Designing a Cartridge Winder with Electronic Control

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ABSTRACT
There are number of winding machines in the market based on either the Random, Precision, or Step Precision winding system. Filtration application requires a uniform lay of yarn or its performance may be affected, hence, for the aforesaid purpose, the precision system would be more apt. Recent trends show an increased use of electronics in all applications, textiles being no exception. The aim of the present work was to develop a filter cartridge winder (laboratory model) based on the precision winding system, controlled electronically. The novelty of this machine lies in the fact that it makes use of a chain to reciprocate the guide mounted on it, unlike the majority of commercial filter winders, which make use of scroll cams to traverse the yarn. Filter winders are specialized winders that produce cartridges in standard sizes of 10”, 20”, 30” and up to 70”. Thus a cartridge winder is quite different from the usual winding machines not only in terms of its traverse length and feed material but also because of the core tube which has to be perforated just as one required for a dyeing process.

Keywords: Electronic control, Gain, Gear factor, Precision winding, Pressure drop, Traverse, Wind ratio.

INTRODUCTION TO WINDING

In a random winding system, the main features include a drum which may be either grooved or plain. The grooved drum not only rotates the package but also traverses the yarn as shown in *Figure 1a and 1b*, [1]; whereas with a plain drum, a separate arrangement has to be provided to reciprocate the yarns as shown in *Figure 2* [2]. Thus the drum is the most important feature of a random winding system.

FIGURE 1A. Random winding system for cheese.

FIGURE 1B. Random winding system for cone.

Figure 1a & *Figure 1b* show a random winding arrangement to produce cheese and cone respectively.

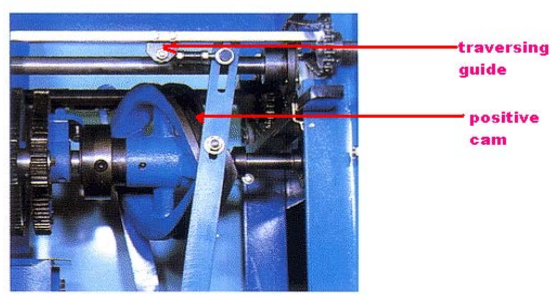

FIGURE 2. Cam traverse suitable for a random winding system as well as for a precision winding system.

Figure 2 shows the cam due to which the follower and hence the lever will move to and fro causing the yarn guide to reciprocate, thus traversing the yarn. This kind of arrangement is possible with a random winding system as well as a precision winding system, where the package is mounted on the spindle. The drive from the spindle goes to the cam, causing the yarn to traverse. Another arrangement normally used on take-up winder is show in *Figure 3* [3], where the yarn is traversed using propeller blades. All of the above mentioned systems are well established in the market.

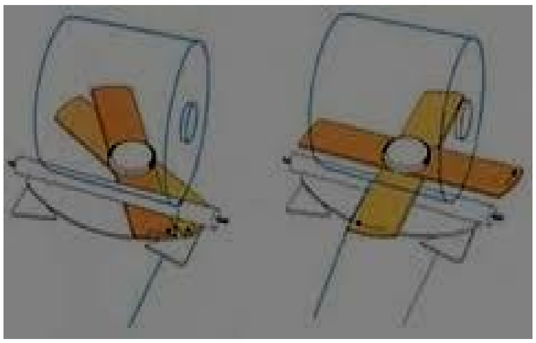

FIGURE 3. Bladed/propeller traverse.

Thus it is quite clear that there can be different means to reciprocate yarn, while rotational motion may be given to the package either by a surface drive or a spindle drive. A servo traverse has been patented, but it is quite different from the developed system since the patent uses only one servo, which is meant for traversing the yarn. Even the mechanical arrangement used there is different.

CONCEPT OF PRECISION WINDING SYSTEM

This section gives a brief understanding of precision winding system and its arrangement is as shown below in the *Figure 4*.

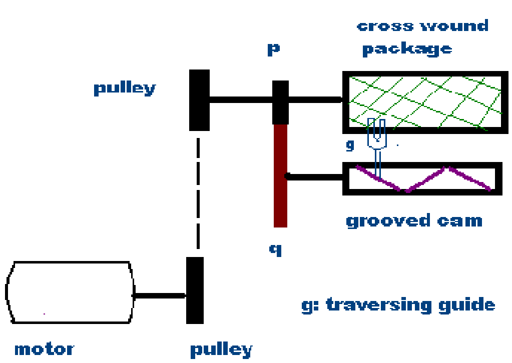

FIGURE 4. Precision winding principle.

The motor drives the pulley on which the package is mounted, whereas the drive to the grooved cam is obtained via the gears p and q from the same shaft.

Theory

The typical characteristics of a precision winding system [4] are as follows:

The surface speed (S.S) of the package would be a function of its speed and its diameter.

$$\mathbf{Surface\ speed} = < pi > \times \mathbf{d} \times \mathbf{n} \qquad (1)$$

where, d=package diameter and n=speed of package (r.p.m).

This value is not a constant but continuously increases, causing a gradual increase in yarn tension. To maintain constant tension, the surface speed should be maintained constant. This can be achieved either by reducing the spindle speed in proportion to the increase in package diameter (variable spindle speed machine) or by using a compensating tensioning arrangement (constant spindle speed machine). The traverse speed (T.S) is function of the traverse length, rotational speed of the spindle and the gear ratio:

$$\mathbf{Traverse\ speed} = \mathbf{2} \times \mathbf{L} \times \mathbf{n} \times (\mathbf{p/q}) \qquad (2)$$

where, L=traverse length, n=speed of package (r.p.m), (p/q) = gear ratio between cam shaft and package shaft.

For a constant spindle speed system, the quantities in the above equation are constant; traverse speed would remain a constant. The winding speed (W.S) is the square root of the sum of the surface speed square and the traverse speed square.

$$W.S = \sqrt{S.S^2 + T.S^2} \qquad (3)$$

But the winding speed would not be a constant, since the surface speed is not constant. The coil angle (θ) is a function of traverse speed and the surface speed

$$\tan < theta > = (T.S) \div (S.S) \qquad (4)$$

It would decrease progressively.

Substituting the values of T.S and S.S from Eq. (1) and Eq. (2) and putting them in Eq. (4) and reducing it, Eq. (4) can be rewritten as

$$\tan < \text{theta} >= 2 \times L \div (< pi > \times d \times T.R) \quad (5)$$

The traverse ratio (T.R) would be the number of rotations made by the package in a double traverse. For example if we say the grooved cam makes one rotation in a double traverse, and then the package makes q/p rotations in a double traverse.

$$T.R = q/p \quad (6)$$

Since the number of teeth on the gears will not change, this quantity is a constant. To prevent patterning, the traverse ratio should be selected so that it is not a whole number, and after every pattern repeat the coils should get displaced precisely. Gain is the precise displacement of the yarn at the end of each pattern repeat. Two quantities are defined, namely, linear gain (L.G) and revolution gain (R.G). Linear gain can be written in the following way:

$$L.G = \text{yarn diameter} \div (\sin < theta >) \quad (7)$$

But R.G is a better known quantity which is written as follows,

$$R.G = L.G \div (\text{cirumference of package}) \quad (8)$$

Substitution of the values of L.G in the above equation, we get

$$R.G = \text{yarn diameter} \div (< \text{pi} > \times d \times \sin < \text{theta} >) \quad (9)$$

where RG stands for revolution gain/double traverse.

$$A.T.R = N.T.R - \text{gain} \quad (10)$$

where A.T.R stands for actual traverse ratio and N.T.R stands for nominal traverse ratio [5].

MATERIAL AND METHODS

Material

It was decided to develop a filter/cartridge winder on the precision winding principle, so that the problem of pattern formation could be avoided, and with a variable spindle speed in order to maintain constant tension. Instead of using a mechanical system like scroll cams to traverse yarn and change gears for obtaining the desired crossing pattern on the package, it was decided to use an electronic system for ease of operation. To traverse the yarn, the medium selected was chain, on which a yarn guide was mounted. Using Eq. (5) it possible to (line shifted and rearrangement) design packages for a particular coil angle/wind ratio.

The traverse ratio means the number of revolutions made by the package when the traversing element covers twice the traverse distance. This application demands that the number of revolutions made by the package in the single traverse should remain fixed every time and at the same time the angular position of the package should be such that the shift (gain) should be uniform and equal after every pattern repeat. Thus both rotational as well as positional controls are of importance. So the next critical thing was to choose those devices which were capable of fulfilling the above requirements. The best and the most reliable option found was that of a servo motor for driving the spindle and the chain. Hence two servo motor of 750 W with 10,000 pulses per minute each were selected for the said application. Servo motors are intelligent, constant torque motor and can run at higher or slower rotational speed. With this background a servo was selected as the driving element and the chain as the traversing element. Its mechanical arrangement is shown in *Figure 7*.

Method

Since both the drives were independent, synchronization was done in the following manner.

A package with a coil angle of 15° is to be designed; let the traverse length be 239mm and the package diameter be taken as 33.6 mm. On substituting these values in Eq. (6) we get

$$\tan < 15° >= 2 \times 239 \div (< pi > 33.6 \times T.R)$$

So

$$T.R = 2 \times 239 \div (< \text{pi} > \times 33.6 \times \tan < 15° >)$$

Let the N.T.R be 17.

This would mean that 17 coils will be laid in a double traverse or 8.5 coils each will be laid in a single traverse due to which the coil comes to the same starting point. If this happens then pattern formation would result. To avoid this, the coils should precisely be shifted by the same amount after every pattern repeat. In the above mentioned case, pattern repeat would be after every double traverse.

So instead of keeping the traverse ratio as 17, a number very close to this can help in preventing pattern formation. If a close wind is required, then the yarn should be displaced equal to the yarn diameter. Thus while designing a package with close wind or open wind, the choice of yarn diameter value plays an important role. The following calculation is an example showing the calculation when yarn diameter of 3mm is chosen. Using Eq. (9) to calculate the R.G

$$\mathbf{R.G} = \mathbf{3} \div (< pi > \times \mathbf{33.6} \times \mathbf{sin} < 15^{o} >)$$

This gives R.G of 0.10987, which on rounding off can be taken as 0.11. The actual traverse ratio (A.T.R) can be found by using Eq. (10),

$$\mathbf{A.T.R} = \mathbf{17} - \mathbf{0.11} = \mathbf{16.890}$$

Thus when the traversing guide travels a distance of 478 mm, the package should make 16.89 revolutions. This would synchronize the two drives. Or in other words when the package servo makes 16.89 revolutions, the traverse servo should complete two revolutions [16.89: 2]. The value of wind ratio is same as gear factor, taken as one of the inputs on the control panel shown in *Figure 9*.

EXPERIMENTAL

Before mounting the servos on the machine, the servos were checked individually. A setup shown in *Figure 5* was created on a table top, where the servo along with its drive was checked for its working.

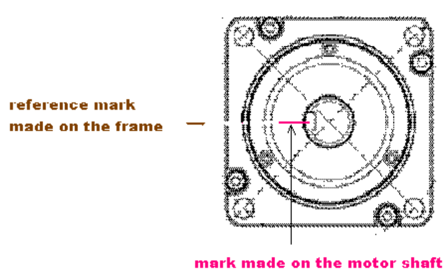

FIGURE 5. Marking on motor shaft and on frame.

Package Servo Trials

The method adopted for checking whether the servo was working as per the command given is shown in *Figure 6*. To ensure whether it's working is correct or not, the servo was programmed to rotate by one revolution. While starting the trial both the marks, that is the one on the servo shaft and the reference mark were made to coincide. Then it was commanded to make one rotation and on completion of one rotation, the marks coincided exactly. This shows that the working was as per the program. Now practically the exact matching of the two marks is not desirable or else it will result in pattern formation. So to make it asynchronous, the command of 16.89 was given to the motor. Here also at the start the marks were made to coincide, but on completing 16.89 revolutions the marks did not coincide but there was a lag, since head wind was used.

Traverse Servo

This servo also was programmed to make one revolution using the same method. It was found that after one revolution, the marks coincided exactly. The length travelled could be checked only after the arrangement was mounted on the machine.

Machine Trials

This was possible only after the development of logic behind the program was completed. Both servos were mounted on the machine and timing belts were used for driving so that slippage between the point of transmission and up to the point of transmission was made minimal. Other than timing belt and pulleys, chain and sprockets have been used which are also positive in action. A similar method was adopted for machine trials also. Practically it was found that one revolution of traverse servo caused the traversing guide to move through a distance of 239 mm. So once the mechanical arrangement was finalized, then the synchronization trails were taken which were also found to be as per requirement. The *Figure 6* shows the passage of the yarn on the said winding machine. The roving is unwound from the supply package, drawn through the guide eye and is then passed through the tensioning arrangement and various rollers and guides. The tension compensator has been specially designed so that it is able to compensate the varying tension in the roving during its traverse stroke. The chain plays an important role as it carries the yarn guide and due to its reciprocating motion the yarn guide and yarn also get linear motion.

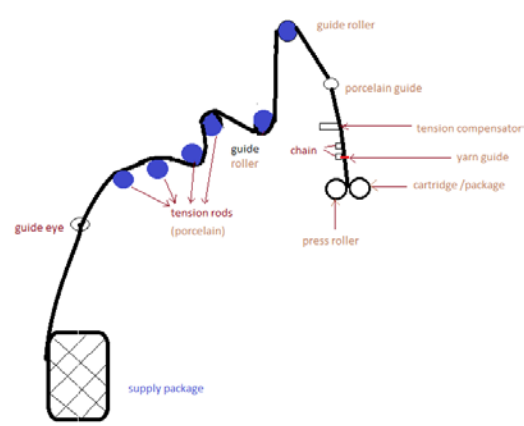

FIGURE 6. Passage of yarn on newly developed winder.

The *Figure 7* shows the machine from its front side. The drive from the traverse servo via timing belt and pulley arrangement comes to a shaft on which driver sprocket is mounted. The package servo drives the cartridge bobbin via set of timing belt and pulley along with chain and sprocket. The chain carries the yarn guide, which will be moved to and fro. Exactly behind the cartridge is the press/surface roller. It is bearing mounted and hence can rotate freely along with the cartridge, due to frictional contact between them. The software used to develop this PLC program was Proficy machine edition 6.5 using ladder logic in external position control mode.

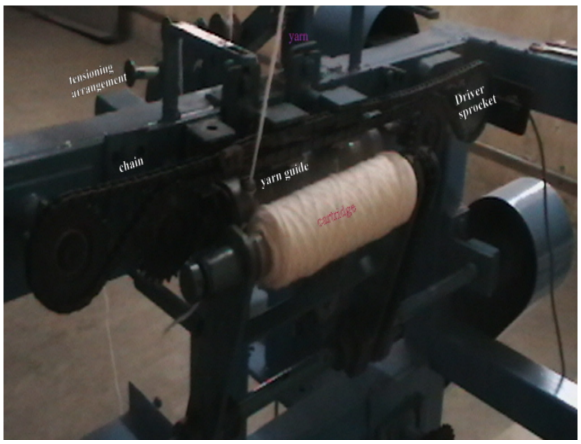

FIGURE 7. Front view of newly developed winder.

The tension compensator shown in *Figure 8* is mounted exactly on top of the cartridge such that it compensates the variation in the path lengths during the traverse. *Figure 9* shows the control panel developed to operate the system.

FIGURE 8. Tension compensator.

FIGURE 9. Control panel and display (newly developed winder).

Functionality Trials

Yarn produced on an unconventional spinning system like DREF shows better performance compared to yarn spun on the conventional system [6, 7]. Since the winder has been developed with the intention of producing filter cartridges, and its functionality can be established only after testing them. *Table I and Table II* show comparative results of cartridges produced on the newly developed winder (ndw) and those produced on a commercial winder with cam traverse and mechanical control. The two test parameters, on which the comparisons have been based, are the pressure drop developed across the filter media and the micron rating. The winding parameters varied for the same are coil angle and tension. Three different targeted coil angles were selected: A (15°), B (25°), and C (35°). And the three average tension levels selected for the study were X (145 gm), Y (242 gm), and Z (360 gm). Other parameters; namely, gain, package diameter, circumferential diamonds, speed and raw material variables were maintained almost identical.

TABLE I. Testing data related to (ndw).

Results on testing	WINDING PARAMETERS ON FABRICATED WINDER					
	Coil angle			*Avg. winding tension		
	A	B	C	X	Y	Z
Pr. drop	10.68	8.628	8.473	10.679	11.046	11.78
†Eff.%	best	better	good	best	better	good

*for a particular coil angle, † Efficiency% is based on particle count in the filtrate.

TABLE II. Testing data related to (cw).

Results on testing	WINDING PARAMETERS ON COMMERCIAL WINDER					
	Coil angle			*Avg. winding tension		
	A	B	C	X	Y	Z
Pr. drop	9.84	8.28	8.086	9.827	10.87	11.94
†Eff.%	best	better	good	good	better	best

*for a particular coil angle, †Efficiency% is based on particle count in the filtrate.

RESULTS AND DISCUSSION:

If we consider from the mechanical point of view and the traversing devices mentioned earlier, then in each case, the traverse length is fixed; so if the length needs to be altered then the traversing element itself needs to be modified. Likewise when the wind pattern is to be altered, a set of gears have to be changed; but with an electronic system this trouble is done away with, due to the use of electronic gearing. Besides this, a stock of gears need not be maintained, making the changes in traverse length, wind ratio or gain very simple. When traversing element has to be moved to and fro, the reversal has to be instant. This means that acceleration and deceleration time would tend to be very small causing high acceleration and deceleration of the system. But if the mass of the system is heavy then the force required in moving it would also be high. With the proposed system, the mass of the reciprocating system is reasonably less, requiring less acceleration and deceleration time. The following figures show the packages produced on the said machine with different coil angles and one diamond along the circumference.

FIGURE 10. Cartridges produced on newly developed winder (ndw).

Figure 10 shows a cartridge that has been produced to seek a targeted coil of 25°, whereas *Figure 11* shows a package designed to achieve targeted coil angle of 35°. Both the packages show a clear cut pattern with one diamond and good roving lay.

FIGURE 11. Cartridges produced on fabricated winder (ndw).

Thus good package with uniform lay and as per the required number of winds is produced. To check whether the cartridges are functionally at par with those produced on commercial winders, cartridges with the same specifications as those produced in the industry were produced. The *Figure 12* shows the change in pressure drop over a time for cartridges of different targeted coil angles produced on our fabricated winder.

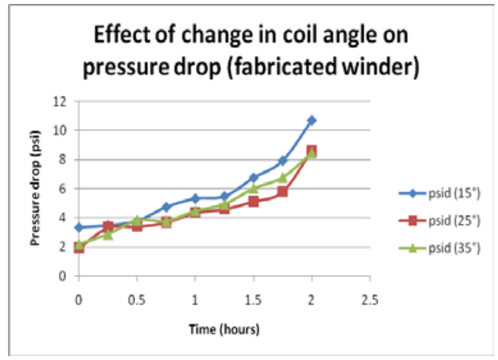

FIGURE 12. Graph of pressure drop versus time for cartridges produced with different coil angles for newly fabricated winder.

Figure 13 shows the same plot for a cartridge wound on a commercial winder. As the coil angle changes the number of coils also change. The pressure drop developed is directly dependent on the resistance offered by the media. With higher coil angle, the yarn content will be less; hence pressure developed will comparatively be less.

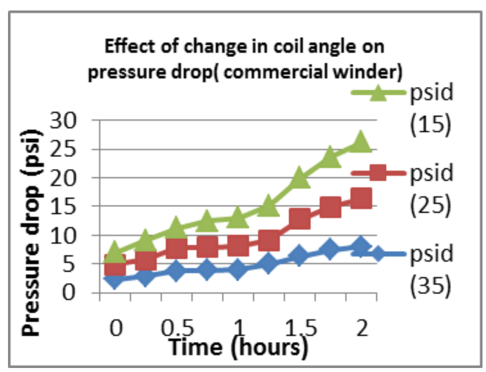

FIGURE 13. Graph of pressure drop versus time for cartridges produced with different coil angles for commercial winder.

The *Figure 14* shows the pressure drop developed when cartridges were produced under different tension levels on our fabricated winder and *Figure 15* shows the same plot when cartridges were produced on a commercial winder. The effect of tension is obvious; the higher the tension level, the greater is the pressure drop, since the passage of fluid no longer remains easy.

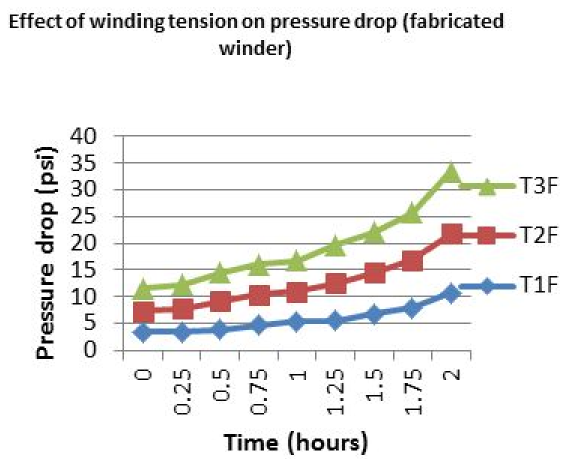

FIGURE 14. Effect of change in tension on pressure drop. With time (T=TENSION, while 1, 2 & 3 indicate different tension levels)

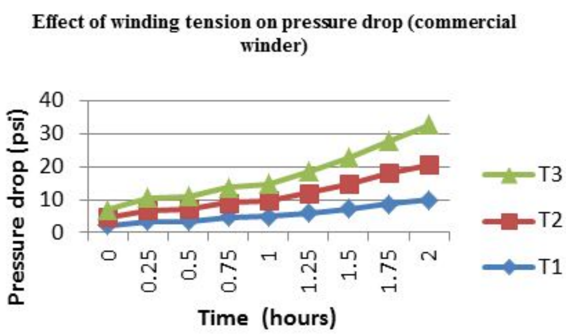

FIGURE 15. Effect of change in tension on pressure drop with time.

The *Figure 16* shows the comparison between the fabricated and the commercial cartridges. They have been produced under identical winding and tested under same testing conditions

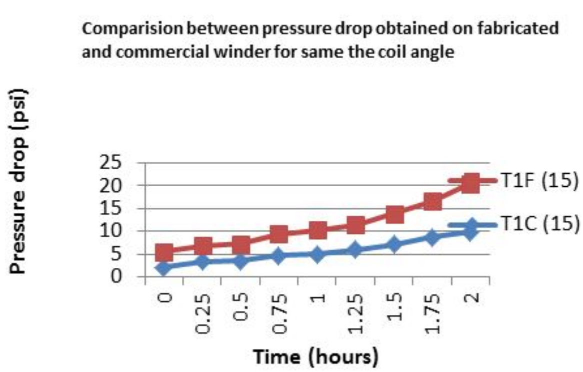

FIGURE 16. Comparative graphs between cw and fw. (F=FABRICATED WINDER, C=COMMERCIAL WINDER)

CONCLUSION

As mentioned earlier this will be a very effective way of overcoming the disadvantages of the mechanical method of changing the winding parameters. The acceleration and deceleration time involved is very less, so almost a linear traverse can be obtained along with a good lay, which is one, of the biggest advantages of the reciprocating system. It can also reduce the inventory cost, a since large number of gears or scroll cams will not be necessary. It will also be possible to wind packages with variable traverse ratios, lengths, and gain effortlessly. The most interesting development is that, the system can be operated on the precision as well as the semi-precision winding principle.

The pressure drop obtained is slightly higher while testing the cartridges produced on fabricated winders, which is probably why they also show better micron rating; yet they are quite close and hence are comparable. But since both the values of pressure drop and rating lie close enough, they may be considered at par with cartridges produced on a commercial winder.

Most importantly the trend observed for the cartridges produced with different traversing systems is the same, which also implies that the electronic system developed is equivalent to the conventional cam traverse system and should be acceptable. Also, the traversing system does not influence the performance of string wound cartridges.

ACKNOWLEGMENT

The authors are grateful to Shri. M.A.Tilwalli of Gururaj Engineers, G.I.D.C, Makarpura, Vaodara, Gujarat, India, for his support and valuable contribution in making this project a success. Authors are also thankful to Shri Samarth Prajapati, who under the guidance of Shri Tilwalli developed the program for this application. The authors would like to express their gratitude to Shri.K.B.Shah of KBS filters, G.I.D.C, Makarpura, Vadodara, Gujarat, India, for allowing them to use his machine to produce the filter cartridges as per requirement.

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