Graded Wound Filter Performance Analysis – Mechanical Filter Produced on Step-Precision Winding Mode

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Abstract

The graded wound filters can be manufactured using the winding technology. It is possible to produce those using different systems/modes of winding like Random, Precision or Step-precision. The study aimed to produce wound filters with three different coil angles on step-precision winding mode to find their performance characteristics. It was found that the pressure drop of filter wound with the lowest coil angle (20°) showed the highest pressure drop (4.72 psi) due to greater yarn content. The micron rating of the same filter was found to be 72 µm. The subsequent coil angle (25°) showed reduction in both the pressure drop (3.966 psi) and micron rating (85 µm). But the highest coil angle showed pressure drop of 0.445 psi and micron rating of 85 µm. The wound filters produced in precision winding mode showed higher values of pressure drop though their build-up parameters were same. This indicates that the filter manufacturers can produce cartridges in step-precision winding mode for better economy especially when produced at lower tension and higher coil angle and requiring rating of 85 µm and above.

Keywords: *micron rating, porosity/surface area, pressure drop, step-precision winding mode, wound filters*

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1. Introduction

The world today is engulfed in several water related issues and days are not far when the struggle between nations/states/people over clean water would become intense. Different types of water filters are available like mechanical, absorption, sequestration, ion-exchange and reverse osmosis; selection of which depends upon the target particle group to be removed. Many a times combination of different filter types is preferred to remove wide range of particles in a heterogeneous mixture. This is especially true in case of domestic water purification plants, where the wound filters act as pre-filters aimed to carry out micro-filtration, while the membrane targets the sub-micron particles including the viruses. The UV lamp kills the microbes and the activated carbon removes particles by adsorption, thus the entire system completes the process of water purification. Winding is a science used to produce the wound filters using the winding technology however not many manufacturers apply this knowledge while producing them for the desired filtration performance. The study aims to analyze the influence of winding mode i.e step-precision winding mode on filtration performance and other related nuances to bridge the gap between wound filter manufacturers and consumers.

2. Material and methods

2.1 Material

Yarns used for filtration application have bulky appearance indicating porous nature [1]. They are usually produced by friction spinning technique where the spinning process parameters influence the yarn properties [2]. Polypropylene DREF spun yarn material was acquired from KBS filters, Makarpura, Vadodara, India. DREF spun yarns used for the study had fineness of 711 Tex (0.831's Ne) which was established after taking an average of 20 readings applying cutting and weighing method. The yarn diameter was found using microscope and an average of 20 readings was found out to be 0.2 cm. Experimental work was carried out in the Textile Engineering Department, The Maharaja Sayajirao University of Baroda, in 2019.

2.2 Introduction to winding systems

Cross wound packages (including wound filters) can be produced using Random, Precision and Step-precision winding mode and their working principles along with characteristics is explained in detail [3]. Random winding mode is not preferable for filtration application due to the problem of pattern formation. The precision winding mode produces packages that are more compact in comparison to the both the step-precision and random winding mode. There is progressive reduction in coil angle that may influence the packing density and their appearances (package edges). The edges of package are not parallel either in case of precision (convex edges) or random winding (concave edges) while almost parallel configuration is obtained on step-precision winding mode [3]. Selection of winding mode significantly influences the package build characteristics. Since wound filters are also an example of cross wound package, the mode of winding can influence its performance characteristics like pressure drop and/or micron rating. Previous works related to hydraulic performance of wound filters are reported on the basis of experiments conducted in the laboratory [4-16]. The influence of winding parameters like coil angle, tension and gain on performance of wound filters built in the precision winding mode is reported [4]. The influence of winding parameters like spindle speed, circumferential diamonds, package diameter and fineness of yarn on wound filter's performance built in the precision winding mode is also reported [5]. The effect of coil spacing on the performance of graded filters in precision winding mode is studied [6]. In another such work the influence of coil number on the performance of graded wound filter for water application built using precision winding mode was investigated [7]. Wound filters have to be analyzed for their performance for which different test methods are available, along with the standard test dusts (air cleaner test dust) used in such test procedures is also reported [8]. There are different varieties of air cleaner test dusts and how their different particle size distributions contribute to the filter test result is also reported [9]. Another such work reported experimental confirmation of performance of wound filters constructed either from cotton or polypropylene, with specific ratings, procured from market [10]. Apart from the established test methods, a modified filter test [11] is reported where the conditions of test were altered to achieve change in the contaminant concentration level. The domestic market makes use of disposable filters but use of hybrid filter is advocated to achieve better results and comparison of performance of different filters like wound filters, thermal molded filters, fixed density filters and absolute rated depth filters using oil as the medium is presented [12]. Efficiency of novel cartridge developed from fiber was compared with wound filter [13]. X-ray technique was used to observe the extent of penetration of dust particles inside wound filters is reported [14]. One such recent work [15] hydraulic performance of wound filters used in domestic plants for drinking water is reported, where emphasis was on the head losses due their placement in the system, while another work investigated clogging pressure for filters with different rating [16]. However, none of them [8-16] used in-house manufactured wound filters on step-precision winding mode nor performance of such filters is reported. This paper focuses on engineering wound filters produced in the step precision winding mode and understand their performance characteristics.

2.2.1 Introduction to step-precision winding

Step precision winding mode is essentially an extended version of the precision winding mode and most importantly recommended to be used for flow applications like that of dyeing or filtration due to supposedly uniform density [3]. A diagrammatic representation of mechanically operated step-precision winding system is shown in figure 1. The motor drives the cross-wound package on which there are several gears labeled as A, B, C, D and E. The traversing cam is mounted on gear shaft carrying gears A', B', C', D', and E'. A & A' is a gear pair and so are B & B', C & C', D & D' and E & E'; at the time only one gear pair is engaged. The gear ratio in each of the gear pair is such that pattern formation will not take place.

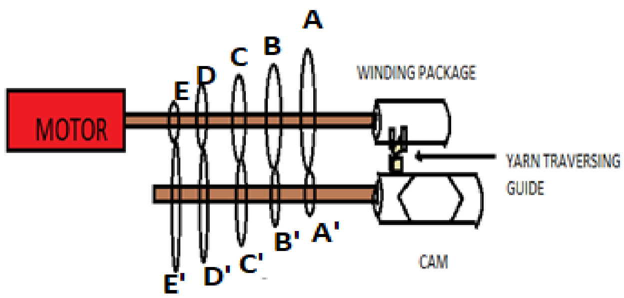

Figure 1: Schematic diagram of step-precision winding system

Suppose when the package is empty at that time gear pair A & A' are engaged. The number of teeth on A & A' would not allow pattern formation to occur. But as the winding starts several layers are laid on the package and there is build up in its diameter leading to reduction in coil angle, just as Precision winding system. But the system ensures almost constant coil angle by shifting from the gear pair A & A' to B & B' which also produces pattern free package and at the same time reduces the number of coils laid on the package (traverse ratio). This happens due to inverse relation between coil angle and traverse ratio; traverse ratio being changed after definite increment in the package diameter to maintain almost constant coil angle. In all a step-precision winding mode combines the positive aspects of Random and Precision winding systems making more apt for certain applications related to fluid flow as explained in the following section.

2.2.2 Producing wound filters on step-precision mode

The most important requirement for a winding system to work on step-precision mode is that there should be provision to reduce the number of coils (wind ratio) at regular intervals so that the coil angle can be maintained throughout the build-up. This requirement is fulfilled in steps and hence the name; the number of coils laid are reduced after a certain amount of package diameter is built-up. In the mechanical system (figure 1) the gears are changed periodically while the same is achieved by the electronic gearing on electronically controlled systems. The experimental work was carried on electronically controlled filter winder [17] and the program allowed the packages to be built to full diameter in 4 steps [18]. This implied that four traverse ratios could be used such that, pattern formation is avoided and the subsequent traverse ratio would be smaller than the earlier one. To actually achieve this when the machine is set in step-precision winding mode the diameter increment and package diameter at each step has to be decided. During the experimental study it was observed that when initial layers of yarn were laid on a perforated core (bare bobbin), the diameter build-up was less and when yarn was wound on yarn its build-up was more, which is explained with help of following example. Suppose the initial package (bare diameter) of the perforated core tube is 34 mm, increment in diameter was taken as 6 mm for the first layer, while for all the subsequent layers it was taken to be 8 mm each; doing this ensured that almost a constant coil angle is maintained.

If a package with X° coil angle is to be produced then the numbers of coils that should be reduced with reference to increasing diameter can be found using equation 1 and equation 2. For calculating the traverse ratio for a particular step, increment mentioned earlier was added to the package diameter of that step.

$$\text{traverse ratio} = \frac{2 \text{ X traverse length}}{\pi \text{ X d X } \tan\theta} \qquad (1)$$

Where d is the package diameter at a given instant and θ is the coil angle.

$$\text{gain} = \frac{\text{yarn diameter}}{\pi \text{ X d X } \sin\theta} \qquad (2)$$

Where d is the package diameter at a given instant and θ is the coil angle.

Using equations 1 and 2, it was found that the actual wind ratios (close) for the four steps during package build-up came out to be 5.973, 4.977, 3.982 and 3.516 considering coil angle of @ 21° and the coil angle could be controlled within ± 0.535° here. Same method of calculation can be followed for the other coil angles too.

2.3 Winding methodology

Wound filter for the experimental studies were produced on electronically controlled filter winder [17] selecting the step-precision winding mode; is stated in section 2.2.2. All packages were wound with an average tension of 55 g, spindle speed of 225 rpm, yarn count and yarn diameter of 0.8's Ne and 2 mm respectively. The packages were produced with three different coil angles of 20°, 25° and 30°. All packages were produced with close wind and one circumferential diamond. The wound filter samples were coded as SPA1, SPA2 and SPA3, where SP stands for step-precision, A stands for angle while 1, 2 and 3 represent the coil angles selected for the trials namely 20°, 25° and 30° respectively.

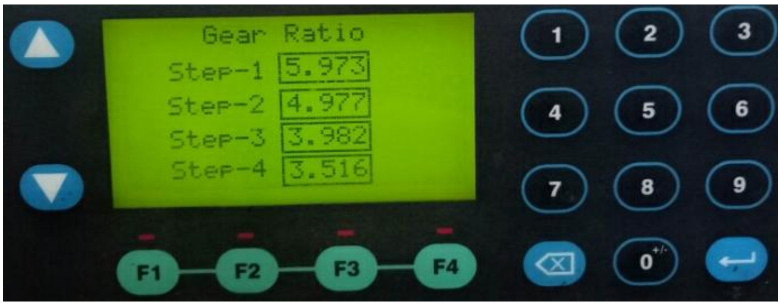

Figure 2: Control panel display set in step-precision winding mode

2.4 Filter testing method

The wound filters were tested in-house on apparatus [19] that uses single pass and is a destructive test method [20]. The test slurry was prepared using ISO A3 test dust as contaminant, with particle size distribution in the range 1-100 µm. The concentration of slurry was 0.1 g/L, pumped to achieve constant flow rate conditions (400 L/h) for duration of 2 hours. The pressure drop was found from the inlet and outlet pressure ports during the test trial whereas the particle size distribution was found from the water samples collected from the respective ports. This was ultimately used in finding the retention efficiency (%) and micron ratings of the wound filters produced in this study.

3. Results and discussion

The wound filters were tested for their pressure drop characteristics and their retention efficiencies (%).

3.1 Pressure drop characteristics

Figure 3 shows comparative performance of the step-precision wound filter samples in terms of pressure drop experienced by each of them during the test trial.

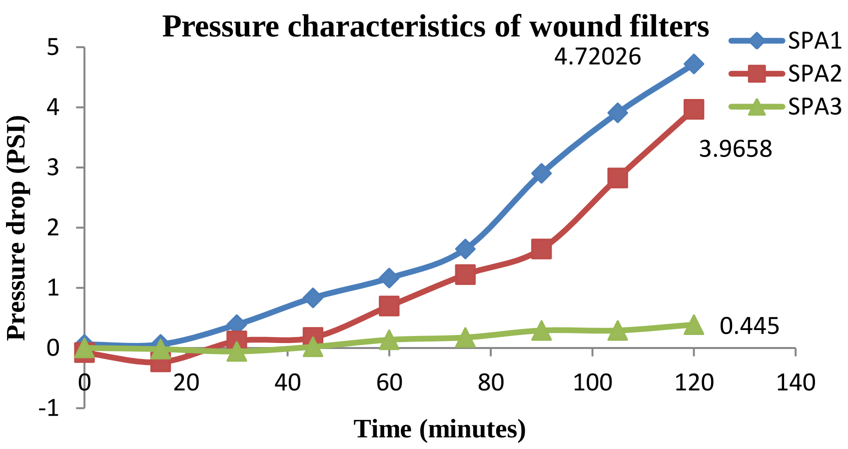

Figure 3: Pressure characteristics of wound filters

It can be seen that the pressure drop experienced by package wound with the least coil angle (A1) showed highest resistance to flow while that with highest coil angle (A3) showed least resistance. These results are in accordance with the results obtained for precision wound filters [21], though the winding parameters may differ. The (%) rise in the pressure drop values of SPA1 and SPA2 is 15.983% while that between SPA2 and SPA3 is 90.244%. The pressure drop of the filter wound with coil angle 20° and 25° are following each other closely but a further increase in angle by a very small amount (only 5°), the pressure drop was reduced substantially indicating that the filter was not able to resist the flow and trap the suspended particle effectively; indirectly affecting its performance. It also implies that if the coil angle is increased beyond 25°, wound filters can show mechanical failure and is true for the said conditions of the wound filter considered in these trials. Trials taken for wound filters produced under similar winding conditions but in precision winding mode showed that the wound filters exhibited higher pressure drop compared to wound filters produced in step-precision winding mode [22], which is essentially due to the compact winding achieved with precision winding and hence the higher pressure drop.

3.2 Retention efficiency characteristics

The inlet and outlet filter samples collected during the test trials of individual wound filters were analyzed on microscope and the dust retention efficiencies were obtained. The micron rating of SPA1 was 72 µm, SPA2 was 85µm while that for SPA3 was 85µm. It can be observed that the micron rating of A1 is better than A2 which was mainly due to higher yarn content which is also the reason for higher pressure drop. Thus, in spite of having similar porosities and surface areas, A1 and A2 filters showed different micron rating and pressure drop values.

The other most obvious result was that the micron rating of SPA2 and SPA3 filters was same but the pressure drop difference between them was the maximum. The coil content in case of A2 filters was more than A3 but no significant improvement in its rating was found or in other words the SPA3 filter showed nominal rating of 85 µm and lower pressure drop in spite of having lesser yarn content. Thus from economy point of view this information should be of prime importance for the manufacturers. Here it is pointed out that when wound filters were produced in the precision winding mode, the micron rating of wound filter with lower coil angle was better (59 µm) and got poorer with angle increment. The filter produced on precision winding mode wound with highest coil angle coped badly than the filter produced on step-precision winding mode [22].

3.3 Influence of available trapping area

The particle trapping capacity of a filter may be attributed to the surface available for the particles to get deposited [23]. The calculated values of available surface area on the basis of physical dimensions for all filters are shown in table 1.

Table 1: Available surface area to trap particles

Filters	Length (cm)	Surface area (cm^2)	% decrease with reference to SPA1T
SPA1T	23	226.8	-
SPA2T	22.7	223.9	1.279
SPA3T	22.5	221.1	2.513

This shows that all wound filters had similar surface areas. Since the build-up involved changing coil number progressively from center to surface, it would lead to change in the coil content present in each layer resulting in different densities across the build-up. Table 2 shows density changes during build up of SPA2T package. The bare bobbin weight was 55.93 g and package was built to give full diameter of 64 mm.

Table 2: Step wise weights build up of SPA2T wound filters

Diameter build-up	Weight at every step (g)	Density (g/L)
Step – 1 (bare – 40 mm)	59.1	1302.46
Step – 2 (40 mm – 48 mm)	60	826.074
Step – 3 (48 mm – 56 mm)	64	660.705
Step – 4 (56 mm – 64 mm)	65	567.054

It was found that the weight increased to 115 g from bare bobbin weight of 55.93 g, which was an increase of 59.1 g. Similarly for the second step the increase in weight was 60 g, and for the third and fourth step increase in weight was found to be 64 g and 65 g respectively. Thus the increase in weight was quite close in every step however the density (mass per unit volume) changed. When the bobbin was bare, the coil number (figure 2) was more making it denser, whereas the coil number reduced progressively as the build proceeded to the surface of the package; leading to less dense packing. The characteristic feature of step-precision winding is that the length over which winding is done remains almost same resulting in similar surface areas and better edges of the wound packages.

This adds up to an important conclusion that the step-wise build up of the wound filters produced in the step-precision winding mode will produce graded filters. The gradual change in the yarn content will produce packages with a gradient lowering its pressure drop compared to filters wound on precision winding mode irrespective of the coil angle at which they were produced. It is known that filter with lower pressure drop last longer and hence will be economical.

4. Conclusions

- The wound filters could successfully be produced on step-precision mode.
- They were produced with three different coil angles for which the traverse ratio was changed in four steps in all cases.
- These filters also showed density gradient that is evident from its density values. The pressure drop of filters wound in this mode showed lower pressure drop than those wound on precision winding mode.
- The porosity of all wound filters came out quite close to one another mainly due to their similarity in surface areas.
- The pressure drop decreased with the increase in the coil angle; trend being similar to that of wound filters produced on precision winding mode but overall the pressure drop shows dependency on the winding mode.
- Wound filters produced with lower coil angle showed higher pressure drop with better micron rating.
- Further increment in the coil angle although resulted in reduced pressure drop but even the micron rating became poorer.
- It is suggested to use highest coil angle selected in the study when wound filter with micron rating of 80 μm or above have to be produced, as the pressure drop experienced will be less and the micron rating is also comparable with the filter wound with slightly higher coil angle; thus being more economical due to lower consumption of yarn.

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