CHAPTER III
EXPERIMENTAL DESIGN

As stated in previous chapter that the importance of making HDD recirculation filters is how to cut the filter into the required size and a control of foreign contamination. This study will cover only how the size of filter or the shrinkage of filter is affected by potential factors. Thus, the process of consideration is scoped only at the cutting process.

This chapter is concerned how the potential factor is identified, what is the constrain for this study and what is the testing procedure that is conducted in order to conclude if those factors affect the shrinkage of filters.

3.1 A Study of Factor Concerned

In this study, there are five factors that are concerned; men, materials, methods, measurements, and machines. They can be illustrated in the cause and effect diagram as shown in figure 3-1.

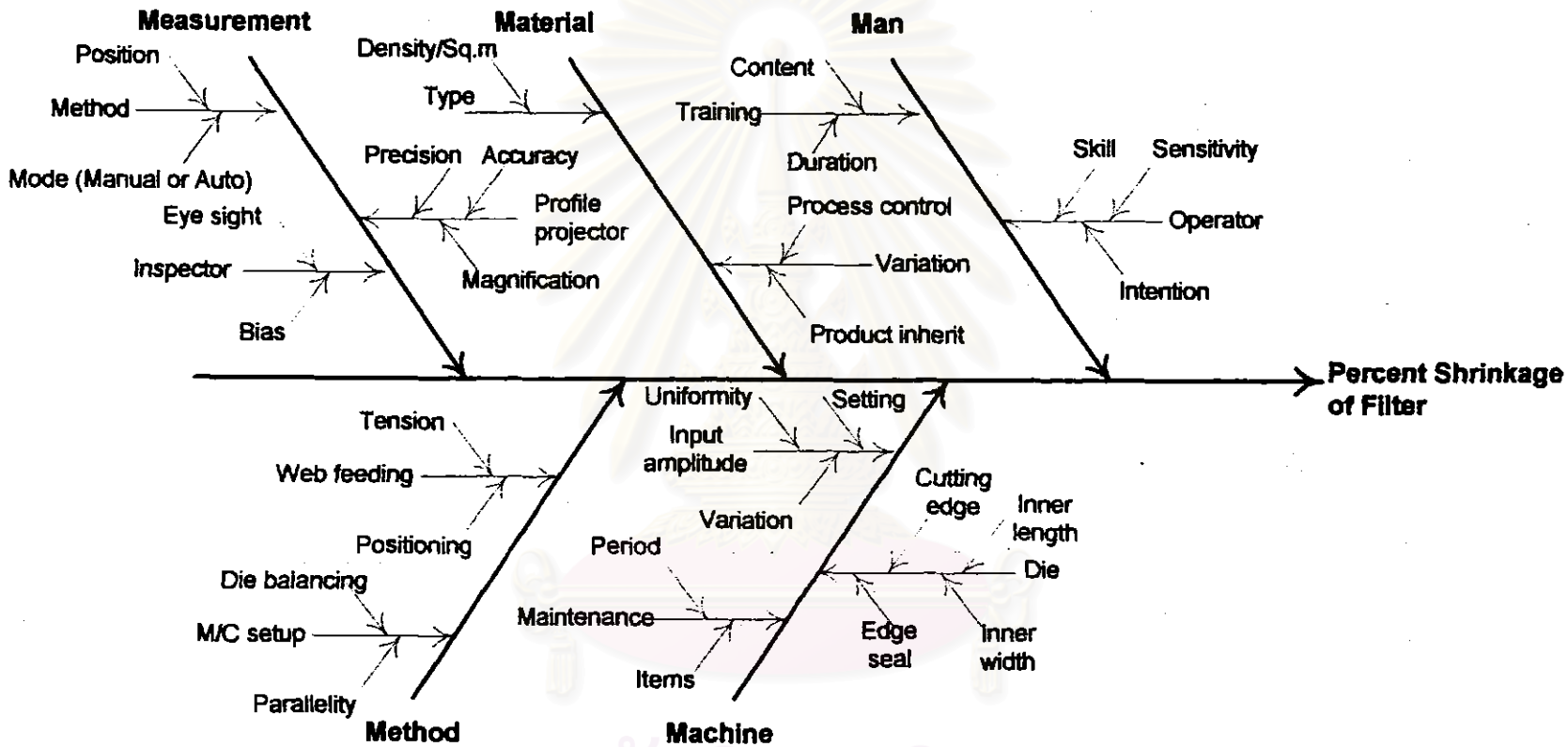

Figure 3-1 : Cause and Effect diagram

3.1.1 Measurement

While measuring the object, the variability in measurements can be influenced by two factors; the profile projector used and the inspector. Because there is only one profile projector used, there will be no variation of using different machine.

The profile projector can measure in two directions (x-y) with 10 times magnification, which has a reading capability of 10μm and ± 10% accuracy. To ensure these properties, the projector is calibrated once every 12 months to cover magnification and reading capabilities. The result of calibrating accuracy is within ± 10% as mentioned.

However, the result of calibrating the magnifier is that the enlargement will be accurate from the center until 10 cm to the left, 15 cm to the right, 12 cm upward and 15 cm downward.

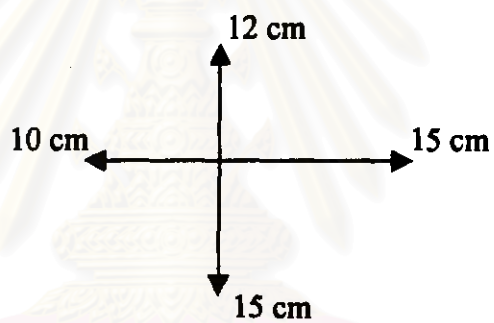

Figure 3-2 : Area that the object should be placed on the projector

Thus, to measure any object in a more accurate way, the object should be placed in the area mentioned above.

To operate the profile projector, there are 2 mode; manual mode and automatic mode. Manual mode is measured by visually target the crosshair to the origin of the object, zero setting and move the stage and target the crosshair to the other end of an object. Then, read the distance. Automatic mode of the measure is done by the edge detector. The detector detect the different light of the profile between the dark area (shadow of an object) and the light penetration. Moreover, it has a skew function to automatically calculate the angle of inclination that may affect the measure distance. Thus, there is not necessary to put the object to be parallel to the crosshair, which is different to the manual mode that the object have to be located as much parallel to the crosshair as possible.

In addition, the reading unit can be chosen among two units, in millimeters and in inches.

For the variability of measurement due to different inspectors, it can be eliminated by using one inspector to measure the whole part.

3.1.2 Material

The materials used for producing filter are made from propylene. At the moment, there are two materials used, GSB-70 and G-100. The terms 70 and 100 indicate the amount of filter fibers in g/m^2. Thus, both materials have filter fiber of 70 g/m^2 and 100 g/m^2 respectively.

The effect of materials on the size of filter may be caused by three factors; the types of Filtrete™ media, the variation between each incoming lot and within lot variation.

For the variation between different lot of Filtrete™ media, it can be ignored by blocking the lot to be tested. When doing the experiment, one lot per each material should be selected.

Because the Filtrete™ is a layer of fiber tows, thus the variation within lot is an inherit property. In the same lot, some areas may be thicker (have more tows) than other areas, which 3M Thailand can not control. However, at the manufacturing source of Filtrete™, the weight of tows per square meter is controlled to be within ± 10 g/m^2.

Thus, we will concern only whether the type of materials used affects the percent shrinkage of recirculation filter.

3.1.3 Man

The training effectiveness and personal skill can cause the difference in the size of filter. When setting the machine, operators have to use feeler gauge for balancing the die. It requires personal sensitivity and skill. Thus, errors can occur when a different person is assigned. Therefore, to eliminate the error, only one operator who has a good performance and skill should be assigned to perform the task.

3.1.4 Method

Actually, the method of welding and cutting Filtrete™ media may have an effect on the percent shrinkage of filter. However, 3M uses only one approach to make the filter by using ultrasonic welding and cutting machine. Thus, the capability and quality of welding and cutting will be no different.

In order to set up the die, the die must be located onto the foundation that is supported by adjustable springs. The distance between the sonotrode and the die must be checked by using feeler gauge to ensure that both surfaces are parallel, that means the uniformly energy applied to Filtrete™. If the gap is not parallel, the adjusted spring at the supporting metal can be adjusted.

After complete die set up, the Filtrete™ will be placed on the supporting, between the die and the sonotrode. Then, feed of the web through the cutting machine by pulling system.

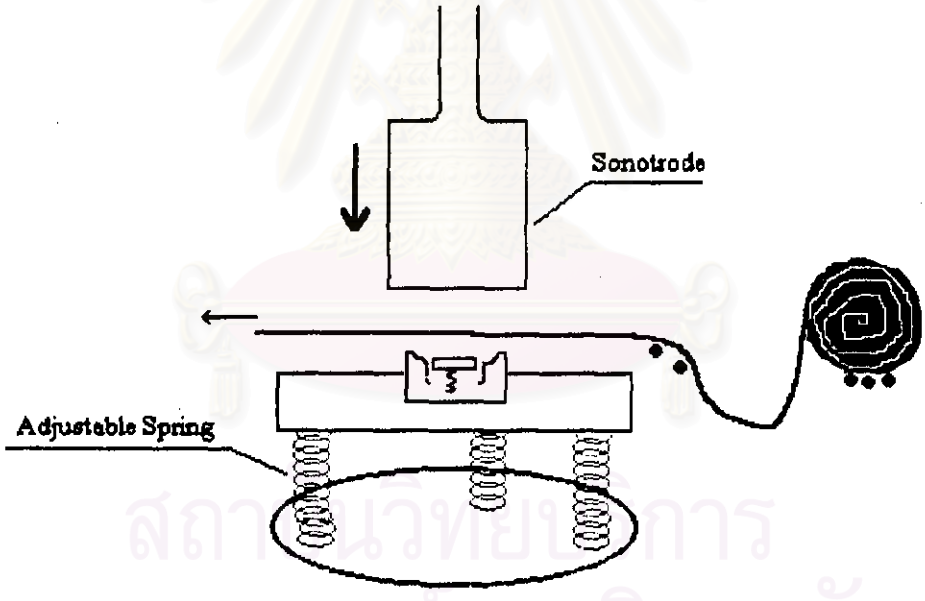

Figure 3-3 : Filtrete™ feeding system

The measuring method is done by using automatic mode for overall length and width while other dimensions are measured by manual mode. Furthermore, in automatic mode, we need to skew the profile before measuring the length and width.

3.1.5 Machine

The machine, in this case, can be classified into two categories; the ultrasonic welding machine and the die. For the ultrasonic welding machine, 3M has only one of it, so the effect of using different machine will not be a cause of different size of filter. The machine is called " Microprocessor Controlled Ultrasonic Welding Press". It is the new method for jointing thermoplastic components. In order to operate the machine, amplitude of input energy is needed to identify. Regarding the Ultrasonic Welding Press, it can vary input amplitude by 4 values; 70, 80, 90 and 100 percent.

To maintain the machine in good condition, 3M has set up the routine maintenance program every six months for general maintenance such as lubricating, setting the pneumatic system and so on. However, there is no maintenance program or system to ensure that the input amplitude is exactly as set and shown on the control panel. Moreover, there is no coordination with the supplier to get more information about the machine such as how to calibrate the output amplitude. However, the amplitude may effect the filter's size and this effect will be evaluated through this experiment also.

For the die, it can be changed depending on the required size of filter. Generally, when the size of filter is identified, the die is design later to fit. The key components of each die that may affect the size of filter are the cutting edge, the edge seal, and the inner width and inner length. All of them can be grouped as "The die characteristic". The effect of the die characteristic will be investigated in this experiment also.

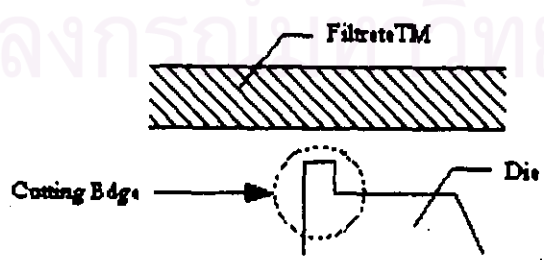

Figure 3-4 : Cutting edge of the die

Regarding the above discussion, five main factors can be classified as controllable and uncontrollable factors as follows:

Controllable factors

- Material — Type of material
- Man — Training
- Measurement — Method and profile projector
- Method — Web feeding
- Machine — Maintenance, die and amplitude setting

Uncontrollable factors

- Material — Variation
- Man — Operator
- Measurement — Inspector
- Method — Machine setup (feeler gauge)
- Machine — Uniformity and variation of input amplitude

In this study, the factors that are uncontrollable were blocked. They are:

- Material variation – Used only material from the same lot.
- Man – Only one operator was assigned to operate the ultrasonic welding press.
- Measurement – Only one person was assigned to measure the filter size.
- Method – The die's set up would be influent by operator feeling because it required feeler gauge as a measuring equipment during die balancing. Thus, only one person was assigned to operate the machine as discussed previously.
- Machine – Used the same ultrasonic welding press and generator for cutting the part through this study.

3.2 Constraint

To study the effect of the die's characteristic on whether it's size has an effect of the filter shrinkage, the study should be proceeded by varying each die's characteristic while other factors are fixed. For example, to study the interaction of cutting edge and edge seal, the experiment should be designed by varying 5 cutting

edge while the edge seal remain the same. Thus, there will be 5 different dies needed. In fact, the cost of the die is very expensive, about 30,000 baht per die and the company was not ready to pay that huge amount of money for the experiment. With that constraint, the experiment was designed by using the existing dies that are different in their characteristics. Thus, the study was done by using 3 different existing dies, which are different in cutting edge, edge seal, inner width and inner length.

Due to the difference of the die's dimension (inner length and width), the percentage of total shrinkage (refer 3.3.4.3) was used as the response of the study in order to eliminate the effect of different size.

3.3 Summery of Experimental Design

3.3.1 Testing Condition

From cause and effect evaluation and constraint, there were three main factors that could affect the size of filters; they were types of Filtrete™, die size (cutting, edge seal, inner width and inner length) and amplitude. The other causes can be ignored or blocked. The effect of each factors will be separately evaluated while other factors are kept constant.

Thus, the experiment would be done by using 3 existing dies, 2 types of materials, and 4 levels of amplitude with the 10 replicates at each testing condition.

a) Evaluation of effects of different materials.

The experiment was done at each die (different condition of edge seal, cutting edge, inner length and inner width) and at each amplitude level. Thus, there were 24 experimental conditions as follows:

Table 3-1 : Testing condition for evaluating effect of material types

Condition #	Amplitude							
	70		80		90		100	
	%SHL	%SHW	%SHL	%SHW	%SHL	%SHW	%SHL	%SHW
Die 1	1	2	3	4	5	6	7	8
Die 2	9	10	11	12	13	14	15	16
Die 3	17	18	19	20	21	22	23	24

b) Evaluation of effects of differences in amplitude level on percent shrinkage of filter.

The evaluation of effects of different amplitude was done at each type of Filtrete™ media and each die to prevent an effect of interaction. This was the same as the evaluation of effects of different Filtrete™ media. During the experiment, the percentage of amplitude was varied into 4 values - 70, 80, 90 and 100, other factors remained constant. The effects were investigated in both length and width directions. Thus, there were 12 experimental conditions as shown in the following table.

Table 3-2 : Testing condition for evaluating effect of amplitude's level

Condition #	Type of Filtrete™			
	GSB-70		G-100	
	%SHL	%SHW	%SHL	%SHW
Die 1	25	26	27	28
Die 2	29	30	31	32
Die 3	33	34	35	36

c) Evaluation of effects of different dies (size of cutting edge, edge seal, inner length and inner width) on percent of filter's shrinkage.

The experiment was done by varying die size while the Filtrete™ type and amplitude remained fixed. Similar to the two previous evaluations, the experiment was done separately at each types of Filtrete™ and at each level of amplitude.

As effect can be found in both length and width direction. Thus, the conditions of experiment were identified in the following table:

Table 3-3 : Testing condition for evaluating effect of different dies

Condition #	Type of Filtrete™			
	GSB-70		G-100	
	%SHL	%SHW	%SHL	%SHW
Amplitude 70	37	38	39	40
Amplitude 80	41	42	43	44
Amplitude 90	45	46	47	48
Amplitude 100	49	50	51	52

3.3.2 Hypothesis Testing Approach

To justify whether the percent shrinkage of filter is affected by the considered factors, the method of hypothesis testing will be a tool. All experiments will be tested by using an analysis of variance or ANOVA.

3.3.3 Replication

At each experimental condition, the ten (10) replicate at each step was introduced through out all experiment in order to minimize an error from the experiment.

3.3.4 Testing Procedure

3.3.4.1. Collect the sample of filter 10 pieces at each condition (at different die, amplitude and material). Therefore, the total number of filter sample

collected was 240 pieces. At this stage, the size (inner length & width, cutting edge, and edge seal) of each die were recorded.

3.3.4.2. Measure the size (width, length and edge seal width) of the collected filters by using the profile projector.

3.3.4.3. Calculate the percentage of shrinkage in both direction-length (%SHL) and width (%SHW) by using following formula:

The percentage of shrinkage can be defined as follows:

1. Percentage of shrinkage in length's dimension

$$= \frac{(\text{Total length of die's size} - \text{Filter's length}) * 100}{\text{Total length of die's size}}$$

2. Percentage of shrinkage in width's dimension

$$= \frac{(\text{Total width of die's size} - \text{Filter's width}) * 100}{\text{Total length of die's size}}$$

Where :

Total length of die's size = inner length + (edge seal + cutting edge)*2

Total width of die's size = inner width + (edge seal + cutting edge)*2

The result of the calculation can be shown as in an appendix C.

3.3.4.4 Analyze the data. The effect of material, amplitude and die (that represents other factors – cutting edge, edge seal, inner width and length) can be analyzed by using Analysis of Variance Method (ANOVA). In this analysis, the statistical software "Minitab released 11.2" was used. The procedure for using this software to perform this analysis was as follows:

a) For example, to analyze the effect of material on % shrinkage of filter at amplitude 80 and die 2. It is the condition # 11 and 12 as shown in table 3-1. The data is in row no 91-100 and 131-140 of appendix C.

b) Run Minitab by selecting ***Stat / ANOVA / One-Way*** on the pull-down menu. Then, select "%SHL" as the "response" and "different types of filtrete" as "factor".

3.3.4.5 Compare the ***F-test statistic*** from Minitab with the ***F- critical value*** from appendix A for checking whether there is significant evidence to reject the null hypothesis.

3.3.4.6 As the study of effects of each factor was run in several conditions e.g. material effect, there were 24 runs and 24 conditions. Thus, there might be different in the result to reject or fail to reject the null hypothesis. This may be caused by experimental error. Thus, the conclusion of whether the factor had an effect on the percent shrinkage of filter was based on the majority of all conditions.

3.3.4.7 After preliminary conclusion on which factors did affect the difference in percent shrinkage of filters, those factors were to be used to predict the shrinkage behavior according to types of Filtrete™ and shrink's direction. Analyzed the suitable multiple linear regression by using Minitab as follows:

a) For example, if the die's characteristics affect percent shrinkage of filters, choose "die's characteristics" as "predictors" and choose "%SHL" as "response".

b) Run Minitab by selecting ***Stat / Regression / Regression*** on the pull-down menu. Then, select "response" and "predictors".

3.3.4.8 Analyzed if the multiple regression was significant for use by comparing the ***F- test statistics*** and ***F - critical value***.

3.3.4.9 Plot interaction effect among significance factors by selecting ***Stat / ANOVA / Interactions Plot*** on the pull-down menu. Then, enter "factors" and "source of response data".

3.3.4.10 Find interaction effect among significance factors by selecting ***Stat*** / ***ANOVA*** / ***Balanced ANOVA*** on the pull-down menu. Then, enter "response" and interesting interaction factors in "model" block. For example, enter "X_1 X_2 X_3 X_1*X_2 X_1*X_3 X_2*X_3 X_1*X_2*X_3".