UNWIND AND REWIND GUIDING

by

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ABSTRACT

Lateral control of a web through a process line involves the use of web guides and control systems at different points in the process. There are three general areas for guiding. Guides are typically located at the terminal ends of the process and in the process section. Guides located at the terminal ends are referred to as unwind and rewind, uncoil and recoil, payoff and tension reel, and other terms that may be specific to certain industries. In between the terminal guides is the process section. Guides in this section are referred to as intermediate guides.

This paper concerns the practical application of terminal guides (unwind and rewind), the control system loop, the control system types, sensor configurations, sensor locations, and response of the system and equipment.

INTRODUCTION

Unwind guiding is the lateral positioning of an unwind roll stand or roll shaft to a fixed point determined by a sensor location. The sensor is mounted independent of the unwind stand and does not move during guiding. Rewind guiding and unwind guiding may appear to be the same, but they are different. Rewind guiding is different because the web is not physically repositioned as in unwind guiding. The web is chased by the rewind stand. The sensor is attached to the rewind stand and moves in unison with the rewind stand. The sensor detects a lateral movement in the web away from the null position of the sensor. The sensor and stand chase the lateral web movement, keeping the edge winding roll in the same position.

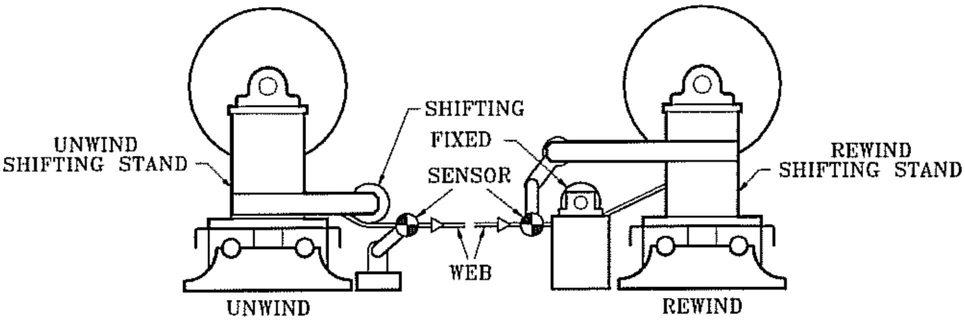


Fig. 1 Unwind and Rewind Guiding

Basic Control Loop

The basic control system is a closed-loop, Type 1, proportional control system. A closed-loop system is one in which the output is sensed and fed back to modify the input. Because the output is subtracted from the input, the loop is referred to as a negative feedback loop. Input command to the loop is the desired web position. Web position error is an input disturbance to the control loop. Output of the system is a velocity proportional to the input web position error. The one integration of web position error to velocity gives the loop its name (Type 1). The web position error is a positive input to the control loop.

In normal operation, the sensor detects a web position error from the sensor null point and sends a signal to the controller. The controller outputs a signal to an actuator which results in velocity out of the actuator. The actuator output velocity moves the unwind or rewind stand repositioning the web back to the desired null point of the sensor, eliminating the error at the sensor.

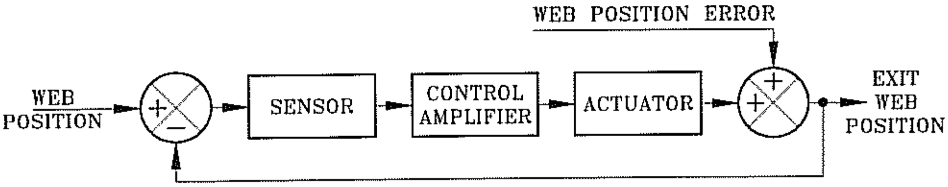


Fig. 2 Basic Control Loop

The ratio of correction rate (output velocity) to error (displacement) at the sensor is known as the open-loop (forward) gain of the system. The gain of the system is determined by the selection of components and adjustment of the control amplifier. The overall system gain is the product of the individual gains of the system components.

SENSOR GAIN $= K_1 = \frac{\text{MILLIAMPS}}{\text{INCH}}$

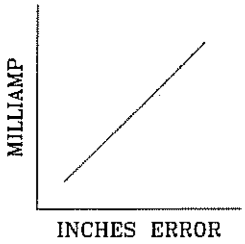


Fig. 3 Sensor Gain

CONTROLLER GAIN $= K_2 = \frac{\text{VOLTS}}{\text{MILLIAMPS}}$

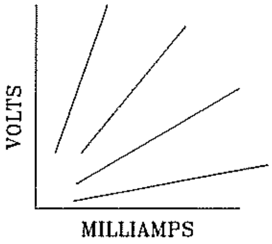


Fig. 4 Controller Gain

ACTUATOR GAIN $= K_3 = \frac{\text{INCH/SECOND}}{\text{VOLTS}}$

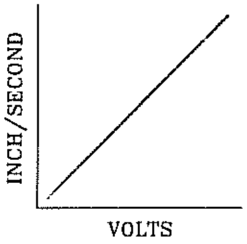
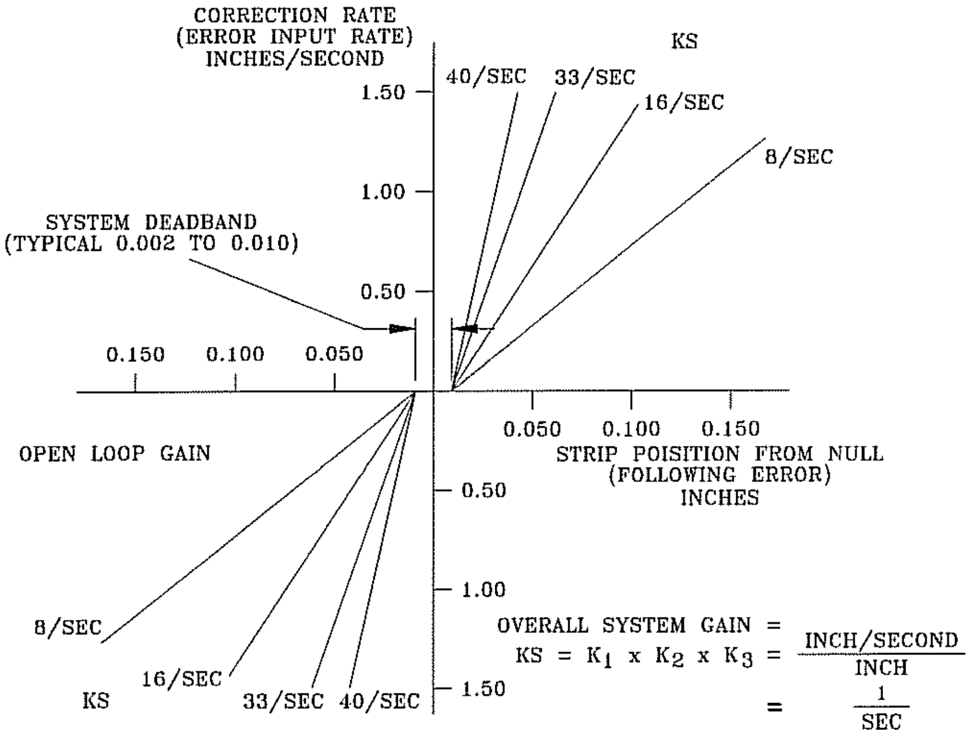


Fig. 5 Actuator Gain



OVERALL SYSTEM GAIN $= \frac{\text{INCH/SECOND}}{\text{INCH}}$

$$KS = K_1 \times K_2 \times K_3 = \frac{\text{INCH/SECOND}}{\text{INCH}} = \frac{1}{\text{SEC}}$$

Fig. 6 Overall System Gain

System performance is limited by the dynamic characteristics of the controller. The closed-loop frequency response of a system can be determined by studying its response to a sinusoidal input. Figure 7 shows typical sinusoidal response characteristics at three frequencies: f_1, f_2, and f_3 (sine waves of frequency and magnitude chosen to not exceed the velocity capability of the system). At low frequency, f_1, the output at the actuator is equal in amplitude and slightly behind in phase or time with respect to the input wave. At higher frequency, f_2, it is possible for the output wave amplitude to exceed the input wave amplitude and to be displaced further in phase. The relationship of the amplitude at this point is dependent upon the damping coefficient of the system. At a still higher frequency, f_3, the output amplitude begins to diminish to a point less than the input amplitude and to be further displaced in phase.

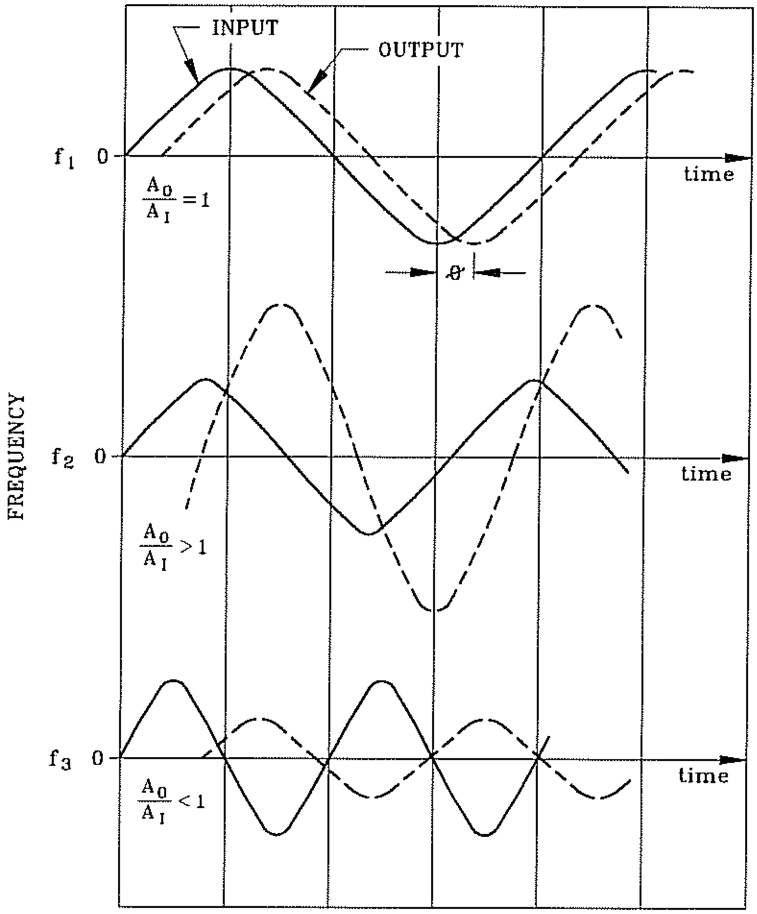


Fig. 7 Amplitude Ratio Vs. Frequency

Typical characteristics of a control system are shown in Figure 8. This is known as a log magnitude plot or Bode plot for a closed-loop control system. the amplitude ratio is plotted in db which is defined as 20 times log amplitude out/amplitude in. The area where the peak in the curves occur is the natural frequency of the control system. Frequencies above the natural frequency are frequencies in the range of f_3 above.

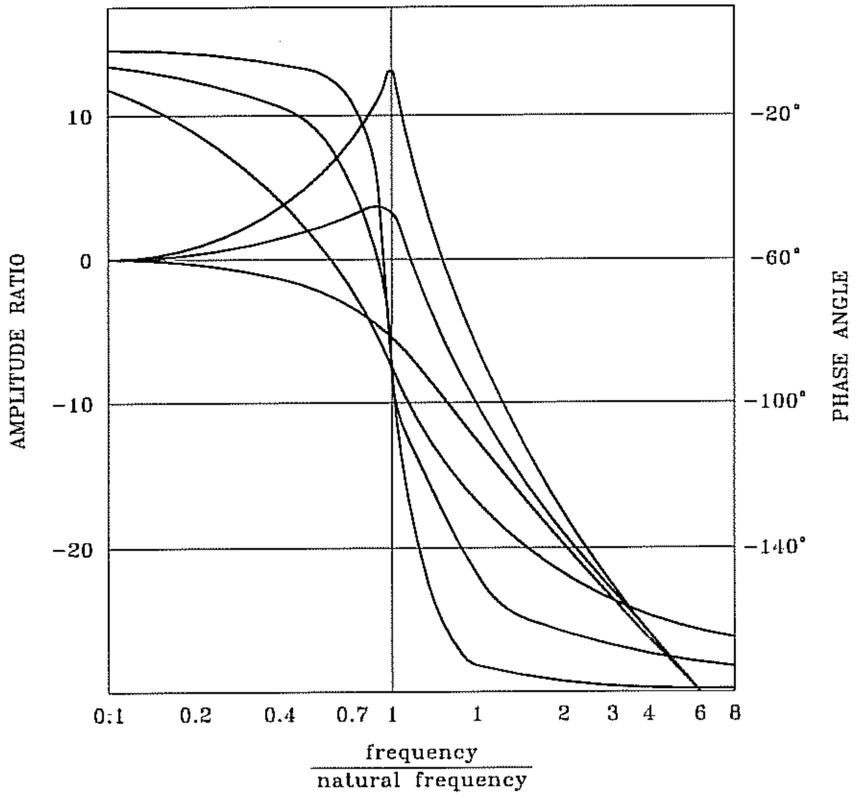
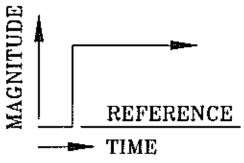
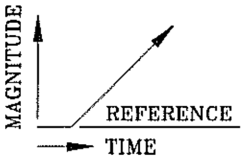
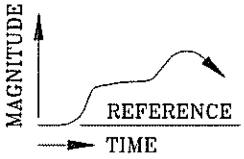


Fig. 8 Bode Plot

There are two types of disturbances or errors as seen by the sensor: steady state (zero velocity errors) and transient (constant and variable velocity errors). Figure 9 illustrates the types of errors and the output characteristics of a Type 1 Control System.

TYPE 1 CONTROLLER

INPUT DISTURBANCE Note 1.	GUIDE ACTION	STRIP ERROR AT SENSOR Note 2.	ACCURACY AT SENSOR
STEP  FIXED DISPLACEMENT OF STRIP FROM DESIRED POSITION AFTER SETTLING OUT	GUIDE POSITION CONSTANT DISPLACED TO CORRECT STEP INPUT	ZERO ERROR	WITHIN DEADBAND OF SYSTEM (TYPICALLY ±0.002 INCH)
RAMP  CONSTANT RATE OF LATERAL RUNOUT AFTER SETTLING OUT	GUIDE MOVING AT A CONSTANT FOLLOWING RATE EQUAL TO RATE OF RAMP INPUT	CONSTANT ERROR AT SENSOR PROPORTIONAL TO RATE OF RAMP INPUT DISTURBANCE	PROPORTIONAL TO RATE OF RAMP INPUT DISTURBANCE MAXIMUM FORWARD GAIN
RANDOM  VARIABLE RATES OF LATERAL RUNOUT	GUIDE MOVING AT A RATE OR RATES CONSISTENT WITH INPUT DISTURBANCE	DEPENDENT ON AMPLITUDE AND FREQUENCY OF DISTURBANCE AS WELL AS FREQUENCY RESPONSE OF THE SYSTEM	WITHIN PROPORTIONAL BAND OF SENSOR

NOTES
1. MAGNITUDE OF INPUT DISTURBANCE NOT TO EXCEED GUIDE CAPACITY.
2. ALL ERRORS ASSUMED TO AVOID SATURATION OF ANY ELEMENT OF THE CONTROL SYSTEM.

Fig. 9 Input Disturbance Vs. System Accuracy

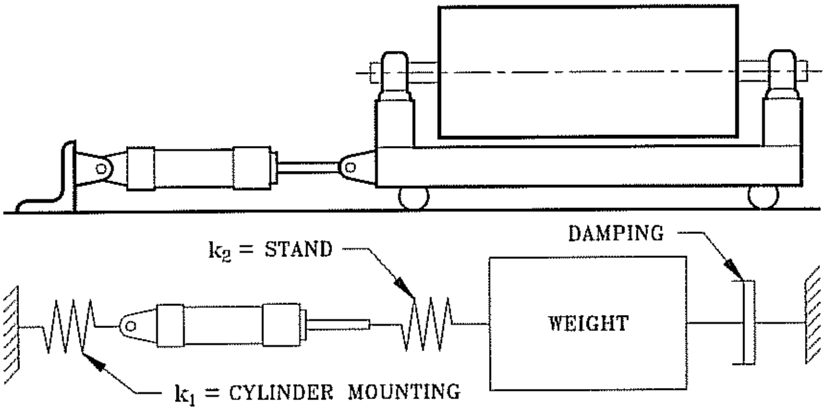
Unwind And Rewind Resonances

Resonances in the control loop impose limitations on the performance of the controller. Resonances occur when the mass being moved by the actuator has a natural vibratory frequency that coincides with the natural frequency of the control loop.

The unwind and rewind assemblies should be designed such that the lateral mechanical natural frequency is two to three times the natural frequency of the controller. This requires that the lateral stiffness of the unwind/rewind stand be calculated and the natural frequency determined. Designing to such a stiffness will prevent a resonance problem occurring between the mechanical structure and the controller. The same can be said for the actuator, whether an electromechanical actuator or hydraulic cylinder. The natural frequency of the actuator should be well above the natural frequency of the controller. Most controllers in web handling today have natural frequencies in the range of 1 to 14 Hertz.

Careful attention must be paid to the stiffness of the actuator mounting, the side plates, and the stand crossmembers. Excessive clearance in the actuator mounting points should be avoided. If the control system is hydraulic, the natural frequency of the oil in compression should be considered. On rewind stands, the lateral stiffness of the sensor support must be considered. Unwind and rewind stands that appear stiff in static situations are often not stiff in dynamic situations. As a result, the control system must be operated at a lower gain setting than optimum, resulting in less performance and accuracy of the control loop.

Figure 10 illustrates a situation where the actuator mounting flexibility is defined by the spring constant k_1 and the stand flexibility by spring constant k_2. The undamped natural frequency can be calculated and compared to the natural frequency of the control loop.



$$k_E = \frac{k_1 k_2}{k_1 + k_2} \text{ \#/inch} \qquad Fn = 3.13 \sqrt{\frac{k_E}{W}} \text{ Hz} \qquad \text{(undamped)}$$

Fig. 10 Unwind & Rewind Stand Natural Frequency

Types Of Control Systems

Control Systems used in the past have been pneumohydraulic and electrohydraulic. The wave of the future is electromechanical control. Each of these types of control systems have a place in unwind and rewind guiding. There are advantages and disadvantages associated with each type of control system. Traditional advantages of the hydraulic control system have been smooth variable speed, ability to apply full force at zero speed, high power density compared to electric motors, high response, and high stiffness in closed-loop control. Major disadvantages are the plumbing required for the hydraulic fluid and the possible contamination of the final product by the hydraulic fluid.

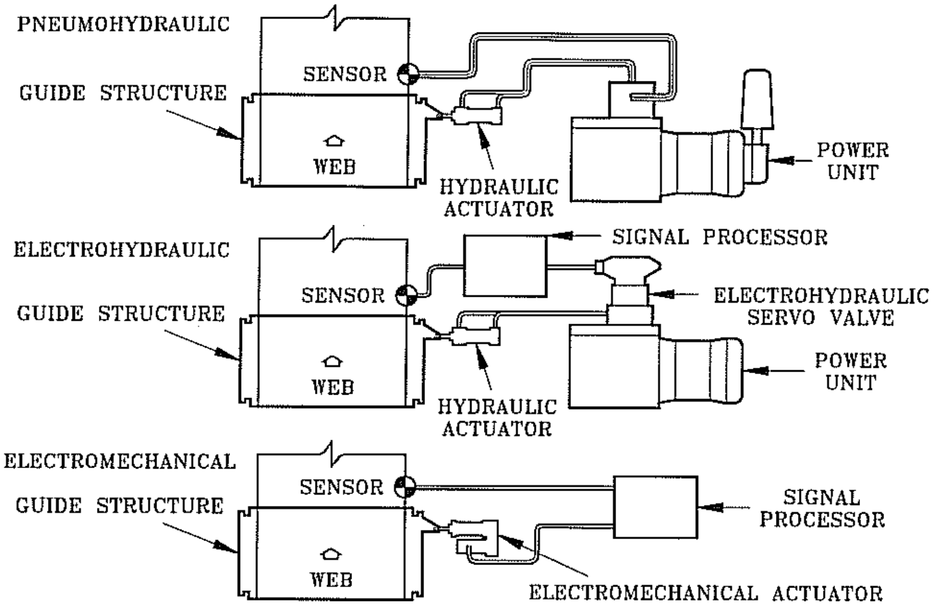
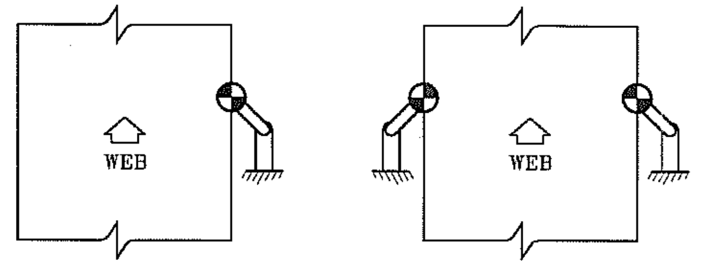


Fig. 11 Types of Control Systems

High-performance DC servomotors have replaced hydraulic control systems in many applications. As electronic controls have improved in the last decade or two and the education of engineers has shifted from mechanical toward electronic control, electromechanical control systems have replaced hydraulic control systems. Many electromechanical control systems are capable of high thrust based on motor horsepower, but the operating thrust is in the range of 10% to 15% of maximum thrust. As the size of the electric motor increases, the mass of the motor rotor becomes a limiting factor in the frequency response of the electromechanical control system. Frequency response of typical electromechanical systems on the market are in the range of 1 to 14 Hertz.

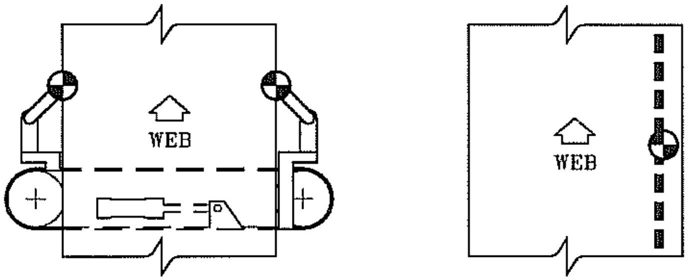
Sensor Configurations

Many types of sensors have been developed and used. These include contact and noncontact using pneumatics, incandescent light, fluorescent light, infrared light, laser light, inductive, and capacitance. Wide- and narrow-gap, as well as wide- and narrow-band edge guide sensors are available. Line guide sensors are available for guiding to a line. The edge sensors can be used as simple edge guide (either edge). The edge guide sensors can also be used in combination as fixed-sensor center guide or as moving-sensor center guide systems. The guiding application will determine the type of sensor(s) and configuration to be used.



EDGE GUIDING

FIXED SENSOR CENTER GUIDING



MOVING SENSOR CENTER GUIDING

LINE OR PATTERN GUIDE

Fig. 12 Sensor Configurations

Sensor Location

Sensor location is highly important in the proper application of a control system. The sensor must be located such that correct feedback is obtained in the control system and excessive phase lag is not present.

On an unwind stand, the sensor should be fixed and located immediately downstream of the unwind stand. As the sensor location is moved downstream from the unwind, phase lag is introduced into the control loop. The phase lag will introduce instability in the control system by allowing the unwind stand to overcorrect before the correction is seen by the sensor. If the sensor is located in the first two-thirds of the unwind exit span, any instabilities due to phase lag will be minimized.

On a rewind stand, ideally, the sensor should be located just upstream of the last fixed idler and connected to the rewind stand with a laterally stiff arm. The web must not slip laterally on the last fixed idler as the rewind stand moves. To ensure that no slippage occurs on the idler, there should be greater than 15° of wrap on the idler. The natural frequency of the arm connecting the sensor to the stand should be two to three times the natural frequency of the controller. If the sensor were to be located downstream of the last fixed idler, positive feedback is introduced into the control loop due to the web being moved away from the null point of the sensor by rewind stand movement. The positive feedback will result in instability in the control system and be seen as a ragged edge on the wound roll.

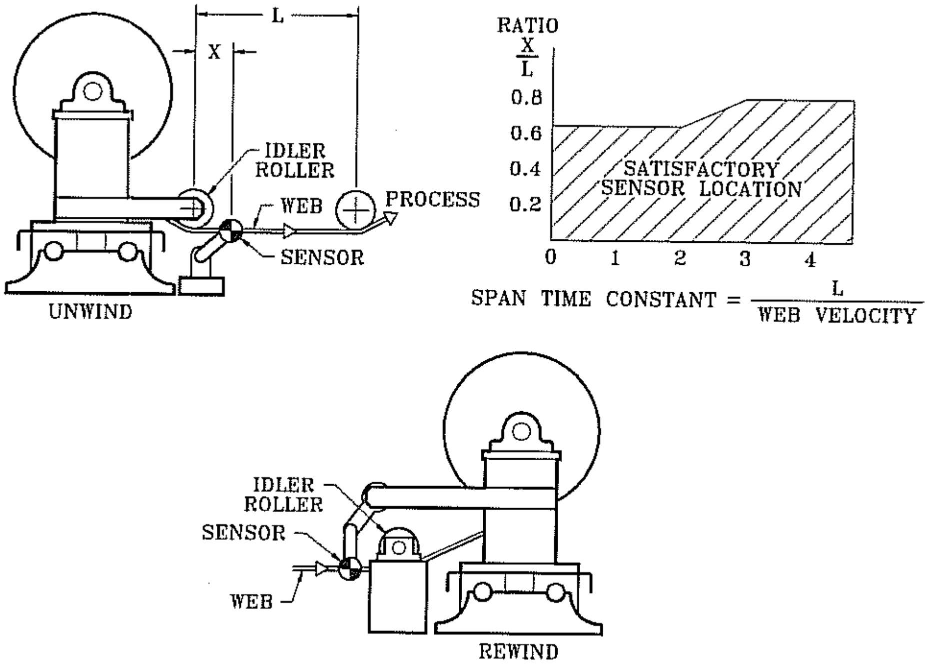


Fig. 13 Sensor Location

Winding Problems

Wound roll defects often blamed on the automatic lateral control system are dishing, coning, and telescoping. These are terms for roll defects where inner layer slippage has occurred.

Winding with low tension leads to loosely wound rolls and is a cause of wrap slippage. Winding with constant tension on a center wind mandrel can lead to wrap slippage. As the diameter of the roll increases, the torque to the mandrel must increase to maintain the constant tension. The increase in torque must be transmitted through the inner wraps to the outer wraps. To transmit the torque, the roll must be wound tight or wrap circumferential slippage will occur as the roll cinches up tight enough to transmit the torque through the wraps. The slippage can be circumferential, lateral, or a combination of both which is most likely.

Wound rolls that have web gauge variations, coating thickness differences across the web, rolls wound with trapped fluids, or wound at high speed entrapping air, all may cause one area of the roll to be wound tighter than another. The layers can then skew slightly during slippage causing a lateral movement of the wraps. The lateral movement is the telescoping seen in the final roll. Sometimes, rolls are wound tight, but due to the radial force on the wraps, the entrapped air, fluid, or coating escapes or extrudes leading to a looser roll. The wraps can then slip.

Another condition occurring in a loosely wound coil is caused by the weight of the outer wraps of the roll on the inner wraps. All of the weight will concentrate on the wraps on the top of the mandrel or, in the case of a surface wound roll, at the point of contact with the drive rollers. As the mandrel or surface drive rollers rotate the roll, a very slight wave front will move in front of the weight concentration.

This wave front is similar to that seen when moving a heavy object on rollers across a carpeted floor. It is due to the weight of the object causing strain in the carpet. In winding, the wave front will also cause the circumferential slippage and cinching to occur.

Therefore, to prevent wrap slippage, the roll must be wound with enough tension to achieve and maintain a tight roll. Using a tapered tension wind starting at the highest possible tension and tapering from that point may prevent telescoping. As the roll diameter increases, the torque will decrease causing the outer wraps to be more loosely wound than the inner wraps. The inner wraps will have less torque to transmit; therefore, there will be less tendency to slip and less telescoping.

By observing the sensor and the roll as it is being wound, wrap slippage can sometimes be seen. As the outer layers are wound on top of each other, telescoping can be seen occurring down inside the roll, well away from the outer wraps. Another indication of slippage in a roll may be scratches on the surface of the product. These scratches may be in the longitudinal, lateral, or diagonal direction on the web. Scratches indicating telescoping will most often be in a diagonal direction. Another method to determine slippage in a roll is by making a straight radial on the end of the roll being wound. If slippage occurs, the straight line will take the shape of a reversed letter "J." The curved portion of the "J" are the wraps that are slipping.

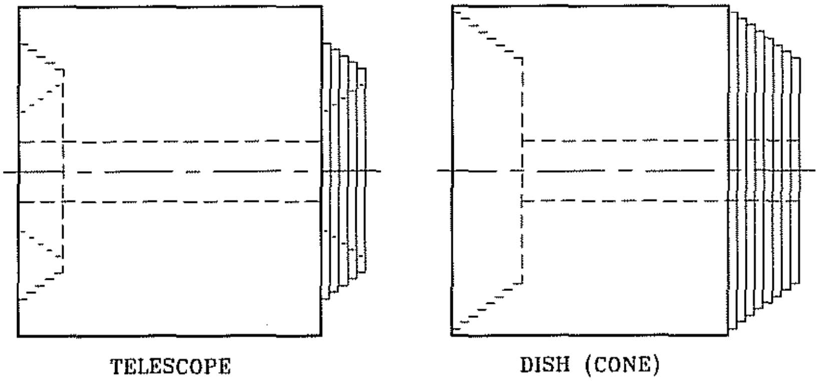


Fig. 14 Roll Defects

Once an unwind or rewind control system has been put into operation and adjusted for satisfactory performance, there are very few components in the system which are subject to change in performance characteristics due to aging.

Should some change in system characteristics be suspected, there are certain items that can be checked. The settings of the guide point and the sensitivity should be checked against those recorded at initial setup. If a substantial change is observed in either setting, these should be restored and the system performance observed. If the sensitivity cannot be restored as high as original, the actuator load points should be checked for wear and looseness. Check all places where mechanical lost motion may occur. In a hydraulic system, check for air in the hydraulic system between the servo valve and the cylinder. Check the hydraulic lines for compliance. If a photoelectric sensor is used, check that correct voltage is being applied to the sensor. Check for dirt on the sensor or reflector. Check that the signal processor power supply is providing the proper voltage. Check for a fouled servo valve.

CONCLUSION

The best control system components and equipment if improperly applied will not give satisfactory results. Therefore, it is highly important that consideration be given to the proper selection and application of control system components. In a production environment, the one thing that should be kept in mind is simplicity of the control system and equipment. More complicated control algorithms can be applied to the lateral control of a web, but in the process, the systems will be harder to adjust and maintain.

By careful observation of unwind or rewind lateral control system problems, solutions can be determined using common sense and a little knowledge of good application practices.

ACKNOWLEDGMENTS

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