TENSION CONTROL WITH AND WITHOUT TENSION SENSORS

by

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ABSTRACT

State feedback has become a widely used method of controlling dynamic systems such as moving webs. In a state controller the present value of all states (i.e. tension, motor speed, and motor torque for each web span) are used to calculate the output of the controller. Since it is not cost effective to measure all of these states, state observers are often used to estimate some of the states. Typically, the state to be controlled (tension in this case) is measured, and observers estimate the other states. It is possible, however, to measure a state other than tension (e.g. motor speed) and generate an estimate of the tension using the state observer. Tension sensors are not needed if this estimated tension is controlled instead of the actual tension.

This paper compares tension control using estimated tension versus tension control using tension sensors. Simulations were run for machines having several nominally identical web spans and nominally identical controllers, motors, and sensors. Since all web spans, motors, etc. are assumed to be identical, tuning parameters were held constant for all simulations. Parameters such as sensor gain were varied from their nominal to study the effect.

Integral feedback was used in all cases. Using tension sensors, the steady state error is dependent only upon the accuracy of the tension sensors. For the sensorless case, steady state error was directly dependent on the accuracy of the torque-measuring device (i.e. torque sensor or torque estimated by the observer), but integral action could not remove all steady state errors.

It is highly desirable that the individual web spans and their associated controls be de-coupled from one another. A decentralized control can then be used for each span. If completely de-coupled, additional web spans will not affect the dynamics of the other spans. Tension control with sensors accomplished this much better than sensorless control. With sensorless control, steady state errors introduced in one span are also seen in all preceding spans. Tension sensors successfully removed such errors. With

sensorless control adding more web spans (and their associated controls) eventually resulted in an unstable system. This was not observed using tension sensor control.

A robust system is one that can tolerate large changes in parameters. Here again, for most parameters control with tension sensors was superior to sensorless control.

NOMENCLATURE

A_j	Cross sectional area of the web in span j (Span j is between roller j-1 and roller j)
d_j	Frictional drag torque on roller j, normalized to R_jF_N
E	Modulus of elasticity
F_N	Normalizing force
f_j	Tension in web span j, normalized to F_N
f_j^*	Reference tension for f_j, normalized to F_N
G_m	Torque gain of closed loop motor control, $T_{rated}/(R_jF_N)$
$\underline{H}$	Vector of observer gains
h_i	The i-th element of $\underline{H}$
K_f	State feedback gain for tension
K_v	State feedback gain for velocity
K_m	State feedback gain for torque
m_j	Torque on motor shaft j, normalized to R_jF_N
M_j	Equivalent mass of motor and roller
R_j	Radius of roller j
s	Laplace transform operator
T_{fN}	Reference tension time constant, (Length of web span)/V_N
T_f	Tension time constant, T_{fN}/v_0
T_m	Torque time constant
T_v	Roll velocity time constant, M_jV_N/F_N
T_{int}	Integrator time constant
T_{rated}	Motor torque at rated motor control input
u_j	Output to motor controller j
V_N	Reference velocity of the web
v_0	Average velocity of the web, normalized to V_N
v_j	Velocity of the web on roller j, normalized to V_N
ε_j	Strain in web j
ε_N	Normalized strain

Barred quantities are measured values (i.e. sensor outputs), and quantities with a caret (e.g. $\hat{f}$) are values estimated by observers.

INTRODUCTION

State feedback has become a widely used method of controlling dynamic systems, such as moving webs. In state controllers the present values of all states are used to calculate the output of the controller. Since it is not always cost effective (or even possible) to measure all states, observers are often used to estimate some of the states using the input(s) and output(s) of the system being controlled. The term "observers" is widely used in the literature for these devices; but some believe (1) that the term "estimator" more accurately describes what is being done. "Observer" implies that the states are somehow being measured, but in fact they are being estimated. However, for the purposes of consistency, the term "observers" will be used in this paper. Typically the state being controlled (tension in this case) is measured, and observers are used to estimate the other states. Wolfermann (2) has made the interesting suggestion that tension sensors can be avoided entirely by measuring other states in order to estimate the tension. The advantage of doing so is not just to save the cost of the tension sensors but also to avoid extra idler rolls. In many cases this advantage is meaningless, however, since very few processes are in a straight line. A typical machine has many idler rolls that are used just to get the web positioned for the next part of the process. Tension sensors can usually be added to one of these already existing rolls.

This paper will compare tension control using estimated tension versus tension control using tension sensors. Specifically, it will examine the sources of steady state error and the robustness of dynamic response (stability) in the face of changing system parameters.

DISCRIPTION OF MODELS

The system being controlled is shown in Figure 1. The three web spans shown will be sufficient for most discussions, but the ideas can be extended to any number of spans. The models used are the same as those used by Reference 2 and use normalized quantities. The tension f_j entering roll j is normalized to F_N. The motor torque m_j and the frictional drag torque d_j are both normalized to R_jF_N. Summing forces and torques on roller j yields

$$sT_v v_j = -f_j + m_j + f_{j+1} - d_j \tag{1}$$

A linear model for longitudinal strain is used. It is the same as the one used in Reference 2 and is given by

$$s(T_{fN} / v_0)\varepsilon_j = -\varepsilon_j + \varepsilon_{j-1} + (v_j - v_{j-1}) / v_0$$

where T_{fN} = (Length of web span)/V_N. The velocities v_j and v_0 (the average web velocity) are both normalized to V_N. Normalized tension is therefore

$$f_j = \frac{F_j}{F_N} = \frac{\varepsilon_j (EA)}{F_N} = \frac{\varepsilon_j}{\varepsilon_N}$$

$$\varepsilon_N \equiv F_N / (EA)$$

The motor control is operated in current feedback mode, and the torque output is therefore given by

$$m_j = \frac{G_m}{(sT_m + 1)} \cdot u_j$$

Gm = $T_{rated}/(R_jF_N)$ is the normalized gain of the motor and its controller.

Each span of the web with its sensors and controls is treated as a separate subsystem as shown if Figure 2. The above equations and Figure 2 show that the states of each subsystem are affected by the strain and velocity of the preceding span and by the tension from the next span. Also shown in Figure 2 is the basic controller for each span. All states are fedback to the controller output along with the integral of the tension error. If sensors are not used for all of the states, state observers can be used; and the estimated states applied to the control in place of the measured states. This is shown, for example, in Figure 3 in which estimated torque is used by the controller in place of measured torque.

SIMULATIONS

In all of the simulations, the webs are taken to be nominally identical and are measured and controlled by nominally identical sensors, controllers and motors. Parameters for the actual webs, sensors, controls, and motors are then changed from nominal in order to study the effect. The values for the state feedback gains K_m, K_v, and K_f, and for T_{int} are those calculated by Wolfermann and Schroeder (3) as providing optimal de-coupling and are shown in Figure 2. Except for observer constants all other system parameters are the same as those used in Reference 3 and are shown in Table 1. In all cases $v_0 = 0.5$. However, changing v_0 had very little affect. For most simulations three web spans will adequately show the required effect. Zero tension is fed into the first span, and the exit tension is zero. Step commands in tension were applied to the three spans as follows:

Span 1: from 0 to 1 at $t = 0$
Span 2: from 0 to 2 at $t = 1$
Span 3: from 0 to 3 at $t = 2$

This will help identify the tensions in the various graphs.

Sensor Errors

Sensor errors of 10% will be introduced into the various systems. Much lower sensor errors are typically achievable, but 10% errors show up well on the graphs.

Tension Control with Sensors, Estimated Torque. Tension control with tension sensors uses the control scheme shown in Figure 3 for each web span. Tension and velocity are measured directly and fedback to the controller. Torque could be economically measured as well (by measuring current); but, in order to avoid giving the impression that extra sensors are required, the simple open loop observer shown will be used to estimate the torque. The controller itself is the same as the one used in Figure 2. The same controller will be used for all control schemes. Note that the control scheme of Figure 3 is truly decentralized. There is no coupling between controllers or between observers in the various spans.

Figure 4 shows the results if there is a 10% error in the tension sensor in span 3. As can be reasonably expected the tension in spans 1 and 2 settle to their commanded values, but the steady state tension in span 3 is 10% below the commanded tension. As in all closed loop systems the quantity applied to the integrator (measured tension in this case) has zero steady state error.

Sensorless Tension Control. Reference 2 suggested several versions of sensorless control. The first two were rejected in that paper for various reasons. The third was characterized as the "realized sensorless tension control"; and its control scheme is shown in Figure 6. Since estimated tension $\hat{f}_j$ is applied to the integrator, estimated tension will be driven to the commanded value. The observer itself is shown in Figure 7 and is the same as the one used in Reference 2. The observer constants (h_1, h_2, and T_h) are those used in that paper. Note that this is not a decentralized control since each observer requires the measured velocity from the prior web span and the estimated tension from the next observer.

Figure 5 shows the results if there is a 10% error in the torque being measured in span 3. The torque sensors in spans 1 and 2 have zero error. Once again the actual tension in span 3 is 10% below the commanded tension. In addition, the tension error in span 3 shows up in spans 1 and 2 as well. The sensorless control cannot correct for errors that occur in any of the spans following it. These errors are therefore cumulative. The disturbance integrator ($1/sT_h$) of Figure 7 ensures that, in the steady state, the estimated velocity $\hat{v}_j$ is equal to the measured velocity $\bar{v}_j$. The steady state estimated tension is therefore given by

$$\hat{f}_j = \hat{f}_{j+1} + \overline{m}_j + 0 \cdot h_2 \tag{2}$$

From equation (1), the steady state value of tension is given by

$$f_j = f_{j+1} + m_j - d_j \tag{3}$$

Since $\hat{f}_j$ is applied to the integrator of the controller $(1/sT_{\text{int}})$, $\hat{f}_j = f_j^*$. Equations (2) and (3) can be combined to give the following expression for actual steady state tension

$$f_j = f_j^* + (f_{j+1} - \hat{f}_{j+1}) + (m_j - \overline{m}_j) - d_j \tag{4}$$

Equation (4) clearly predicts both of the effects shown in Figure 5. Steady state error depends upon both torque measurement accuracy and errors in the next tension. Equation (4) also predicts that frictional drag forces (d_j) will not be corrected by the sensorless control. This will be addressed shortly, but torque measurement accuracy must be addressed first.

High accuracy torque sensors are readily available although they are probably somewhat more expensive than tension sensors of the same accuracy. However, high accuracy torque measurement does not include motor current measurement. A survey by *Control Engineering* (4) lists the torque accuracy of vector drives at 3% and of AC servos at 10%. The accuracy for DC drives is comparable. This is essentially the accuracy of G_m, the motor torque gain. This is clearly inadequate for high accuracy tension control.

Sensorless Tension Control with Estimated Torque. Some might hold out hope that the integrating action of observers might remove the motor torque inaccuracy. The control scheme of Figure 8 tries to do this using the observer of Figure 9. This observer is the same as that of Figure 7 (Sensorless Tension Control), but a model of the motor and its controller has been added along with another observer gain term (h_3) that provides error correction to the motor model. Presumably this term will help correct for motor torque inaccuracy. From Figure 9, the steady state estimated tension using this observer is given by

$$\hat{f}_j = \hat{f}_{j+1} + G_m^e(u_j + 0 \cdot h_3) + 0 \cdot h_2 \tag{5}$$

The superscript "e" is used to denote that this is the value assumed by the estimator. Combining equation (5) with equation (3) gives the steady state tension.

$$f_j = f_j^* + (f_{j+1} - \hat{f}_{j+1}) + (m_j - G_m^e u_j) - d_j$$

Substituting for actual torque gives

$$f_j = f_j^* + (f_{j+1} - \hat{f}_{j+1}) + (G_m - G_m^e)u_j - d_j \tag{6}$$

Comparing equation (6) with equation (4) reveals that errors in G_m have taken the place of errors in torque measurement. Figure 10 verifies this showing the results with a 10% error in G_m in the third web span. The 10% error in G_m results in a 10% error in tension, and the error is still passed forward into all spans prior to it. Furthermore, equation (6) predicts that this control scheme cannot correct for friction errors. Estimating torque has the same errors as measuring torque via motor current (3% to 10%) and will not be considered further.

Friction Errors

The next simulations introduce friction errors into some of the spans. The same step changes in commanded tension are applied as before so that the tension in each span can be easily identified. In addition, frictional drag of 0.1 is applied to various spans as follows:

Span 1 (none)
Span 2 at t = 3
Span 3 at t = 5

Tension Control with Sensors, Estimated Torque. The results for the control with tension sensors (Figure 3) are shown in Figure 11. The friction errors were introduced as just described, but the control has responded to the errors so well that their effect cannot be observed. Just to prove the point, Figure 12 shows the results if the same errors are applied to this system, but the commanded tensions are 0.01 times smaller than the commands previously applied. A friction error 10 times larger than commanded tension is still driven to zero.

Sensorless Tension Control. The results for the sensorless control of Figures 6 and 7 are shown in Figure 13 with command levels back to the original higher levels of 1.0, 2.0, and 3.0. No sensor errors are present. Figure 13 confirms what was revealed by equation (4). Sensorless control cannot correct for errors caused by friction, and such errors are cumulative. Friction errors in span 2 appear in span 1, and friction errors in span 3 appear in both spans 1 and 2. The first span sees the accumulated friction errors of all following spans.

State Observers with Tension Sensors

The above steady state problems with sensorless control are not caused by the use of observers but by the choice of sensors used to generate the estimates. One of the advantages of state observers is that the estimated state is a filtered estimate of the actual state. This advantage can be exploited while still retaining the advantages of tension sensors by using a control scheme such as the one shown in Figure 14. Its observer (shown in Figure 15) estimates tension using using tension error to correct the estimate, and it estimates torque open loop. The most important difference between this observer and the observer for sensorless control is that, with tension sensors, the disturbance integrator ($1/sT_h$) gets its input from $\bar{f}_j - \hat{f}_j$ rather than from $\bar{v}_j - \hat{v}_j$. This ensures that in the steady state $\bar{f}_j = \hat{f}_j = f_j^*$; and steady state error depends only on tension sensor accuracy. This is, of course, the same as if the tension sensor output were connected directly to the controller integrator ($1/sT_{int}$). The observer gains in Figure 15 were selected to filter the tension with a complex pole at 5.0 Hz (damping factor = 0.71). A zero occurs at 5.5 Hz.

Figure 16 shows the results with the same reduced levels of commanded tensions and the same frictional errors as were applied in Figure 12. Note reduced command levels were used once again so that the 0.1 step in drag could be observed on the plot. Compare this to Figure 13 for the sensorless control which uses 100 times larger commanded tensions but the same frictional errors.

Robustness to Changes in Parameters.

The errors discussed so far are the only ones that affect steady state accuracy. Other parameters can affect dynamic performance, however, and are studied next. Only three of the above controls were considered. Sensorless tension control with estimated torque was not considered because of its inherently low steady state accuracy. As before three web spans were used, and parameters were varied one at a time from nominal. In this case, the same parameter variations were applied to all three web spans at the same time. The results are shown in Table 1. The table lists the multiplier that, when applied to the parameter, results in an unstable system. Where entries have the notation of ">" or of "<" the system was still stable at that multiplier but a multiplier greater than 20:1 was considered excessive.

Table 1 also shows relative advantage between the controls with tension sensors and the sensorless control. A "++" indicates a large advantage (>5:1), and a "+" indicates a small one. Both controls with tension sensors have a decided advantage in ε_N+, G_m-, T_v-, T_v+, and T_f+. They both had a slight advantage in ε_N- and T_f-. The sensorless control had a slight advantage only in T_m+.

For the entries marked with an "*", none of the systems become unstable; but the performance of the sensorless control deteriorated badly. For example, Figures 17 through 19 show the results for the three control schemes when the value of ε_N was set to a value of 10 times greater than nominal (i.e. ε_N+). Both of the controls with tension sensors have a clear advantage. Note that ε_N is greater than nominal when E is less than nominal since $\varepsilon_N = F_N/(EA)$. Plots for $T_f+=10$ are very similar.

Stability with Additional Web Spans.

If there were no interaction between web spans or between observers, every web span would have the same eigenvalues. Adding additional web spans and controls would add more eigenvalues to the system, but they would be at locations that already existed. Adding web spans would, therefore, never lead to instability. Figure 20 shows the results if six spans are controlled using sensorless tension control. A unit step of tension was commanded in the first web span at t=0. The actual tensions in all six spans are displayed. The system is unstable! Figure 21 shows the eigenvalues for sensorless control for 1 to 6 web spans. Only positive conjugates with real parts >-120 are shown. The eigenvalues for a system with a single web span are plotted with "o". Those for systems having 2 to 6 web spans are plotted with "x". The plot contains an unstable eigenvalue at approximately 31 radians/sec (5 Hz). This corresponds well with the oscillation of Figure 20.

Figures 22 and 23 show the same plots for systems controlled with tension sensors. All three controls show a progression of eigenvalues from –80+j410 towards the imaginary axis; but, for systems up to six web spans, the worst case damping factor has only decreased from an initial value of 0.199 for one span to 0.168 for six spans. For the controls with tension sensors, the eigenvalues near zero (the offending ones for the sensorless control) do not change at all when web spans are added.

Some skepticism should be applied to these results since it requires calculating the eigenvalues for matrices of order up to 42. We are encouraged, however, by two observations. Firstly, the matrices in question are very diagonalized. Secondly, the progression of eigenvalues is very orderly. The eigenvalues near –80+j410 have a linear progression; and, for the two controls with tension sensors, the eigenvalues nearest to zero do not change at all. This implies that these eigenvalues are accurate. The progression of eigenvalues near zero for the sensorless control is not as orderly, but instability has been verified in this case by simulation (Figure 20).

The most likely reason why the sensorless control becomes unstable with more web spans is that it has more coupling between subsystems. The difference of coupling one more state does not seem significant but no other theoretical explanation has been found.

SUMMARY

Table 2 summarizes the differences just discussed between sensorless control and control with tension sensors.

REFERENCES

1. Franklin, G. F., Powell, J. D., and Workman, M. L., Digital Control of Dynamic Systems, 2nd ed., Addison-Wesley, New York, 1980, p. 240.
2. Wolfermann, W., "Sensorless Tension Control of Webs", Proceedings of the Fourth International Conference on Web Handling, Oklahoma State University, 1997, pp. 318-340.
3. Wolfermann, W. and Schroeder, D., "New Decentralized Control in Processing Machines with Continuous Moving Webs", Proceedings of the Second International Conference on Web Handling, Oklahoma State University, 1993, pp. 96-116.
4. Bartos, F., "Vector Control Competes with Electric Servos", Control Engineering, Vol. 46, No. 2, Feb. 1999, pp. 92-98.

FIGURES AND TABLES

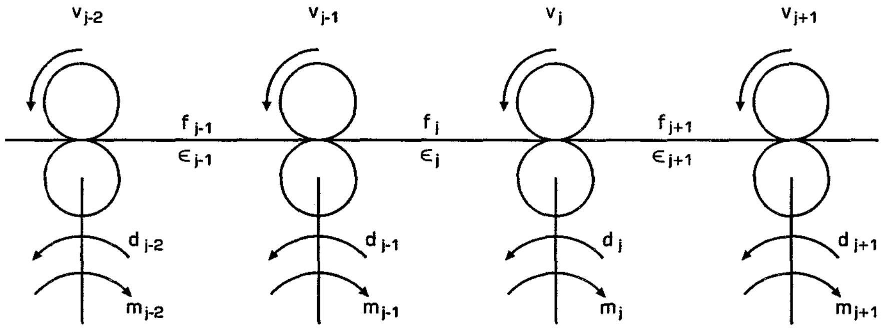

Figure 1
Model of Mechanical System

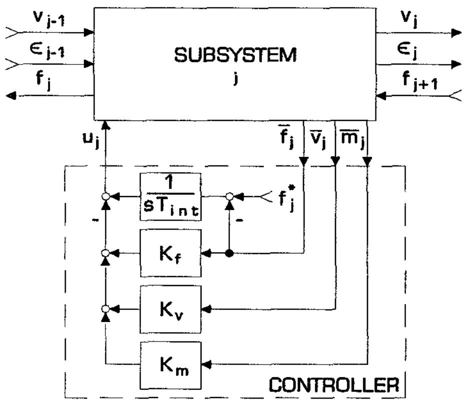

Figure 2
Full State Controller
for a Single Web Span
($K_m = 2$; $K_v = 314$; $K_f = 312$; $T_{int} = 0.6$ ms)

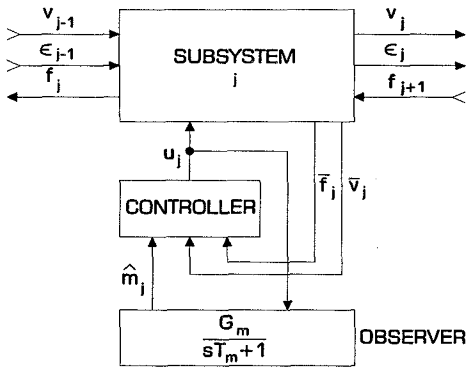

Figure 3
Control With Tension Sensors,
Torque Observer

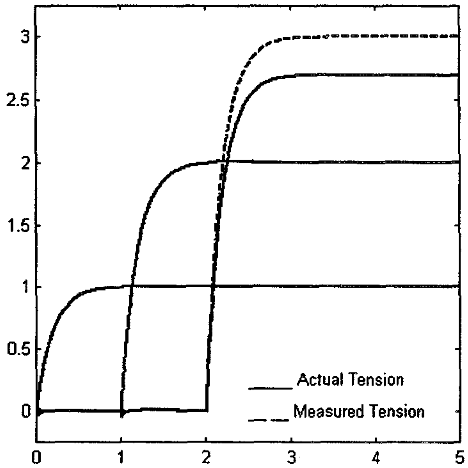

Figure 4
Control with Tension Sensors,
Torque Observer
10% Sensor Error in Span 3 Only

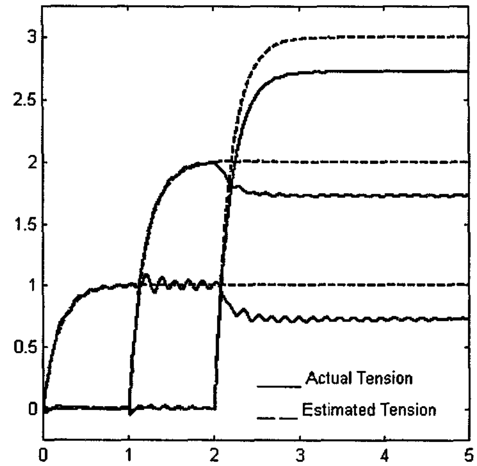

Figure 5
Sensorless Control
10% Error in Torque Sensor in Span 3 Only

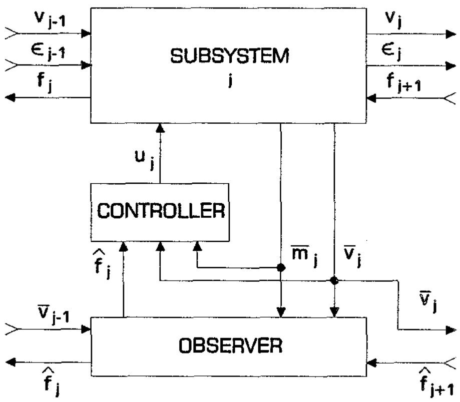

Figure 6
Sensorless Tension Control

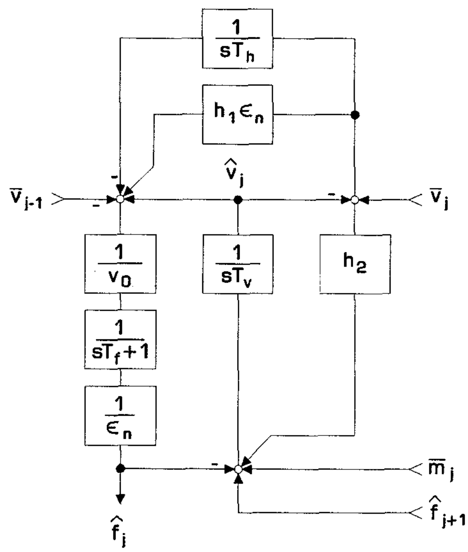

Figure 7
Observer for Sensorless Tension Control
($h_1 = -5.5$, $h_2 = 6.0$, $T_h = 0.316$)

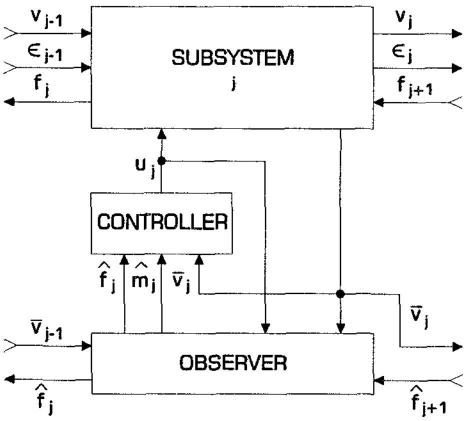

Figure 8
Sensorless Tension Control
With Estimated Torque

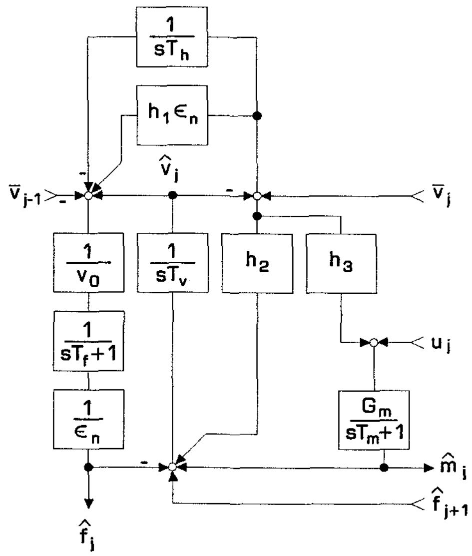

Figure 9
Observer for Sensorless Tension Control
With Estimated Torque
($h_1 = -5.5$, $h_2 = 6.0$, $h3 = 2.0$, $T_h = 0.316$)

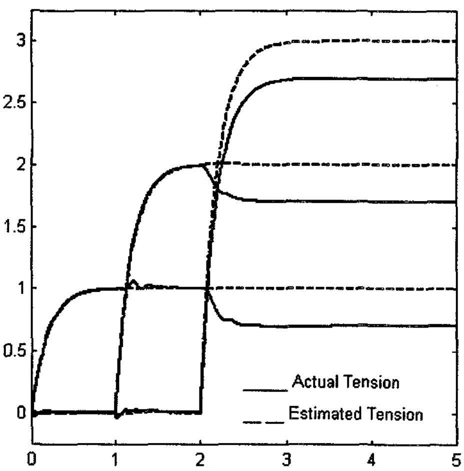

Figure 10
Sensorless Control with Estimated
Torque, 10% Error in G_m in Span 3 Only

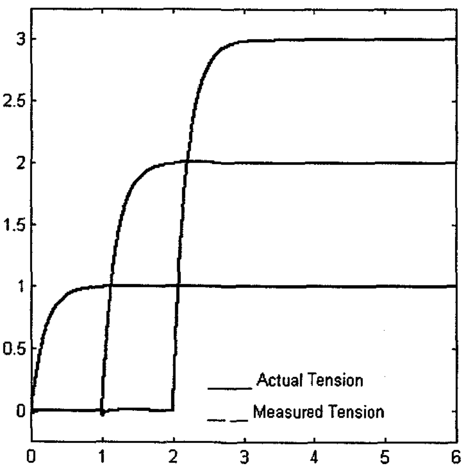

Figure 11
Control with Tension Sensors,
Torque Observer
0.1 Friction Error in
Spans 2 (t>3) & Span 3 (t>4)

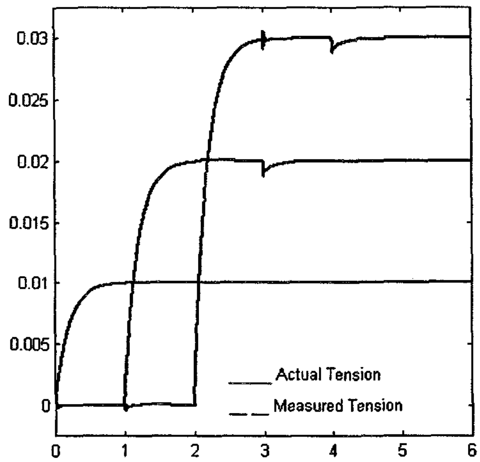

Figure 12
(Reduced Command Levels)
Control with Tension Sensors,
Torque Observer
0.1 Friction Error in
Spans 2 (t>3) & Span 3 (t>4)

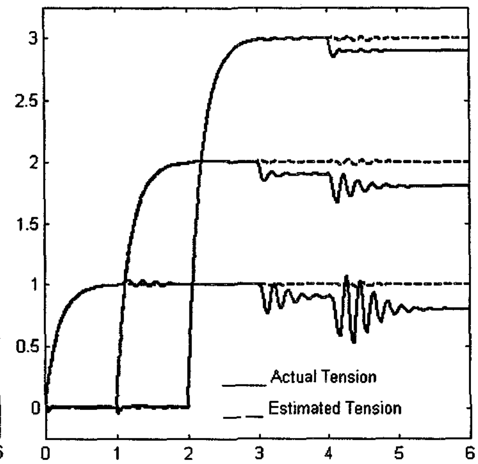

Figure 13
Sensorless Control
0.1 Friction Error in
Spans 2 (t>3) & Span 3 (t>4)

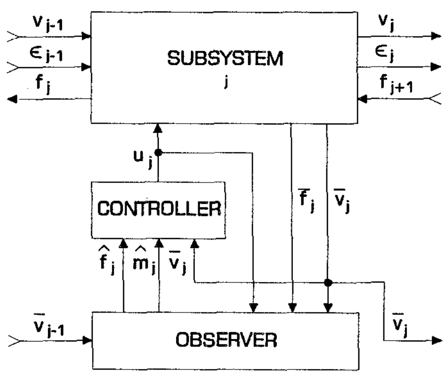

Figure 14
Control With Tension Sensors
and Tension Observer

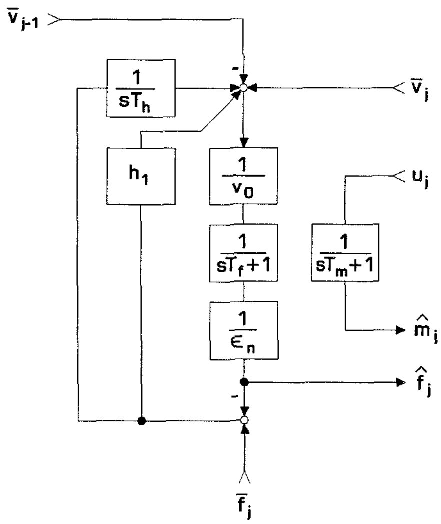

Figure 15
State Observer for
Control with Tension Sensors
(Tension Observer)
(h_1 =0.0851, T_h = 0.517 s)

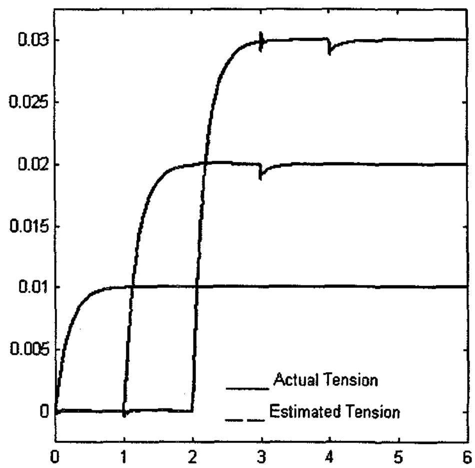

Figure 16
(Reduced Command Levels)
Control with Tension Sensors
and Tension Observer
0.1 Friction Error in
Spans 2 (t>3) & Span 3 (t>4)

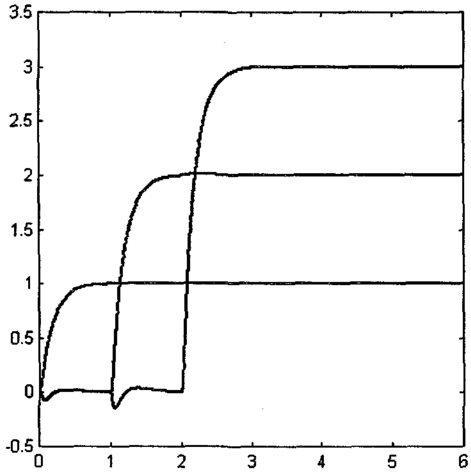

Figure 17
Control with Tension Sensors
Torque Observer
Modulus of Elasticity
10 times lower than nominal

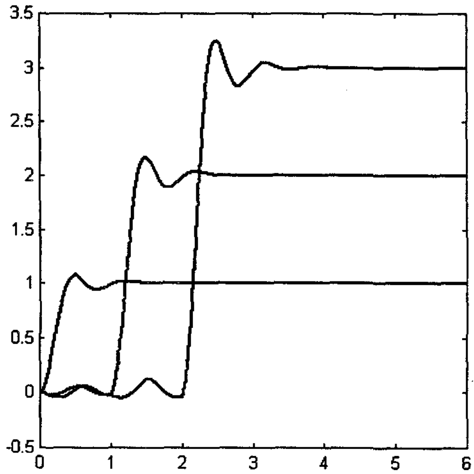

Figure 18
Control with Tension Sensors
Tension Observer
Modulus of Elasticity
10 times lower than nominal

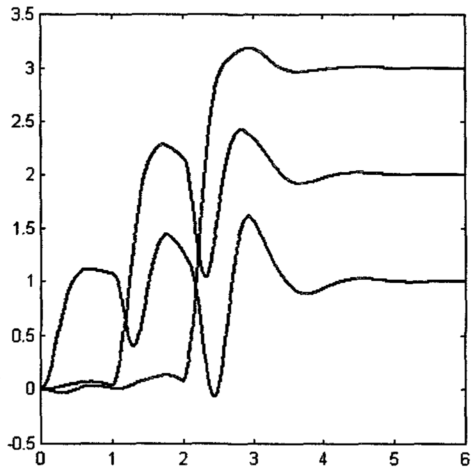

Figure 19
Sensorless Control
Modulus of Elasticity
10 times lower than nominal

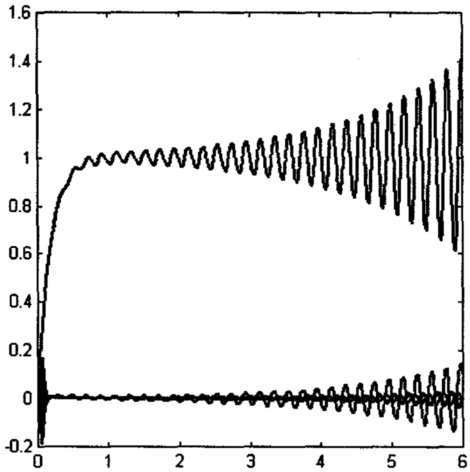

Figure 20
Sensorless Tension Control
Six Identical Web Spans, No Errors,
Step Command Applied to First Span

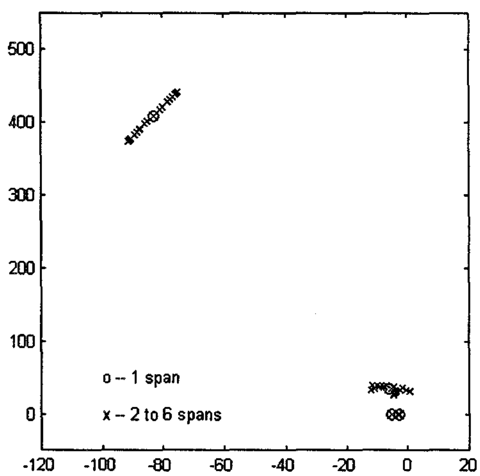

Figure 21
Sensorless Tension Control
Eigenvalues with real part > -120,
1 to 6 Identical Web Spans

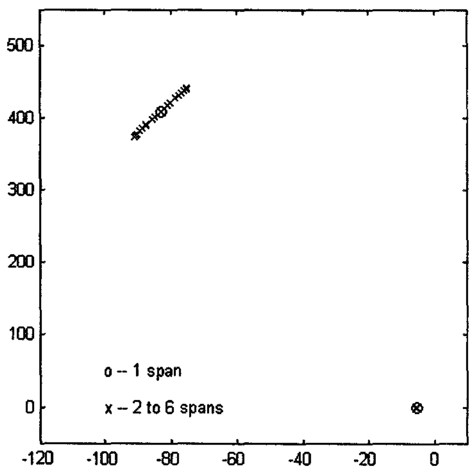

Figure 22
Control with Tension Sensors,
Torque Observer
Eigenvalues with real part > -120,
1 to 6 Identical Web Spans

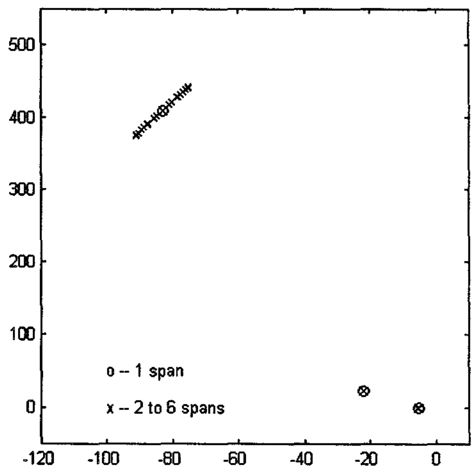

Figure 23
Control with Tension Sensors,
Tension Observer
Eigenvalues with real part > -120,
1 to 6 Identical Web Spans

		Ratio to Nominal that Causes Instability		
	Nominal Values	**With Sensors, Torque Observer (Fig. 3)**	**With Sensors, Tension Observer (Fig. 14 & 15)**	**Sensorless (Fig. 6 & 7)**
ε_N-	0.004	0.46 +	0.21 +	0.50
ε_N+		10* ++	10* ++	10*
G_m-	1.73	<0.05 ++	<0.05 ++	0.32
G_m+		>20.0	>20.0	>20.0
T_m-	3.8 ms	<0.05	<0.05	<0.05
T_m+		1.9	1.9	2.2 +
T_v-	0.415 s	<0.05 ++	<0.05 ++	0.96
T_v+		>20.0 ++	>20.0 ++	2.2
T_f-	0.49 s	0.46 +	0.21 +	0.60
T_f+		10* ++	10* ++	10*

Table 1
System Parameters and Ratio to Nominal that Causes Instability
Control with Sensors vs. Sensorless Control for 3 Web Spans

*Systems remained stable at this value, but the performance of the sensorless control deteriorated badly at this value. See Figures 17 through 19.
++ = Large Advantage (> 5:1); + = Small Advantage

Sensorless Tension Control	Control With Tension Sensors
Needs no extra rollers.	May or may not need an extra roller to measure tension.
Cannot correct for friction. Cannot correct for friction or measurement errors in the next span, and such errors are cumulative.	Accuracy depends only on tension sensor.
Requires high accuracy torque sensor (current measurement or torque estimate are only 3% to 10% accurate).	Requires high accuracy tension sensor.
	More robust to changes in parameters.
	Handles additional web spans better.
Observers provide filtering.	Optional observers provide filtering.

Table 2
Comparison of Sensorless Tension Control and Control with Tension Sensors

M. R. Leonard
Tension Control With and Without Tension Sensors
6/7/99 Session 1 2:15 – 2:40 p.m.

Question - Stephen Krebs, Web Technology
Can you imagine the combination of the sensor and an observer in order to increase or improve dynamics of the tension control?

Answer - M. R. Leonard, Magnetic Power Systems
In this particular case that's not what we saw. The observer can provide filtering but in fact the dynamics of the filter of the state feed back gains are outside the observer. So I don't believe so.

Comment - Stephen Krebs, Web Technology
Usually you have to acquire the tension measurement quickly such that you can setup the observer much faster.

Answer - M. R. Leonard, Magnetic Power Systems
In this case we did use the observer to do the filtering, so we could use the observer for that and get the same response. Notice we did get the same responsiveness as if we did use true measured values.

Questions - Wolfermann, Technical University of Munich
The instability you have in your system is a principle problem if you use a decentralized control and a decentralized observer, because there is an interaction of the observer and controllers. There is no general solution of this problem. You have to find out the poles of the controller. What I didn't understand is you cannot compensate the friction. There are two parameters in the system; one is friction and the other is the elasticity in your system. You don't speak about that; you can't connect the two parameters that are clear, but the friction you can. If you use an indicator in your observer. You can get the forces without an error.

Answer - M. R. Leonard, Magnetic Power Systems
In doing so I give up the ability in changes in modulus of elasticity. Right?

Comment - Wolfermann, Technical University of Munich
Yes, that's right

Comment - M. R. Leonard
There is an alternative and that is giving up the ability to correct for modulus of elasticity. I have also modeled that and interesting enough the model control basically looking like a control that is a simple change in torque. You can command torque change in the model in tension, in fact the tension is additive. You can't command tension span too and expect it to be that. It will be in span 1 plus what you have expanded. So the control ends up acting identically to a system that had torque device. Interestingly enough of all the ones that I have simulated, that particular one has a steady state error based on velocity measurement an error in velocity center. That was the only one that had that. And those velocity state errors ended up being identical to the state errors if you had simple open loop speed control drop out of control; meaning a .01% tension center having velocity

center more or less is .01 of the draw, .01 of the sensor and that ends up being .01 of the EA, ends up multiplied by the modular times cross action area. Acting like open velocity so you can correct for frictional errors but in doing so you open yourself up to velocity errors that are not corrected for and you open yourself up to the fact that you must not have centralized control that is having changes in tension rather than in commanding tension.

Questions - Duane Smith, Black Clawson Co.
You used measured force to solve the problem, maybe with a very slow measurement.

Answer - M. R. Leonard, Magnetic Power Systems
That's what we did in that one case. We didn't use a slow filtered tension, instead we used the observer to filter the tension.

Questions:
We handle highly extensible webs under draw control with tension feed back and setting of the draw by the operator. You say by using a sensor along with an observer meter, whatever you call it, that you have closed loop draw control by this type of very low modulus materials? Is that what your suggesting?

Answer - M. R. Leonard, Magnetic Power Systems
I wouldn't call it draw control in that case, those are two distinct things, it is still tension control.

Questions:
Instead of using draw control in a closed loop system, using a tension transducer and estimator to give you better control than just your draw.

Answer - M. R. Leonard, Magnetic Power Systems
That's correct.