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DETERMINING DOMINANT PROCESS PARAMETERS IN POLYESTER YARN WINDING

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ABSTRACT

The manufacturing of spiral conveyor starts from yarn winding process in which the monofilament yarn is wounded around a hot mandrel mold to produce a spiral yarn. Due to several process parameters, the formation of the spiral's diameter size can be inconsistent. Thus, it is important to determine the most dominant process parameter that affects the diameter of the formed spiral. In this study, design of experiment based on Taguchi method is used to investigate several parameters effect on the formation of spiral fabric. The investigation is based on the accuracy of the major and minor dimension of spirals being produced according to the specified dimension for several different factors and levels of the process parameters. It is found that process tension is the main parameter that affects the accuracy of the major dimension and the second heater gap is the main parameter that affect the accuracy of the minor dimension. In conclusion, these two process parameters need to be properly controlled to ensure good quality spiral is produced during the yarn spiral winding process.

1.0 INTRODUCTION

Today, technical textile is widely used for many applications. By definition, technical textile is 'textile for non-apparel, non-household/furnishing end uses, whose values are highly based on their technical performance and functional properties'. On the other hand, advanced technical textile is defined as 'technical textiles that have some technological advancement in the material and/or the application'. The preference usage of technical textiles compare to other kinds of materials is that in textile products the configurational functions of fiber are effectively utilized and resulted to optimum performance to cost ratio. This is possible as the configurational functions of fiber consists of the following element; high flexibility, high mechanical load, high specific area and technologies easiness in transformability into textile structural material. Due to these elements, technical textile has been selected as an alternative material in many applications (Matsuo, 2008)

This has resulted to the increased of market value of technical textiles as in the year of 2000 and 2005, sales values of USD 9290 million and USD 11560 million respectively have been recorded. Major portion of these come from industries such as automotive, medical and hygiene, agriculture, construction, geotextiles and other industrial purposes (Bryne, 2000).

In the paper industry, for example, the advanced technical textiles have been utilized to make conveyor fabric for paper machine component. This conveyor fabric transfers the newly formed wet paper web from forming section towards the dryer section in the paper making production line. In dryer section, the paper web is pressed onto the hot cylinders surface in order to increase the drying rate of the paper. To obtain high drying rate efficiency, the design and construction of the fabric should be tailored to a specific standard for the water vapor to be released effectively. The flatness of fabric is also an important criterion to ensure consistent paper drying.

The construction of dryer fabric comprises of the interlacing of machine direction yarns (warp) and cross machine direction yarns (weft) as shown in Figure 1. Figure 2 shows two types of dryer fabric that are available in the market namely the woven fabric and spiral fabric.

Woven fabric is manufactured through a weaving machine while spiral fabric is processed through yarn winding process to form spirals. The spirals are then meshed together and joining wires which act as weft are used to link adjacent spirals. Spiral fabric may or may not be 'filled' with filler materials in the later process dependent on the require permeability.

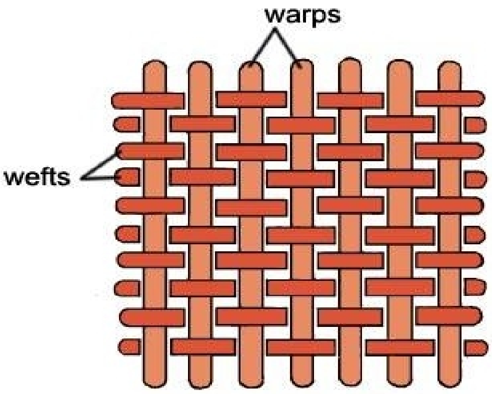

Figure 1. Warp and weft interlacing
(Source: Heathenhistory.co.uk)

Figure 2. Types of dryer fabric design - woven and spiral
(Source: KB Fabrics)

Yarn winding is a common process in the textile related industries for winding the newly processed yarn after the extrusion process onto the spool or for winding the yarn out of the spool to form semi-finished product. The process requires special machine to produce yarn according to the acceptable dimension specification. Thus, controlling the machine parameter especially the machine speed is very critical. With a relatively high speed, such as at 2000 m/min for SAHM 302E machine, the precision winding and rewinding of yarn is subjected to defect if the machine is not properly monitored and controlled (Johnson, 2000).

Compare to the yarn winding, spiral winding process is a type of yarn winding process with different principle. It involves the process of forming spiral shape from yarn by winding the yarn along a heated mandrill at high speed. Thus, it is slightly complex than winding yarn process due to addtional process parameters. Again failure to identify, monitor and controll the machine process parameters leads to poor spiral yarn product which at the end will result in low quality of spiral fabric. For that reason, the ultimate aim of this industrial research is to conduct systematic investigation to determine which process parameters that have dominant influence on the spiral sizes being produced base on the following Taguchi's philosophy of robust design (Roy, 1990):

- Quality should be designed into the product and should not be inspected into it.
- Quality is best achieved by minimizing the deviation from the target. The product should be designed in such a way that it is immune to uncontrollable environment factors (noise factors)
- The cost of quality should be measured as a function of deviation from the standard and the loss should be measured system-wide.

2.0 METHODOLOGY

2.1 Design of Experiment

In this study, Taguchi method is employed to plan out the experimental design and trial setup. The method was developed by a Japanese quality guru; Dr. Genichi Taguchi in order to improve the quality of manufactured goods in Japan. Although Taguchi method is argued to be similar to factorial design of experiment, the Taguchi method only conducts balanced/orthogonal experimental combinations which is believed to be more efficient than the former (Summers, 2003). This technique is proven to be able to reduce product development cycle time for both design and production stage and corresponds to cost saving and increase of profit. Due to its usefulness, the technique has been globally applied and implemented beyond manufacturing sector after 1980s' (Taguchi et al., 2001, Westerdale and Kazmer 2008, Anoop and Kumar 2013, Karna et al., 2012). Nevertheless, only a few studies have been found to apply this method in the textile industry research area. One of the studies is by Ishtiaque. (Ishtiaque et al., 2006), in which the effect of spinning process variables such as hank on lap, draft in different machines in spinning sequence, number of doublings on the properties of ring, rotor and air jet yarns were investigated using this method. Apart from that, (Webb et al. 2007) and (Webb et al., 2009) focused on splicing parameters effects such as blast pressure, blast duration, chamber design and cutting synchronization towards splice strength and later optimized them. Other researchers have put effort to optimized parameters such as yarn type, type of knitted fabric and tightness factor to achieve the maximum air permeability.

The main advantage of Taguchi method is its efficiency in that multiple factors can be considered at once and the optimal parameters can be identified with fewer experimental resources compare to the traditional DOE approach (Peace and Taguchi, 1992). Taguchi defines three quality characteristics in the analysis of Signal to Noise (S/N) ratio namely the larger-the-better, the lower-the-better and nominal-the-best in which this study will focus in order to to reduce variability around the target. The S/N ratio for each of process parameter is computed based on S/N analysis. Regardless of the category of quality characteristics, a larger S/N ratio corresponds to better quality characteristics. Therefore, optimal level of process parameter is the level of highest S/N ratio. Base on the S/N analysis, the statistical analysis of variance (ANOVA) can be performed to determine which process parameter is statistically significant for each quality criteria (Lakshminarayanan, 2008).

2.2 Material and Machine

The material for this research is a man-made round polyester yarn (PET) with cross section diameter less than 1.0 mm. PET is considered as one of the most popular fibres in technical textile and widely applied in manufacturing of geotextiles, tyre cord, car air bag and seats and etc. The fibre has a good balance between reasonable cost and performance properties, good mechanical properties and dimensional stability with fairly heat resistance which makes this material versatile to be applied in different industries (Matsuo, 2008).

The machine use in this research is a non-commercial spiral winding machine. The winding mechanism of the machine is driven by a motor which drives the yarn out of the spool until the spiral is formed. Once the yarn comes out from the top of the spool, it is continuously feed to a tensioner system to ensures constant winding tension before entering the heating area. At this heating area, the yarn will be formed into spiral shape to a specify major and minor dimension by winding it along a mandrill. Figure 3 shows an illustration of the spiral winding machine with its controllable components in brackets.

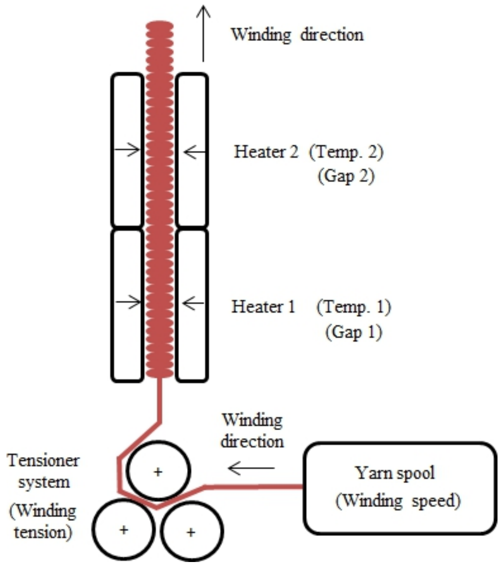

Figure 3. Illustrations of spiral winding machine and its controllable components

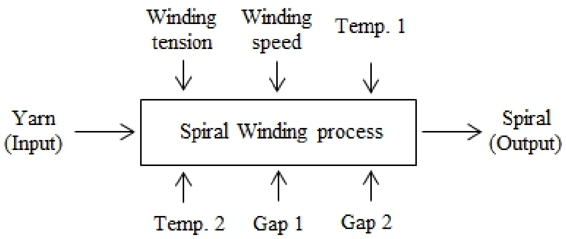

Figure 4. Process parameters for spiral formation

Figure 4 shows an input-output diagram of the spiral making process for additional clarification. There are six process parameters being identified as controllable factors. Due to secrecy policy of the company, the parameters value unfortunately cannot be disclosed. However, the range of the values are provided. They are: Winding tension(A) in the range 10-30%, Winding speed(B) in the range of 1000 – 2000 rpm, heater 1 and heater 2 labeled as Temp.1(C) and Temp. 2(D) respectively. The temperatures are set in the range of 100-150°C. Other process parameters are Gap 1(E) in the range of 4.00 - 5.00 mm and finally Gap 2(F) in the range of 4.50 - 5.50 mm. Three levels are considered for each parameter as indicated in Table 1.

Table 1. Factors and levels in spiral winding process parameters

Symbol	Parameter	Level 1	Level 2	Level 3
A	Tension (%)	A1	A2	A3
B	Speed (rpm)	B1	B2	B3
C	Temp. 1 (˚C)	C1	C2	C3
D	Temp.2 (˚C)	D1	D2	D3
E	Gap 1 (mm)	E1	22	E3
F	Gap 2 (mm)	F1	F2	F3

The ranges of parameters selected for this study comes from the machine technical data. The design of experiment for the experimental run was performed by using statistical analysis software. An L27 orthogonal array of three levels and six factors was selected as shown in Table 2.

Data were collected by running the 27 experiments randomly. To ensure the reliability and robustness of the data being collected, ten readings were recorded for each experimental run at an interval of 2 minutes each.

Table 2. L27 orthogonal array for the experimental run

No.	Tension	Speed	Temp. 1	Temp. 2	Gap 1	Gap 2
1	1	1	1	1	1	1
2	1	1	1	1	2	2
3	1	1	1	1	3	3
4	1	2	2	2	1	1
5	1	2	2	2	2	2
6	1	2	2	2	3	3
7	1	3	3	3	1	1
8	1	3	3	3	2	2
9	1	3	3	3	3	3
10	2	1	2	3	1	2
11	2	1	2	3	2	3
12	2	1	2	3	3	1
13	2	2	3	1	1	2
14	2	2	3	1	2	3
15	2	2	3	1	3	1
16	2	3	1	2	1	2
17	2	3	1	2	2	3
18	2	3	1	2	3	1
19	3	1	3	2	1	3
20	3	1	3	2	2	1
21	3	1	3	2	3	2
22	3	2	1	3	1	3
23	3	2	1	3	2	1
24	3	2	1	3	3	2
25	3	3	2	1	1	3
26	3	3	2	1	2	1
27	3	3	2	1	3	2

The responses or output from the experiment are spiral major and minor sizes (dimensions). Figure 5 shows the configuration of the spiral measurement.

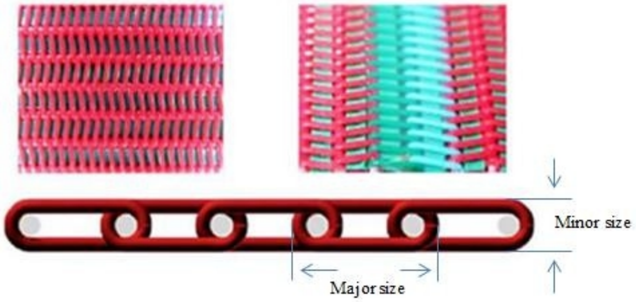

Figure 5. Spiral major and minor dimension

Major dimension is 6.3 ± 0.1mm and minor dimension is 4.3 ± 0.1mm. The measurement of the spiral sizes is recorded directly once the spiral exits the heating area by using a calibrated thickness gauge of ±0.01mm accuracy. Due to these small dimensions and tolerances, the spiral making process requires higher standard of quality control. Failure to comply with the specified dimensions within the tolerances can lead to dysfunctional fabric conveyor against the intended requirements and specification such as fabric air permeability and flatness. In this study, the main process parameter contributes to the major and minor dimensions will be identified. The interactions between process parameters is ignored for the present.

3.0 RESULTS AND DISCUSSION

3.1 Response to Signal to Noise Ratio and Means

In Taguchi method, the term Signal to noise ratio (S/N ratio) means the desirable effect (mean) for the output characteristic and the term 'noise' represents the undesirable effect which made up of signal disturbance for the output characteristic which influence the outcome due to external factors called noise factors (Kamaruddin et al,. 2010). The objective of any experiments that employs Taguchi's method is always to determine the highest S/N ratio of the result. This is because high value of S/N ratio indicates that the signal is outstanding compare to the effects of noise factor. To obtain the targeted spiral dimensions for this study, nominal-the-best is selected from the three categories of quality characteristic as discussed earlier in this paper. The formula of Nominal-the- best S/N ratio can be expressed as (Montgomery, 1991).

$$\eta = -10\log\left(\frac{\mu^2}{\sigma^2}\right) \tag{1}$$

where, η : S/N ratio
μ : mean
σ^2: variance

In this experiment the effect of each parameter is separated for different levels. For example, the mean of S/N ratio for tension at levels 1,2 and 3 can be calculated by averaging the S/N ratios of the experimental run 1-9, 10-18 and 19-27 respectively. The mean of S/N ratio for the rest of the parameters are computed in similar manner. The mean of S/N ratio for each level of the parameters corresponds to both spiral sizes of major and minor sizes are calculated separately and presented in the Tables 3 and Table 4.

The aim of the experiment is to determine the highest possible S/N ratio for each parameter being studied. It is an indicator that the signal is higher than the random effects of the noise factor and corresponds to minimum variance. From the tables it can be deduced that the factor-level combinations of A1, B3, C1, D3, E1, F3 and A1, B1, C3, D2, E3, F1 provide better signal in the formation of spiral major and minor dimensions respectively with minimal variations. These findings provide meaningful information to determine the most significant parameter that affect the formation of major and minor spiral dimensions through Analysis of Variance (ANOVA).

Table 3. The S/N response for major dimension

		Mean S/N ratio (dB)		
Symbol	Parameter	Level 1	Level 2	Level 3
A	Tension	52.87	51.55	52.32
B	Speed	52.00	51.68	53.05
C	Temp. 1	53.10	51.67	51.97
D	Temp. 2	52.28	51.82	52.63
E	Gap 1	53.40	52.14	51.19
F	Gap 2	51.16	52.29	53.29

Table 4. The S/N response for minor dimension

		Mean S/N ratio (dB)		
Symbol	Parameter	Level 1	Level 2	Level 3
A	Tension	54.48	53.73	53.17
B	Speed	54.21	55.14	52.02
C	Temp. 1	53.47	53.90	54.00
D	Temp. 2	54.20	54.32	52.85
E	Gap 1	53.51	53.65	54.22
F	Gap 2	54.87	54.09	52.41

3.2 Analysis of Variance

The relative effect of different spiraling process parameters towards the major and minor dimension was obtained by decomposition of variance, known as analysis of variance (ANOVA). Table 5 and 6 show the ANOVA analysis for major and minor dimension.

Table 5. ANOVA for major dimension

Parameter	Sum of Square	DOF	Variance	F-ratio	P	Contribution (%)
Tension	0.1369	2	0.0684	304.78	0.000	87.36
Speed	0.0003	2	0.0002	0.72	0.505	0.21
Temp.1	0.0003	2	0.0002	0.85	0.447	0.24
Temp.2	0.0049	2	0.0025	10.92	0.001	3.13
Gap 1	0.0020	2	0.0010	4.48	0.031	1.28
Gap 2	0.0122	2	0.0061	27.14	0.000	7.78
Error	0.0031	14	0.0002	-	-	-
Total	0.1598	26	-	-	-	100

Table 6. ANOVA for minor dimension

Parameter	Sum of Square	DOF	Variance	F-ratio	P	Contribution (%)
Tension	0.0012	2	0.0006	7.74	0.005	0.78
Speed	0.0050	2	0.0025	33.00	0.000	3.34
Temp.1	0.0000	2	0.0000	0.33	0.724	0.03
Temp.2	0.0002	2	0.0001	1.48	0.262	0.15
Gap 1	0.0022	2	0.0011	14.75	0.000	1.49
Gap 2	0.1397	2	0.0699	930.84	0.000	94.20
Error	0.0011	14	0.0001	-	-	-
Total	0.1494	26	-	-	-	100

Most of the P-value are less than 0.05 except for speed and Temp. 1 for major dimension and additional Temp. 2 for minor dimension. This shows overall F-test is statistically significant with confidence level of 95% and more. The larger the F-value means the more significance of the particular process parameter that affect the output results (Webb et al., 2009). Based on Table 5, it is found that Tension is the dominant parameters that affect the major spiral size with F-value equals to 304.78 and 100% significance level. The percentage contribution is 87.36%. This is followed by Gap 2 with 7.78% contribution while the rest of the parameters are not significant to the output and can be neglected. As for minor dimension as shown in Table 6, it is greatly affected by Gap 2 with F-value equals to 930.84 and 100% confidence level. The percentage contribution is 94.20%. The rest of the parameters are insignificant and can be neglected.

4.0 CONCLUSION

It can be concluded that major dimension and minor dimension of spiral are dominantly affected by Tension based on 87.36% contribution as shown in Table 5 and Gap 2 based on 94.20% contribution as shown in Table 6. Thus, these two parameters need to be properly controlled to stabilize the production process in order to produce the targeted spiral sizes. This finding is expected to assist the machine operators and the technician in the yarn winding production line to focus on the two process parameters for good quality of yarn product.

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