CAS* System and Some of Its Dynamic Characteristics

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Abstract

The Continuous Automated Spinning System developed by the Toyo Spinning Co., Ltd. is briefly described and some of its dynamic characteristics are discussed in this article.

Each card is equipped with a reserve box which receives cotton in loose form and supplies it to the card without forming laps. Cards produce sufficiently uniform slivers without the aid of separate metering device, such as the piano motion.

A uniform distribution of cotton to reserve boxes is insured by a simple on-off control system on the unit hoppers and the branch conveyors.

Super Auto Drawer (SAD) contains an automatic sliver-evening device which is essentially an open-loop control system. To get the best evening action, the proportional gain K_T and the memory time are set to the value given by the equations below.

$$K_T = 1$$

$$r = \frac{(\text{Memory time}) - (\text{Transportation time within the SAD})}{(\text{Servo time constant})} = -0.6$$

Since the Sliver Reversing Drawer (SRD) cuts incoming slivers at constant intervals, SRD slivers contain stepwise changes in their weight, but such changes are perfectly smoothed out by the sliver-evening device in the SAD.

The sliver-to-yarn Ultra High Draft (UHD) Ring Frame converts SAD slivers directly into yarns at a draft ratio of 360.

1. Machine Arrangements in the CAS System

The CAS System consists of two sections, the BCD Unit and the sliver-to-yarn frames. The BCD

Unit contains a blowing machine, cards, and an SRD and an SAD connected to each other by means of automatic transportation to make a single production unit. The sliver-to-yarn spinning frame is called the UHD Ring Frame which is usually tended

Fig. 1 Schematic view of CAS-Continuous Automated Spinning System

* Toyobo Continuous Automated Spinning System.

by the Toyobo Auto Doffer (TAD). The whole arrangement of the CAS System is shown in Fig. 1.

Cotton blended, opened and cleaned in the blowing machine ① is fed to the condenser hopper ② connected to the blowing machine. The condenser hopper, in turn, evenly feeds a number of unit hoppers ③ located at the end of each row of cards. The unit hopper delivers cotton to the branch conveyor ④ which supplies reserve boxes ⑤ fitted to individual cards. A reserve box receives cotton at its upper end, converts it into cotton fleece and supplies the feed roll directly.

The blowing¹⁾ machine produces at the rate of 200~300 kg/h and supplies to 36~60 cards.²⁾ Six to 10 cards, depending on the grade of cotton and yarn count, are grouped in one row.³⁾

Slivers from one row of cards are combined on a belt conveyor to be fed directly to the Sliver Reversing drawer (SRD) ⑦ without recourse to manual can-doffing.

The SRD draws card slivers supplied by the belt conveyor, stores drawn slivers consecutively in a number of built-in cans, and picks up 9~11 trailing ends of the stored slivers to double them in the second set of rolls, thereby reversing the direction of sliver travel. All this process is carried out automatically without manual handling.

Doubled slivers delivered by the SRD are fed directly to the Super Auto Drawer (SAD) ⑧ which is equipped with an automatic sliver-evening device to produce slivers uniform enough for the sliver-to-yarn frames. The SAD is additionally equipped with an automatic can doffer which needs no manual handling other than placing empty cans on a conveyor and removing full cans.

Both the SRD and SAD have a delivery speed of 120 meters per minute.

Since the number of operators tending the BCD Unit is only 20% of the number needed for conventional machines, the BCD Unit is provided with a centralized indicating panel which quickly warns the foreman of operating troubles. The foreman directs the crew with a wireless telephone system.

Since card slivers go through a sliver conveyor, SRD and SAD without any take-up devices in between, a speed differential of even 1% in start-up and stopping damages, breaks or slackens the sliver. Therefore the motors driving these machines are electrically coupled to insure fully synchronized operations at all times. The synchronizing system is a lowcost, simplified selsyn consisting of wound rotor induction motors.

Thanks to the automatic evening device and other provisions, the BCD sliver compares favorably with conventional finisher drawer slivers in evenness, fiber parallelism and Uster U%.

The UHD Ring Frame which converts BCD slivers directly into yarns ranges in its draft ratio from 300 to 500. UHD Ring Frames are, at present, used in a Toyobo mill to produce 40s yarns at a draft ratio of 360.4) While the UHD Ring Frame is designed for speeds up to 15,000 r.p.m., they are currently run at 12,000 r.p.m., with 15 ends down per 400 spindle an hour.

The Toyobo Auto Doffer (TAD), having 12 cams, doffs 8 spindles at a time to cover one ring frame in 3 minutes. Ends down due to doffing are only 2%, much fewer than in manual doffing.

The TAD with just one operator can doff 70 to 80 ring frames (about 30,000 spindles) spinning 40s yarns.

Fig. 2 compares the CAS System with a conventional system in block diagrams. Pictures 1(a), 1(b) and (2) show the BCD Unit and Toyobo Auto

Fig. 2 Conventional spinning system and CAS System

Picture 1(a) The CAS System

Picture 1(b) End view of CAS System

Picture 2 UHD Ring Spinning Frame and Toyobo Doffer

Doffer installed in a Toyobo mill.

So much for a brief description of the CAS System. In what follows the authors discuss some of the mechanical characteristics of the CAS System

which bear importance on product quality. They are (1) the effect of doubling in the SRD, (2) the automatic sliver evening device in the SAD, (3) synchronization of the BCD Unit, and (4) the drafting system of the UHD Ring frame.

2. Automatic Sliver-evening Device in SAD

Slivers delivered by the SAD are supplied to the UHD Ring Spinning Frame for conversion directly into yarns. Therefore, SAD slivers must be sufficiently high in uniformity to make up for the elimination of roving frames. On account of this, SAD is equipped with an automatic sliver-evening device which always produces highly uniform slivers.

In fact, a finisher drawer is the best machine to equip an automatic evening device, since the finisher drawer is close enough to the spinning frame for the sliver quality to reflect on yarn quality and since the rate of production per head is large enough to justify the added equipment cost.

The sliver-evening device can be either an open-loop system or a closed-loop system. After a theoretical investigation, a decision was made in favor of the open-loop system because it was found to attenuate sliver weight variations in a considerably wider frequency range than the closed-loop system, as the reducing ratio $A(u)$ in Fig. 3 clearly shows. $A(u)$ is defined as the factor by which percentage variations in sliver weight are attenuated by the sliver-evening device, assuming the variations to be a sinusoid of frequency u rad/min. Curves ① and ② in Fig. 3 show $A(u)$ for a condition in which a process represented by a pure time delay is controlled by a closed loop PI controller.

The non-dimensional parameters α and δ are defined as follows:

Fig. 3 Open-loop control and closed-loop control compared in terms of reducing ratio

$$\alpha = T_i/T_a \quad \delta = L_d/T_a \quad \dots\dots(1)$$

where T_a is the servo time constant, T_i is the integration time, L_d is the transportation time between the draft zone and the measuring element, and K_a is the proportional gain.

Curve ③ shows $A(u)$ for a condition in which the same process is controlled by an open-loop controller. Parameters γ and u are defined as follow:

$$\gamma = (L' - L_f)/T_a \quad \dots\dots(2)$$

$$u = \omega T_a \quad \dots\dots(3)$$

where L' is the memory time, L_f is the transportation time between the measuring roll and the draft zone, and ω is the angular frequency of sinusoidal weight variations. Curve ③ is displaced considerably to the right of curves ① and ②. This means at once that the open-loop system attenuates weight variations in a wider frequency range than the closed-loop system does.

The open-loop control, however, has a drawback, in that it fails to confirm the result of its own control. This makes the system somewhat susceptible to long-term drift in the average sliver weight. A separate air micrometer is provided, therefore, to inform the operator of the actual delivery weight and to make zero-point adjustments when required.

The sliver weight-evening device is shown diagrammatically in Fig. 4.

The detecting element consists of a pair of measuring rolls MR which convert the sliver thickness into a roll displacement. The memory device MD is a slowly rotating wheel with many slide pins placed around its periphery. Displacement of the measuring roll changes the position of slide pins, which position is preserved while the wheel makes a 1/4-th of a revolution to be sensed by a small follower lever

Fig. 4 Automatic sliver weight control device of the SAD frame

which actuates the pneumatic transmitter PT. The signal thus converted into air pressure A_2 is fed to the pneumatic servo PS which changes the front roll speed in proportion to A_2 . A_1 is the air supply to the transmitter PT and the pneumatic servo PS. The full-stroke movement of the plunger of the pneumatic servo PS changes the front roll speed by $\pm 20\%$. The pneumatic servo is equipped with a manual adjusting handle by which the average front roll speed can be shifted manually. With the aid of manual speed shift the servo can cover a wide speed range of 1 : 4. Therefore, no separate change gears are provided for product changeovers.

We now analyze the sliver-evening device in the light of automatic control theories. Several assumptions are made as to the characteristics of the various parts of the evening device to describe them with linear transfer functions. One of the most important assumptions is that an incremental change in the front roll speed brings about a proportionate change in the weight of the output sliver. On this and several other assumptions the block diagram shown in Fig. 5 is obtained to describe the whole sliver-evening device.

Fig. 5 Block diagram of automatic sliver evening device

The following symbols are used:

$z(t)$ Thickness of the sliver on the measuring roll
 $x(t)$ Thickness of the sliver leaving draft zone
 $v(t)$ Front roll speed

K_m Proportional gain of measuring roll MR

K_e Proportional gain of transmitter PT

K_a Proportional gain of pneumatic servo PS

L_f Transportation time

L' Memory time

T_a Time constant of pneumatic servo PS

Subscript 0 denotes the average or standard value and subscript 1 the deviation from the average.

The transfer function of the pneumatic servo is of this form:

$$K_a G_a(s) = \frac{K_a}{1 + T_a s} \quad \dots\dots(4)$$

The transfer equation describing the overall characteristics derives from the block diagram in Fig. 5, thus:

$$\frac{X_1(S)}{x_0} = \left(1 - \frac{Z_0}{v_0} K_m K_e K_a G_a(s) e^{-(L'-L_f)s} \right) e^{-L_f s} \frac{Z_1(s)}{Z_0} \quad \dots\dots(5)$$

Substituting $K_m K_e K_a \frac{x_0}{v_0} = K_f$ and equation (4) into equation (5), we obtain:

$$\left\{ \frac{X_1(S)}{x_0} / \frac{Z_1(S)}{Z_0} \right\} = \left(1 - K_f \frac{e^{-(L'-L_f)s}}{1 + T_a S} \right) e^{-L_f s} \quad \dots\dots(6)$$

Let a stepwise change in the input $Z_1(S)/Z_0$ result in a permanent deviation in the output $X_1(s)/X_0$, the value of K_f must satisfy the condition:

$$\lim_{s \rightarrow 0} \left(1 - K_f \frac{e^{-(L'-L_f)s}}{1 + T_a S} \right) = 0 \quad \dots\dots(7)$$

Fig. 6 Reducing ratio for the open-loop control

therefore,

$$K_f = 1$$

To express the overall characteristics in a single function, we define the reducing ratio $A(u)$ as

$$A(u) = \frac{\text{Percentage amplitude of sinudoidal weight variations in output sliver}}{\text{Percentage amplitude of sinudoidal weight variations in input sliver}} = \left| \frac{X_1(ju)}{x_0} / \frac{Z_1(ju)}{z_0} \right| = \left| 1 - K_f \frac{e^{-\gamma u}}{1 + ju} \right| \quad \dots\dots(8)$$

$A(u)$ is plotted against nondimensional frequency u for $K_f=1$ and different values of γ (see Fig. 6). Evidently, the best value for γ is $\gamma=-0.6$, since it makes $A(u)$ small in most parts of the frequency range concerned and without forming a sharp peak. Therefore, a rule was made to set the memory time L' to the value that makes $\gamma=-0.6$.

Since the SAD must smooth out the stepwise changes in sliver weight produced in the SRD, the optimum setting, $K_f=1$ and $\gamma=-0.6$, must always be maintained in work-a-day mill operations.

Fig. 7 shows input sliver thickness $z(t)$, front roll speed $v(t)$ and output sliver thickness $x(t)$ obtained in mill operations of the SAD where $z(t)$ was measured with an airmicrometer. The high accuracy of the servo is clearly shown by the good correspondence between $z(t)$ and $v(t)$. Output sliver weight $x(t)$, as a result, is controlled within a very close tolerance.

Fig. 7 Input sliver weight front roll speed and output sliver weight obtained in the mill test of SAD

3. SRD and its Relation to SAD

The Sliver Reversing Drawer (SRD) does the work of a conventional breaker drawer, plus the creeling part of the second drawer, in a completely automatic sequence. The SRD, then:

- Doubles a number of card slivers, passes them through a draft zone and stores the drafted slivers temporarily in built-in sliver cans.
- Automatically picks up the trailing ends of the slivers stored in the built-in cans, to reverse the direction of their travel.
- Combines 9~11 of these slivers and delivers them to the SAD.

The three items above, a) b) and c), are nothing

but the basic functions of a conventional drawing frame. Therefore, SRD improves sliver evenness and fiber parallelism in the same manner as a conventional drawing frame does. The SRD, however, requires no attendants and its speed of 120 m/min is considerably higher than in most drawing frames. The SRD has made an outstanding contribution, in that it has paved the way for automatically doubling a number of slivers and, at the same time, reversing the direction of creeling. Without the invention of such a device, drawing frames can never be made automatic because without the means for automatic doubling the drafting zones should be connected tandem, making the delivery speed too fast to be practical, and without the reversing of the direction of sliver travel, product quality would deteriorate greatly. The SRD doubles 8 slivers twice; this amounts to doubling of 64 slivers.

To reverse the direction of sliver travel, the SRD naturally must cut the sliver at constant intervals. This unavoidably produces stepwise changes in the weight of delivered slivers, as Fig. 8 shows. Although the magnitude of the stepwise changes is within the tolerance limit, they certainly form local disturbances that need to be smoothed out in the SAD that follows the SRD.

Fig. 8 Stepwise change in the weight of SRD sliver

Fig. 9 shows how the evening device in the SAD attenuates the stepwise weight variations. The figure assumes that the input sliver thickness increases abruptly by 10% at $t=0$, as indicated by Z. The sliver-evening device senses this change and starts to increase the front roll speed $V(t)$ at $t=L'$. But for this corrective action, the output sliver would make a stepwise change in weight at $t=L_r$. The output sliver weight is the difference between this imaginary stepwise change and the corrective action $V(t)$ shown as the bottom curve in Fig. 9. The curve made clear by the hatched area is the curve for $\gamma=0.6$. The others are the curves for $\gamma=0$ and $\gamma=1$. Here again, as on the reducing ratio $A(u)$, $\gamma=-0.6$ gives the best control result. That is to say, the stepwise change of 10% is reduced to a small disturbance of a magnitude $\pm 5\%$ and made very short in duration. In practice, such a brief disturbance tends to be smoothed out further in subsequent processes until it is indistinguishable in the final products.

Fig. 9 Smoothing by the SAD of a stepwise change in input sliver weight (calculated values)

4. Synchronization of BCD Unit by Simplified Selsyn

As we have said before, a speed differential of even 1% among cards, sliver conveyors, SRD and SAD must be avoided to insure normal operation. In other words, these machines must always be run in perfect synchronization. The much larger inertia and the consequent slower starting of the card than other machines in the BCD Unit, however, makes

the synchronization somewhat difficult. The usual way to synchronize machines with differences in starting characteristics is to use DC motors, but this costs too much to be suitable for use in spinning mills. It was, therefore, decided to use the simplified selsyn for the synchronization of the BCD Unit. As shown in Fig. 10, it does not require the DC source and is reasonably low in equipment cost. M_1 and M_2 in Fig. 10 are the two (or more) induction motors of the wound rotor type requiring synchronization. R is the common resistance in the secondary circuit which is set to its largest value when the motors are started. It decreases gradually as the speed builds up and is finally reduced to a fixed value which produces a slip of 20~30% in full-speed running.

Fig. 10 Simplified power selsyn system
(Wound-motor induction motors with common resistance in the secondary circuit)

Fig. 11 explains the basic principle of the simplified selsyn system. E_1 and E_2 are the voltages induced by the two motors in the secondary circuit. Current I_c in the secondary circuit is proportional to the difference E between E_1 and E_2 and lags E by 90° in phase angle. The torque which keeps the two motors synchronized is in direct proportion to current I_c . In response to disturbances, such as start-up and stopping, I_c makes a damped oscillation and finally tends to zero as the equilibrium is reached.

Fig. 11 Vector diagram of synchronization

The simplified selsyn system functions as a synchronizer only when the following inequality is satisfied:

$$|W_1 - aP_1| - |W_2 - aP_2| < F$$

where W_1, W_2 = Rated horse power of the two motors to be run synchronously

P_1, P_2 = Load horse power on each motor

a = Coefficient dependent on the motor heat loss. It is approximately 1.3.

F = Power required to keep the motors synchronized. F depends on motor characteristics.

To meet this restriction, flywheels are installed on the motor shafts of SRD, SAD and the sliver conveyor. They make their starting characteristics close to that of card. Fig. 12 shows how these machines accelerate and decelerate during start-up and stopping. Cross-marked lines show the transient when the machines are run synchronously. The solid and broken lines are the transients when they are run individually.

Fig. 12 Starting and stopping characteristics of SAD, SRD and card

5. UHD Ring Spinning Frame

In some of the conventional spinning systems that use the Simplex Roving Frame, drawing slivers are drafted only twice and without any doublings of slivers or rovings. Therefore, there is basically no reason why the two draftings in the roving frame and the ring frame should not be carried out on a sliver-to-yarn frame. Assuming the

draft ratios in the Simplex Roving Frame and in the ring frame to be 7 and 50, respectively, the overall draft ratio is $7 \times 50 = 350$. In other words, a super-high draft frame can have a draft ratio up to this value. The only disadvantages in omitting the roving frame are (a) that the advantage of roving twist is lost, and (b) that the reversal in the direction of drafting cannot take place.

Disadvantage (a) is compensated for in the UHD Ring Spinning Frame by using the apron to its maximum control effect and also by folding the fleece in three layers by means of special guides.

Disadvantage (b) causes no undesirable effects so long as the drawing sliver is high enough in fiber parallelism and contains approximately equal numbers of leading fiber hooks and trailing fiber hooks. The SAD sliver perfectly satisfies this condition as a result of sliver doubling in the SRD. Omitting the roving frame has the advantage of freeing the spinning system from drawbacks common to roving frames, such as the differences in roving tension between the two sides of the frame and inadequate adjustment of bobbin speed to the package diameter. Therefore, spinning from drawing slivers on a sliver-to-yarn frame equipped with properly designed sliver guides and aprons is considered preferable to conventional spinning systems.

If further improvement is needed on the UHD Ring Spinning Frame, it is the development of a method to creel the heavy drawing sliver on the sliver-to-yarn frame in a minimum of floor space.

Fig. 13 shows the drawing rolls of the UHD Ring Spinning Frame. A is intended primarily

A. Five-roll two-apron system for higher yarn counts

B. Four-roll one apron system for lower yarn

Fig. 13 Draft systems used in UHD Ring Spinning Frame

for high yarn counts with the bulk of drafting done in two apron zones. B is used primarily on low yarn counts with the draft divided between an apron zone and a roller zone. Both A and B have additional drafting zones which serve as the breaker zone. Representative yarn qualities obtainable on rolls A and B are listed below. Yarn count is 40s. Although B is not suitable for spinning 40s, it needs less care than A and is perfectly satisfactory for lower counts and synthetic blend yarns.

Hitherto the evaluation of drafting systems has been based only on yarn quality measurements such as appearance tests, Uster U% and, at most, Uster Spectrograph. However, these tests often fail to give a high correlation with the final fabric quality. The authors propose to evaluate yarn quality in terms of the autocorrelation function of the sliver weight variations computed accurately with the aid of a special-purpose analog computer.

The special-purpose computer that can take any kind of random signal convertible into a DC voltage has developed by the authors for this purpose. Just now the computer is taking signals has been developed by the authors for this purpose and directly from the Uster yarn thickness meter. The DC voltage representing yarn thickness is first modulated into a train of rectangular pulses with the pulse duration varied in proportion to the voltage. The pulse train is then recorded on a magnetic tape to be played on the analog correlator unit. The

Fig. 14 Autocorrelation function of yarn irregularity

correlator then reads out the recorded signal by means of two read-out heads spaced an adjustable distance apart. The two signals are then mutually multiplied, demodulated and fed to an integrator to be integrated for a predetermined time. The autocorrelation function thus obtained is recorded on a strip chart.

Fig. 14 shows the autocorrelation functions a, b and c of three 40s yarns spun on three different roll arrangements, A, B and C. A and B have been mentioned earlier. C is a conventional roll arrangement. A comparison of the three curves clearly shows that B is not good enough for spinning 40s yarns and is suitable only for lower counts, while A, in spite of its high draft ratio of 360, gives yarn quality comparable to that of conventional spinning systems.

7. Conclusions

The authors have outlined the Continuous Automated Spinning System developed by the Toyo Spinning Co. (Toyobo), Osaka, Japan and discussed some of its mechanical characteristics. The work for further improvement of the CAS System has by no means ended, and the authors and other Toyobo engineers expect future opportunities to discuss further developments.

The authors' findings on the dynamic characteristics of the CAS System are summarized thus:

(1) The reserve box feeds cotton to a card uniformly without the aid of a separate metering device, such as the piano motion.

(2) The best performance is obtainable on the automatic sliver-evening device of the SAD by setting the proportional gain to the value given in equation (7) and by the memory time satisfying the condition $r = -0.6$ in equation (2).

(3) The SRD makes possible a complete elimination of human labor from the drawing process. SRD produces stepwise changes in the weight of output sliver but they are practically eliminated in the SAD, making no defects in the final product so long as the condition discussed in (2) above is satisfied.

(4) The synchronized running of cards, SRD and SAD by the simplified selsyn system requires the addition of flywheels on the drive shafts of the last three machines to modify their starting characteristics.

(5) The UHD Ring Spinning Frame has proved to be perfectly practical in a wide product range. Improvements on the method of creeling to cut down on the floor space requirement are being considered.

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 - [2] F. Murakami, T. Shoman and S. Kase; *J. Text. Mach. Soc. Japan, English ed.*, Vol. 6, No. 1 (June 1960)
- 1) Blowing machine used in the CAS System is practically a conventional one. An existing blowing machine is, therefore, adaptable to the CAS System.
 - 2) Metallic clothing must be used on CAS cards to minimize down time by eliminating the need for grinding and daily stripping. It is recommended to equip cards with Toyobo Card Analyzer for improved dust shedding and a high card yield.
 - 3) Conventional cards can be adapted to the CAS System. For a new installation, however, it is recommended to use 2 sets of Multi-cards ⑥ in each row.
 - 4) The BCD Unit can also be used with conventional spinning system consisting of roving frames and ring frames.