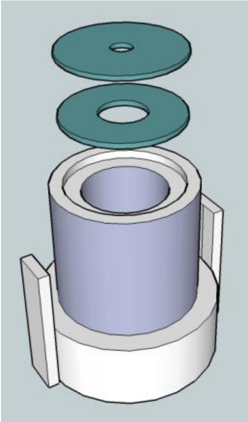


Figure 3.30: *Concept Restrictor*

Construction time: These could easily be constructed from metal or plastic in a day or two.

Modification level: It is a bit uncertain how the change in pressure will affect the rest of the machine. It might cause the motor to run slower. Apart from that the influence on the rest of the system would be minimal.

Robustness: The wear on the restrictors would be minimal, they would be very robust.

Usability: It would take some time to get them set at the right pressure level. Once this is done they will be very simple to change and use. It is not certain that all pressure levels could be attained.

Cost: Plastic or metal plates could be obtained for free from Chalmers.

Final selection

For the pressure actuator subsystem the Restrictor concept was selected due to its simplicity and low influence on the overall sound level.

Detailed construction - Restrictor

The restrictor plates were constructed using 2 mm thick plastic that was cut into circular plates that would fit inside the spray arm holder (diameter of 21 mm). Different sized holes were drilled in the center of the plates. Different sizes were tested and finally 7.1 mm and 8.2 mm holes were used which gave a pressure level of "very low" and "low" respectively in the lower spray arm. Due to the extra space required by the plates a thin layer had to be rasped off of the bottom of the spray arm holder. Tests were made with very thin aluminum plates, but they were too weak to withstand the pressure without bending.

3.3.5 Water pressure sensor

It was thought that the easiest and most accurate way of measuring the pressure would be to use a standard pressure meter. Therefore, no concepts were developed for a pressure sensor.

A pressure sensor was required to be able to set the spray arm pressure at the desired levels. A temporary sensor was constructed in order to verify the initial theory supporting the Restrictor concept. Using this temporary sensor a relative measurement could be attained, which would then be supported by a more accurate pressure sensor measurement later on. The reason why this temporary sensor was made was that constructing and fine-tuning the restrictors would take some time, and the more precise pressure sensor could not be borrowed for that amount of time. The temporary sensor was constructed using an air pressure sensor placed in a chamber separated from the water by a membrane. A 500 ml PET-bottle was used as pressure cell and tough plastic bags as membrane. The construction was sealed using glue. See Figure 3.32. Several models were constructed before a usable one was obtained. See Figure 3.31.

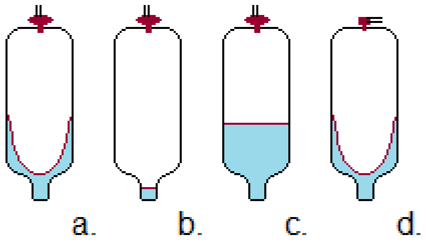


Figure 3.31: *Different temporary pressure sensor constructions*

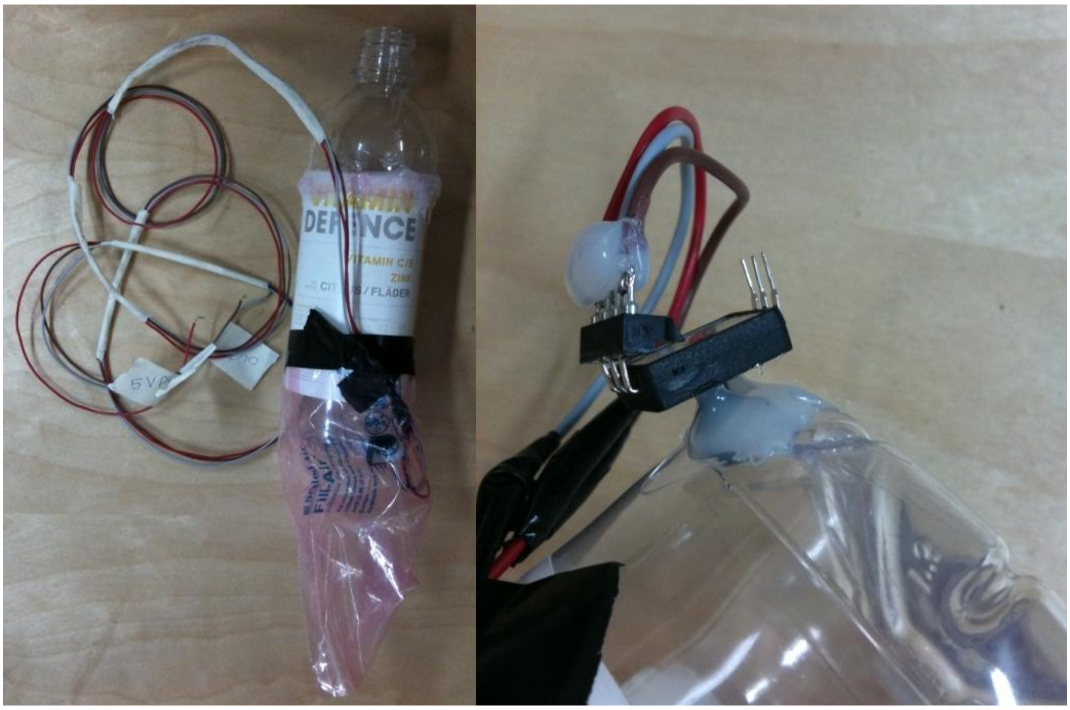


Figure 3.32: *The fourth working water pressure sensor*

First sensor (Figure 3.31a.)
Pressure cell volume: $0.5*10^{-3}$ m^3
Membrane area: $8.5*10^{-3}$ m^2
Sensor: ASKO DW20
Results: Not usable. The signal was saturated due to a too large membrane. It could be improved by using a smaller membrane or a pressure sensor with a larger measuring span.

Second sensor (Figure 3.31b.)
Pressure cell volume: $0.58*10^{-3}$ m^3
Membrane area: $0.35*10^{-3}$ m^2
Sensor: ASKO DW20
Results: Not usable. Too small changes in signal due to a too small membrane. It could be improved by using a larger membrane or a more sensitive sensor.

Third sensor (Figure 3.31c.)
Pressure cell volume: $0.4*10^{-3}$ m^3
Membrane area: $2.8*10^{-3}$ m^2
Sensor: ASKO DW20
Results: Not usable. The sensor values showed signs of drifting and did not return to a zero level between tests. This was probably caused by a leak or a damaged sensor.

Fourth sensor (Figure 3.31d.)
Pressure cell volume: $0.5*10^{-3}$ m^3
Membrane area: $8.5*10^{-3}$ m^2
Sensor: ELFA pressure sensor SPD-015-G-2
Results: The results can be seen in Figure 3.33.

The initial tests resulted in an implied relationship between the hole diameter and the pressure as can be seen in Figure 3.33.

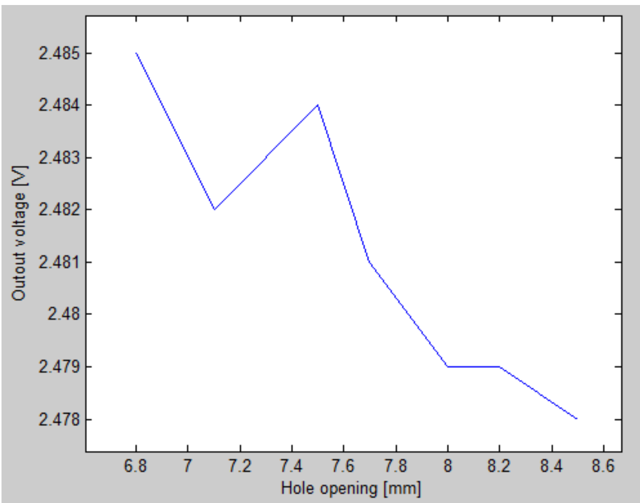


Figure 3.33: *Results from preliminary water pressure tests*

It was detected that the restrictors could not be used to increase the pressure, only to decrease it. This meant that either the experiment boundaries had to be changed or another concept would have to be selected for development. Reasoning that the Restrictor concept would be easier and faster to implement and that the competing concept, using a more powerful motor, would make sound tests unusable (which were thought to be very important at ASKO), it was decided to change the experiment boundaries. The new pressure levels were set as in Figure 3.34.

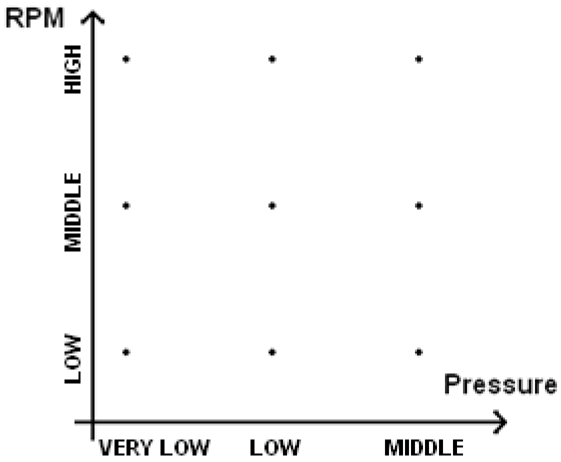


Figure 3.34: *New experiment levels*

Some different restrictors were prepared for the more accurate pressure test. The pressure sensor used was an Elite Digital Manometer HM3500, DLG300 (serial no. 1020203) used at ASKO (see Figure 3.35). It was set to measure the 10 seconds average pressure in kPa. The standard deviation of the readings was 0.21 kPa.

Figure 3.35: *Pressure measurements*

The sensor was placed over the holes indicated in Figure 3.36. A simplification was made; the same size of restrictors was used in the upper and lower spray arm. This meant that the pressure levels for the upper spray arm would not be evenly distributed across the pressure span. It would be very difficult and time-consuming to match the restrictors to get the exact wanted levels in both the upper and lower spray arms, so this simplification was accepted considering the time gain. The results from the upper test could thus not be evaluated in the same way as for the lower one.

The two extra spray holes in the bottom of the machine that provide extra water on the dishes from below were covered using glue.

Figure 3.36: *Spray arm holes used for pressure tests*

3.4 Test environment documentation

Independent variables which were to be kept constant were strictly monitored and documented.

Temperature

The room temperature and in-machine air temperature were measured, but could not be kept constant. This was not considered a problem since it varied very little and was thought to have little influence on the dependent variable.

Input water temperature at the water tap was also measured. This varied somewhat during the day due to variations in water usage in the building. The influence of the water temperature on the machine was considered to have minor effects on the results, but it would affect the washing-time which in turns would affect the results.

Humidity

Room and in-machine humidity was measured and documented. These variables could not be controlled but were quite stable during the tests.

The temperature and humidity measurements were done using a simple measuring station built as depicted in Figure 3.37. This allowed for quick and accurate reading of sensor values.

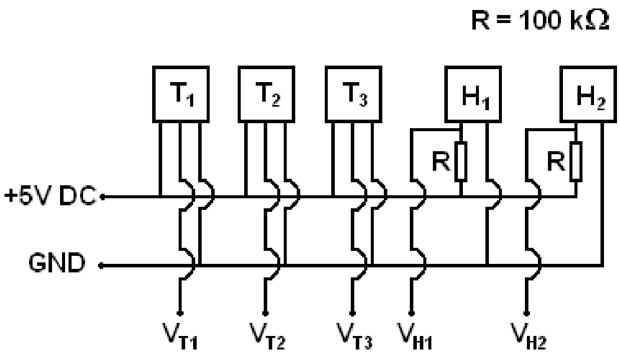


Figure 3.37: *Sensor rig circuit*

The circuit is depicting three National Semiconductor temperature sensors model LM35 TO-92 (accuracy ±0.5°C) and two Sencera humidity sensors model H25K5A (accuracy ±5%RH). A photo of the rig can be seen in Figure 3.38.

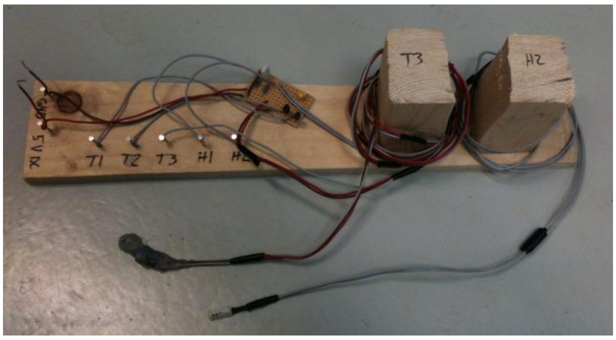


Figure 3.38: *Sensor rig*

Water properties

Water properties, such as chemical composition and water hardness, could not be controlled. This was recognized as a source of inaccuracy. The water hardness was considered to be at a fairly constant level throughout the experiment, and was measured to 3 ºdH.

Time

Due to the construction of the dishwasher program washing time varied depending on the input water temperature. Colder input water resulted in the machine taking longer time to heat it to the set level, thus prolonging the washing procedure. The time was measured using the machines built-in time indicator. The small changes in washing time were considered to have a minor effect on the test results. This was considered an acceptable source of inaccuracy since it was thought that using a pre-set program would contribute to the ecological validity, as mentioned earlier.

Sound level

Sound tests were made during the experiment to see how a change of spray arm rotation speed or water pressure would influence the general machine sound. For this purpose a Reed sound level meter model ST-805 was used to measure sound levels in dBA and dBC. It was run in slow mode which presented the 1 second averages with an accuracy of ±1.5 dB. The measurement was taken during the washing period of the program at a distance of 200 mm from the machine front, as indicated in Figure 3.39. The results are presented in chapter 4.2 Sound level tests.

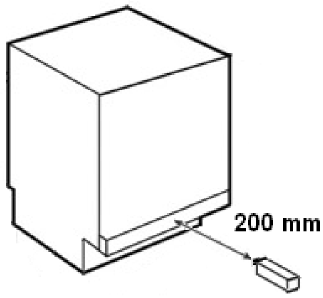


Figure 3.39: *Sound meter placement*

Energy and water usage
For every test-run the approximate energy usage was measured. The amount of water used by the machine was also measured. Energy and water usage were seen as system indicators rather than independent variables related to the washing performance. They were collected to verify that the system was running as it should.

3.5 Experiment Execution

A defined order of when and how to do each step in the test was set before the experiment commenced. This was done to minimize the risk of inaccuracies in the result due to variances in how the test was performed. One entire test run is described step by step below.

First, the plates were washed clean using approximately 10 ml Sun detergent and dried using paper. They were then painted within the specified area using the template and left to dry for 10 minutes.

While the plates were drying the air, in-machine and input water temperatures were measured as well as the humidity. The correct restrictors were put in place in the machine and the energy measurement instrument was set to zero.

When 10 minutes had elapsed the speed of the spray arms were set by fine tuning the output voltage from the power supply unit while checking the rotation speed on the bike computer. The plates were set in place and the Quick program started. After the first water intake sound measurements were made when the spray arms were rotating.
When the machine had finished the energy usage was read and the output water was measured, which had been collected in a bucket. Photos of the plates were taken and the plates were put in the machine again while the results were analyzed.

4 – INTERMEDIATE RESULTS

Tests were only done on plates in the lower basket due to initially bad results. It was decided to continue with the lower ones and add the upper in a second experiment.

4.1 Performance

The performance is presented as a cleanness percentage in Figure 4.1. If the score is 0 it means that the plate was not cleaned at all, if the score is 100 it means that the plate was totally clean.

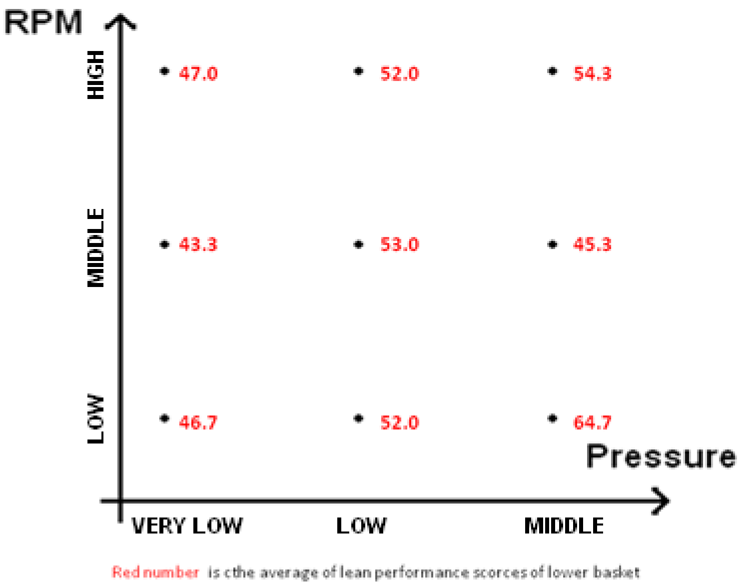


Figure 4.1: *Performance scores of first experiment*

Table 4.1: *Detailed results from first test*

Pressure [kPa]	*Rotation speed [rpm]*	*1st Test*	*2nd Test*	*3rd Test*	*4th Test*	*5th Test*	*6th Test*	*Avg.*	*σ*
Very low	*Low*	34	47	59	--	--	--	46.7	12.5
	Middle	37	39	54	--	--	--	43.3	9.3
	High	36	53	52	--	--	--	47.0	9.5
Low	*Low*	36	60	61	--	--	--	52.3	14.2
	Middle	53	42	44	59	56	64	53.0	8.6
	High	37	57	62	--	--	--	52.0	13.2
Middle	*Low*	54	64	76	--	--	--	64.7	11.0
	Middle	37	40	59	--	--	--	45.3	11.9
	High	37	63	63	--	--	--	54.3	15.0

As Table 4.1 shows, the lower basket cleaning performance seemed to be not so stable.

The standard deviation is quite large at almost every point. E.g. the standard deviation is nearly 15 % at low pressure level with low rotation speed.

The test result proved inconclusive, so some improvements to the test method would have to be made in order to get more stable data. During this test, one can see a trend that middle pressure with low rotation speed could enhance the cleaning performance. The cleaning performance is improving when the water pressure was increased. In addition the rotation speed only affected the cleaning performance to some extent in this experiment. The response surface figure and its sectional view are represented in Figure 4.2 and 4.3.

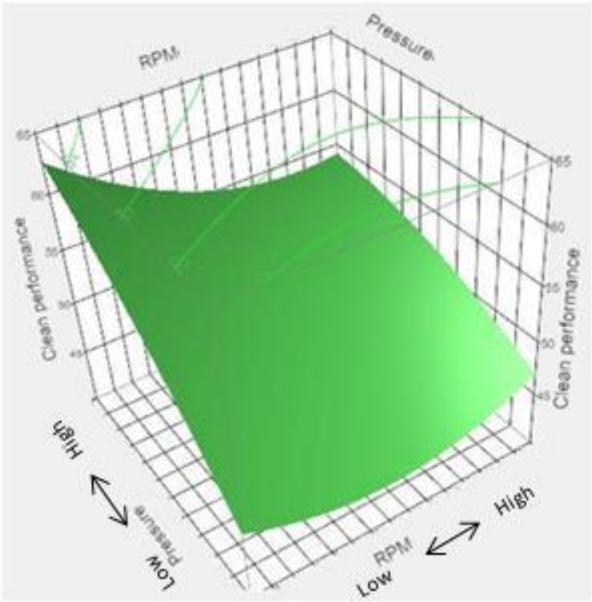


Figure 4.2: *Response surface plot of results from the first experiment*

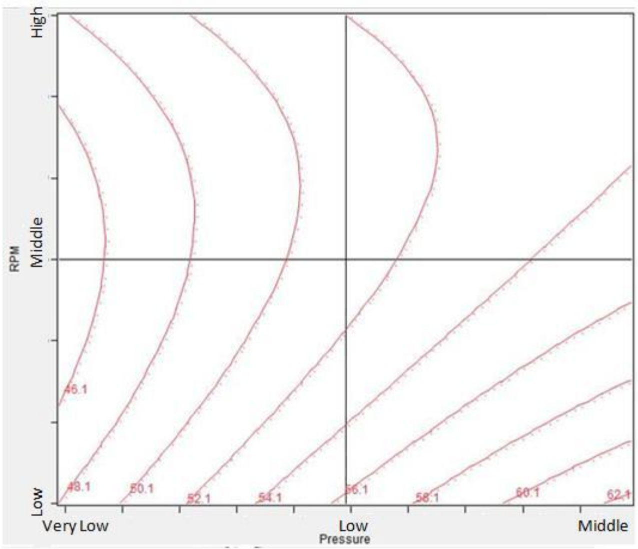


Figure 4.3: *Response surface contour plot of results from the first experiment*

In the Figure 4.3, the contour lines show the level of cleaning performance at two variables is a curve with a constant value. As can be seen, at a rotation speed between high speed level and middle speed level cleaning performance changes very little with increasing pressure, whereas at a low rotation speed the pressure has a lot more influence on the performance. Still, this is only an indicator since the variation was very high.

4.2 Sound level tests

The results from the sound tests are presented in Figure 4.4.

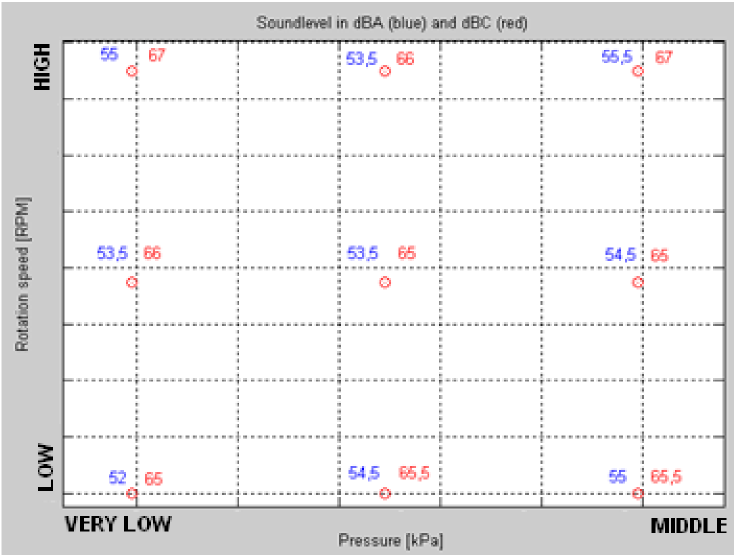


Figure 4.4: *Results from sound test at Chalmers laboratory*

The differences between testing points are not very large. In fact most changes are smaller than the measurement equipment accuracy of ±1.5 dB. This indicates that the sound level does not change much depending on pressure or rotation speed within the span that was tested. The measured sound levels cannot be seen as absolute values, since the machine could not be isolated from all other sound sources in the laboratory. The ambient sound level in the laboratory was perceived to be fairly constant during the tests. As can be seen in the difference between the dB(A) and dB(C) levels, there was a large contribution of sound below the range of human hearing.

Taking both equipment inaccuracies and unpredictable laboratory ambient sound into account it was decided to make more accurate sound tests at ASKO. The result from these can be seen in chapter 5.4.

4.3 Energy consumption

The energy consumption varied between 0.13 and 0.17 kWh. This was due to different test run time, which depended on the input water temperature. The power consumption/input water temperature relation is plotted in Figure 4.5.

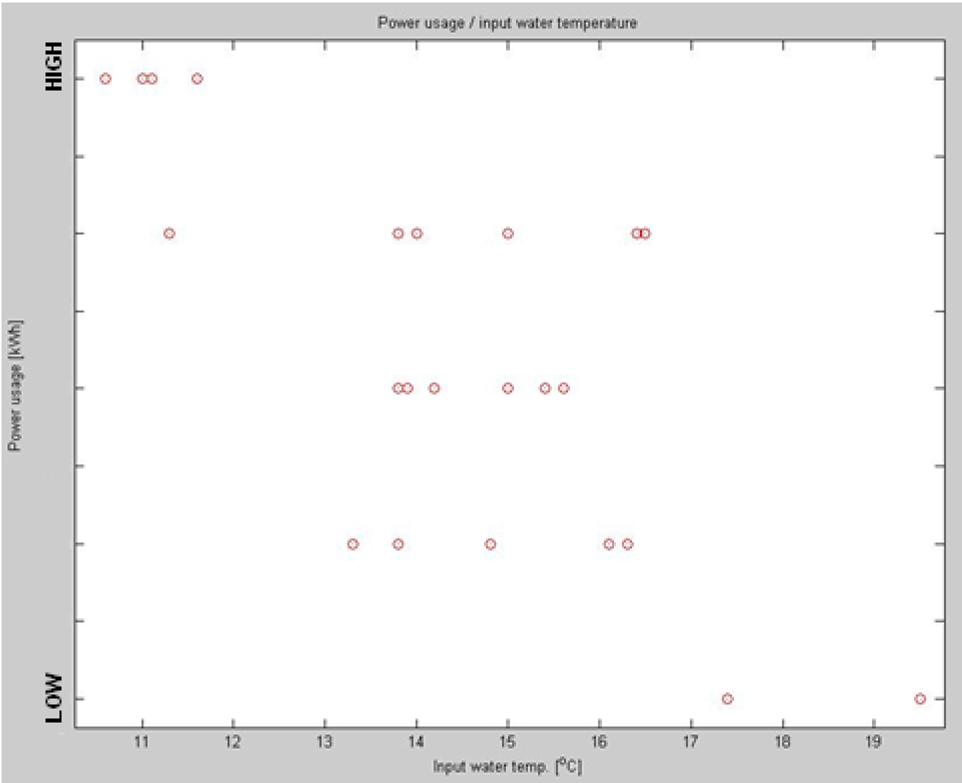


Figure 4.5: *Power usage contra input water temperature*

The graph suggests that the power consumption is proportional to the inverse of the temperature of the input water.

5 – FURTHER IMPROVED EXPERIMENT

Since the measurements from the first experiment were subject to large inaccuracies, it was decided to try to analyze the sources of these inaccuracies and try to control them. In order to do this, a table of potential sources of errors was made and the estimated influence of each of these was analyzed (see Table 5.1). Suggested solutions to the potential problems were generated through brainstorming.

Table 5.1: *Evaluation of possible sources of error*

Potential source of error		**Evaluation**	**Solution**
Painting	Paint	Paint properties might change when markers have been used a lot.	Do a test with a new and an old marker. If this influences: only use new markers.
	Plates	Worn and scratched plates might give an uneven result.	Do tests with new plates.
	Drying	Drying time does influence the result.	Is already kept constant.
Time	In machine	Time is not constant during tests due to the dishwasher program. This must be kept constant.	Use special settings in machine and use an external timer to keep time in machine constant.
	Drying	This has been done using paper which might influence the surface of the plate.	Let plates dry without touching the surface.
Temperature	Room	Has little effect on dishwasher performance.	No changes needed.
	Input water	Does affect the time variable.	Does not need to be controlled if the temperature in the machine is controlled as described below.
	In machine	Affects the performance a lot, and should be better controlled.	The machine should be set to run until it reaches 30° C before the dishes are put in.
Humidity		Uncertain how the humidity affects the results. Humidity has been constant during tests.	No changes needed.
Detergent	Build-up	This might be the reason for the drift in the previous results. Should be avoided.	Wash plates one time extra without detergent between every run.
	Wear on plates	Surface properties might change during test due to wear caused by repeated washing with detergent.	New plates should be washed several times before use, to get them stable.
Water	Properties	Chemical composition of water changes constantly. It is difficult to evaluate the effects of this.	If none of the other solutions work, all tests could be done at ASKO where strictly controlled water is used.

The outcome of this analysis was that time and temperature should be fixed, new plates should be used and the machine should be cleaned more properly between test runs.

5.1 Research for new experiment

Some research was done on how to stabilize the results according to the solutions from Table 5.1. Tests were done with new plates and paint. All changes to the experiment are described in detail below.

5.1.1 Test of new plates

In order to avoid problems with differences in plate surface influencing the results new plates were tested. The plates tested were:

Färgrik Tallrik 27 cm, Color: white, IKEA ID: 301.462.75
Lugn Tallrik 23 cm, Color: beige, IKEA ID: 133.123
Dinera Tallrik 32 cm, Color: beige, IKEA ID: 100.570.67

Before the plates were tested they were washed with detergent several times. The first tests proved fruitless; the plates were totally cleaned from all paint already after 30 seconds of washing. Apparently the surface was too smooth for any paint to stick. In an attempt to make the surface more rough, the plates were scraped using a dish sponge. The sponge was too soft to affect the surface and the plates were still cleaned from all paint.

Steel wool was used to very lightly scrape the plates. This resulted in more paint being left on the plates after the washing procedure, but the results were very unstable. To scrape the plates evenly across the surface proved difficult. Several attempts were made to stabilize the results but without success.

Finally, it was decided to use the same set of plates as in the previous experiment, since they had proved stable enough independently, even though the surface properties varied within the set.

5.1.2 Test of old and new marker

Tests were made to determine if the properties of the marker changed during use. A whole test run was done with a new marker at machine standard speed and pressure. The test was re-done using an old, almost finished, marker. There was a difference of 7% in the average plate score. The old paint was slightly more difficult to remove than the new one. It was decided that markers should be used until it was about 10 % full, then change to a new one to avoid this drift.

5.1.3 Stabilizing time and temperature

To get the desired temperature level a temperature sensor was placed in the machine, the Quick-wash program was started and then stopped when the water temperature reached 30 ° C. The program was aborted, while keeping the hatch closed, and the service mode was accessed. The prepared plates were then inserted and the machine water pump was started. Time was controlled using an external analogue clock. This procedure was predicted to decrease inaccuracies due to changes in time and temperature.

5.1.4 New pressure measurements

To ensure that the pressure levels were still correct, the pressure was measured again using the same equipment as before. Pressure levels had dropped a little bit. The levels were adjusted accordingly, and the restrictors slightly modified to get the desired levels, but the name of pressure level were named as same. The new pressure levels can be seen in Figure 5.1.

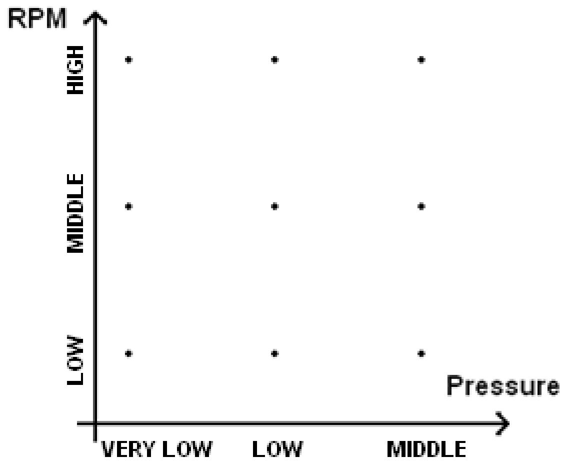


Figure 5.1: *New experiment levels*

5.1.5 New Experiment Execution

The plates were washed clean using 5 ml Sun detergent, and then washed again without detergent to remove all residual detergent. They were put in a stand, at a 90° angle, to dry for 20 minutes. They were then painted within the specified area using the template and left to dry for 10 minutes. One template for each plate was used to be able to do the painting as simultaneously as possible.

While the plates were drying the correct restrictors were put in place in the machine and the regular Quick-wash program was started. Input water and room temperature was documented. The start of the program was timed so that the temperature in the machine would reach 30° C when the 10 minutes were up. The machine was stopped and set into service mode which allowed for access to specific machine functions. Spray arm speed was set using the power supply unit and the bike computer. The plates were put in place and the machine was then set to run the water pump. The plates were cleaned for three minutes, which was timed using an analogue clock. Photos of the plates were taken and the plates were put in the machine again while the results were analyzed.

5.2 Cleaning performance results

Due to the uneven pressure levels in the upper spray-arm these results could not be used. Only the lower basket results were analyzed. The evaluation methods were the same as for the first experiment. If the plate was not cleaned at all, it got a score of 0, and if the plate was totally cleaned a score of 100. The new test result can be seen in Figure 5.2.

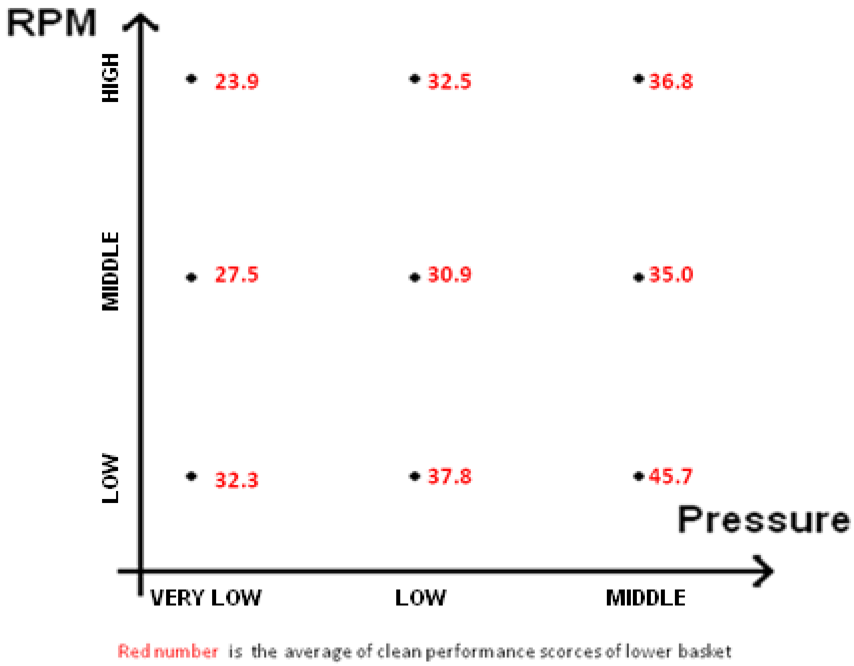


Figure 5.2: *Performance scores of improved experiment*

Table 5.2: *Detailed performance results from improved experiment*

Pressure [kPa]	*Rotation speed [rpm]*	*1st test*	*2nd test*	*3rd test*	*4th test*	*Avg.*	*σ*
Very low	*Low*	30.6	33.9	--	--	32.3	2.4
	Middle	26.9	28.1	--	--	27.5	0.9
	High	20.6	27.3	--	--	23.9	4.8
Low	*Low*	40.7	34.9	--	--	37.8	4.1
	Middle	27.2	33.4	30.5	32.7	30.9	2.8
	High	30.7	34.4	--	--	32.5	2.6
Middle	*Low*	46.7	44.7	--	--	45.7	1.4
	Middle	34.2	35.8	--	--	35.0	1.2
	High	38.3	35.3	--	--	36.8	2.2

In the improved experiment, the standard deviation of the cleaning performance was much lower than in the intermediate result. The standard deviation between two tests at the same point is between 0.9 and 4.8 as Table 5.2 shows.

During the new test, it was confirmed that high pressure at low rotation speed could enhance the cleaning performance, as suggested in the intermediate results. In opposite, the cleaning performance was decreased a lot at low pressure and high rotation speed. This trend is obvious considering Figure 5.2 and 5.3.

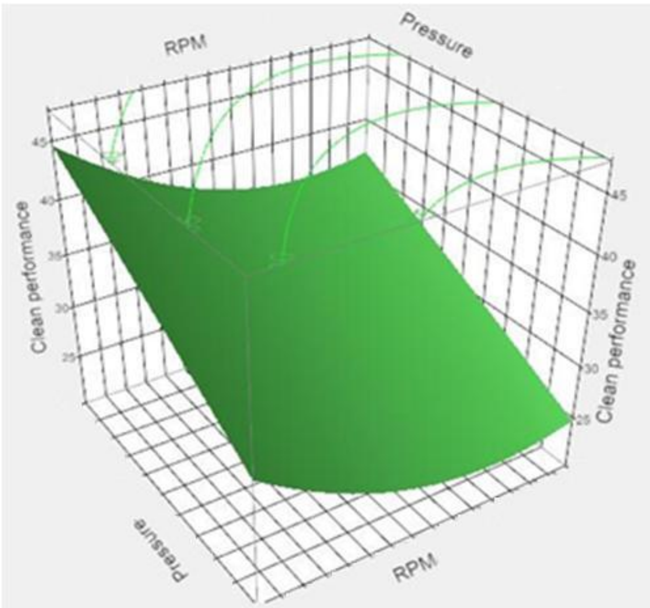


Figure 5.3: *Response surface plot of final results*

As can be seen in Figure 5.4 the contour lines indicate that the worst rotation speed is between middle speed and high speed. In another hand, the performance is more sensitive to changes in water pressure at lower rotation speeds. This is indicated by the density of contour lines around lower speeds in Figure 5.4.

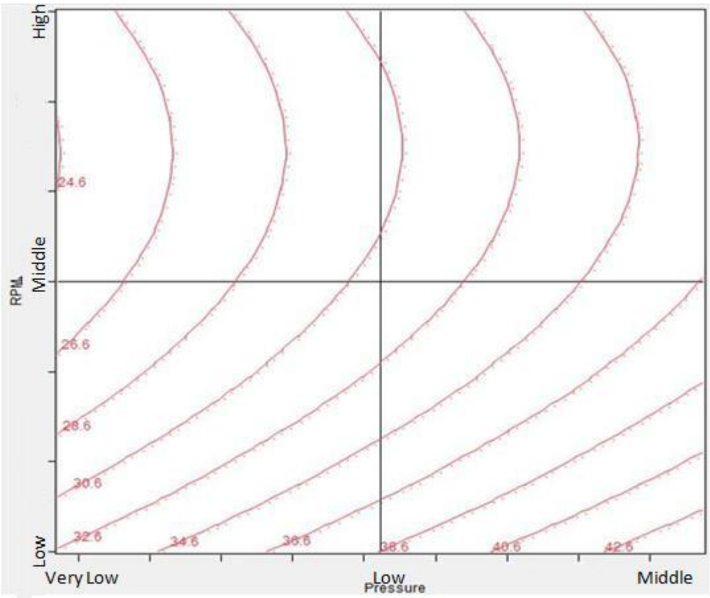


Figure 5.4: *Contour plot of final cleaning performance results*

5.3 Validation tests at ASKO

The external validity of the test method was evaluated by performing some of the test points using the standardized test method at ASKO (see Figure 5.5). This was done to see how well the simplified test method generalizes, if the simplifications using fewer plates and paint concur with the standardized test methods. Due to the cumbersome procedure of the standardized test the only points tested were very low pressure with high speed and middle pressure with low speed. Two tests were made on each point.

Figure 5.5: *Standardized tests at ASKO*

The expected outcome was that the lower pressure setting would acquire the worst results while the higher pressure setting would acquire better results.

This was confirmed by the validation tests. Results are measured relative a standard machine, 1 would mean equal to standard machine and 1.05 would mean 5% better than the standard. The test results are presented in Table 5.3.

Table 5.3: *Results from standardized tests at ASKO*

Pressure [kPa]	*Rotation speed [rpm]*	*1st Test*	*2nd Test*
Very low	*High*	0.76	0.78
Middle	*Low*	1.07	1.12

The higher pressure and lower rotation speed enhanced the cleaning performance by 7 to 12% compared to the reference dishwasher. On the other hand, the cleaning performance went down 22 to 24% at the lower pressure level. This means a span of approximately 33%. These figures can be compared to the simplified test, which indicates an improved performance of approximately 15% at high pressure and low speed and a loss of performance by around 35% at low pressure and high speed, i.e. a span of 50 %. The simplified test method appears to be valid, but more sensitive than the standard method.

5.4 Sound tests at ASKO

More accurate sound tests were made at ASKO to document how changes in pressure and rotation speed affect the machine sound level. The tests were made according to ISO 3743 in a reverberation room built for this purpose. The machine was placed in a wooden cabinet used when testing according to standard IEC60704-2-3, as can be seen in Figure 5.6, to mimic the kitchen environment. An insulated plastic can was put on top of the motor to block out as much of the motor sound as possible. The machine was fully loaded with clean dishes.

The test was run two times at every preset level of speed and pressure. Three tests were then run at different speed levels without any water in order to determine how much of the sound that was coming from the motor and spray arm pulley system. The results are presented in tables 5.4-5.7.

Figure 5.6: *Sound test setup at ASKO*

In the third test at very low pressure and at the second tests at low pressure and middle pressure (all marked in red) there was a change in sound due to that a part of the spray arm holder broke down and had to be replaced. The accuracy at the same level was quite high and can be seen if the first and second tests in Table 5.4 are compared. Results in A-weighted sound power level relative to 1 pW.

Table 5.4: *Dishwasher sound power level test – very low pressure level*

Pressure level	*Rotation speed [rpm]*	*First Test [dB(A)]*	*Second Test [dB(A)]*	*Third Test [dB(A)]*
Very low	*Low*	44.86	44.85	46.00
Very low	*Middle*	45.33	45.15	46.07
Very low	*High*	46.63	46.71	46.95

Table 5.5: *Dishwasher sound power level test – low pressure level*

Pressure level	*Rotation speed [rpm]*	*First Test [dB(A)]*	*Second Test [dB(A)]*
Low	*Low*	*46.32*	*46.34*
Low	*Middle*	*47.10*	*46.53*
Low	*High*	*47.86*	*47.34*

Table 5.6: *Dishwasher sound power level test – middle pressure level*

Pressure level	*Rotation speed [rpm]*	*First Test [dB(A)]*	*Second Test [dB(A)]*
Middle	*Low*	*48.67*	*48.02*
Middle	*Middle*	*48.97*	*48.40*
Middle	*High*	*49.83*	*48.72*

Table 5.7: Dishwasher sound power level test – background noise test

Pressure level	*Rotation speed [rpm]*	*Sound Test [dB(A)]*
0	*Low*	*33.31*
0	*Middle*	*37.90*
0	*High*	*42.00*

Studying the frequency plot of the tests of Table 5.7 it was found that the pulley system contributed a lot to the background noise. This means that the tests cannot be seen as exact levels for the D5900, but the influence of rotation speed and water pressure can still be seen. This is depicted as a contour plot in Figure 5.7.

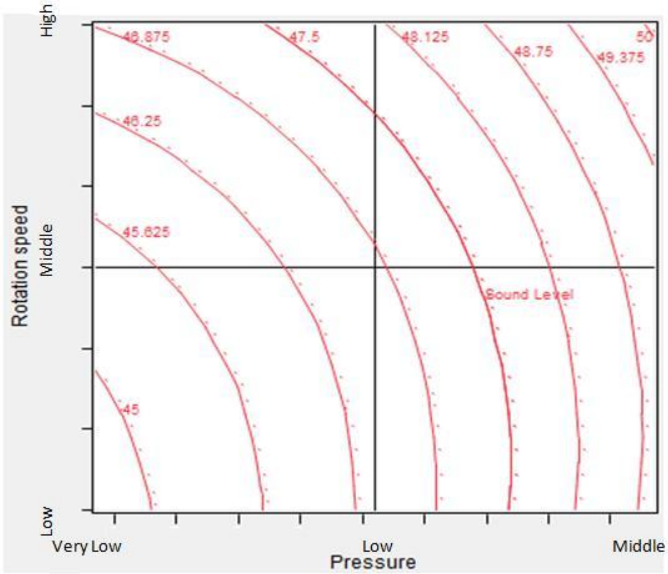


Figure 5.7: *Results of sound tests*

As the plot describes, the sound level is rising more rapidly at higher pressure levels. It appears that the rotational speed has less influence as the pressure increases. The water pressure obviously has the largest influence on sound power level.

5.5 High pressure tests

Some further tests were done to see if the trend of better cleaning performance would continue at even higher pressure levels. A more powerful water pump was put in the machine which could increase the water pressure in the lower spray arm. This pressure level is marked as high pressure level. Because of a difference in pump structure, the cleaning performance was not directly comparable to the previous experiment result. Therefore two of the same points as in the previous tests were done again so that the relative score could be compared. The new test was implemented at the middle pressure level and high pressure level and rotation speed as low speed level and high speed level. The test procedure was exactly the same as for the improved test.

The results are shown in Table 5.8. As can be seen in Figure 5.8 it seems that the initial hypothesis is valid. The best cleaning performance was acquired at highest water pressure and lowest rotation speed.

Table 5.8: *Results of higher pressure test*

Pressure [kPa]	*Rotation speed [rpm]*	*1st test [%]*	*2nd Test [%]*	*Average [%]*	*σ*
Middle	*Low*	19.0	19.1	19.1	0.1
	High	15.4	15.5	15.5	0.1
High	*Low*	26.6	26.6	26.6	0.0
	High	20.8	20.7	20.8	0.1

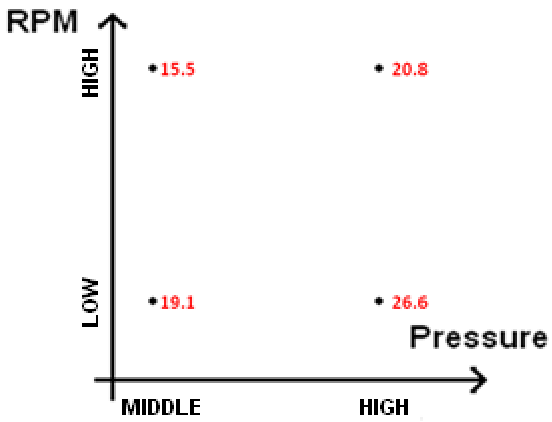


Figure 5.8: *Results of higher pressure test*

6 - DISCUSSION

6.1 The simplified test method

The test method, i.e. the use of plates, paint and camera, proved adequate for performing the tests. The small changes made in the independent variables could be detected as changes in the dependent variable without it getting saturated. The method was successfully used to map the influence of pressure and rotation speed on the dishwasher performance. It is hard to stabilize all influencing variables, a dishwasher system is quite complex and many factors influence the results.

The internal validity was considered high enough for the results to be reliable. At the final stage the standard deviation was as low as 3%. This inaccuracy could probably be traced back to the painting of the plates, which was hard to standardize, but this could not be scientifically proved. The high internal validity was achieved at some cost of ecological validity. Some parameters that are not constant in real-life were kept constant during the tests. The use of an almost empty dishwasher and the use of paint instead of food to soil the plates also lowered the ecological validity. However, this fact did not seem to influence the external validity, considering the good results from the standardized tests at ASKO. Exploring the two independent variables, rotation speed and pressure, in the same experiment contributed to the high external validity. The results indicate that they are closely coupled.

Although the method cannot be used to evaluate dishwasher performance for external use, due to the global standardization, it can be useful as an alternative for in-house tests. It can be prepared and performed quicker than the standardized method. One test-run can be done and analyzed in 60-90 minutes, whereas the standardized test takes several hours. Little or no training is needed to do the analysis. Another benefit of the developed method is that it can detect smaller changes in washing performance. Smaller changes in mechanical structure of the dishwasher, for instance, can be evaluated using the method.

One drawback is that the paint is very sensitive to the use of chemicals. The plate surface also influences the results a lot. Further investigations could be made to try to find or construct plates that have more homogenous surface. This could improve the test method and enable the experimenter to draw conclusions about performance at different positions in the dishwasher. In order to use the method one has to try different detergents and plates to find a level that is fitting for the experiment. When a desired level of cleanness has been found smaller changes in the span can be made by changing the washing time.

6.2 Design of Experiments

The choice of a factorial design with three levels for each variable was suitable for the conducted experiment. Considering the relatively small differences in response between the levels, having more levels would not improve the experiment. The accuracy of the test method would also limit the usefulness of more levels. Displaying the results as a response surface using JMP made the data easily interpretable. Automated interpolation of data and calculation of accuracy saved a lot of time. Not having control of every detailed calculation was not seen as a problem.

6.3 Regarding the test rig

The test rig worked well during all the experiments. It was built using relatively low cost parts and was still robust enough to withstand the washing procedure. There were some minor problems with leakage at the top where a hole for the axis had been made, but this did not influence the tests. There were also some problems with rust on the axis getting the lower bearing to jam. The bearing had to be replaced and the axis had to be dried properly when the machine was not in use. A stainless-steel axis should have been used.

The rotation speed actuator and sensor were easy and quick to set up and use. They worked perfectly. The pressure actuator was also simple to use and very simple to construct. It enabled proper sound tests to be made without changing motor sound influencing the results. The drawback of using this method was that the pressure could not be increased. This altered the experiment plan, and an additional experiment with another motor had to be done in order to confirm the performance trend.

Even though the test rig was not a highly complex system to develop, using proper development methods was beneficial since it ensured that the final result would fulfill all requirements and be usable for the experiments. It also ensured that all possible solutions were explored, and that the best suited for the task was selected.

6.4 Results from the first experiment

The results from the first tests were inconclusive. One might say that the tests indicated that the dishwasher performance was better at higher pressure and lower speed, but the inaccuracies were too large to draw any certain conclusions. It was obvious that more testing was needed and that the test method would have to be improved. The assumption that the changes in the dishwasher program time, caused by changes in input water temperature, would not affect the results was erroneous. This initial test showed how sensitive the test method was and how large inherent variances the dishwasher system had. These variances explain the reason for the large variances in the standardized tests.

The sound level measurements were not accurate enough either. Good measurements were very hard to acquire in the noisy environment at the facilities at Chalmers. The use of the sound meter gave an indication of that sound level did change depending on rotation speed and water pressure and that further sound tests would be of interest.

6.5 Results from the improved experiment

The final results were quite satisfying. The relative washing performance could be charted with good precision. The reliability of the tests was thought to be fairly high. Enough points were made to acquire a low standard deviation; less than 2.5% at most testing points, but a bit more than 4% at a few. Regarding external validity, the results from the standardized tests at ASKO support the final results. There was only time to do four tests, but they were all indicating the same conclusions (see Chapter 5.3 Validation tests at ASKO).

One drawback of the higher pressure is the higher sound level. A tradeoff has to be made between washing performance contra sound level and energy usage. Figure 6.1 could be used for this purpose.

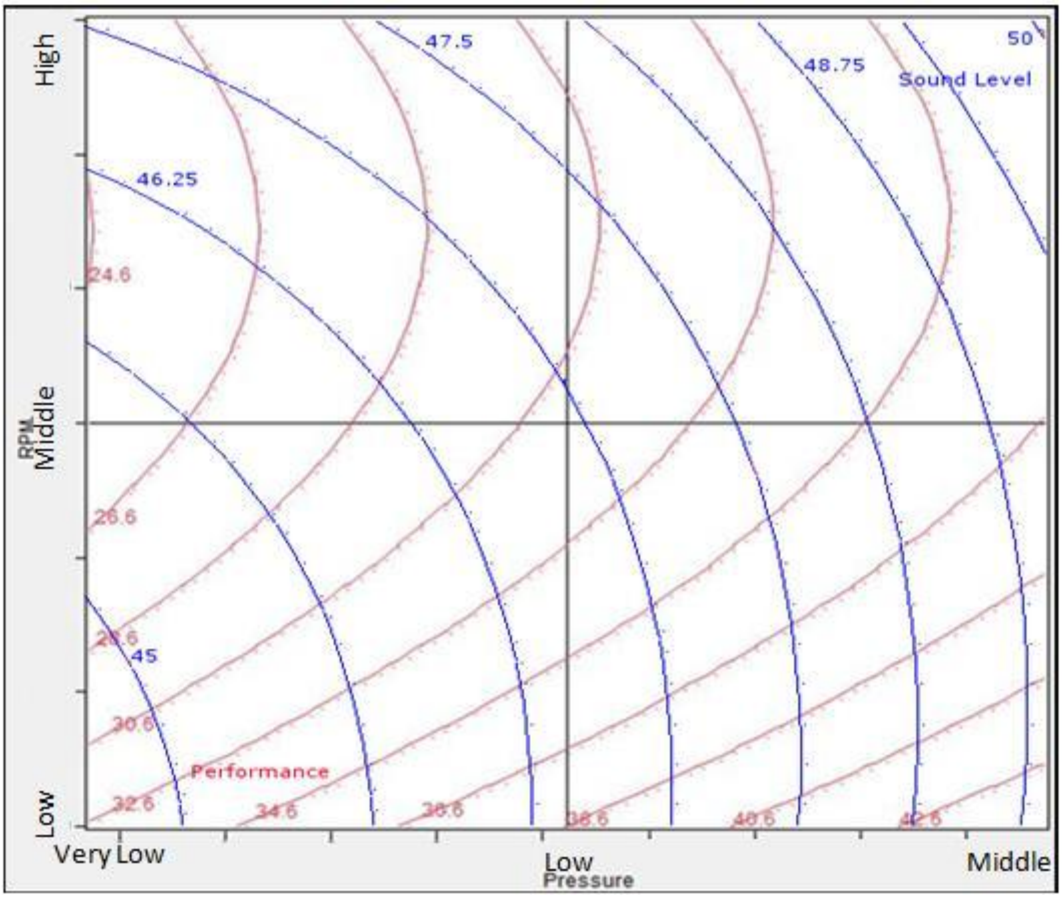


Figure 6.1: *Contour plot of performance level (red) and sound level (blue)*

As can be seen in Figure 6.2 the sound level could be lowered by more than two decibel while still performing as well as before if the rotation speed is lowered from middle speed level to low speed level, and decreasing the pressure to low pressure level. Using a smaller motor could lower both production costs and energy usage as well. If the pressure is kept at the current level and the rotation speed is decreased to low speed level, as depicted in Figure 6.3, the performance could be increased by about 10% without increasing the sound level.

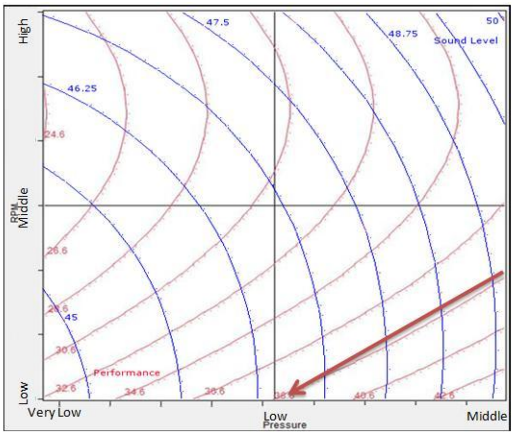


Figure 6.2: Suggestion for lower sound level

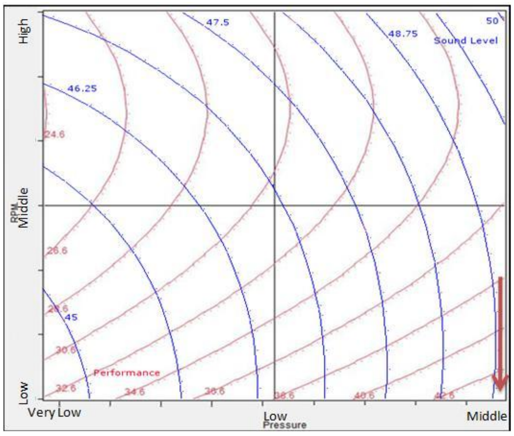


Figure 6.3: Suggestion for better performance

7 - CONCLUSIONS

The reliability of the results are thought to be high enough for it to be used as basis for decisions regarding the rotation speed and water pressure in new developed dishwasher models at ASKO. It was proved that higher water pressure and lower rotation speed could increase the washing performance. The charts presented in Chapter 6 should be used to find a proper trade-off between sound level and cleaning performance. Different proposals will have to be tested since the exact levels differ from model to model, but the general trend should be the same. Research should be done exploring what other characteristics are affected by the changes before any changes are made.

The developed simplified test method could be used at ASKO to test new modifications to dishwashers in order to save time and resources. For instance when testing a new water pump motor. It should be seen as a complement to their standardized methods.

Future work that would be of interest includes doing sound tests at higher pressure levels. These tests could be a bit difficult to do without changing the sound levels. It would also be interesting to see how the energy consumption changes with an increasing pressure. If this is significant compared to the effect of changing input water temperature and water usage or not.

REFERENCES

Baiduzhidao. *Brainstorming*. Retrieved 12 April 2010 from Baiduzhidao: http://zhidao.baidu.com/question/473887

Courant, R., Robbins, H. & Stewart, I. (1996): *What Is Mathematics? An Elementary Approach to Ideas and Methods.* Oxford University Press

Fargnoli, M., Rovida, E. & Troisi, R. (2006). *The morphological matrix: Tool for the development of innovative design solutions.* Politecnico di Milano, Department of Mechanics

Institute for Transport Studies, University of Leeds. Problem Identification. Retrieved 8 April 2010 from leeds.ac.uk: http://www.konsult.leeds.ac.uk/public/level1/sec08/index.htm

Milton, J.S. & Arnold, J.S. (2003): *Introduction to probability and statistics*. McGraw-Hill

Mindtools. *Brainstorming*. Retrieved 12 April 2010 from Mindtools: http://www.mindtools.com/brainstm.html

Montgomery, D.C. (2009): *Design and Analysis of Experiments, 7th Ed.* John Wiley & Sons

Shuttleworth, M. (2008). *Experimental Research*. Retrieved 5 April 2010 from Experiment Resources: http://www.experiment-resources.com/experimental-research.html

Stevens, R., Brook, P., Jackson, K. & Arnold, S. (1998), *System engineering coping with complexty.* Pearson Education

Ulrich, K.T. & Eppinger, S.D. (2008), *Product design and development.* McGraw Hill

Weber, Donald & Skillings, John H. (2000): *A first course in the design of experiments: a linear models approach*. CRC Press

Wikipedia. *Central composite design*. Retrieved 21 November 2009 from Wikipedia: http://en.wikipedia.org/wiki/Central_composite_design

Wikipedia. *Contour line*. Retrieved 27 April 2010 from Wikipedia: http://en.wikipedia.org/wiki/Contour_line

Wikipedia. *Design of Experiments*. Retrieved 18 November 2009 from Wikipedia:

http://en.wikipedia.org/wiki/Design_of_experiments

Wikipedia. *Ecological validity*. Retrieved 28 November 2009 from Wikipedia: http://en.wikipedia.org/wiki/Ecological_validity

Wikipedia. *Factorial experiment*. Retrieved 19 November 2009 from Wikipedia: http://en.wikipedia.org/wiki/Factorial_experiment

Wikipedia. *Fractional factorial experiment*. Retrieved 19 November 2009 from Wikipedia: http://en.wikipedia.org/wiki/Fractional_factorial_design

APPENDIX

Appendix A: Target specification

Design of experiment methodology Specifications

Requirement		***Value range***	***Weight 1 - 10***
FR1	Minimize the number of test runs	< 45 times	7
FR2	Fit our test profile	Y/N	8
FR3	Give highly reliable results	Y/N	8
D1	Be relatively simple to use		5
D2	Be supported by earlier experiments		6

Simplified test method Specifications

Requirement		***Value range***	***Weight 1 - 10***	
FR1	Physically possible to implement		Y/N	9
FR2	Be quick to prepare	< 30 min	Y/N	6
FR3	Easy and quick to reset value	< 30 min	Y/N	7
FR4	Easy to determine result		Y/N	8
FR5	Possible to grade relatively accurate		Y/N	8
FR6	Low cost		Y/N	5
D1	High ecological validity			8
D2	Safe to use			7

Rotation speed actuator Specifications

Requirement		***Value range***	***Weight 1- 10***	
FR1	Possible to achieve target value	*masked*	Y/N	9
FR2	Quick to prepare for use	< 30 min	Y/N	6
FR3	Measure velocity with high accuracy	± 0.5 RPM	Y/N	6
FR4	Not affect other parameter		Y/N	9
FR5	Affect other function as little as possible		Y/N	8
FR6	Robust enough to withstand washing procedure		Y/N	7
FR7	Durable	> 300h	Y/N	6
FR8	Be able to work in different temperatures	5 - 90 ℃	Y/N	5
FR9	Be water proof		Y/N	8
FR10	Physically possible to produce prototype within time frame	< 3 days	Y/N	5
FR11	Low cost	< 1500 SEK	Y/N	3
FR12	Be safe to use		Y/N	6
D1	Should be easy to set the value			7
D2	Modify the dishwasher as little as possible			6

Rotation speed sensor Specifications

Requirement		***Value range***	***Weight 1 - 10***	
FR1	Be able to measure rotation speed	*masked*	Y/N	9
FR2	Quick to prepare for use	< 30 min	Y/N	6
FR3	Measure velocity with high accuracy	± 0.5 RPM	Y/N	6
FR4	Not affect other parameter		Y/N	9
FR5	Affect other function as little as possible		Y/N	8
FR6	Robust enough to withstand washing procedure		Y/N	7
FR7	Durable	> 300h	Y/N	6
FR8	Be able to work in different temperatures	5 ~ 90 ℃	Y/N	5
FR9	Be water proof		Y/N	8
FR10	Physically possible to produce prototype within time frame	< 1day	Y/N	5
FR11	Low cost	< 300 SEK	Y/N	3
FR12	Be safe to use		Y/N	6
FR13	Easy to replace	< 60 min	Y/N	5
D1	Should be easy to get the value			7
D2	Modify the dishwasher as little as possible			6

Water pressure actuator Specifications

Requirement		***Value range***	***Weight 1 - 10***	
FR1	Possible to achieve target value	*masked*	Y/N	9
FR2	Quick to prepare for use	< 30 min	Y/N	6
FR3	Measure velocity with high accuracy	± 0.5 kPa	Y/N	6
FR4	Not affect other parameter		Y/N	9
FR5	Affect other function as little as possible		Y/N	8
FR6	Robust enough to withstand washing procedure		Y/N	7
FR7	Durable	> 300h	Y/N	6
FR8	Be able to work in different temperatures	5 - 90 ℃	Y/N	5
FR9	Be water proof		Y/N	8
FR10	Physically possible to produce prototype within time frame	< 3 days	Y/N	5
FR11	Low cost		Y/N	3
FR12	Be safe to use		Y/N	6
D1	Should be easy to set the value			7
D2	Modify the dishwasher as little as possible			4

Water pressure sensor Specifications

Requirement		***Value range***	***Weight 1 - 10***	
FR1	Be able to measure pressure	*masked*	Y/N	9
FR2	Quick to prepare for use	< 30 min	Y/N	6
FR3	Measure pressure with high accuracy	± 0.5 kPa	Y/N	6
FR4	Not affect other parameter		Y/N	9
FR5	Affect other function as little as possible		Y/N	8
FR6	Robust enough to withstand washing procedure		Y/N	7
FR7	Durable	> 300h	Y/N	6
FR8	Be able to work in different temperatures	5 ~ 90 ℃	Y/N	5
FR9	Be water proof		Y/N	8
FR10	Physically possible to produce prototype within time frame	< 1day	Y/N	5
FR11	Low cost	< 600 SEK	Y/N	3
FR12	Be safe to use		Y/N	6
FR13	Easy to replace	< 30 min	Y/N	5
D1	Should be easy to get the value			7
D2	Modify the dishwasher as little as possible			6

Appendix B: Morphological Matrix

Simplified test method Morphological matrix

Indicator	Regular plate	Cup	Fork / Knife	Bowl	Metal Plate	Plastic Plate
Shape	Round	Square	No Shape			
Analysis method	Eyes	Computer / camera				
App method	Brush-Painting	Spray-painting	Fill-painting	Food debris		
Preparation method	Heat	Air dry	Freeze	Wet		
Soiling agent	Food stuff	Paint	markers			
Program	>Temperature >time	<Temperature <time	>Temperature <time	<Temperature >time		
Machine environment	Full Dirty	Full clean	empty	50/50 clean/dirty		

Rotation speed actuator Morphological matrix

Adjustment system	Knob-Step	Knob-Stepless	µ- Controller	Computer control	Manual	
Influence method	Motor	Water + turbine	Electrical + magnetic	Friction	Inertia	
Placement	External	In compartment	Motor compartment			
Power source	Electrical	Potential energy	Handcraft	Diesel / Petrol	Water pressure from tap	
Data Communication method (between adjustment system and actuator)	Bluetooth	IR	WIFI (radio waves)	Data bus	Wire (As voltage)	Manual

Water pressure actuator Morphological matrix

Adjustment system	Knob-Step	Knob-Stepless	µ- Controller	Computer control	Manual	
Influence method	Motor	Change pipe/arm volume	Change waterflow	Change diameter of pipes		
Placement	External	In compartment	Motor compartment			
Power source	Electrical	Potential energy	Handcraft	Diesel / Petrol	Water pressure from tap	No energy source
Data Communication method	Bluetooth	IR	WIFI (radio waves)	Data-bus	Wire (As voltage)	Manual

Rotation speed sensor and water pressure sensor Morphological matrix

Power source	Electricity	No power				
Measuring method	No contact	contact				
Data communication Method	Bluetooth	IR	WIFI (radiowaves)	Data-bus	Wire	Manual reading
Placement	External	In compartment	Motor compartment			

Appendix C: Kesselring Matrix

Rotation speed actuator Kesselring matrix

Concept		**Frictioner**		**Ex-motor**		**In-Motor**		**Turbine**		**Heavy arm**	
Rotation speed actuator	**Weight**										
Demands	1-10	**Value**									
Possible to achieve target value	9	*0**	**0**	*8*	**72**	*8*	**72**	*8*	**72**	*0**	**0**
Should be easy to set the value	7	*1*	**7**	*7*	**49**	*7*	**49**	*5*	**35**	*2*	**14**
Quick to prepare for use	6	*8*	**48**	*9*	**54**	*9*	**54**	*8*	**48**	*8*	**48**
Not affect other parameter	9	*10*	**90**	*10*	**90**	*10*	**90**	*10*	**90**	*10*	**90**
Affect other function as little as possible	8	*10*	**80**	*8*	**64**	*6*	**48**	*7*	**56**	*9*	**72**
Possible to produce prototype within time frame	5	*5*	**25**	*6*	**30**	*1*	**5**	*2*	**10**	*5*	**25**
Modify the dishwasher as little as possible	6	*7*	**42**	*5*	**30**	*3*	**18**	*2*	**12**	*7*	**42**
Be able to work in different temperatures	5	*4*	**20**	*8*	**40**	*3*	**15**	*5*	**25**	*8*	**40**
Be water proof	8	*8*	**64**	*9*	**72**	*6*	**48**	*6*	**48**	*9*	**72**
Durable	6	*5*	**30**	*8*	**48**	*8*	**48**	*8*	**48**	*9*	**54**
Robust enough to withstand washing procedure	7	*8*	**56**	*7*	**49**	*9*	**63**	*8*	**56**	*9*	**63**
Low cost	3	*10*	**30**	*7*	**21**	*5*	**15**	*6*	**18**	*9*	**27**
Be safe to use	6	*8*	**48**	*8*	**48**	*5*	**30**	*8*	**48**	*9*	**54**
Measure velocity with high accuracy	6	*4*	**24**	*8*	**48**	*8*	**48**	*8*	**48**	*7*	**42**
Total	Pass/Failure		564		**715**		603		**614**		643
* it cannot achieve all the values											

Rotation speed sensor Kesselring matrix

Concept		**Click counter**		**Bike computer**		**Listen**		**Light sensor**		**Lookie Lookie**	
Rotation speed sensor	**Weight**										
Demands	1-10	Value									
Be able to measure rotation speed	9	*9*	**81**	*9*	**81**	*9*	**81**	*9*	**81**	*9*	**81**
Should be easy to get the value	7	*7*	**49**	*9*	**63**	*9*	**63**	*7*	**49**	*9*	**63**
Quick to prepare for use	6	*7*	**42**	*9*	**54**	*10*	**60**	*7*	**42**	*9*	**54**
Easy to replace	5	*5*	**25**	*8*	**40**	*10*	**50**	*5*	**25**	*7*	**35**
Not affect other parameter	9	*6*	**54**	*9*	**81**	*10*	**90**	*9*	**81**	*8*	**72**
Affect other function as little as possible	8	*8*	**64**	*10*	**80**	*10*	**80**	*10*	**80**	*9*	**72**
Possible to produce prototype within time frame	5	*7*	**35**	*9*	**45**	*10*	**50**	*7*	**35**	*9*	**45**
Modify the dishwasher as little as possible	6	*7*	**42**	*8*	**48**	*10*	**60**	*7*	**42**	*10*	**60**
Durable	6	*6*	**36**	*8*	**48**	*10*	**60**	*8*	**48**	*9*	**54**
Be able to work in different temperatures	5	*7*	**35**	*7*	**35**	*10*	**50**	*7*	**35**	*8*	**40**
Be water proof	8	*5*	**40**	*8*	**64**	*10*	**80**	*6*	**48**	*8*	**64**
Robust enough to withstand washing procedure	7	*7*	**49**	*9*	**63**	*9*	**63**	*8*	**56**	*9*	**63**
Low cost	3	*7*	**21**	*8*	**24**	*10*	**30**	*6*	**18**	*9*	**27**
Be safe to use	6	*6*	**36**	*8*	**48**	*10*	**60**	*6*	**36**	*8*	**48**
Meassure velocity with high accuracy	6	*8*	**48**	*8*	**48**	*5*	**30**	*9*	**54**	*6*	**36**
Total	Pass/Failure		657		**822**		**907**		730		814
* it cannot achieve all the values											

Water pressure actuator Kesselring matrix

Concept		Power motor		Restrictor		Arm volume		Holy	
Water pressure actuator	**Weight**								
Demands	1-10	**Value**							
Possible to achieve target value	9	*9*	**81**	*4*	**36**	*3*	**27**	*0***	**0**
Should be easy to set the value	7	*8*	**56**	*2*	**14**	*1*	**7**	*3*	**21**
Quick to prepare for use	6	*9*	**54**	*10*	**60**	*4*	**24**	*4*	**24**
No affect other parameters*	9	*10*	**90**	*10*	**90**	*10*	**90**	*5*	**45**
Affect other function as little as possible	8	*10*	**80**	*10*	**80**	*10*	**80**	*10*	**80**
Possible to produce prototype within time frame	5	*7*	**35**	*9*	**45**	*4*	**20**	*8*	**40**
Modify the dishwasher as little as possible	4	*6*	**24**	*8*	**32**	*4*	**16**	*6*	**24**
Durable	6	*9*	**54**	*9*	**54**	*9*	**54**	*8*	**48**
Robust enough to withstand washing procedure	7	*9*	**63**	*9*	**63**	*9*	**63**	*9*	**63**
Be water proof	8	*9*	**72**	*10*	**80**	*10*	**80**	*9*	**72**
Be able to work in different temperatures	5	*7*	**35**	*10*	**50**	*10*	**50**	*10*	**50**
Low cost	3	*5*	**15**	*9*	**27**	*2*	**6**	*9*	**27**
Be safe to use	6	*8*	**48**	*9*	**54**	*10*	**60**	*9*	**54**
Meassure velocity with high accuracy	6	*8*	**48**	*4*	**24**	*3*	**18**	*3*	**18**
Total	Pass/Failure		755		709		595		566
* Except Rotation speed									
** It cannot achieve all values									