PREVENTING NEGATIVE ISSUES AT NIP ROLLER

By

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ABSTRACT

Dealing with film scratches, wrinkles, and air entrapment is a problem that many converters are faced with on a regular, if not daily basis. Part of the problem is the rollers they have to work with at the nip point. Granted, rubber covered rollers at the nip point is a proven technology that has been utilized for many years. However, with the technological advancements in designing and manufacturing Carbon Fiber Reinforced Plastic (CFRP) rollers there are benefits to consider in utilizing this technology at the nip roll.

Carbon fiber rollers can be designed and manufactured as single-pipe or double-pipe depending upon the performance requirements of the roller. At the nip roller is where the majority of the benefits can be realized with the double-pipe design. While this double-pipe roller design is not new and is known as Airy or Bessel Point support, the historic design included a steel or an aluminum double-pipe roller with bearings attaching the inside to the outside pipe to reduce deflection of the nip roll.

The double-pipe carbon fiber roller utilizes a lightweight carbon fiber inner and outer roll as well as carbon fiber attachments from the inner to the outer roller. This design allows for 1/3 – 1/10 the deflection of a single-pipe carbon fiber roller design. The lower roller deflection causes a reduction in cross web pressure variation at the nip roller.

NOMENCLATURE

w : Distributed Load[N/m]
L : Beam Length[m]
E : Modulus of Elasticity(Young's modulus)[Pa]
I : Moment of Inertia of Area[m4]
M : Mass of roller shell[m4]
do : Pipe Outer Diameter[m]
di : Pipe Inner Diameter[m]

INTRODUCTION

Rollers with a cylindrical shell made of Carbon Fiber Reinforced Plastic (CFRP), called "carbon fiber rollers" are well known for their high-level of performance that cannot be matched by steel and aluminum rollers. Initially, carbon fiber rollers were primarily used for printing presses, including rotary newspaper printing presses, but recently they have been increasingly adopted into production lines for film, non-woven fabric and metal foils, winders and slitters, coaters and laminators.

In winding and nipping process, contact rollers and nip rollers are used which require a lower deflection. One of the primary reasons for film wrinkle is air entrapment. Air is entrapped during the winding and nipping process. Lower roller deflection allows for less air entrapment. Recently films have become thinner and wider and the film quality requirement continues to increase. Less wrinkles, uniform quality, and cost reduction continue to be important and so operating at higher production speeds without compromising quality is constantly explored. This is one of the reasons for the acceptance of the double-pipe roller design. Carbon fiber rollers allow for a lower deflection than steel or aluminum rollers however, for winding and nipping applications a double-pipe carbon fiber roller design was developed for lower deflection than the single-pipe carbon fiber roller.

Typically, rollers shells are made as a single-pipe design. When lower deflection is required, a double-pipe carbon fiber roll design can be utilized.

WHAT IS A CARBON FIBER ROLLER?

Rollers which have a shell made from CFRP are called a carbon fiber roller. A carbon fiber roller shell and a metal journal are jointed with adhesives (Figure 1). Carbon Roller surface treatments and coatings can be included in the Carbon Roller design as they can with traditional steel or aluminum rollers. These surface treatments can include, rubber coating, chrome plating and thermal spraying.

The comparison of the material properties between CFRP, steel, and aluminum is shown in Table 1. CFRP is lighter than aluminum and stiffer than steel. From the characteristics, low weight and high stiffness, carbon fiber roller has the following advantages over metal rollers.

- Low deflection: Precision coating/laminating, Less film wrinkling
- Low inertia: Less film scratching, Energy saving
- High natural frequency: Higher line speed, Less vibration

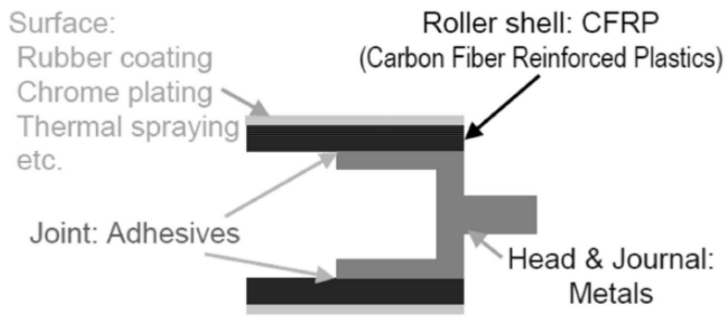


Figure 1 – Basic Structure of Carbon Roller

Material		Aluminum	Steel	CFRP
Density	[g/cm³]	2.7	7.9	1.7
Young's modulus	[GPa]	69	206	240

Table 1 – Material Property Comparison

ROLLER SHELL PERFORMANCE DESIGN

The following equations are the basic formulae for roller performance designing. These are based on simply supported beam theory.

$$\text{Deflection(Ymax)}\ [\text{m}] = \frac{5wL^4}{384EI} \qquad \{1\}$$

$$\text{Geometrical moment of inertia (I)}\ [\text{m}^4] = \frac{\pi}{64}(d_o{}^4 - d_i{}^4) \qquad \{2\}$$

$$\text{Rotational Mass Moment of inertia(I)}\ [\text{kg}\cdot\text{m}^2] = \frac{1}{8}M(d_o{}^2 + d_i{}^2) \qquad \{3\}$$

$$\text{Natural frequency (f)}\ [\text{Hz}] = \frac{\pi}{2}\sqrt{\frac{EI}{wL^4}} \qquad \{4\}$$

$$\text{Critical speed (Vcrit) [m/min]} = 60 * f * d_o * \pi \qquad \{5\}$$

CFRP is lighter than aluminum and stiffer than steel. It means that weight and mass are lower than metals and elastic modulus is higher than metals. The carbon fiber roller can deliver superior performance, such as lower deflection, lower inertia, and higher natural frequency, compared to metal rollers.

Further explanation shows, from Eq. 1, the roller deflection varies directly with the fourth power of the roller length. So, when the roller length is doubled, the deflection becomes quadruple. Metals, such as steel and aluminum cannot change the value of the weight and the modulus. So the only controllable parameter is "I" which comes from

Eq. 2. Concerning metals, the only option for reducing deflection is increasing roller diameter. The moment of inertia is calculated from the weight and the diameter (Eq. 3). And from Eq. 4 and 5, the roller critical speed is inversely proportional to the square root of the roller length ($L2=\sqrt{L4}$). So, when the roller length is doubled, the critical speed is reduced by one fourth. High modulus roller shell (E) and light weight (w) materials achieve low deflection, low inertia, and high critical speed with longer roller face width.

Actual designed roller performance advantages are shown in Table 2.

Tension = 20kg/m
Design speed = 1/2Critical speed × 0.8

Existing roller

Material	OD [mm]	ID [mm]	Face Length [mm]	Weight [kg]	Deflection [mm]	Moment of Inertia [kg·m²]	Design Speed [m/min]
Steel	140	130	2,000	43	0.08	0.18	1,010

Need lower weight (weight saving)

Material	Weight	Deflection	Moment of Inertia	Design Speed
Aluminum	21	0.16	0.08	1,000
CFRP	17	0.06	0.06	2,330

Table 2 – Design Examples of Light Weight and Low Inertia Roller

ADVANTAGES OF DOUBLE-PIPE CARBON FIBER ROLLER

One of the primary causes of film wrinkle is air entrapment. In the film production process, air is entrapped and causes the film to wrinkle. Air entrapment occurs during the nipping and winding process. Roller deflection is a key factor of air entrapment meaning that higher roller deflections will lead to higher level of air entrapment. The single pipe roll design has been used for over 25 years as an alternative to steel or aluminum rollers in reducing roller deflection.

However, films have become thinner and wider and the requirement for film quality continues to increase. While fewer wrinkles and uniform quality are required, cost reduction is always important so increased processing speeds are considered and explored.

As processing line speeds increased, the single-pipe design did not keep roller deflection low enough to handle air entrapment issues. The double-pipe roller design allows the deflection of the roller face to be1/3～1/10 of conventional single-pipe carbon fiber rollers.

STRUCTURE OF DOUBLE-PIPE CARBON ROLLER

The structure of double-pipe Carbon Roller is as follows:

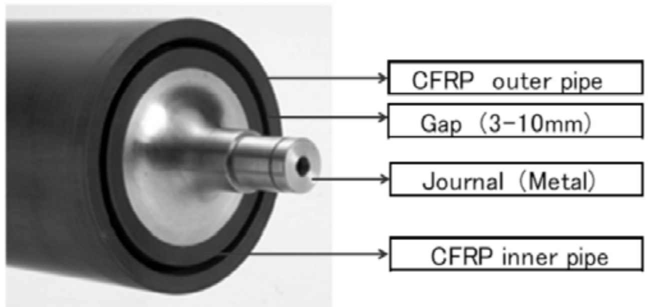


Figure 2 – Double-pipe Carbon Roller Structure

COMPARISON BETWEEN SINGLE-PIPE AND DOUBLE-PIPE ROLLER

When a single-pipe carbon fiber roller contacts film, the deflection causes space between the roller and the film. To avoid this, usually a rubber coated roller is designed with a crown shape. The crown shape is determined by a certain contact force. If the contact force changes, the crown shape is not adaptable.

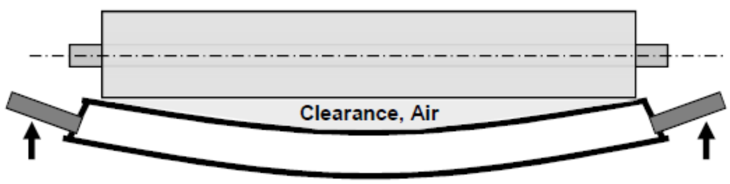


Figure 3 – Single-pipe Carbon Fiber Roller Contacts Film

While a double-pipe carbon fiber roller doesn't have crown shape, the inner roller bends, but due to the gap between inner and outer pipe, the inner roller deflection does not propagate to the outer roller.

Roller deflection of contact face becomes 1/3～1/10 of conventional roller.

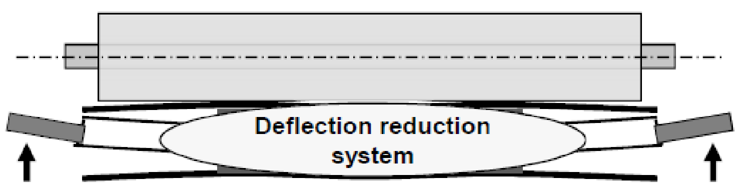


Figure 4 – Double-pipe Carbon Roller Contacts Film

ROLLER DEFLECTION

Comparison: φ120X2200 same shape rollers

1. Aluminum single roller
2. Single-pipe Carbon Fiber Roller

3. Double-pipe Carbon Fiber Roller

Aluminum Single Roller

- 0.37mm of deflection is shown below under 30kg/1900mm of load
- Deflection variation range is Δ0.38mm under the load conditions below

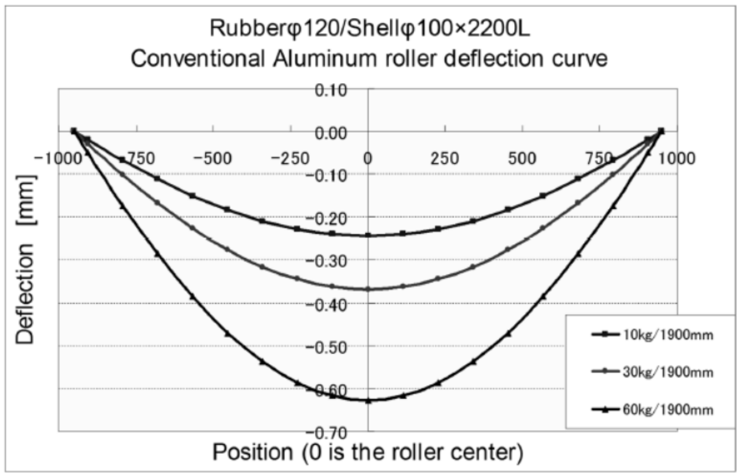


Figure 5 – Aluminum single -pipe roller deflection

Single-Pipe Carbon Fiber Roller

- Deflection 0.08mm, 1/5 of conventional Aluminum roller
- Deflection variation range Δ0.08mm, 1/5 of conventional Al roller

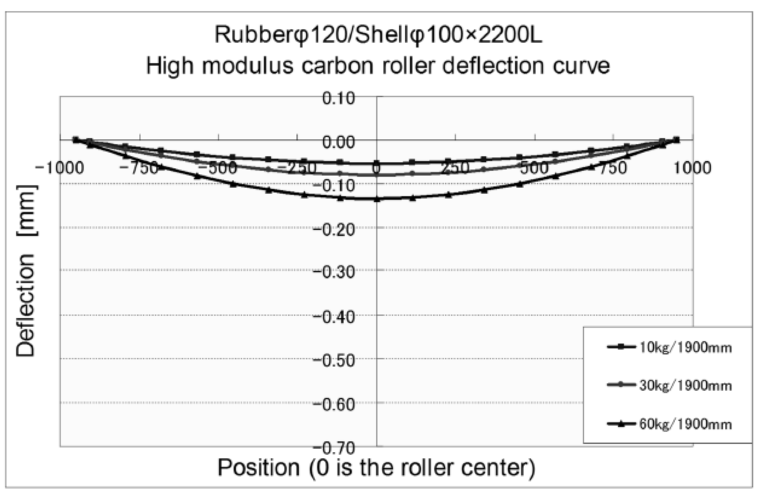


Figure 6 – Single-pipe carbon roller deflection

Double-Pipe Carbon Fiber Roller

- Deflection 0.012mm, 1/40 of Al roller & 1/7 of CFRP single pipe roller

- Deflection variation range Δ0.012mm, 1/5 of Al, 1/7 of single pipe carbon fiber roller

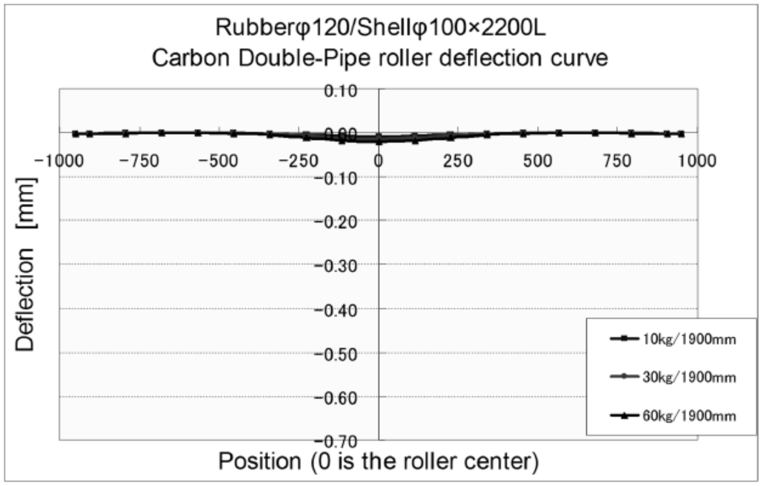
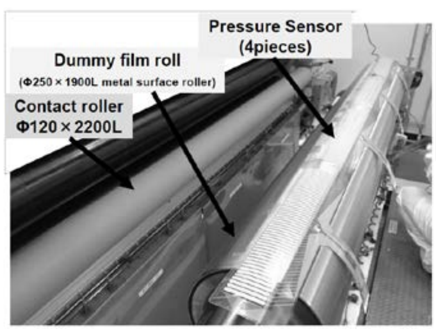
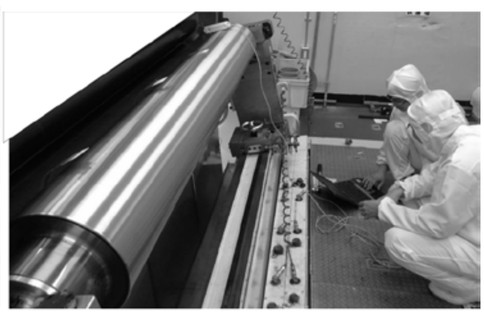


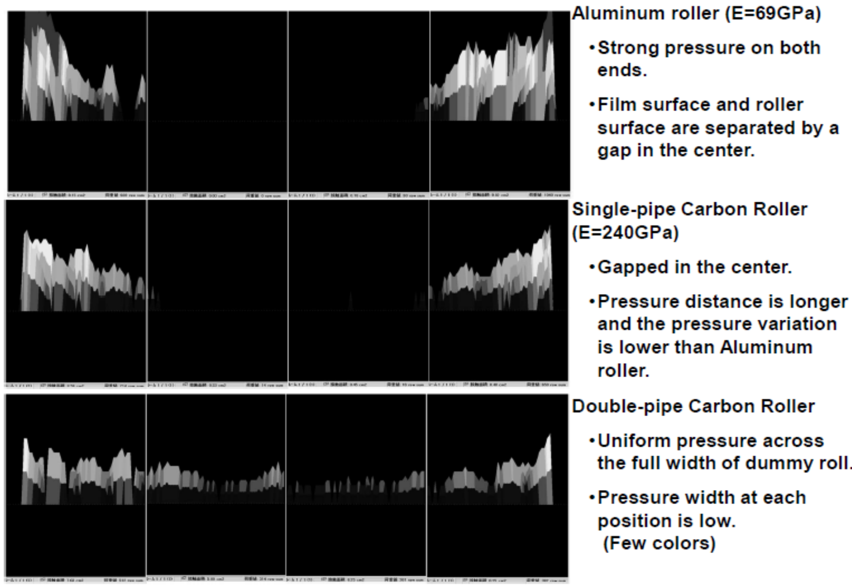
Figure 7 – Double-pipe carbon roller deflection

MEASURE CONTACT PRESSURE CAN BE MEASURED WITH PRESSURE SENSOR

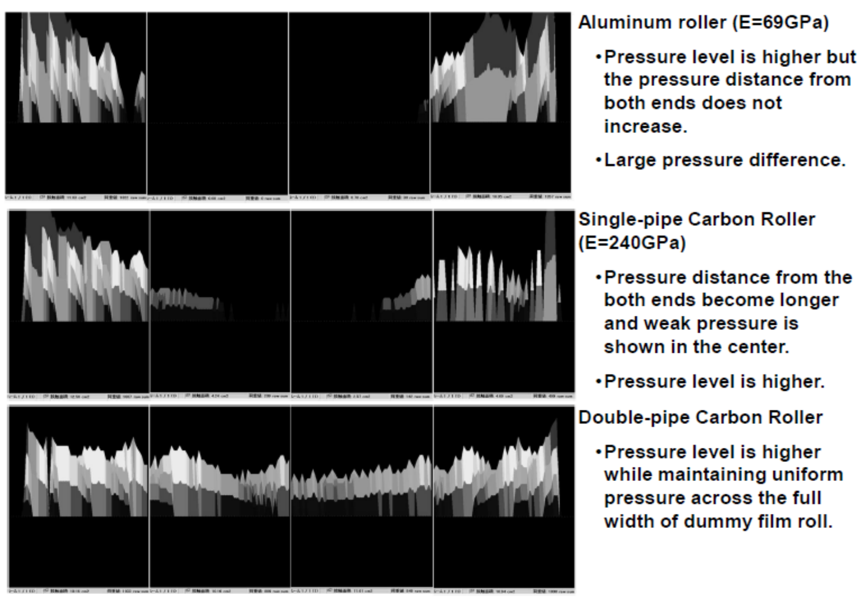




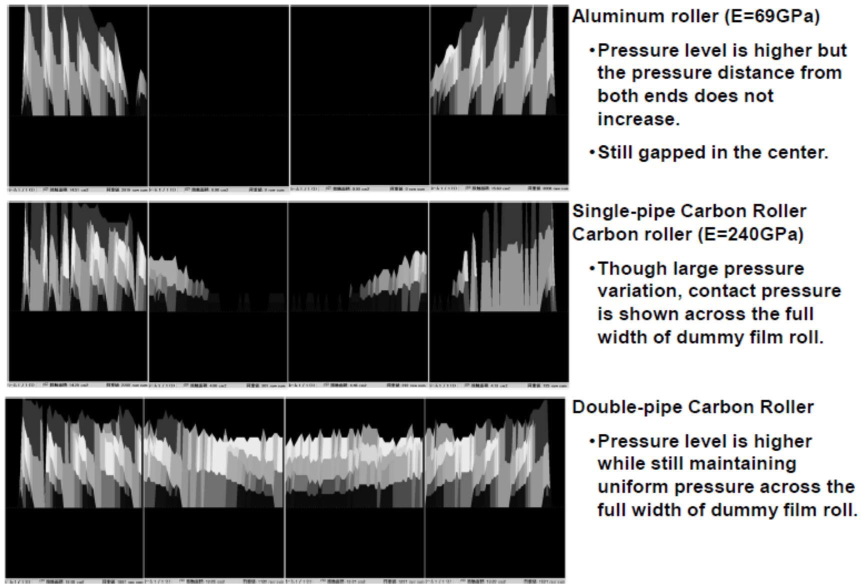
Contact Force Examples: ① 10kg/1900mm ② 30kg/1900mm ③ 60kg/1900mm



Result – Contact force 10kg/1900mm



Result – Contact force 30kg/1900mm



Result – Contact force 60kg/1900mm

Aluminum roller and single-pipe carbon fiber roller contact:

Center portion of roll shows no contact while the edges show heavy contact.

Double-pipe carbon fiber roller contact across roll face:

Narrow area and uniform contact

CONCLUSION

<u>Aluminum Single-Pipe Roller (E=69GPa)</u>

Contact pressure is concentrated on the both ends of dummy film roll. Even if the roller surface is rubber coated, a gap at the center of the roll still exists. Also, there is a large variation in pressure along the longitudinal axis of the roller.

<u>Single-Pipe Carbon Fiber Roller (E=240GPa)</u>

The modulus is higher than aluminum and therefore the deflection is lower. The contact pressure is distributed more evenly across the face of the roll when utilizing a single pipe roller design than with an aluminum roller.

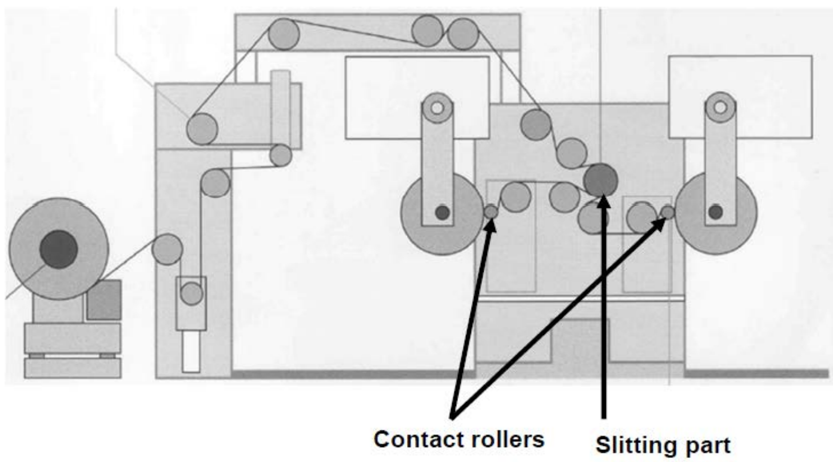
Double-Pipe Carbon Fiber Roller (E>120GPa)

Shows uniform pressure across the full width of dummy roll across varied levels of contact force.

APPLICATION

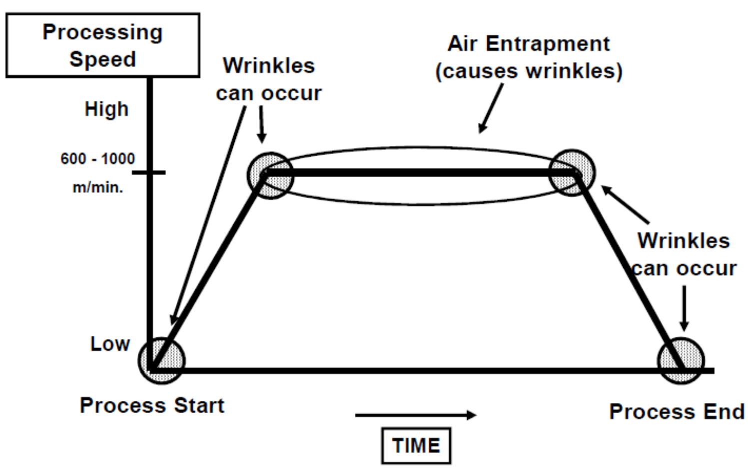
Winding Process after Slitting

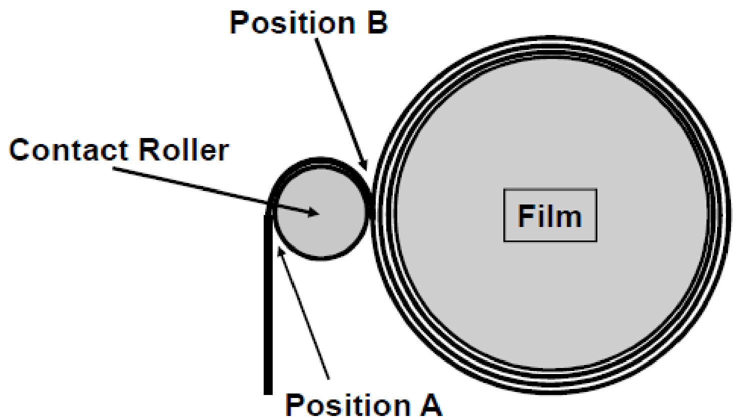
After slitting, films are wound at high speed. Contact (touch) rollers are used in this process.



Slitter

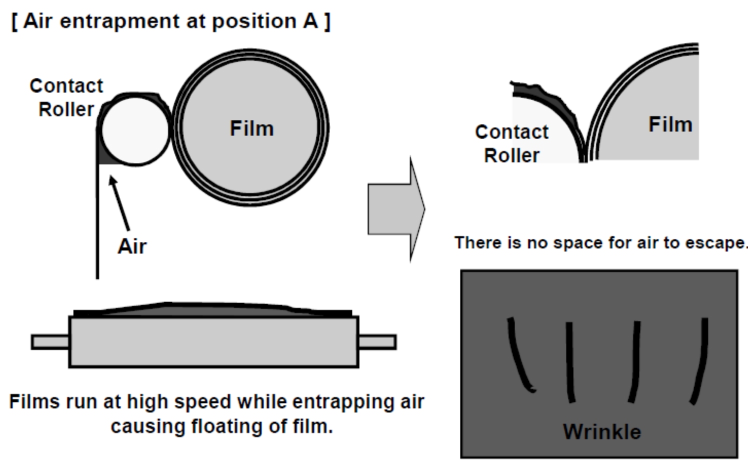
PET film slitting speed can regularly be as high as 600-1000m/min. The primary issues during this process are that wrinkles in the film can occur and operating at high speeds can cause air entrapment.



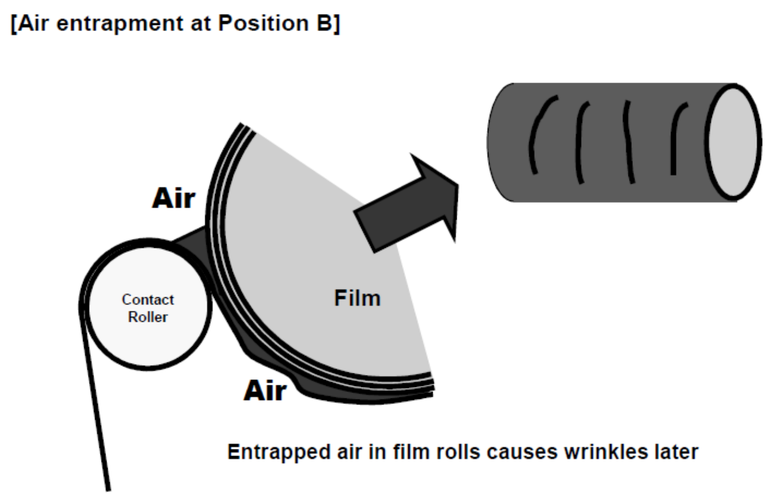


This is a typical contact pattern. Air at position A & B is entrapped in the process.

Films run at high speed while entrapping air causes floating of film.



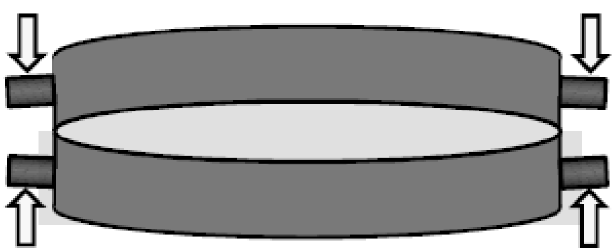
Air can be trapped at the contact roller due to deflection of the contact roller. When air is entrapped in the film, it escapes through the ends of the roll after winding and causes the film to wrinkle.



Lower deflection and uniform contact is effective to reduce air entrapment. Even at low processing speeds wrinkles can occur because of air entrapment.The double-pipe carbon fiber roller design is effective in reducing these issues.

Nip Process

Nip processes (coating, laminating, tension cutting…etc) also need to have uniform contact, but high load levels cause lower contact at the center of the roller.



There are several ways to achieve uniform contact.

(A) Increase modulus by increasing roll diameter.
- Increases weight of roller
- No contact at center of roller with high nip load.

(B) Crown shape of roller surface
- Narrow load margin for best nip condition
- Becomes less effective as roller wears.

(C) Higher modulus of CFRP single pipe carbon fiber roller
- No contact at center of roller with high nip load.

The negative issues listed above are reduced by utilizing the double-pipe carbon fiber roller.

- Deflection 1/3 ～1/10 of single-pipe Carbon Roller.
- Uniform contact across roller face
- Low deflection at high load level.
- Wider operating margin of contact pressure.

FEATURES

There are primarily 3 important aspects of double-pipe carbon fiber rollers:

(A) Ability to increase processing speeds.
(B) Ability to reduce load force while maintaining even contact across roll face.
(C) Can make processing easier due to increase in operating margin.

With single pipe rollers, the operating margin for good winding is very narrow (If the conditions change a little, wrinkles can occur quickly). However, with double pipe rollers, the operating margin is wider, so if the conditions change, uniform contact across the face of the roller allow for successful processing.

MANUFACTURING TECHNOLOGY OF DOUBLE-PIPE CARBON FIBER ROLLER

While double-pipe roller design is not new and is known as Airy or Bessel Point support, the historic design included a steel or an aluminum double-pipe roller with bearings attaching the inside to the outside pipe to reduce deflection of the nip roll. However, double-pipe metal rollers are too heavy to use in the film manufacturing process. So they were not widely adopted.

CFRP allows for the manufacture of a lightweight double-pipe roller but for an effective finished roller the design of the roller is crucial. The placement and shape of the attachments between the inner and outer shell is also very important to the successful operation of the double-pipe roller. Finally, the effective balancing of the double-pipe roller is essential to its performance. All these factors must be taken into account and effectively managed to produce consistently high quality double-pipe rollers.

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