# Practical Experience with Control of Drives of an Accumulator in a Web Processing Continuous Line

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***Abstract*—The paper contributes to a study of web a vertical type accumulator in a continuous line. It is focused on control of parallel drives driving the looper car and is pointing out key problems the engineer meet at tuning controllers of the accumulator drives. Although the control structure is well known, practical hints to estimate empirically some parameters of the systems are presented. The accumulator mechanics was modelled and simulated results are presented. They are compared with the results obtained by measurement on the real accumulator system. The results obtained by both methods show a good agreement that confirm correctness of the simulation model.**

***Keywords–continuous line; web accumulator control; tension control; position synchronisation***

## I. INTRODUCTION

To ensure constant flow of web materials in continuous technological web processing lines the material running into the line from a coil must be stored in web accumulators. They create an integral part at entry and exit of the line. We devote our attention to the entry accumulator, as the exit accumulator performs a reverse – complementary function.

Our research is concentrated to the vertical accumulator. The entry accumulator accumulates the web material during exchange of the coil on unwinder and on its output it ensures constant speed of the web, regardless variations of the web speed at entry of the line. Two types of accumulators according to the arrangement could be there: the horizontal web accumulator and vertical (tower) one. The second one is subject of our research. Except of the speed control, the drives of the accumulator ensure also tension control in the web, so that the tension on the output from the accumulator is constant, regarding changes in the speed. The control task is relatively simple when theoretically analysed, but in case of practical realization, the specialist has to face a set of problems, e.g. the accumulator drives have to develop the torque consisting of several components: the torque that is necessary to creating the tension, to overcome friction and weight of the accumulator mechanism as well as weight of the web in the accumulator and bending properties of the web material.

The authors in [1-4] present mathematical models of the accumulator. They are concentrated to derivation of a nonlinear simulation model. Different control algorithms for the accumulator drive: PI controller, robust $H_\infty$ controllers and state control with observer, are applied in [5-8]. All the references miss the comparison with a real industrial line and do not mention any practical experiences and problems the engineer must face at commissioning.

Therefore, although this paper starts with describing a model of the system and control of synchronization of the looper car drives and finally it presents practical experience from the real system behavior.

## II. LAYOUT OF A TOWER WEB ACCUMULATOR

Fig. 1 shows an arrangement of the investigated part of the continuous line serving for processing of aluminum webs. The vertical accumulator consists of 4+2 rolls fixed on its bottom part and 5 rolls fixed on a horizontally moving looper car, thus it consists of four loops of the web.

The looper car is moving up and down, depending on the difference of between speeds of outputting and inputting web. Its moving part is indicated in Fig. 1 with darker colour.

## III. POSITION CONTROL OF THE LOOPER CAR

### *A. Description of the Control Scheme*

The looper car is lifted by chains which on each side is driven through gear by a motor. There is mounted a cog-wheel on output of each gear which is belted by a chain. The chain is fixed on the top of the accumulator looper car. Each motor is equipped by the speed sensor on the motor shaft and the position sensor placed on the gear output.

The control structure is shown in Fig. 2. The output of the tension controller is the reference speed, which is corrected by the speed correction consisting of speed difference between the outputting and inputting web. As the looper car is driven by two drives, it could led to a position deviation of one drive against the other. To avoid this, the control structure is usually completed by the looper car position control enabling synchronisation of position of both drives where one of drives works as a master and the second one as a slave, following the position of the first one.

The speed of the first drive of the accumulator is determined by Eq. (1) and at the second drive by Eq. (2):

$$v_{Accu1} = v_{e\_sec} - v_{Process} + \Delta v_{PI\_ten} \tag{1}$$

$$v_{Accu2} = v_{e\_sec} - v_{Process} + \Delta v_{PI\_ten} + \Delta v_{PI\_pos} \tag{2}$$

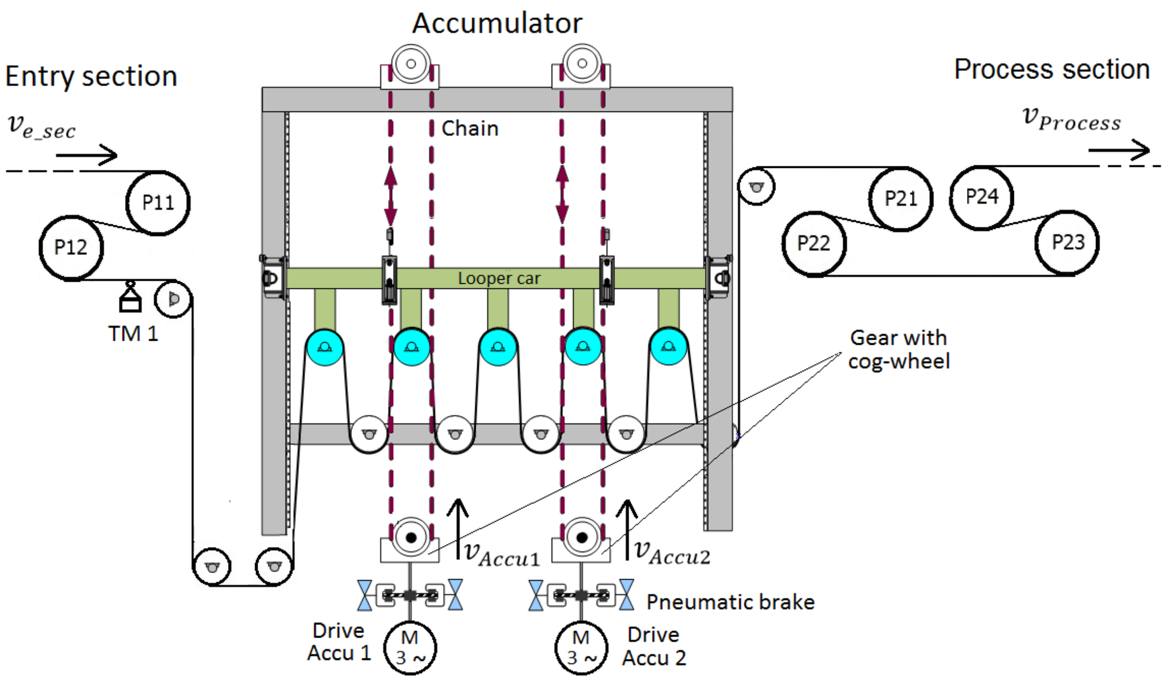



Figure 1. Layout and position of the web accumulator in the investigated continuous line together with linked parts of the line

where:

| | |
|---|---|
| $v_{Accu1}$ | speed of the accumulator drive 1, |
| $v_{Accu2}$ | speed of the accumulator drive 2, |
| $v_{e\_sec}$ | speed of the entry section, |
| $v_{Process}$ | speed of the process section, |
| $\Delta v_{PI\_ten}$ | output from the tension controller, |
| $\Delta v_{PI\_pos}$ | output from the position controller. |

The torque of the speed-controlled drives is limited in order to prevent development of extremely high tension that would lead to failures (web break) or could damage the equipment. The torque limit consists of the following components:

$$M_{Accu} = M_T + M_{Wc} + M_{Ws} + M_{Fr} \tag{3}$$

where:

| | |
|---|---|
| $M_T = F_p R_{oz}$ | torque to create tension in the web |
| $M_{Wc} = M_c g$ | torque compensating weight of carriage |
| $M_{Ws} = l_s w_s t_s \delta_m g$ | torque compensating web weight |
| $M_{Fr}$ | torque compensating the friction |

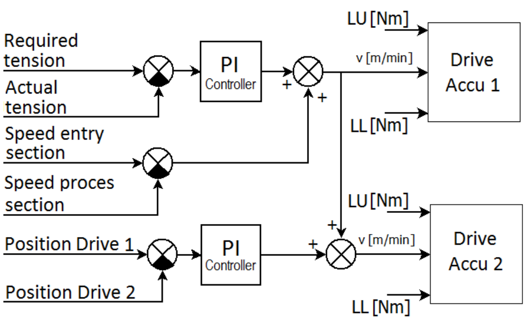



Figure 2. Principal diagram of control of accumulator drives

## B. Measurement of Losses in the Accumulator

The weight of the carriage and the friction value can be estimated by measurement of accumulator loses. This measurement can be done by increasing the speed of the drive in steps. 20 steps are done from zero to nominal speed. The motor is kept during a period of 10 s on a constant speed value and then the actual value of the motor torque is measured. The result of the measurement is a table with 20 values of speed and corresponding friction torque values, which also contain the torque from the carriage weight (see Fig. 3).

When measuring it is necessary to have a database in which desired speed and corresponding torque values are recorded. The value of the measured torque for the given speed presents the value that is added to the motor torque limit.

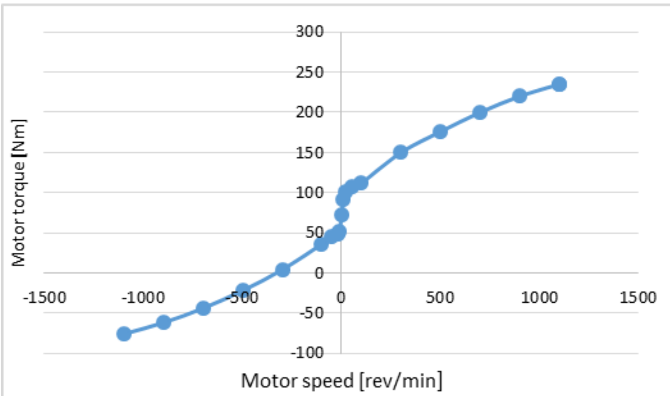



Figure 3. Measured torque-speed characteristic for friction torque and carriage weight torque

Based on this measurement, we can rewrite the equation (3) to:

$$M_{Accu} = M_T + M_{Wc+Fr} + M_{Ws} \quad (4)$$

The motor torque is limited to the tension determined by the equation (4) and increased by 20 %, which is shared by two motors. 20% of motor torque is a torque reserve for the case of acceleration and deceleration, of for the case of improper losses measurement $M_{Wc+Fr}$..

Also, such an increase would not led to breaking the web during dynamic states. Thus, the torque limit of one drive is set to the value of:

$$M_{Accu1,\ Accu2} = 0{,}6\ M_{Accu}\ i \quad (5)$$

### C. Tuning of Controllers of Accumulator Drive System

Basic parameters of the accumulator drive system in the continuous line for processing of aluminium webs, shown in Fig. 4, are: an induction motor (P = 58 kW, U = 400 V, M = 480 Nm, I = 112 A, n = 1150 rpm with the gear ratio i = 303) is equipped by a speed sensor and is supplied by a frequency converter. The accumulator and its drive are designed for the tension range in the web form 6,5 kN to 65 kN.

Figure 4. Drives of the looper car on a real continuous line

Parameters of the controllers were set-up empirically on the site, considering various operating modes. In aluminium industry, the stable tension is considered, varying within the boundary of ±1 %. This was the criterion for the controllers tuning.

The tuned parameters of the controllers are:

- tension controllers: $T_i$ = 1500 ms, $K_p$ = 0,25.
- position controller: $T_i$ = 1000 ms, $K_p$ = 0,2.

Both drives should lift the looper car simultaneously. Any difference in the position of the left and right side of the looper car lead to a mechanically damage of the accumulator mechanics. In the chapter III. mentioned master-slave system is introduced in the drive system and thus it avoids any mechanical problems.

The drives are completed by a pneumatic brake that has to carry the weight (approx. 19 tons) of the mechanism after stopping. For the reason, the carriage would not cause any decreasing at opening the brake (even falling to the ground of the accumulator), the drive must develop the force that is larger than the weight of the mechanism, i.e.

$$M_{Act\_Accu} > M_{Hv+Tr}\ .\ i \quad (6)$$

The drive starts its rotation in both directions by a small positive speed and offset that creates a torque in a positive direction.

If the condition (6) is fulfilled, then the pneumatic brake can be opened and drive accelerates to the required speed. The process of opening the brake are shown in Fig. 5 and Fig. 6.

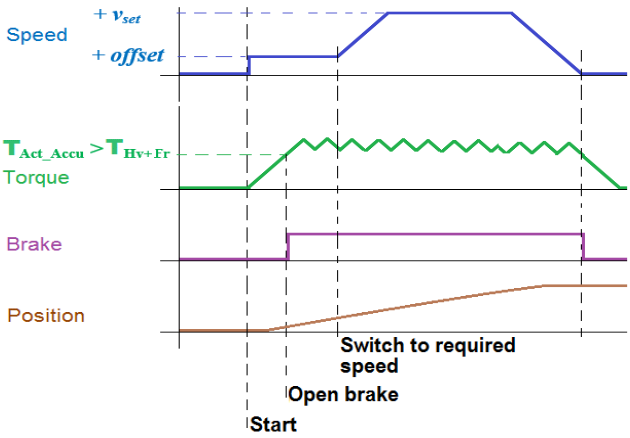



Figure 5. Opening the pneumatic brake of the accumulator when the drive is accelerating the drive to the positive direction

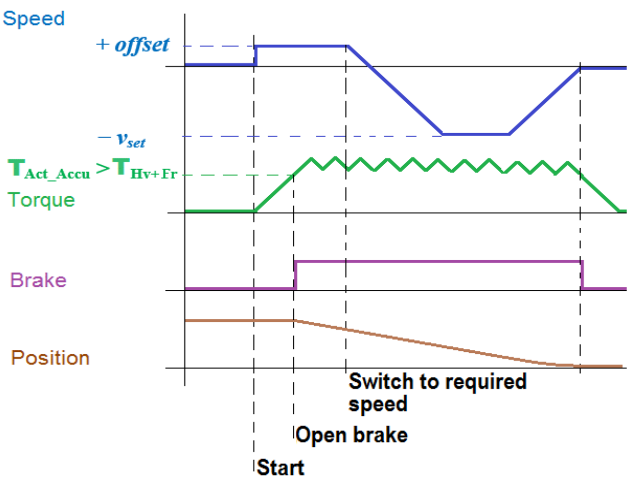



Figure 6. Opening the pneumatic brake of the accumulator when the drive is accelerating the drive to negative direction

## IV. Simulation of the Looper Car Drive System

Fig. 7 shows the simulation scheme of the accumulator mechanics, drive and its control part. The scheme contains a model of the web, model of the looper and model of the accumulator drive. The entry and process drives are not modelled here.

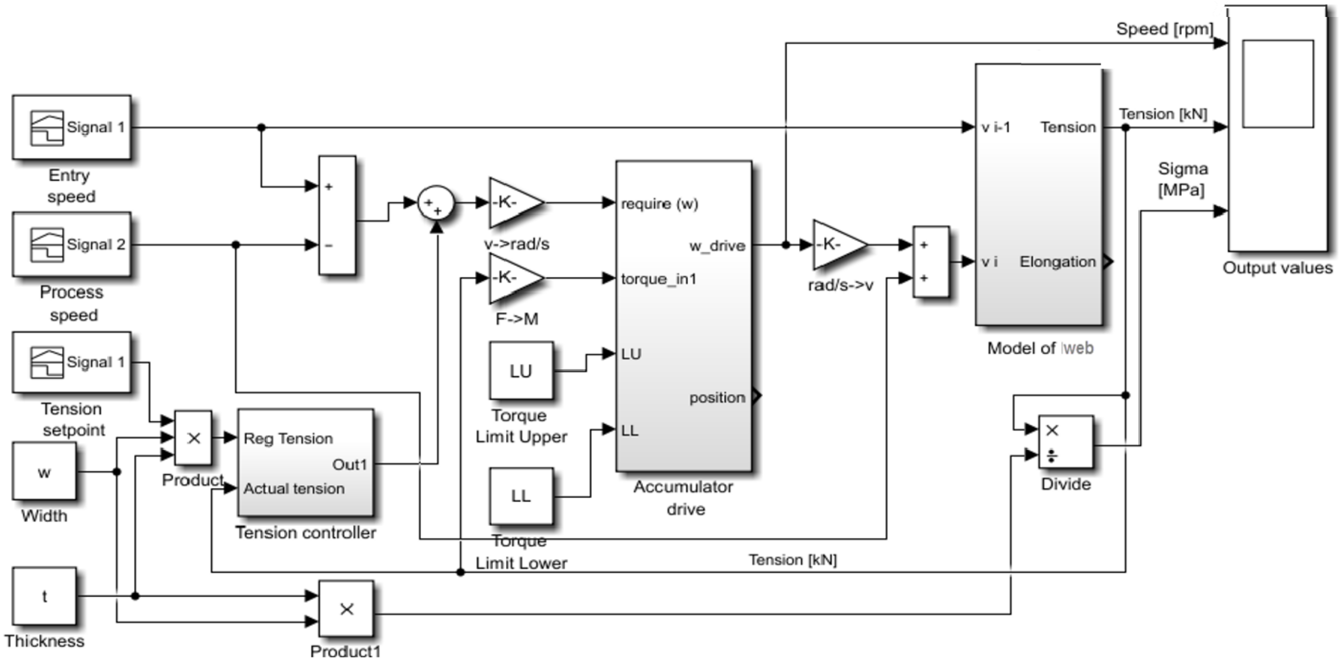



Figure 7. Simulation scheme of the looper car in Simulink

There are ramp generators instead of entry and process drives, which generate the speed of the web inputting into the accumulator and the speed of the web entering the technological process. If the speed of inputting material is higher than that of the outputting material, the accumulator is filling and vice versa. Note, that the parameters of the web model are designed according to the aluminum tensile test.

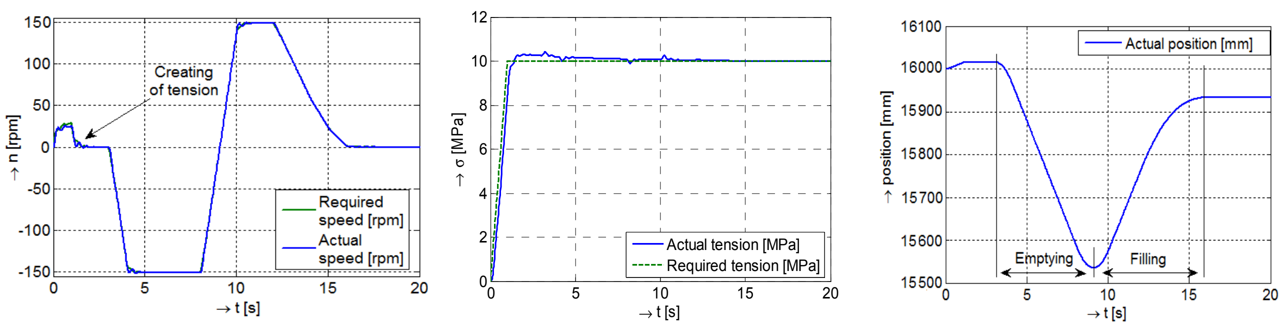
The tension in the web passing through the accumulator is influenced by the speed of the entry section, the speed of the process section and simultaneously also by the speed of the looper car. The elasticity and damping of the web material can be modelled as a linear first order system, but better results are obtained when using a nonlinear model of the web, as published in [8] and [9]. The tension in the accumulator is to be found at the output of the simulation scheme in Fig. 7. Simultaneously, it is led as a feedback into the tension controller. Simulation scheme does not show the compensation of friction and also the compensation of the moment of inertia of rotating parts.

Material dimensions (width and thickness) present input variables in the simulation model, so the simulation model in Fig. 7 can be used various production assortment.

Fig. 8a shows the speed response of the accumulator motor. The tension in the web, which is located in the accumulator, is created at first. The accumulator motor rotates in positive direction what means, that the looper car is lifting and this causes web tension. When the tension is increased to the reference value in Fig. 8b, the motor speed decreases, reaches zero and remains in the standstill.

The position of the looper car is shown in Fig. 8c. When the tension is created, the accumulator is filling. The position of the car is changing from 16,0 m to 15,5 m. Afterwards, the accumulators begins to empty. During the whole operation of filling and emptying the tension in the web is stable.

The described mode of operation was adjusted due to reason of easy comparison the simulation results with the time courses obtained from the real system, as shown in Fig. 9.




a) b) c)

Figure 8. Time courses of accumulator drive in dynamic state at filling and emptying the accumulator storage
a) Speed of the drive, b) tension in the web in the accumulator section, c) position of the carriage

## V. Experimental Results

The control structure is implemented into the control system and the controllers were tuned at commissioning of the continuous line. The line was designed for processing of aluminium webs. It contains entry and exit accumulators and in the process section there is annealing furnace. Tension control systems of its sections was described in [7] and [8].

After debugging the control program, the time responses shown in oscillogram in Fig. 9 were measured. Note, that the real position of the looper car in the line corresponds to the position from simulation if Fig. 8c. The nomenclature of the recorded signals is shown in Table 1. At first, the accumulator is emptying from the position 16 080 mm to the position 15 800 mm (the signal *p* denoted as EACCU_ActPos[mm] ). This is the case when the web in the entry part is slowing down or stops and the web in the process part is moving by constant speed. Then the accumulators starts to fill in as it is the case when the entry part of the line speeds up.

The tension is kept on a constant value 10 MPa (the signal σ = TM 1 ActTen[N/mm2] ). The drives of the accumulator receive the speed reference in the range -200 to 300 rpm (signals n1 and n2, EACCU SetSpd[rpm] ). The speed of the looper car is given by difference of the speed in the entry and process sections and is influenced by the tension and position controllers. The position difference between the first and the second drive ($\Delta p$ = Error EACCU Pos M1-M2 [mm] ) is also shown in Fig. 9. The highest difference is 0,6 mm.

TABLE 1 Nomenclature to Fig. 9.

| | | |
|---|---|---|
| $n_1$ | EACCU1 ActSpd [rpm] | - Actual speed of the first drive M1 |
| $n_1$ | EACCU1 SetSpd [rpm] | - Speed reference of the first drive M1 |
| $n_2$ | EACCU2 ActSpd [rpm] | - Actual speed of the second drive M2 |
| $n_2$ | EACCU2 SetSpd [rpm] | - Speed reference of the second drive M2 |
| $p$ | EACCU1 ActPos [mm] | - Actual position of the first drive M1 |
| $p$ | EACCU2 ActPos [mm] | - Actual position of the second drive M2 |
| $\sigma$ | EACCU_Set_Ten [N/mm2] | - Reference of tweb tension in accumulator |
| $\sigma$ | TM1 ActTen [N/mm$^2$] | - Actual tension in web in accumulator |
| $\Delta p$ | Error EACCU Pos M1-M2 [mm] | - Difference between position of M1 – M2 |

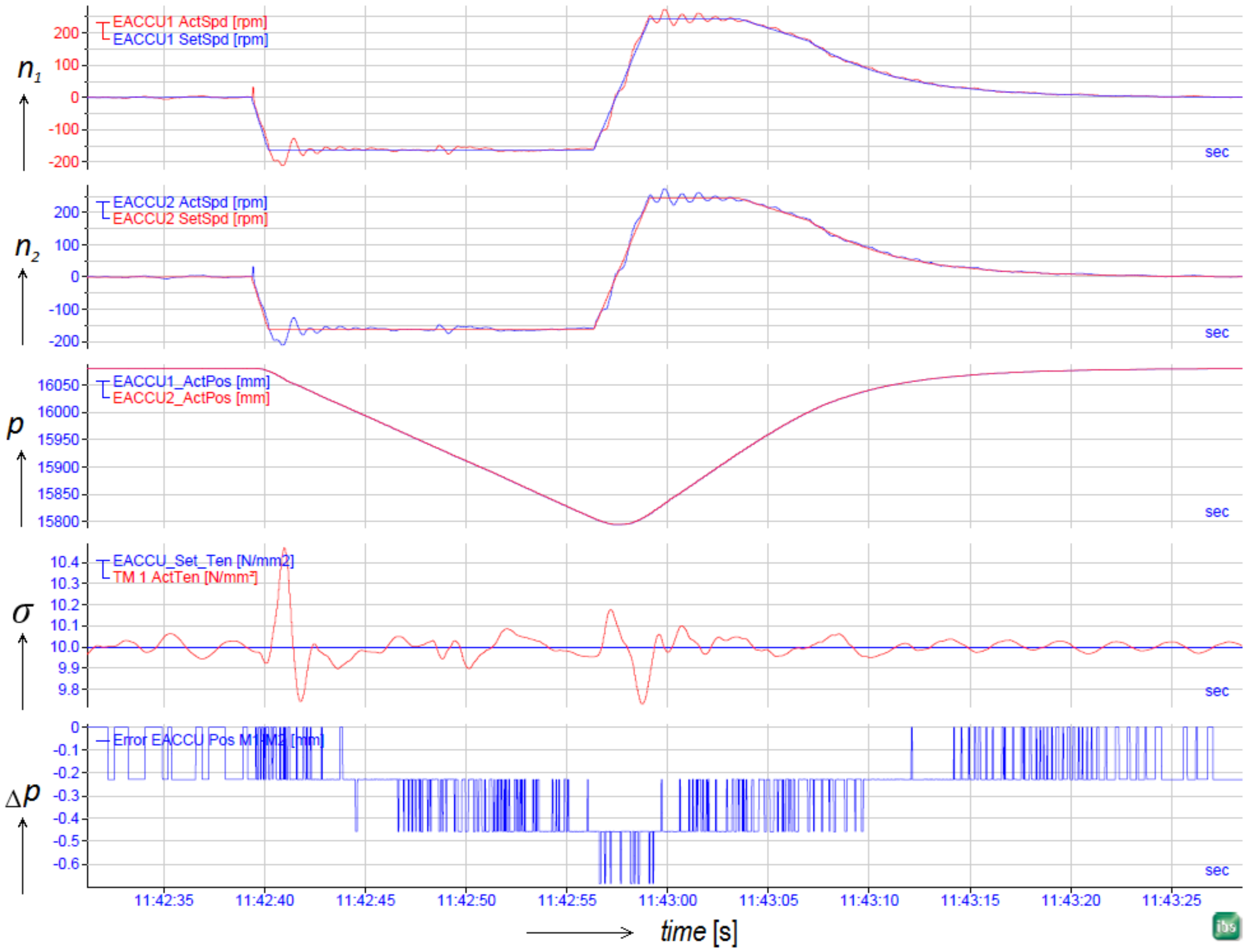



Figure 9. Time courses of the variables at the accumulator filling up and discharging

## VI. Conclusions

The paper analyses dynamic behaviour of the looper car in a vertical entry accumulator of a continuous web processing line. The storage of the web is created by multiple loops which lengths are changed by lifting the looper car.

Based on principle of tension control of the web inside the accumulator at variable speeds of the inputting and outputting web and the speed of the looper car in accumulator and considering also a nonlinear model of the web a simulation model of the accumulator part is developed. The scheme enables to simulate various operating modes – creating the tension, filling and emptying the web storage. According to the simulation model the similar control structure for a real technological line was developed and realised. The measured results from the real system were compared with those obtained from simulation model and a good agreement was obtained.

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