FAST WINDER CHANGE WITH REDUCED INFLUENCE ON FILM TENSION

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ABSTRACT

For a 2 station turret winder it is shown that the film length increases at winder change (turret rotation, cutting arm movement und contact roller movement). It is shown how this change in length must create a change of winder surface speed and in film tension. An optimized way to control the three movements and it effect on film tension is shown.

NOMENCLATURE

r_{CR}	radius contact roller [m]
r_{W1}	radius full winder [m]
r_{W2}	radius empty winder (core) [m]
r_{TD}	radius turret [m]
r_{CA}	radius cutting arm [m]
l_{TD_CR}	distance center of contact roller to center turret [m]
l_{W1_CR}	distance of centers contact roller and winder 1 [m]
l_{W2_CR}	distance of centers contact roller and winder 2 [m]
l_{CR_CA}	Distance of center contact roller and turning point cutting arm [m]
l_{CR_CT}	Distance of center contact roll and roller of cutting arm [m]
l_{FI}	Length of film in inlet of winder [m]
l_{CR}	Length of film on contact roller [m]
l_{W1}	Length of film on winder 1 [m]
l_{W2}	Length of film on winder 2 [m]
l_{F1}	Length of film in step 1 [m]
l_{F2}	Length of film in step 2 [m]

l_{F3}	Length of film in step 3 [m]
l_{R1_R2}	Length of film between the refernce points R1 and R2 [m]
v_F	speed of film [m/s]
φ_{TD}	angle turret [rad]
φ_{CA}	angle cutting arm [rad]
δ_{CR}	contact angle cutting arm [rad]
δ_{W1}	contact angle winder 1 [rad]
δ_{W2}	contact angle winder 2 [rad]
δ_{CT}	contact angle cutting arm roller [rad]
ω_{TD}	rotational speed turret [rad/s]
α_{TD}	rotational acceleration turret [rad/s2]
F	longitudinal force in film [N]
J_{CR}	rotational inertia contact roller [kg*m2]
J_{W1}	rotational inertia winder 1 [kg*m2]

TR	Tension Roll
CR	Contact Roll
CA	Cutting Arm
CT	Cross Cutter
W1	winder 1
W2	winder 2
TD	Turret Drive

INTRODUCTION

Production quality and production stability are the main goals for people having responsibility for the production settings and the people being responsible for designing and building equipment. Stability has to be granted during the hours of “normal” production as well as during special line situations. This paper deals with the winder change in a film production line. The demand for a winder change is a very fast change from the finished roll (old roll) to the empty roll. Duration for a winder change, which occurs about every hour at today’s film production lines is approximately 15 seconds. As well known to machine designer and operators running the line the event of winder change creates a high risk of product failures, like wrinkles and film breaks. This paper describes the physics of longitudinal force changes induced by the winder change. Also a solution for the described winder is shown.

DESIGN OF THE WINDER

The winding machine discussed here consist of following main parts:

The tension pick up roll for measuring the longitudinal force.

The contact roller, which can produce a set force to control the wound in tension [1]. During the winder change the contact roller is positioned away from the winder roll to a safe back position.

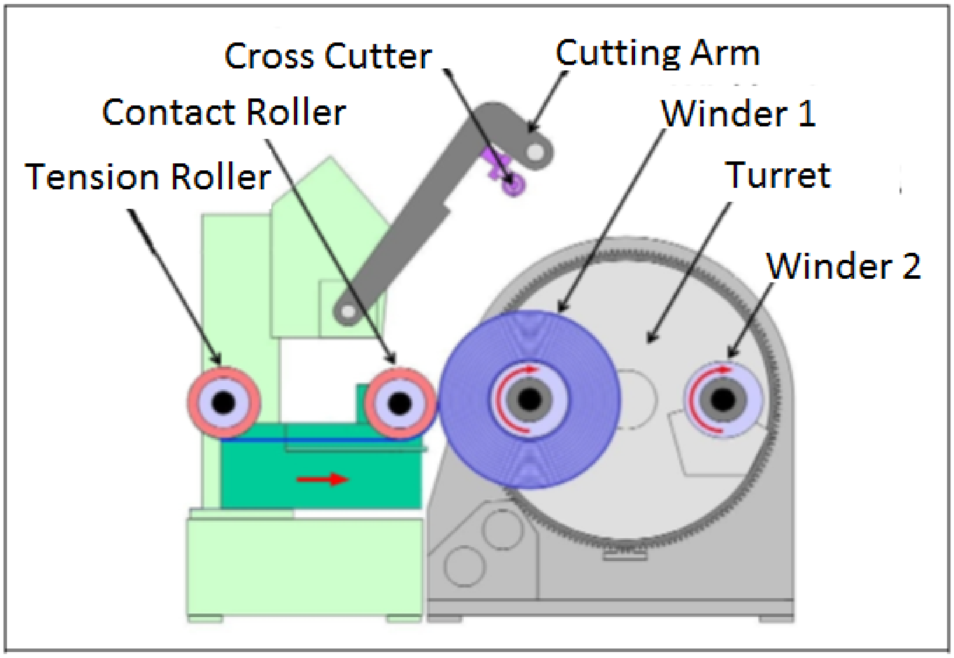

Figure 1 – General Winder Design

The winder roll is driven by a winder motor. This motor is run in torque control mode during winding, which also allows to influence the wound in tension.

The turret holds both winders and rotates for the winder changing.

The cutting arm consists of the cutting arm roller with a cross cutter. Both can swing towards the empty core after the turret has moved.

The sequence of winder change is as followed. We describe here the basic sequence one after the other. In practice more than one action is done simultaneously. Later the effects are shown how this individual actions influence the film tension.

A. The contact roller retracts
B. The turret turns by 180 degree or pi radians
C. The cutting arms moves in. For the first part the cutting arm roller does not touch the film yet. Later the cutting arm roller deflects the film path.
D. The cross cutter moves across the film and cuts the film.
E. After that the film is wound onto the new roll.

In the following we explain the length of film in the winder and later their influence to the film tension.

STANDARD PROCEDURE OF WINDER CHANGE

The standard functionality is that each motion is designed individually for fastest action. Some interlocks and boundary conditions are respected to avoid collisions, e.g. between cutting arm and full winder. The film tension can be influenced be setting the torque of the winder. But as shown later, the set torque does not correspond 1:1 to the film tension.

If problems occur, the winding torque is increased or the speed of the turret motion is reduced. So the way to control the tension during winder change resembles more trial and error than an engineering work.

LENGTH OF FILM PATH

The length of film path is not constant during winding. Each of the above mentioned motions influences the film length in a certain not trivial but defined way. The change of film length is not influenced by the line speed. Therefore the system will be explained for a line with speed 0. When talking about film tension, the line speed has to be considered also.

<u>Steps 1 to 3 : individual motions</u>

In Step 1 the film length is increased because the full winder is moved further away from the old position and therefore making the distance from the contact roller to the full winder bigger.

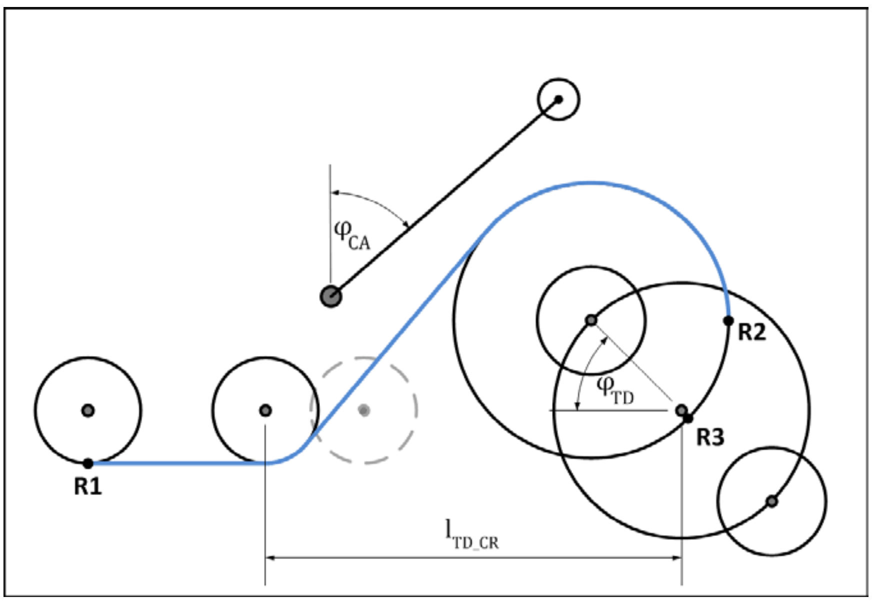

Figure 2 – Step 1: Free Turning

In Step 2 the cutting arm touches the film path. This creates an extra need for film length, because the film is deflected further towards the floor.

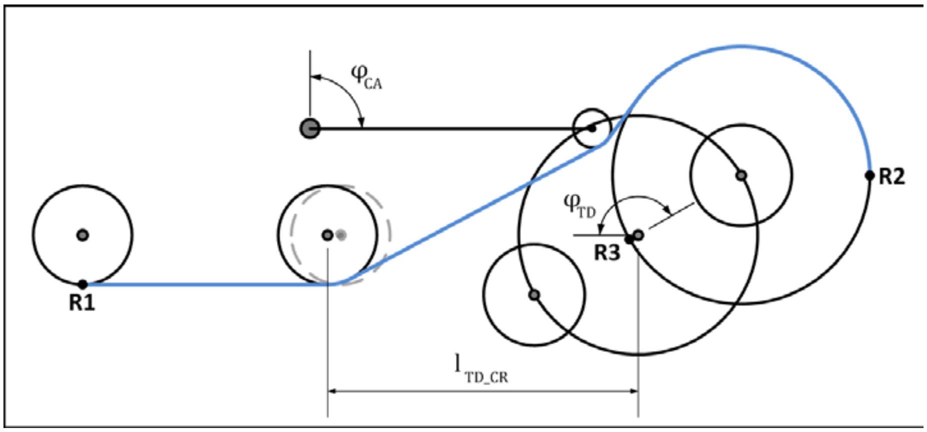

Figure 3 – Step 2: Cutting arm touches film

The step 3 is after the empty winder W2 touches the film also. Then the movement of the contact roller is towards the empty core. This is needed, because the film has to be pressed on the empty core to keep the film force during the actual cutting process. During the actual film cut the contact roller acts more like a nip roller than a contact roller (For this reason the contact pressure – nip pressure- is higher than during regular winding).

The movement of the contact roller towards the empty core also increases the film length.

Calculation of Step 1

The detailed different lengths are shown in picture 4

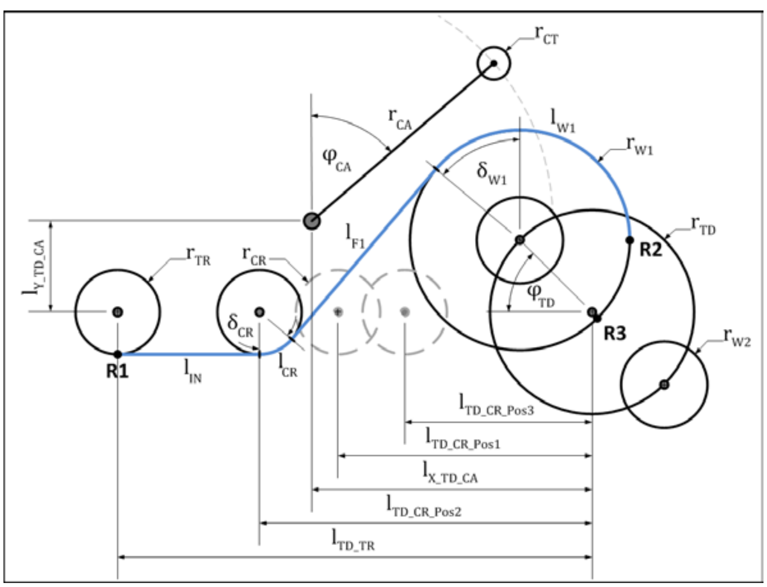

Figure 4 – Details for Step 1 calculation

Reference point R1 is the lower position on tension roller (6 o'clock position). Reference point R2 is the 3 o'clock position on winder 1. Please note that R2 is always the rightmost position on the winder 2 and does not rotate with the turret.

$$l_{R1\_R2} = l_{IN} + l_{CR} + l_{F1} + l_{W1} \qquad \{1\}$$

$$l_{IN} = l_{TD\_TR} - l_{TD\_CR} \qquad \{2\}$$

$$l_{CR} = \delta_{CR} * r_{CR} \qquad \{3\}$$

$$l_{W1} = \left(\delta_{W1} + \frac{\pi}{2}\right) * r_{W1} \qquad \{4\}$$

The length l_{F1} can only be calculated after l_{W1_CR} has been solved. The triangle given by the centers of CR, TD und W1 is solved by the formula {5}.

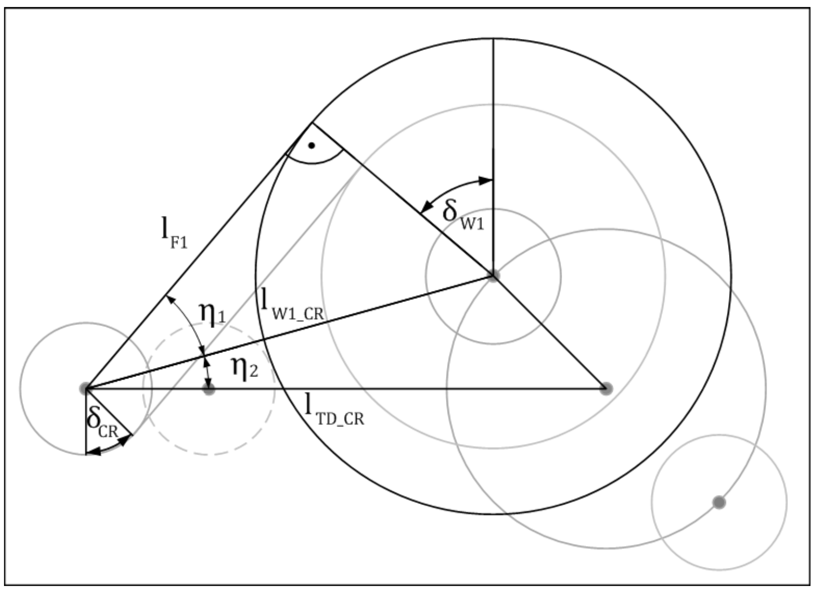

Figure 5 – Film length between Contact roller and winder 1

$$l_{W1\_CR} = \sqrt{r_{TD}^2 + l_{TD\_CR}^2 - 2 * r_{TD} * l_{TD\_CR} * \cos(\varphi_{TD})} \qquad \{5\}$$

For the length of the free span between the contact roller and the winder 1 can easily be solved by constructing an auxiliary rectangular triangle through center of the contact roller and the center of the winder 1 and a cathetus of $r_{W1} + r_{CR}$. With other words the length $l_{F1}$is the same as a tangent from the center of contact roller to an auxiliary circle around the center of winder 1 and a radius of $(r_{W1} + r_{CR})$.

$$l_{F1} = \sqrt{l_{W1\_CR}^2 - (r_{W1} + r_{CR})^2} \qquad \{6\}$$

The angle δ_{CR} and δ_{W1} are equal and are the sum of η_1 and η_2. The result is shown in formula {7}.

$$\delta_{CR} = \delta_{W1} = arcsin\left(\frac{r_{W1}+r_{CR}}{l_{W1\_CR}}\right) + arcsin\left(\frac{r_{TD}* sin(\varphi_{TD})}{l_{W1\_CR}}\right) \qquad \{7\}$$

<u>Calculation of Step 2: data for cutting arm</u>

For the first part of the turret movement, the position of the cutting is limited to avoid a contact of the cutting arm to winder 1. Without displaying the calculation for this, we assume, that the cutting arm does not touch the winder 1.

When the cutting arm touches the film we have following situation (Figure 6):

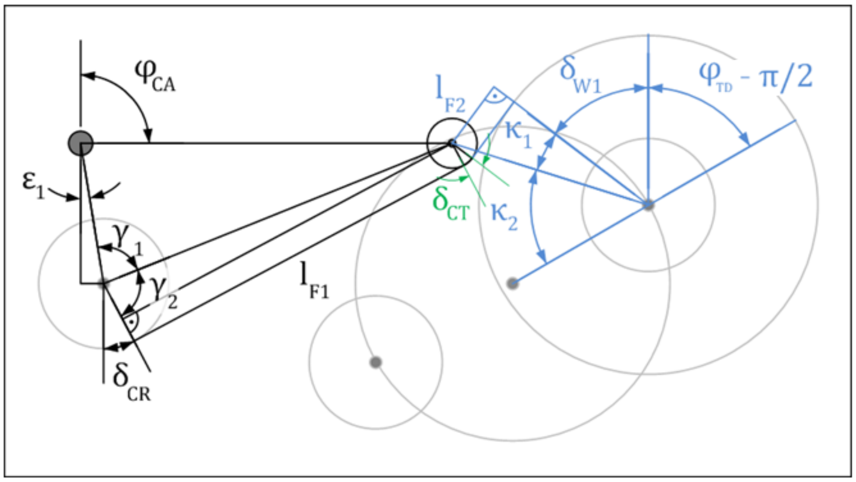

Figure 6 – Angles an Film length when cutting arm touches film

The two angles γ_1 *and* γ_2 can be calculated from the known lengths and distances according to

$$\gamma_1 = arccos\left(\frac{l_{CR\_CA}^2 + l_{CR\_CT}^2 + r_{CA}^2}{2* l_{CR\_CA}^2 * l_{CR\_CT}^2}\right) \qquad \{8\}$$

$$\gamma_2 = arccos\left(\frac{r_{CR} - r_{CT}}{l_{CR\_CT}}\right) \qquad \{9\}$$

This allows us to calculate the angle of the cutting arm δ_{CR}:

$$\delta_{CR} = \pi + \varepsilon_1 - \gamma_1 - \gamma_2 \qquad \{10\}$$

On the side of the winder we can calculate the new wrap angle on winder 1 again by using an auxiliary circle around center of winder 1 and the tangent into center of cutting arm roller:

$$\kappa_1 = arccos\left(\frac{r_{W1} + r_{CT}}{l_{W1\_CT}}\right) \qquad \{11\}$$

$$\kappa_2 = arccos\left(\frac{r_{TD}^2 + l_{W1\_CT}^2 - l_{TD\_CT}^2}{2 * r_{TD} * l_{W1\_CT}}\right) \qquad \{22\}$$

$$\delta_{W1} = \pi - \kappa_1 - \kappa_2 - \left(\varphi_{TD} - \frac{\pi}{2}\right) = \frac{3}{2}\pi - \kappa_1 - \kappa_2 - \varphi_{TD} \qquad \{23\}$$

$$\delta_{CT} = \delta_{W1} - \delta_{CR} \qquad \{24\}$$

An finally the complete length of film path from reference point R1 to reference point R2:

$$l_{R1\_R2} = l_{IN} + l_{CR} + l_{F1} + l_{CT} + l_{F2} + l_{W1} \qquad \{25\}$$

The still missing length l_{IN}, l_{CR} and l_{W1} are calculated as in Step 1 . The rest as follows by using rectangular triangles.

$$l_{F1} = \sqrt{l_{CR\_CT}^2 - (r_{CR} - r_{CT})^2} \qquad \{26\}$$

$$l_{F2} = \sqrt{l_{W1\_CT}^2 - (r_{W1} + r_{CT})^2} \qquad \{27\}$$

$$l_{CT} = \delta_{CT} * r_{CT} \qquad \{28\}$$

This gives us complete solution for formula {25}, where the individual parts are taken by the formulas {26} to {28}.

Calculation of Step 3: Winder 2 touches the film also

For this case we have to expand the formulas again.

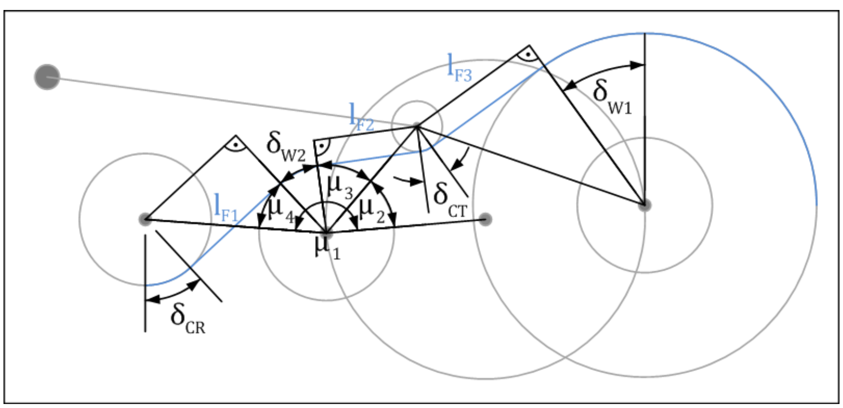

Figure 7 – Calculation for Step 3

$$\mu_1 = arccos\left(\frac{l_{W2\_CR}^2 + r_{TD}^2 - l_{TD\_CR}^2}{2 * l_{W2\_CR} * r_{TD}}\right) \qquad \{29\}$$

$$\mu_2 = arccos\left(\frac{l_{W2\_CT}^2 + r_{TD}^2 - l_{TD\_CT}^2}{2 * l_{W2\_CT} * r_{TD}}\right) \qquad \{30\}$$

$$\mu_3 = arccos\left(\frac{r_{W2} + r_{CT}}{l_{W2\_CT}}\right) \qquad \{31\}$$

$$\mu_4 = arccos\left(\frac{r_{W2} + r_{CR}}{l_{W2\_CR}}\right) \qquad \{32\}$$

$$\delta_{W2} = \mu_1 - \mu_2 - \mu_3 - \mu_4 \qquad \{34\}$$

$$\delta_{CR} = arcsin\left(\frac{r_{W2} + r_{CR}}{l_{W2\_CR}}\right) - arccos\left(\frac{l_{TD\_CR}^2 + l_{W2\_CR}^2 - r_{TD}^2}{2 * l_{TD\_CR} * l_{W2\_CR}}\right) \qquad \{35\}$$

For calculating the wrap angle for the cutting arm roller δ_{CT} and to find the tangent point to W2, we have to find the angle $\delta_{W2\_vertikal}$, which is toward the vertical line through the center of winder 2.

$$\delta_{W2\_vertikal} = \delta_{CR} - \delta_{W2} \qquad \{36\}$$

$$\delta_{CT} = \delta_{W1} - \delta_{W2\_vertikal} \qquad \{37\}$$

The values of l_{IN}, l_{CR}, l_{CT} and l_{W1} are shown in step 2. The others follow here by the use of known rectangular triangles.

$$l_{F1} = \sqrt{l_{W2\_CR}^2 - (r_{W2} + r_{CR})^2} \qquad \{38\}$$

$$l_{F2} = \sqrt{l_{W2\_CT}^2 - (r_{W2} + r_{CT})^2} \qquad \{39\}$$

$$l_{F3} = \sqrt{l_{W1\_CT}^2 - (r_{W1} + r_{CT})^2} \qquad \{40\}$$

$$l_{W2} = \delta_{W2} * r_{W2} \qquad \{41\}$$

$$l_{R1\_R2} = l_{IN} + l_{CR} + l_{F1} + l_{W2} + l_{F2} + l_{CT} + l_{F3} + l_{W1} \qquad \{42\}$$

Even if it is a long and cumbersome calculation, we have a complete solution for the film length for every position of turret rive, position of contact roller and position of cutting arm.

SIMULATION STANDRAD CASE

Now we use the above formulas to start a simulation in Scilab [2], an free software similar to Matlab:

For a given motion of contact roller, turret and cutting arm we calculate for every instant the additional film length.

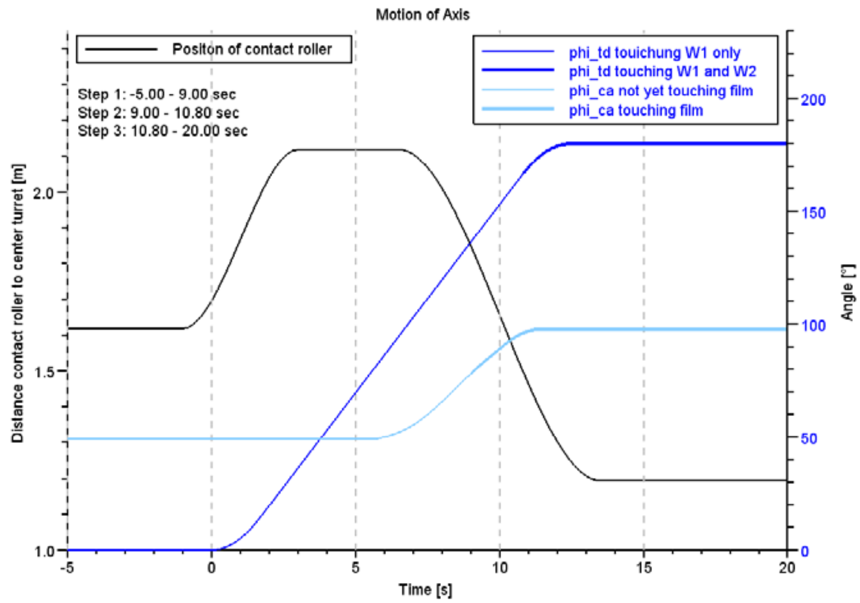

Figure 8 – Motion of turret, cutting arm and contact roller

We see, that the motion starts with retraction the contact roller (time = -2s) and then the turret rotation starts (0s). During a 1 s period the turret rotation comes to a fixed speed and reduces the speed only for the stopping process. At 12 s all motion are finished.

This creates an additional film length of as shown in Figure 9:

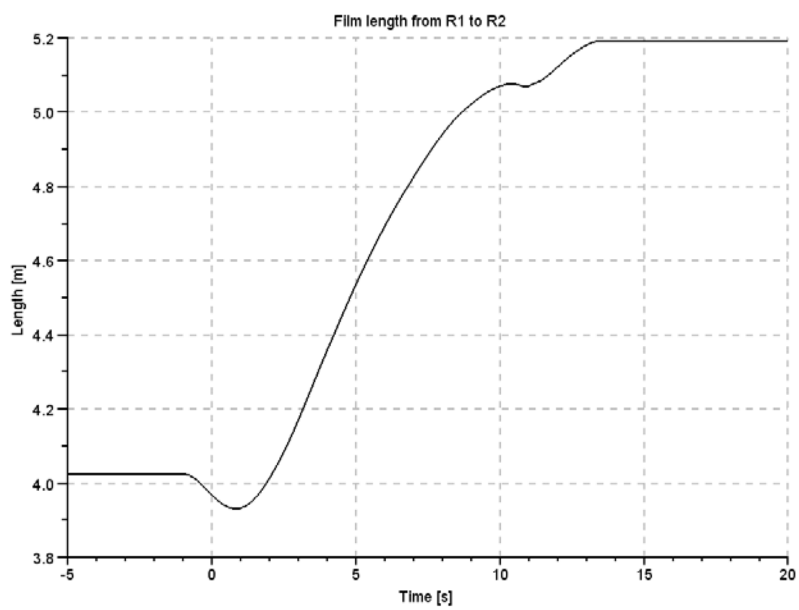

Figure 9 – Film length for standard motion

The varying film length requires a changing surface speed of the winder:

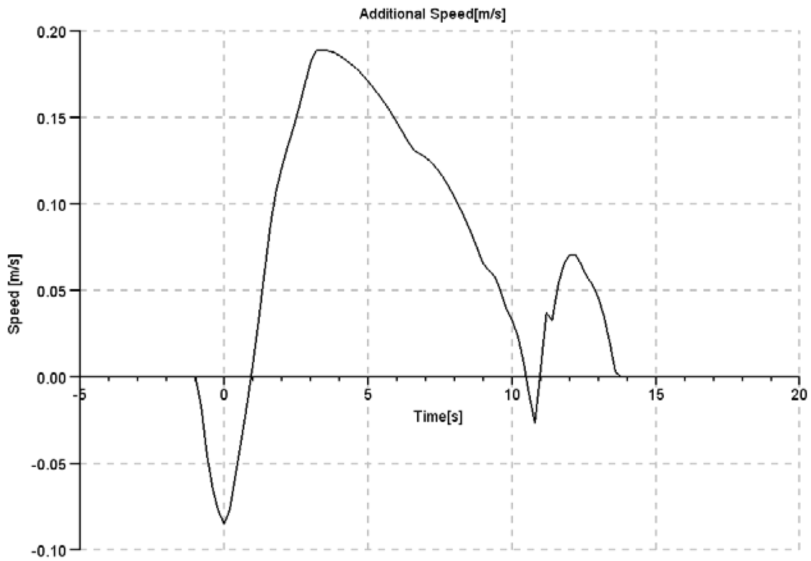

Figure 10 – Additional speed for winder

To follow that speed it requires an acceleration and deceleration of the winder. The force for this acceleration is normally only transmitted by the film. This creates additional forces to the film (increase and decrease). For easier understanding we assume the film to be perfectly stiff. Fortunately in practice the film will elastically dampen the force peaks.

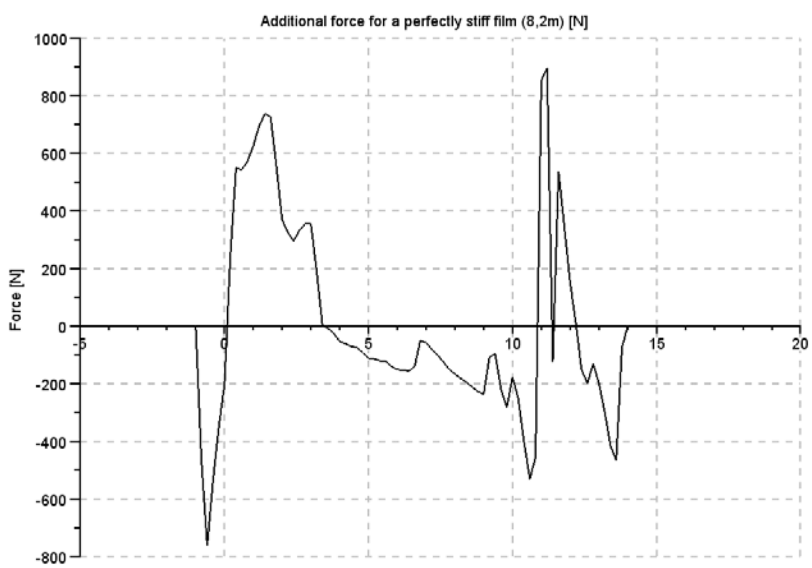

Figure 11 – Force change due to winder changing

We want to discuss the most important impacts:

First we retract the contact roller and the film gets loose (-2s to 0s) . If this is a problem to the production line, operators will increase the film tension for the winder change period.

Later, when the turret moves, the film tension increases, because the film length needed can only be taken from slowing down the full winder W1. If the high tension is bad to the production, operators will try to decrease the tension.

So we have the situation, that we have only a small corridor of film tension to run the line. Maybe we cannot solve both problems with one set of film tension. Normally the only solution is to take a longer time for winder change by reducing the turret speed: i.e. more product is lost during winder change.

OPIMIZATION OF THE INDIVIDUAL MOTIONS

After understanding the effect of the turret turning speed and the other motions, we look for an optimized coordinated turning procedure, to have minimum effect on the film tension.

It has to be understood, that by design the film length after tuning the turret drive must be longer than before. Thus there must be a speed change. The optimization goal is to have only one speed change to lower winder speed at the beginning of winder change and one back o original speed at the end. Both changes should be in a smooth soft way as shown in Figure 12. This will result in a low force change.

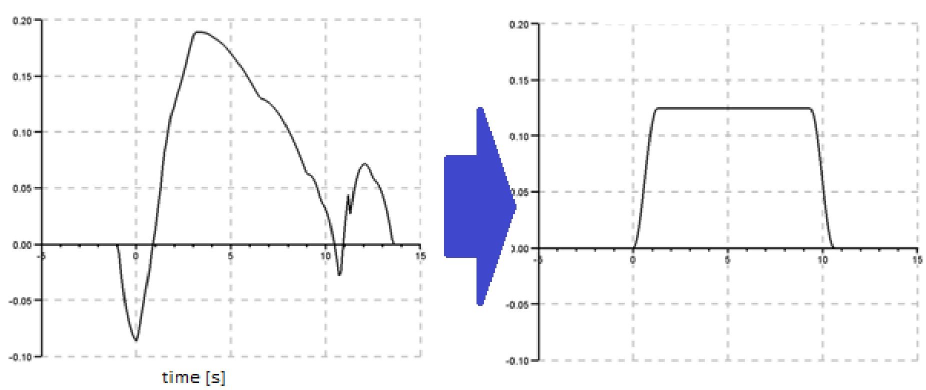

Figure 12 – Basic Idea of optimization: optimization of speed change

This lead to a specific speed of all three motions. The contact roll is not retracted at all, but stays in the original position. The turret starts with a given speed but reduces the speed towards the end. The cutting arm comes in slowly. Before the end the contact roller comes in fast to compensate the extra film length from the winder W1 coming down. The contact roller also makes a short back and forth movement to keep the film length to the desired value.

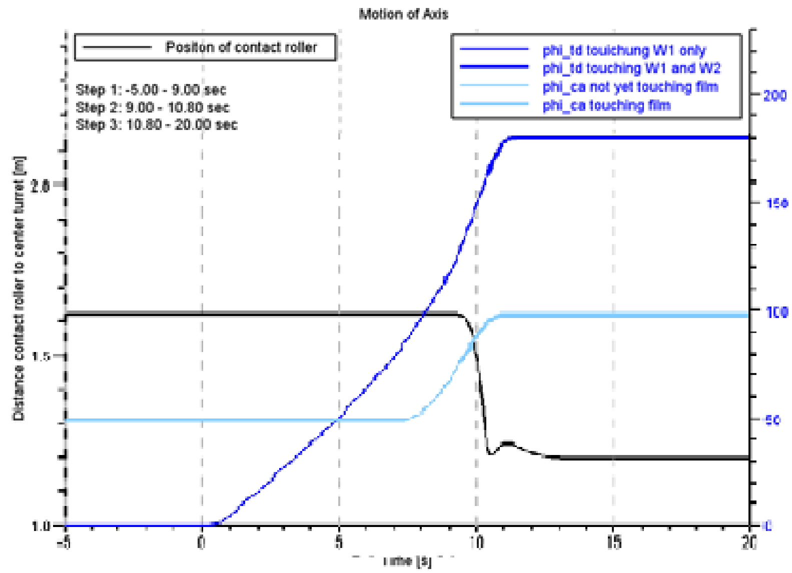

Figure 13 – Optimized Motion

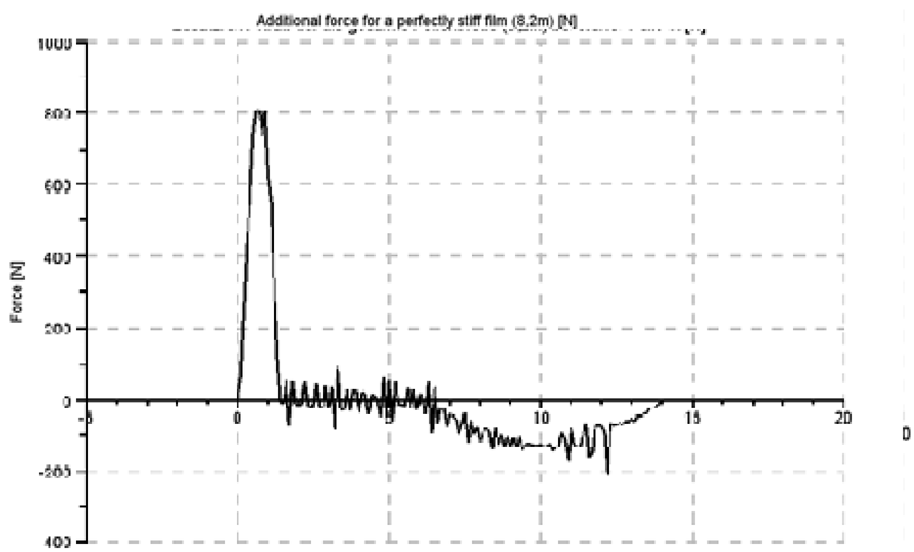

Figure 14 – Forces with optimized motion

We see that the only significant force peak is at the beginning of turning. This can be influenced by a softer acceleration of the turning drive. For this presentation we wanted to keep the total time for winder change constant. This first peek can be compensated by a feed forward control to the winder torque, because it is well known, when and with which amplitude it occurs.

All other force peaks from Figure 11 (standard turning) have been compensated.

CONCLUSION

The force changes during winder change can be explained and calculated. An alternative control of the emotions helps to reduce the force peeks. We hope that the solution can be used also for winders and unwinders with different geometry.

REFERENCES

1. B. Sieber, "Mechatronic Damping for Contact Rolls in Film Winders," Proceedings of Ninth International Conference of Web Handling, Stillwater, Oklahoma, 2007.
2. http://www.scilab.org/