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AN EXPERIMENTAL WEB TENSION CONTROL SYSTEM: SYSTEM SET-UP

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Abstract:
This paper describes the set-up, the technical choices and the preliminary model validation of a new experimental web tension control system composed by four sections and realized by the authors. Interesting considerations about the accuracy of the sensors used and about the applicability of linear models for designing the controller of the system are already shown.

The systems handling web material are very common in the industry; but there exist many sources of disturbance e.g. roller non circularity, roller change, web sliding, change of web-elasticity; due to the strong coupling between web velocity and web tension, these disturbances, introduced by elastic web, are transmitted to the web tension that can result in a web break or fold. For this reason it is very important to realize a laboratory system that can simulate the real behavior of a web transport system for applying the theoretical studies about web handling systems behavior and control.

Key Words: Winding Systems, Web, Tension Control

1. INTRODUCTION

The system handling web material such as textile, paper, plastic, polymer and metal are very common in the industry. Web is usually transported by many drive rollers and idle rollers and it is processed in several consecutive sections such as coating, laminating and printing treatments. Web processing operations contain the functions of both transport speed and tension controls. Since the tension control covers wide range of applications, keen interest has been observed in this area of research over a long time in the industry. The process is composed of many drive rolls connected to motors, guide rolls, and dancer rolls. Then the system is regarded as a large drive system mechanically connected together with the web, which is expected to operate at the demanded variable speed and tension.

The modeling and the control of web handling systems have been studied for several years; in order to design a better control system or to identify the plant parameters experimentally, correct modeling is necessary. On the web dynamics itself, as already discussed by one of the authors [1],[2], lumped parameters expressions may be used to designate a web section between two adjacent drive rolls, but there is the necessity of incorporating the property of visco-elasticity to the web; at this proposal mainly two models [3] are used (Maxwell model and Voigt model). Some experimental system results were recently carried out [4]; but the system designed and developed by the authors has completely different characteristics of complexity

An investigation on the applicability and validation of Maxwell model and Voigt model is already shown in this paper. The validation of the models is attempted by tuning a minimum set of parameters.

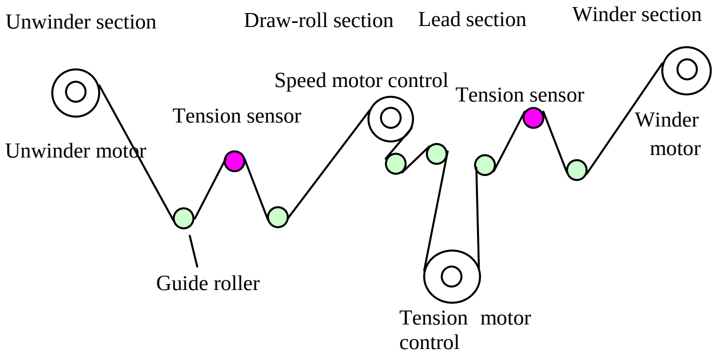

Figure 1: Schematic diagram of the web tension system.

2. WEB TENSION SYSTEM

The scheme of the system that the authors aimed to realize is shown in a simplified manner in Fig. 1 and is a complete set for a web-processing model. The system under investigation is a 4 motors set-up composed by an unwinder section followed by guide rollers that support a tension sensor, a lead section (speed controlled) with S-wrap, a draw roll section followed by guide rollers that support a tension sensor and, finally the winder section.

The experimental system was realized towards the Department of Control Engineering of Kyushu Institute of Technology and is shown in the photo in Figs 2 and 3.

Is possible to note that all the system is mounted on a mechanical frame in order to fix each roller to the skeleton using appropriate pillows; moreover the four motor shafts are rigidly connected to the corresponding rollers by means of universal joints (photo in Fig. 3) in order to avoid slippage of indirect connections (like belts of chain) and are linked to the skeleton using acrylic bolt in order to reduce the vibration (further photos and details in the full paper).

An accurate alignment of the shaft of each motor with corresponding roller has been necessary in the preliminary phase of setting of the system.

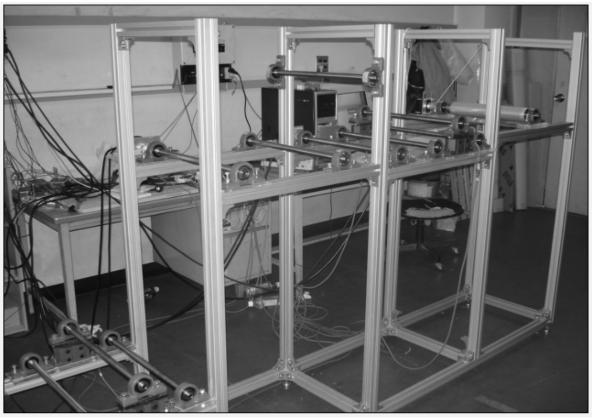

Figure 2: Experimental system.

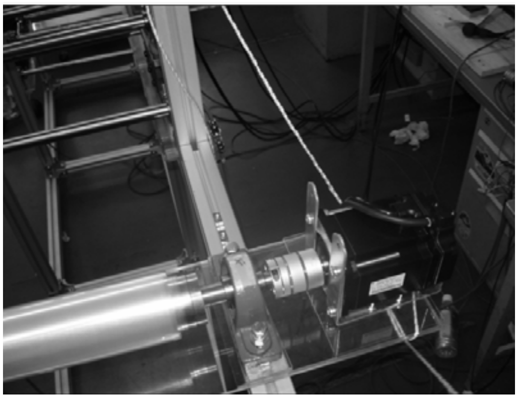

Figure 3: Experimental system: a detail.

3. THE THEORETICAL MODEL

The model developed in this work for the tuning of control system will follow the general lines expressed in [1] and is based on the following laws;

- the law of conservation of mass for the web section for evaluating the relation between the speeds (named v_a and v_b) of two adjacent rolls and the strain ε in the web (Equation 1). For the web of the ordinary two drive rolls, the length L of the span is considered constant, because the strains in general have fairly small values compared to unity;

$$\varepsilon(t) = \frac{1}{L} \cdot \int [v_b(t) - v_a(t)] dt \tag{1}$$

- assuming that the web does not completely slide on the roll, the web velocity is considered equal to the roll linear velocity. The velocity v_k of the k_{th} roll can be obtained through a torque balance in function of the tension forces F_{k+1} and F_k applied to the roll from the web, (Equation 2). ω_k is the rotational speed of roll k, J_k is the roll inertia, r_k is the roll radius, U_k is the motor torque applied to that roll;

$$\frac{d(J_k \cdot \omega_k)}{dt} = r_k \cdot (F_{k+1} - F_k) + U_k \tag{2}$$

- for taking into account the linear viscoelasticity of web-material expressed as combination of linear springs and dashpots, two models were considered and compared in this work; the Maxwell model and the Voigt model [1,2,3]. The relation between the tension force F applied to the web and the strain ε in the Laplace domain is expressed in Equations 3 (Voigt model) and 4 (Maxwell model).

$$F(s) = A \cdot \eta \cdot (\frac{1 + T_v \cdot s}{T_v \cdot s}) \cdot s \cdot \varepsilon(s) \tag{3}$$

$$F(s) = \frac{A \cdot \eta}{1 + T_m \cdot s} \cdot s \cdot \varepsilon(s) \tag{4}$$

where A is cross sectional area of the web, η is the viscosity modulus, $T_m = T_v = \eta / E$, E is the elastic modulus; the Equations (3) and (4) can be expressed in an unified way like in Equation (5) adapting $P(s)$ to the equations (3) and (4) [1].

$$F(s) = P(s) \cdot s \cdot \varepsilon(s) \tag{5}$$

Additional assumptions are taken into account; constant value of the cross-sectional area A of the web for all the system, constant value of the radius of the unwinder and winder section and neglect able effects of guide rolls on the web tension.

Therefore, the model of the system is shown in a block diagram in Fig. 9, where J_{uw}, J_l, J_{dr} and J_w are the total moment of inertia of each roll referred to the motor shaft, L_{uw}, L_l and L_{dr} are the web lengths of unwinder section, lead section and draw roll section, r_{uw}, r_l, r_{dr} and r_w, are the radius of driven rollers in unwinder section, lead section, draw roll section and winder section respectively, u_1, u_2, u_3 and u_4 are the manipulated variable corresponding to the torque control signals (u_u, u_l, u_{dr}, u_w) of the four servomotors used, and y_1, y_2, y_3 and y_4 are the controlled variable corresponding to the unwinder tension (F_{uw}), lead speed (v_l), draw-roll section tension (F_{dr}) and winder speed (v_w).

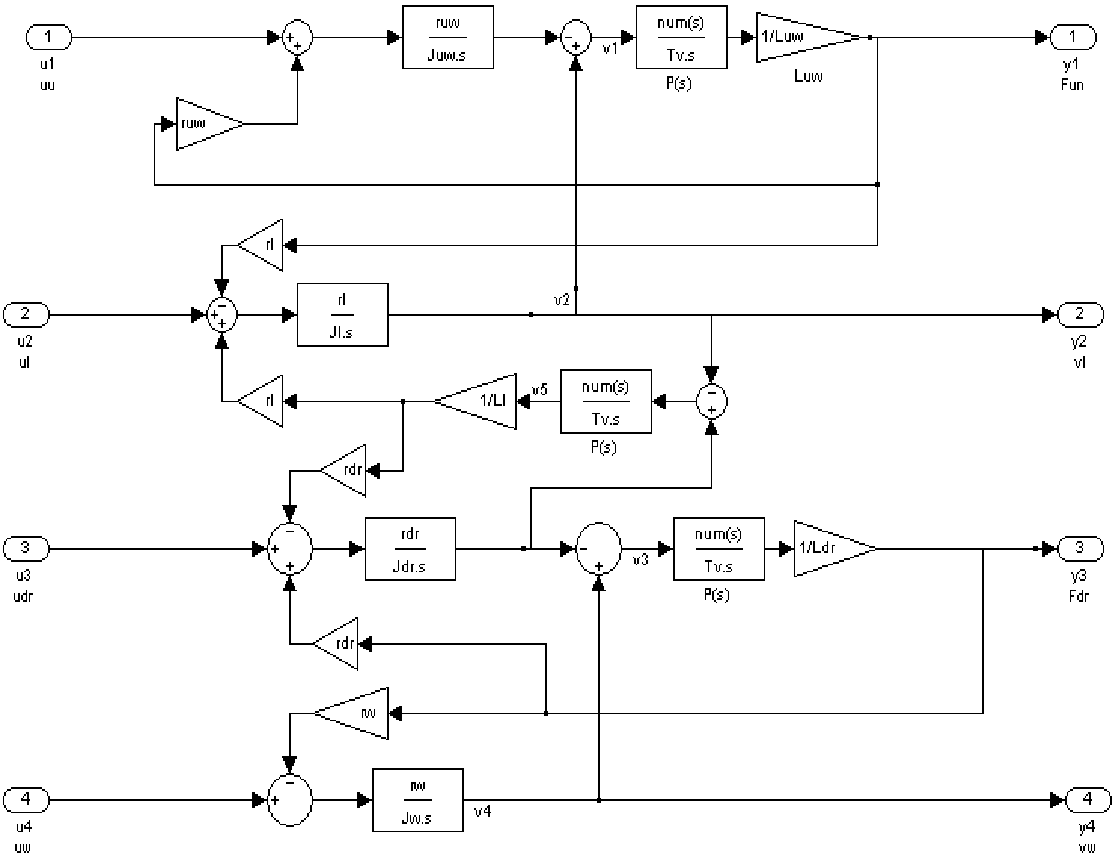

Figure 4: Block model of the system.

4. PRELIMINARY EXPERIMENTAL IDENTIFICATION OF THE THEORETICAL MODEL

The experimental system was initially experimentally identified using acquisition cards and sensors as schematically shown in Fig. 10. The inputs to the system are the torque control signals (u_u, u_l, u_{dr}, u_w) of the four servomotors used; the servomotors are the same type but have different ratings. The servomotors of the unwinder and winder section (model Sgmas-08ACA21 Yaskawa 750 W maximum power), powered [5] by single phase 200 VAC filtered by analogical filter (SCHAFFNER mod FN2070-16-07); the servomotors of the lead section and draw-roll section (model Sgmas-01ACA21 Yaskawa 100 W maximum power) powered by the same type of power supply but with different analogical filters (SCHAFFNER mod. FN2070-6-07). The 4 servomotors are set in torque control mode, and the inner control torque loop is considered immediate compared with the system dynamic in such a way that the torque values are effectively inputs for the system. At this proposal several regulations were made in Servopack set-up in order to optimise the inner control loop. The outputs of the systems are the tension forces measured by tension sensors after the unwinder section and the draw-roll section (termed F_{uw} and F_{dr} respectively, defines as average value of the couple of tension sensors for each section), and the speed measured by encoder mounted on the servomotors for the lead section and the winder section (termed v_l and v_w). In details the tension sensors (model MG010 Nireco) used are placed at each side of the web after the unwinder section and the lead section in such a way to have a double value of tension for each section one referred to the right side and one referred to the left side of the web. The guide roller positioned before and after the tension sensors are necessary for having a definite slope of the web before and after tension sensors [6]. A consistent phase of calibration of the tension sensor was already necessary for studying the repeatability of the measures.

The inputs signals (Fig. 10) are sent to the motors by using a 4 channels D/A board (model PCI 3343 Interface), the tension signals feed a 4 channels A/D board (model PCI 3180 Interface), the 4 motor encoder signals (including the speed signals of unwinder section and lead section) feed a digital counter (model PCI-632206 TK Interface). Several tests were carried out for studying the accuracy of the encoder feedback considering each motor independently from the system.

In particular the possibility of driving the motors in "speed control mode" [5] was used to estimate the behaviour of the motors encoder feedback.

In Fig. 5 is shown the calibration curve for the feedback encoder related to winder motor with a sampling acquisition time of 100 ms and considering the average speed on several samples; the behaviour shows for all the encoder considered, a good linearity.

The noise added to the encoder feedback in the modality "speed control mode" was already analysed (e.g. Fig. 6). In particular in Fig. 6 is shown the digital encoder feedback when a speed of 1900 RPM is requested to the winder motor; the average value is 8746 pulses for each sampling time (100 ms), but a certain oscillation is evident; statistically defined by a standard deviation of 29 (0.3 % of average value).

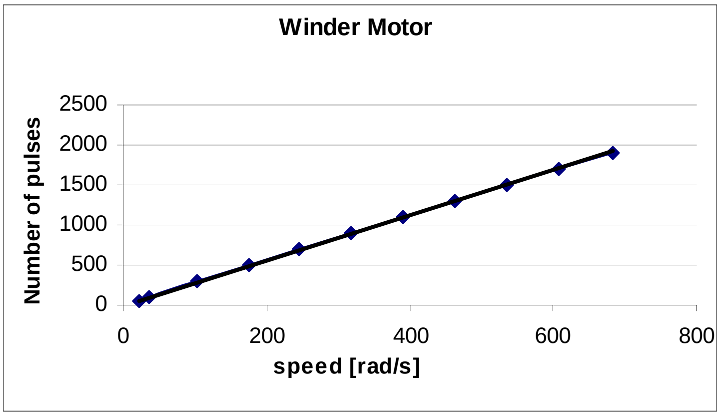

Figure 5: Calibration curve for encoder of winder motor.

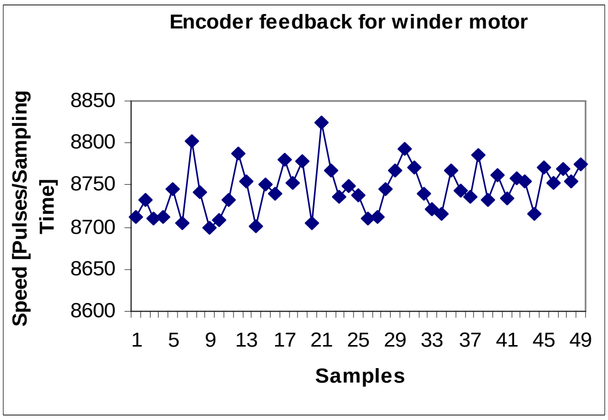

Figure 6: Analysis of the noise added to the encoder.

Similar behaviour was observed for all the speed values used in the calibration curve; in Fig. 7 is shown the percentage standard deviation/average value of all the speed used for encoder calibration for motor 4 in "speed control mode".

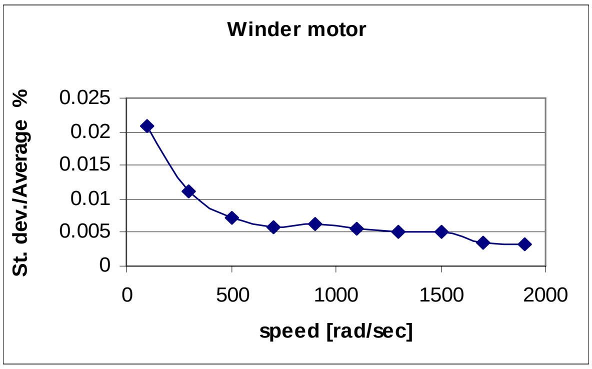

Figure 7: Analysis of the percentage.

The analysis carried out in Figs 6-7 was repeated decreasing the sampling time of the acquisition; but worst results were obtained with a sampling time of 10 ms about the oscillation of digital encoder feedback in a situation of "speed control mode" [5]. For this reason, the sampling time of the experimental tests for the estimations of other parameters of the system model was fixed at 100 ms.

Some digital filter were furthermore tested to decrease the noise of the digital encoder feedback; good results were obtained with moving average filters; in Fig. 8, e.g., is shown the behaviour of the encoder feedback of Fig. 6 with a moving average digital filter applied on 5 samples.

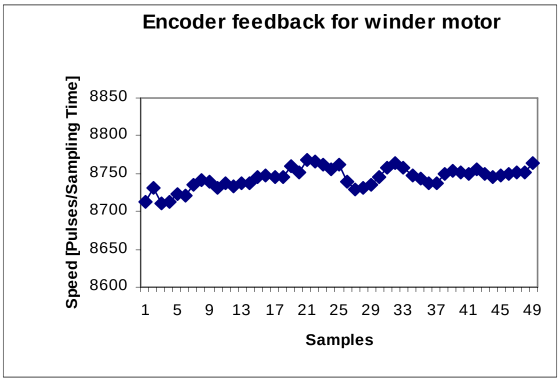

Figure 8: Analysis of the noise added to the encoder feedback with digital filter.

Moreover some tuning parameters are necessary for tuning the models. The parameters of the experimental systems are shown in Table I.

Table I: Data assumed, measured and identified for modelling the system.

Name	Symbol	Value
Total length between winder and unwinder	L [m]	3.15
Unwinder section length	L_{uw} [m]	1.2
Lead section length	L_l [m]	1.02
Draw-roll section length	L_{dr} [m]	0.93
Unwinder roller radius	r_{uw} [m]	0.025
Lead section roller radius	r_l [m]	0.01
Draw-roll section roller radius	r_{dr} [m]	0.01
Winder roller radius	r_w [m]	0.025
Web thickness	T_h[mm]	0.04
Young modulus of the web	E[N/m^2]	109
Web width	W [m]	0.35
Moment of inertia for unwinder	J_{uw} [kgm^2]	0.006
Moment of inertia for lead section roller	J_l [kgm^2]	0.0008
Moment of inertia for draw-roll section roller	J_{dr} [kgm^2]	0.001
Moment of inertia for winder	J_w [kgm^2]	0.006
Viscosity coefficient (Voigt model)	η[Ns/m^3]	10^9
Viscosity coefficient (Maxwell model)	η[Ns/m^3]	10^9

In particular, the moments of inertia, were experimentally carried out (using the experimental set-up previously shown) driving each motor with constant values of torque and estimating the proportionality factor with the angular acceleration (read by encoder feedback) of the corresponding roller. In such a way the inertia of each motor was either included in the inertia of the corresponding roller. An example of this experimental identification for the unwinder motor is shown in Fig. 9.

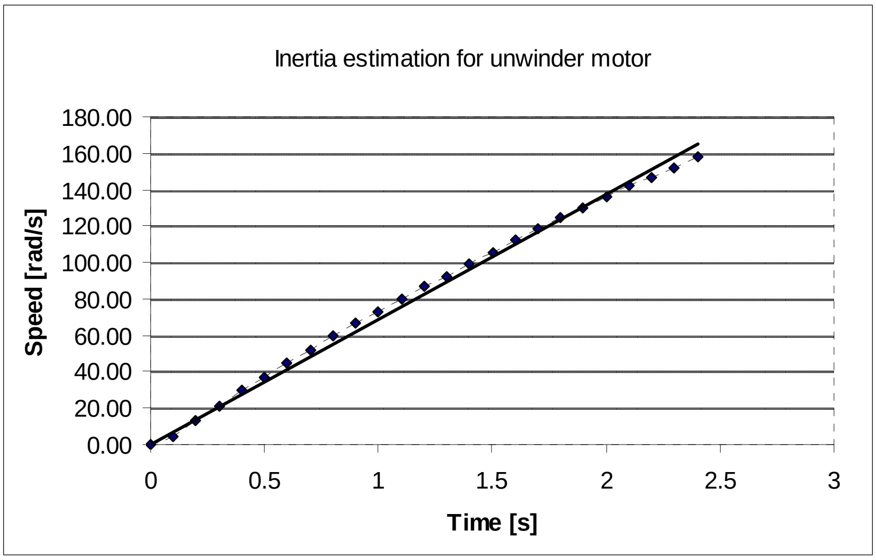

Figure 9: Experimental inertial estimation for winder motor.

Moreover the viscosity coefficient η was estimated minimizing the difference between the experimental behaviour (outputs y_1, y_2, y_3, y_4) of the system respect to a known sequence of inputs (u_1, u_2, u_3, u_4) with the corresponding behaviour of the Voigt and

Maxwell models. One of the result of the comparison between experimental and theoretical behaviour with the estimated viscosity coefficients η is shown in Figs 11 (Voigt model) and 12 (Maxwell model) considering a constant input u_4 of 2.34 Nm and evaluating the draw-roll section force F_{dr} (output y_3). Voigt model and Maxwell models have often in the past used for describing the properties of visco-elasticity of the web.

This is only a first preliminary phase in the modelling the system; no friction torques were considered in this treatment, so not a good overlapping between theoretical and experimental data is expected by the authors for long time tests. This choice is justified from the thing that, in the preliminary phase, several control simulations are necessary to understand if the experimental realised system may be controlled in speed and tension.

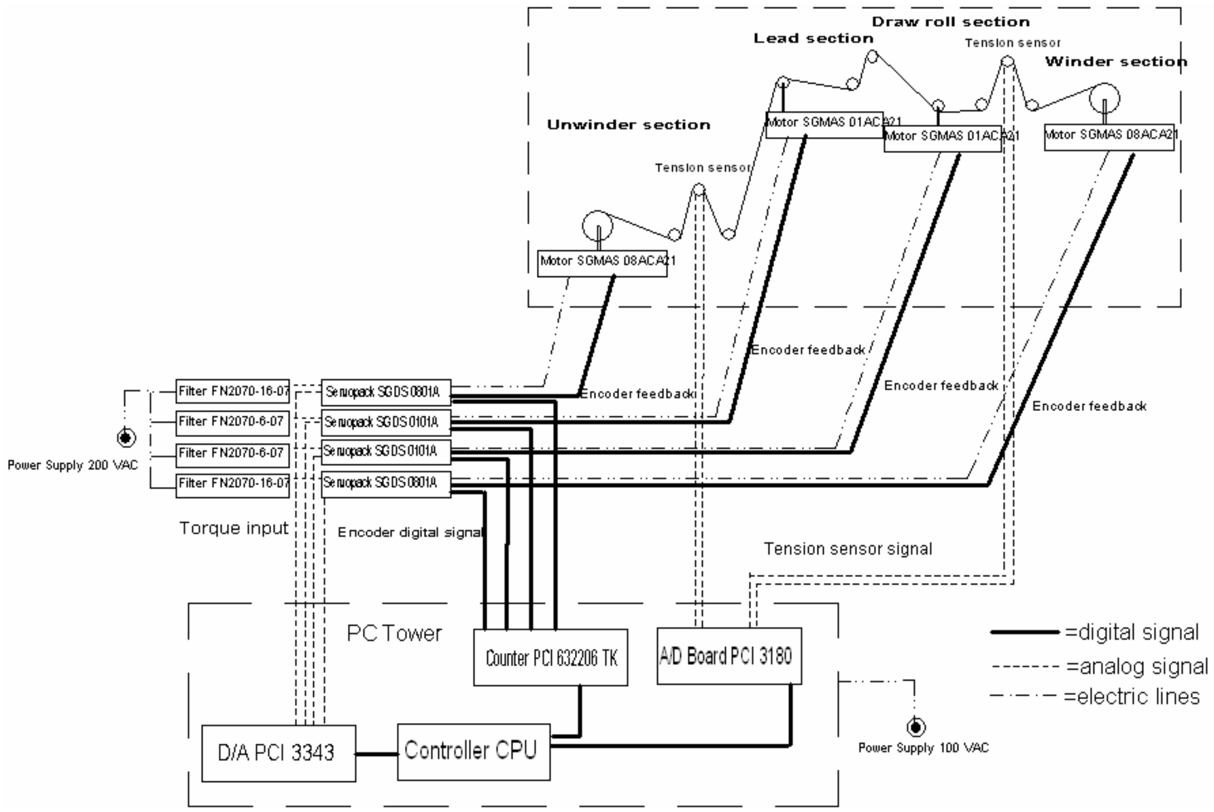

Figure 10: Description of the experimental system.

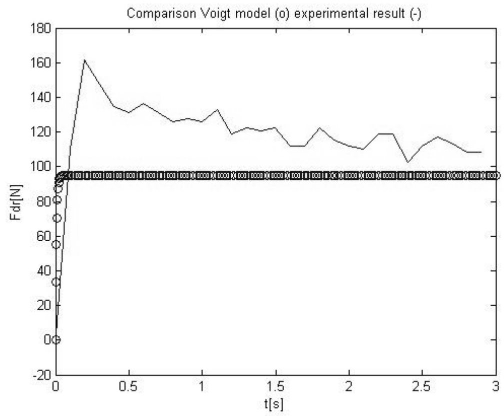

Figure 11: Comparison using Voigt model.

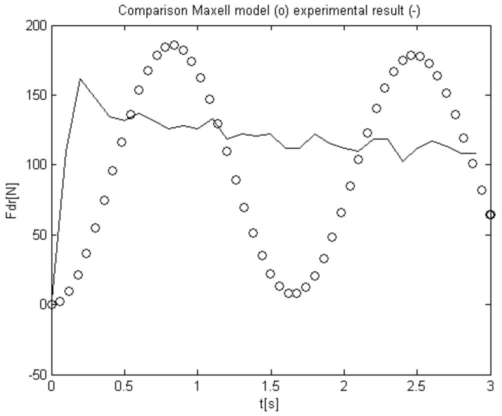

Figure 12: Comparison using Maxwell model.

5. CONCLUSION

The set-up of a new experimental web tension control system has been shown in this paper. The experimental system is characterized by four different sections, high number of rollers positioned at different levels, long way of the web (polypropylene as example) in the different sections. A mechanical support was conveniently designed to mount all the elements of the experimental system.

The main scope of this paper is to show the difficulties and the design choices for realising an experimental complex web tension control system including the commercial elements used for building such a system. A detailed calibration of the

The preliminary model shown in this paper is the starting point to try, from now on, to design a control algorithm in such a way to control simultaneously the web tension (lead section and winder section) and the web speed (unwinder section and draw-roll section).

6. ACKNOWLEDGMENT

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