PROGRESS IN O·E SPINNING

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WORLD LITERATURE SURVEY 1968-1974

By

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Shirley Institute Publication S16

Price £15 (UK)
£16.50 (overseas)
£5 (Shirley Members)

ACKNOWLEDGEMENTS

The authors gratefully acknowledge permission to reproduce the illustrations that appear in this literature review. The source is given in the caption beneath each illustration.

Particular acknowledgement is made to H.M. Stationery Office for permission to reproduce the large number of patent drawings in this book.

ERRATA

Since this book was first printed (mid-1975), a number of small errors in the text have been discovered. These are listed below, together with corrections.

Page	Line	Error	Correction
4	12	L is a value of breaking length	L is a value of extended length
4	30	breaking length	extended length
5	17	booked	hooked
12	21	fron	front
15	27	FIG 159	(159)
15	32	is sacrificed	may be sacrificed
	35	particles being	particles, being
16	46	bolt	belt
	47	bolt	belt
17	8	a least	at least
	29	stem	system
19	9	FIG 42	(42)
21	4	poor	good
22	16	system	systems
28	11	minimum	maximum
29	48	Bowden	Bowles
30	42	/30% cotton	/33% cotton
37	50	Fings.	Figs.
41	20	loose	lose
43	2	locket	LOCHER
48	17	STmachine	ST machine
	30	Houget	Houguet
50	52	accurate	ARCUATE
54	45	minimum	maximum
55	5	Poznam	Poznan
57	25	of	or
	39	Usti n Orilici	Usti nad Orlici
59	28	imput	input
62	7	junction	function
	21	imput	input
64	12	rector	vector
113	Caption to Fig 73	Gessner Rotor	Landwehrkamp Opening Roller
121	col 1	Usti rad Orlici	Usti nad Orlici
Ref. 97		Should read 'Bowles and Davies, Shirley Institute Bulletin	Vol. 41 p. 19 1968 Vol. 41 p. 158 1968 Vol. 42 p. 19 1969

Contents

Introduction

Open-end spinning - the present position

During 1963-1969 a substantial research programme was carried out by the Shirley Institute on this new technology of spinning - the process of Break Spinning or Open-end (O-E) Spinning. The work culminated in the publication of the well known Shirley 'Break Spinning Report' (1). This report presented a comprehensive study of the patent literature, a classification of the various devices and systems described, and an assessment of the technological and economic possibilities of this method of yarn production.

With the availability of commercial machines, further work was undertaken during the period 1969-72 to keep abreast of developments and to inform Members accordingly (2). The economic implications have been constantly reviewed and reported on (3) (4), and it is not the intention to deal with this subject here.

Following the rapid development of open-end spinning machines employing the rotor principle, it became apparent that the Shirley Institute would need to increase its research effort in the interest of its Members and, if possible, make a contribution to a fuller understanding of the new technology. With this objective a commercial machine has been ordered, for installation in early 1975.

A research programme has been proposed covering a period 1974-1977, which includes a cooperative exercise with I.T.F. (Institut Textile de France). This collaboration will provide complementary effort in particular areas and will give access to a wider range of commercially available machines.

Initially a literature survey has been carried out and the findings are presented in the present publication. The survey covers reported work and patent publications from 1968 to May 1974, and is concerned with the technological aspects of O-E spinning, using the short-staple rotor spinning system. Reference is made in the Appendix, however, to developments in air vortex, electrostatic and rotor type O-E spinning machines for long-staple fibres.

1·0 Basic principles of O-E rotor systems

A general outline of the O-E spinning process which utilizes the rotor system is illustrated in Fig. 1. Here, sliver is fed to a separating device from which single fibres are transported by an air-flow and are deposited into the rotor. Twist is then forced into the collection of fibres as they are removed from the rotor, to form yarn. In describing the basic principles involved in O-E rotor spinning the process can, therefore, be divided up into the following three stages: (i) fibre separation and fibre transfer, (ii) fibre collection, and (iii) twist insertion.

1.1 Fibre separation and fibre transfer

In order to impart twist into a ribbon of fibres, one end must be rotated relative to the other. In ring spinning it is the finished end of the yarn which is rotated by the action of the spindle as the yarn package is made. In the open-end process, however, the rotor rotates the yarn end on to which new fibres are constantly fed. The latter method of inserting twist requires a break in the fibre feed if false twist is to be avoided, and the break must occur without disturbing the uniformity in mass per unit time. This is achieved by separating the sliver into individual fibres. The free fibres should be straight along their entire length with a small space between each single fibre. During O-E rotor spinning this break in the fibre feed can be observed in the rotor, as illustrated in Fig.2.

There are two commonly accepted methods of fibre separation (a) roller drafting separation and (b) combing roller separation. Neither method is the ideal, but most commercial machines incorporate the combing roller system. The combing roller produces better individual fibre separation, the roller drafting method being limited by its mechanical draft ratio. Fibre separation by roller drafting keeps the fibres straight and less liable to damage whereas the combing roller creates hooks on the fibres and may cut or damage them.

1.1.1 Fibre separation by roller drafting

In the published literature, the standard double apron drafting system as used in ring spinning is generally used for this method of fibre separation. The practice is to use the drafting systems to supply only part of the total draft required to obtain free fibres. Air suction is then used to complete the separation of the fibres as they are transported by the air-flow to the rotor. Krause (5) reports that the total mechanical draft ratio of the double-apron drafting system should be within the range of 20-40 and that if higher draft ratios are used, short fibres will prove difficult to control.

There are optimum conditions for both front roller speed and the air suction in order to achieve adequate fibre separation. Because of such problems as fibre lapping and 'fly' these factors have to be determined empirically.

As a guide, and to a first order approximation, a minimum front roller speed for a mechanical draft within the specified range can be calculated using Krause's equation:

$$V \geqslant 4.\, S.L \;\frac{1}{l}\; g. \qquad \text{(A)}$$

where V is the front roller surface speed

S is the distance the fibres accelerate in the front zone to attain the speed V.

g is the acceleration due to gravity

l is the fibre length,

and L is a value of breaking length.

In deriving this equation, the fibres in the sliver were considered as solid rods, so that a constant acceleration in the drafting zone could be assumed. The force producing this acceleration must be sufficient to pull a single fibre from the sliver without disturbing the surrounding fibres. This force is the vector difference between the static frictional force of a fibre being pulled out from the sliver and the inertia force of the remaining fibres.

From observations of elastic behaviour and crimped configurations of fibres in slivers, Krause has assumed that fibre acceleration does not take place instantaneously along its entire length, but propagates from the leading to the trailing fibre end as shown in Fig.3. Momentary acceleration of the fibres, therefore, only occurs in a rather short distance S when compared to their extended fibre length, depending on frequency and size of crimp deformation. For cotton, as an example, the estimated values of S are between 0.5 - 1 mm. The breaking length L is approximately 30 mm. Hence, the minimum front roller speed necessary to achieve single fibre flow would be 300 m/min (3,500 rev/min). This speed is above the practical limit of conventional drafting systems, hence the need for air stream draft.

Krause carried out observations of the number of separated cotton fibres in the cross-section of an air stream for different front roller speeds, and obtained the frequency distribution curves shown in Fig.4. These curves show that the distribution in the air stream improves as the front roller speed increases, that is, there is a greater probability towards single fibre flow. It should be noted that the low number of fibres in the cross-section given in the figure is largely the result of the air suction draft. This draft was kept constant throughout the observations. Lord (6) has reported that the fibre fringes at the front rollers should contain a maximum of 200 fibres projecting from the roller-nip, if the rollers are at optimum speed.

Work carried out at the Shirley Institute has also shown that a higher degree of fibre separation is obtained when the front roller speed is increased. To overcome the speed limitation of a conventional system, a five-line double-apron arrangements was used, the front rollers being separately driven. It was found for various fibre types that, for successful operation, the total mechanical draft had to be within the range of 20-50 and the optimum front roller speed of the order of 1,000 rev/min.

1.1.2 Fibre separation by combing roller

Fig. 5 illustrates a typical combing roller and Fig.6 shows the difference between the arrangement of the combing roller separation device and that of the drafting roller system.

The action of the combing roller is similar to that of the taker-in region of a conventional carding machine. The important regions are ringed in Fig.7. Region I is the sliver feed region. Here the sliver cross-section changes to a rectangular shape having a width less than the overall width of the wire clothing on the combing roller. II is the opening region, where fibres are booked from the sliver fringe by the combing roller teeth. When the roller reaches the end of region III the fibres are completely separated from the sliver. IV is the removal region and forms part of the air transport passage. In this region aerodynamic forces are of most concern. These forces transfer the fibres from the teeth of the combing roller into the air streams, allowing further separation. The degree of fibre separation, and the fibre transfer from the combing roller to the air-stream will depend upon the working angle of the teeth and the speed of the combing roller. These parameters are determined empirically.

The fibres are transported by the air-stream to the rotor collecting surface. The exit of the transport passage, region V, must be designed so that the air-stream velocity does not exceed the velocity of the rotor collecting surface. The fibres will then tend to remain straight on leaving the exit and will be further accelerated when their leading ends touch the collecting surface.

In region IV the behaviour of the air-flow is a major factor and the velocity profile in this region is shown in Fig. 8. The velocity increases in the radial direction from the combing roller towards the wall of the transport passage, and here boundary flow conditions apply. From this velocity distribution and with the application of Bernoulli's theorem, it follows that a pressure reduction occurs in the radial direction away from the combing roller. It is this pressure difference which results in the removal of the fibres from the roller to the high-velocity air-stream, simultaneously straightening them as they are removed (7). To further illustrate the process, Figs. 9a, b, c and d show the successive stages in the doffing and straightening of a single fibre. Fibres which have a tendency to stick to the combing roller clothing will be removed by an air swirl as each fibre reaches the edge A (Fig.8).

The action of aerodynamic forces as well as the centrifugal and Coriolis accelerations will cause the fibres to travel towards the rotor as shown in Fig. 9d. The fibres would be expected to remain straight during transport since the narrowing of the transport passage towards its exit causes the air-flow to accelerate the fibres continuously. On reaching the exit of the transport passage, the air-flow suddenly changes its direction and its speed fall abruptly. The fibres, however, will be accelerated further as they are deposited on to the collecting surface of the rotor.

It is reported (7) that in order to achieve good doffing and transportation of the fibres, the air velocity must be within 1.5-2 times the circumferential velocity of the combing roller. This is ensured if a flow rate of 1.5 to 2 litres/sec (an underpressure of 100 to 200 mm of water) is maintained. In practice the rotor may be designed to produce such a suction or alternatively an external pump may be used.

1.2 Fibre deposition

The separated fibres leaving the exit of the transfer channel will have a velocity (V_2) whose magnitude is less than that of the circumferential velocity (V_3) of the rotor. From Ripka's (8) kinematic consideration of the fibre flow, the fibres are accelerated to the velocity V_3 on touching the wall of the rotor. Thus the fibres are further separated by a draft V2/V3 .

If the kinematics of the fibre passage as a whole are considered (Fig.10), the following draft ratios can be determined:

$$D_{10} = \left|\frac{\bar{V}_1}{\bar{V}_o}\right| \qquad \text{(B)}$$

$$D_{12} = \left|\frac{\bar{V}_2}{\bar{V}_1}\right| \qquad \text{(C)}$$

$$D_{23} = \left|\frac{\bar{V}_3}{\bar{V}_2}\right| \qquad \text{(D)}$$

$$D_{3p} = \left|\frac{\bar{V}_p}{\bar{V}_3}\right| < 1 \qquad \text{(E)}$$

$$D_{p4} = \left|\frac{\bar{V}_4}{\bar{V}_p}\right| < 1 \qquad \text{(F)}$$

where $\bar{V}_o < \bar{V}_4 < \bar{V}_p < \bar{V}_1 < \bar{V}_2 < \bar{V}_3$.

The velocities V0 and V1 are apparent from Fig.10. V2 and V3 are the exit fibre velocity from the transport tube and the rotor velocity respectively. Vp is the peel-off velocity, relative to the rotor surface. V4 is the velocity at which the yarn is removed from the rotor; its magnitude is commonly referred to as the 'production speed'.

If, when the fibres are being deposited into the rotor, the free end of a priming yarn is introduced into the rotor, this yarn will be forced against the deposited ring of fibres. Removing the yarn tail will cause the fibre ring to be peeled off the rotor wall. Twist is simultaneously inserted into the fibre ring as it is peeled off (see Fig.2). The peel-off velocity Vp has a magnitude greater than the yarn removal velocity $\overline{V}4$ but less than the rotor velocity $\overline{V}3$. Therefore, as equations D and E indicate, during deposition and twist insertion the fibres are compacted to give the required yarn linear density. The compacting action during deposition is called 'doubling' or 'back-doubling'. Back-doubling can be described as the number of fibre layers forming the fibre ring which is ultimately twisted to produce the required yarn. In practice the compacting of the fibres during twist propagation is so much smaller than in the deposition stage that it is usually neglected. Lord (9) and others have shown that the number of back-doublings can be calculated directly if the diameter of the rotor, the speed of the rotor, and the production speed are known.

The equation given is

$$\text{No. of back doublings } B = \pi \frac{DNp}{|\overline{V}_4|} \quad \text{\_\_\_\_\_\_\_\_\_\_}(G)$$

where D is the rotor diameter

Np is the rotor speed in rev/min

and $|\overline{V}_4|$ is the production speed

It is widely reported that the good intrinsic evenness of open-end spun yarns is the result of the back-doubling action. Theoretical and experimental work has therefore been carried out in order to evaluate the maximum wavelength of a disturbance in the sliver likely to be erased during the doubling. From such work Krause (5) and Nagaeva (10) have shown that irregularities in the sliver less than 1.6 D will not appear in the yarn.

1.3 Twist insertion

During twist insertion, the peeling-off point moves relative to the rotor surface at a speed $\overline{V}p$. But as the rotor is also rotating with a circumferential speed of $\overline{V}_3$, the peeling-off point will have, relative to an inertial frame, a rotational speed proportional to the sum of the two velocities. It is this rotational speed which gives theorectically the amount of twist per unit length inserted in the yarn. For example, if $\overline{V}_4$ is the production speed, the twist per unit length is given by:

$$\text{Twist} = \frac{|\overline{V}p| + |\overline{V}_3|}{|\overline{V}_4|} \quad \text{\_\_\_\_\_\_\_\_\_\_}(M)$$

However, since $|\overline{V}_3| >> |\overline{V}p|$ it is usually accepted that one rotation of the rotor will insert one turn of twist into the yarn.

During rotor spinning the yarn tail configuration, the associated relative velocities, and the forces acting in the rotor can all be diagrammatically illustrated as in Fig.11 and Fig.12. Both figures show the rotor chamber observed along the axis of rotation. Fig. 12 also indicates the forces acting within the yarn exit area; the shaded region represents the yarn trumpet or doffing tube. The yarn configuration shown is that obtained when the peel-off point rotates in the same direction as the rotor (designated the 'positive' direction). Negative direction of rotation can occur, but this produces a poor spinning performance and, consequently, a low-quality yarn. The published theoretical works are largely concerned with positive rotation of the yarn tail during spinning.

The rotation of the yarn tail is responsible for picking up the fibres from the collecting groove of the rotor, supplying twist to the newly attached fibres and thus achieving continuity of the strand.

The strand (yarn) must have sufficient tensile strength to withstand the spinning tension imposed on it by the system. This tension will be some function of the rotor diameter and its speed, the yarn count and the frictional parameters of the fibre/metal surfaces. For continuous operation, the amount of twist (twist factor) must be sufficient to utilize the available fibre strength (a more detailed account is given in Appendix 10.5). Unfortunately the fibre configuration in the collecting groove of the rotor is such that the fibre extent is less than the actual length and the total available fibre strength is never fully utilized in the yarn (9).

Minimum values of twist for successful spinning are therefore higher than those used in ring spinning (Fig.15). For the same reason the twist factor required to obtain optimum yarn strength is much higher than the ring spinning equivalent.

Lower strength of O-E yarns is a commonly reported feature but minimum values for a given yarn equate well with ring spun yarn and it is claimed that this is perhaps the more important parameter to meet the requirements of further processing.

2·0 Contemporary O-E rotor spinning machines (short-staple)

It would appear that O-E spinning is generally accepted on economic terms up to about 17.5 tex (36 cotton count), but this economic evaluation may need revision in view of the rising rate of inflation. It may be that, in the absence of technological advance, the upper count limit at which costs break even with ring spinning will be lower, and this could restrict the range of viable operation of this method of spinning to comparatively coarser counts. At present the tendency is to make comparisons between machines, and choice is clearly influenced to some degree by extended delivery dates. A list of known O-E rotor-spinning machines is given in Table 1. Many of these were on show at the '73 Greenville ATME Exhibition.

With the exception of the Rotorspin 883, O-E spinning machines are assembled from a number of double-sided sections. The BD200 series and the MS400 are assembled from multiples of a "40 unit-section", 20 rotor positions on each side of a section. This allows the choice of up to 240 units per machine; 200 units is, however, the normal assembled machine size. The standard number of assembled rotors on other double-sided machines varies from 140 on the Rotorspin 885 (28 rotors per section) to 192 on the S.A.C.M. Integrator. The Rotorspin 883 is a single sided assembly of 100 rotors, with five sections each having 20 rotor positions.

Sliver can sizes (cans are now used in preference to bobbins) depend on whether the sliver is fed from the top or from the bottom of the machine. The top-to-bottom O-E machines facilitate the use of larger cans than do the bottom-to-top machines, but since creels have to be fitted for the former type, machines utilizing this method occupy more space. Because existing drawframes can accommodate the larger can size, top-to-bottom machines, particularly the Rotorspin 883, are more favoured as a direct replacement for the ring spinning frame. Bottom-to-top O-E machines which need special drawframes delivering into small sliver cans and which require less space are claimed to be more suited to a modernization or re-equipment scheme. Drawing frames such as the Elitex HP.300 (production rate 300 m/min), Platt's Mercury 743 (300 m/min), Ingolstadt's SB 92 (350 m/min) and the Japanese Verta Draft (200 m/min) are all designed to supply sliver in the required small-size cans.

Of the O-E machines listed in Table 1, only Platt, Ingolstadt, and Rieter machines are known to have a built-in trash extraction device. This is incorporated in the fibre-separating mechanism. S.A.C.M. offer on request such a cleaning device built in to the Integrator and the Czechs have incorporated a new yarn trumpet in their rotor units, to assist trash removal. At present, the trash-extraction unit incorporated into the fibre-separating zone appears to be most effective and enables the O-E spinning of lower grade cottons. Machines without trash-extraction units will require stricter blowroom conditions and the use of a tandem card is recommended during sliver preparation even when medium-grade cottons are used. The questions of sliver preparation and trash extraction will be considered later.

In addition to providing trash-removal facilities on O-E spinning machines, manufacturers have given particular attention to the suitability of the yarn package for subsequent processes and to the ergonomics of the O-E spinning operation. The yarn is usually cross-wound to form parallel cylindrical packages of varying sizes (see Table I). A problem which weavers (14) encountered when using O-E yarns spun on the earlier BD200, was the frequent sloughing during the re-winding processes. This was caused by the absence of any pattern breaking mechanism in the package winding device fitted on the machine. The problem has now been eliminated.

Platt International Ltd have reported (16) that their packages will fit conveniently on to 2-for-1 twisting machines, (with care) on knitting machines and directly on shuttleless looms as weft packages, as well as onto Unifil loom winders.

Most of the O-E machines have mechanisms for forming a yarn reserve, to facilitate bobbin tailing. On the Ingolstadt RU 11 this is accomplished by the use of a hand appliance. The BD200 R has a yarn suction system called the 'third hand' which, with the use of specially designed tubes, produces an adequate length of yarn reserve.

The BD200 R is fitted with a number of labour-saving devices (15). For example, to improve the yarn appearance, a semi-automatic piecing-up system is built in, giving what is considered the best cut and shaped yarn tail for piecing up, and this ensures that the operative uses the correct length of 'priming' yarn tail.

Platt machines are fitted with a length-measuring device which activates a flashing light when the whole machine needs doffing. This is additional to the 'ends-down' indicator which is fitted to most machines. Ingolstadt have fitted to their RU 11 a conveyor system which aids the procedure of doffing. Howa advertise an automatic piecing and tying device called the AYPT, designed to fit their MS400 machine. This device finds the yarn break and pieces it, then removes any slubs formed, thus reducing any necessity for clearing.

With automatic piecing and improved bearings it seems reasonable to expect later models of O-E machines to operate at much higher speeds (17). At present only two O-E machines, the Czech BD200-BDA-2G and the Japanese Hs-260 Hi-spin, are reported to operate at high rotor speeds, that is, speeds in excess of 50,000 rev/min. It is known, however, that a number of machine manufacturers are to test-run prototypes fitted with Sussen's high-speed rotor system (17), which allows rotor speeds of up to 100,000 rev/min.

Little in the way of machine details is available on the Hs-260 (see Table 1), but the BD200-BDA-26 is reported to be largely automatic (18) (19), in that electronic devices are fitted for use in operations such as starting-up the spinning process, piecing-up during end breaks and doffing. The rotor drive is an electronically controlled independent motor, which ensures optimum rotor starts and precision-running.

New machines offer the spinner an improved machine control system, and an advance in the ergonomics of the spinning procedure. Modifications are being made to (a) the fibre separating mechanism, (b) the internal shape of the rotor and (c) to the design of the yarn trumpet. Rotor bearings and drive units have been significantly improved, resulting in higher rotational speeds and a longer working life. Devices for automatically cleaning the rotor chamber and alternative types of piecing and doffing arrangements are in prospect.

3.1 Fibre separation

3.1.1 Fibre separation by roller drafting

Table 1 indicates that few machine makers utilize the apron and roller drafting system as a separating device. Toray Industries Inc. (formerly Toyo Rayon Co. Ltd and Howa Machinery Ltd) have taken out patents (20) (21) describing modifications to the drafting system used on the first model of the RS400 series of machines.

The sliver is fed to a conventional apron and roller drafting system and further subjected to an ejector device (Fig.16) positioned below the front roller. Fig.17 illustrates the detail of fibre separation. The drafted sliver enters the ejector through which compressed air is fed. When the air flows through the region indicated as the separating passage, its velocity will increase creating an under-pressure. This produces a force sufficient to detach individual fibres from the drafted sliver mass. Thus, the condition is achieved where free fibres in an air stream are transported to the rotor.

The optimum parameters of the ejector device will vary according to the type of fibre being processed. Howa reports that with this device no fibre damage occurred during opening and that fully extended parallel fibres were observed in the resultant yarn.

3.1.2 Fibre separation by combing roller

The results of work on the suitability of the combing roller as a fibre-separation device (22) (23) (24) (25) (26) have indicated that when compared with the drafting roller system a higher degree of fibre separation can be achieved. This is, however, at the expense of fibre breakage. Staple diagrams constructed from fibres before and after the opening stage show a significant reduction in the mean fibre length. Fibres which fail to be removed from the combing roller can interfere with the fibre flow, producing neps and end breaks. Differences in the performance of the system occur when different types of fibres are processed and the characteristics of the roller clothing must be chosen to suit the fibre being spun.

3·0 Technological review

New machines offer the spinner an improved machine control system and an advance in the ergonomics of the spinning procedure. Modifications are being made to (a) the fibre separating mechanism, (b) the internal shape of the rotor and (c) to the design of the yarn trumpet. Rotor bearings and drive units have been significantly improved, resulting in higher rotational speeds and a longer working life. Devices for automatically cleaning the rotor chamber and alternative types of piecing and doffing arrangements are in prospect.

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