# Tension Controllers for a Strip Tension Levelling Line

**Daniel Magura, Viliam Fedák, Padmanaban Sanjeevikumar and Karol Kyslan**

**Abstract** Strip material processed in continuous production lines causes a mechanical coupling among tension rolls driven by a multi-motor drive system. Thus, the drives are mutually mechanically coupled and influenced in their operation. One of the key techniques, to guarantee the output product quality in the fibre, paper, plastic and metal plating industries, consists in controlling the strip tension on a preset value that should be set differently for each section of the line. This paper describes two newly developed types of tension controllers: a tension controller with the ramp and a stepper tension controller, which are suitable for the line sections with high and low level of the tension, respectively. The proposed controllers were verified experimentally on a real tension levelling line.

**Keywords** Tension controller · Stepper controller · Ramp generator

D. Magura
BWG k.s., Prešov, Slovakia
e-mail: daniel.magura@gmail.com

V. Fedák · K. Kyslan
Department of Electrical Engineering and Mechatronics,
Technical University of Košice, Košice, Slovak Republic
e-mail: viliam.fedak@tuke.sk

K. Kyslan
e-mail: karol.kyslan@tuke.sk

P. Sanjeevikumar (✉)
Department of Electrical and Electronics Engineering,
University of Johannesburg, Auckland Park, Johannesburg, South Africa
e-mail: sanjeevi_12@yahoo.co.in

P. Sanjeevikumar
Research and Development, Ohm Technologies, Chennai, India

 
A. Konkani et al. (eds.), *Advances in Systems, Control and Automation*,
Lecture Notes in Electrical Engineering 442, https://doi.org/10.1007/978-981-10-4762-6_4

# 1 Introduction

During technological process in strip processing lines, the processed material changes its mechanical properties. Strip causes mechanical coupling of motors, and thus, they are mutually influenced in their operation. In manufacture and processing of continuous strips such as paper products, plastic films, metal foils and rubber profiles, it is important to maintain the tension and the speed of the strip at the set point values between consecutive pairs of driving rolls. In order to achieve required quality of the outgoing strip, the tension in the strip and its elongation in each line section should be kept within specified, preset boundaries. Unprecise tension control may result in deterioration of the material quality, strip deformation or even in a strip breaking.

From the technological point of view, the tension in the strip should be kept at constant, preset value, regardless variations of the strip speed. Several control methods to keep the constant tension are known, [1–6]. The authors in [1] present the tension control using PI controller, where variable parameters of the controller are calculated according to the diameter of the rolls, inertia and strip speed. In [2], a strip tension controller based on feedback information about the position difference between two rollers is proposed. The tension controller is implemented in parallel with the speed controller and improves dynamic reaction to changes in the strip tension.

Complex systems usually require the involvement of fuzzy tension controllers, but for users it is troublesome to modify the table of the fuzzy controller, [3]. The authors [4] have published a methodology for a self-tuning fuzzy controller, in which the control parameters can be changed so that the whole system has sufficient stability and performance in the presence of variable system parameters or structure uncertainty. Some methods, based on implementation of observer techniques replacing tension transducers, were published in [5, 6]. Such solution is suitable for low-cost applications. The authors [7] have realized a control algorithm for continuous line designed on the basis of the II. Lyapunov method in laboratory environment.

One of the key problems in processing the strips is to get flat-rolled products of high flatness quality. Strip shape equipment—flatteners or levellers—generally presents the heart of most manufacturer's or service centre's coil processing lines [8]. The quality of unflattened strips can be improved in strip tension levelling lines, the main part of which is a tension leveller [9].

The goal of this paper consists in presenting two developed tension controllers, which can be used in various applications of the direct strip tension control: for the line sections with high tension, a tension controller with the ramp was developed, and for the line sections with low tensions, a stepper tension controller is introduced. The operation of both controllers has been verified practically at experimentation on a strip tension levelling line for aluminium sheets.

## 2 Description of the Strip Levelling Line

A tension levelling line is divided by material storages into three parts (Fig. 1) containing the following machines:

- Entry section:
  - Uncoiler(s),
  - Side trimmer,
  - Strip connecting station (joiner).
- Strip processing section:
  - Annealing section (oven),
  - Tension leveller—Levelflex,
  - Cleaning section.
- Exit section:
  - Inspection table,
  - Drum shear,
  - Recoiler(s).

Arrangement of the machines in the line (arrangement of working and transport rolls) depends on application and customer requirements: some machine changes directly mechanical properties of the strip material (e.g. at annealing, or in rolling mills), the other ones deal with the surface treatment (cleaning—pickling, galvanization, zincification, coating, straightening, etc.), or serve for manipulation of the processed strip—its transport, loading the strip into the line, accumulation/storage of the strip, connecting its endings, cutting the strips, etc.

The rolls and the working machines are mutually bounded by the processed strip. From the technology of strip processing, it follows that a different tension in the strip is required in each from the line sections.

In the analysed line, the block "Technological Process" in Fig. 1 contains a part of the line with an annealing oven because during cold rolling (prior entering the

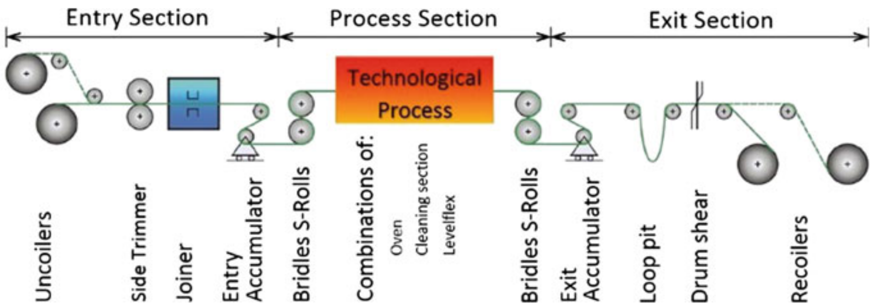



**Fig. 1** Diagram of a continuous strip levelling line

strip into the analysed line), the aluminium strip solidifies, has residual stress and must be annealed to regain its formability for further processing.

From the point of view of tension levelling technology description, it follows that there are two types of the line sections: high strip tension and low strip tension. For each from these categories, we have developed a special tension controller:

(1) The sections in which tensions in the strip reach the highest values (high tensions) which are necessary for getting the strip with the high flatness. Such sections usually occur in the entry and output sections of the line (in case of aluminium strip having the tensions of $\sigma$ = 5–10 MPa) and in levelling section (with very high tensions of $\sigma$ = 15–70 MPa) consisting of a roller levelling device and bridles (tension rolls). The designed tension controller is described in the Sect. 3.2.
(2) The sections with low-level tensions (low tensions) what is the case of a technological section inside (in our case an annealing oven with a long length section—about 100 m, where the strip is supported by hot compressed air and the tension reaches values round $\sigma$ = 1 MPa). The designed tension controller is described in the Sect. 3.3.

Proposed structures of these tension controllers were successfully implemented for the control of tensions in the line sections of a strip levelling line produced by company BWG.

## 3 Tension Control

The basic formula used for calculation of a required strip tension is based on the relationship between the tension $F_p$ acting on the roll on the motor torque $M_T$ [8]:

$$M_T = F_p \cdot R \tag{1}$$

where $R$ is radius of the tensional roll.

Except of the torque $M_T$ causing the tension in the strip, the total motor torque consists also from the acceleration component $\left(J\frac{\mathrm{d}\omega}{\mathrm{d}t}\right)$ and friction component $(M_{Tr})$.

When considering the gear ratio $j$ for creating the required tension $F$, the motor must develop the torque:

$$M_M = \frac{1}{j}M_T + \frac{1}{j^2}J\frac{\mathrm{d}\omega}{\mathrm{d}t} + M_{Tr} \tag{2}$$

Having to disposal measured mechanical losses and moment of inertia of each drive in the line then, in an ideal case, the actual value of the tension should correspond to the required value of the tension in the section between the working rolls [10].

Of course, in the praxis it is impossible to measure nor to obtain mechanical losses (depending also on the strip speed) within the whole speed range and simultaneously also to consider the temperature of the motors and the environment, material friction nor friction in the bearings. For this reason, to control the strip tension, the tension controllers are used.

## 3.1 PI Tension Controller

At first, let us consider dynamical properties of a classical PI tension controller presenting the simplest controller that is often used in the tension control circuit. Its advantage consists in its easy implementation—it is usually implemented in the library of each digital control system, and thus, one does not need to program it. The controller can be set up and tuned directly on place at commissioning of the line. Its tuning does not require any extra burden but sometimes it is necessary to modify or adapt the controller parameters according to variable speed of the strip and/or for various materials of different quality and cross sections.

Another problem the PI controller meets presents an oscillating value of the tension signal on its input, which is measured or estimated from other process variables. This also causes oscillations of the PI controller output value which gives rise to undesirable oscillations that are led into the motor torque limiter. In praxis, we try to avoid using a classic PI controller with constant parameters for the control of the strip tension. It is more advantageous to use developed simple tension controllers, as presented in this paper.

## 3.2 Tension Controller with Ramp Generator

We use this kind of controller for controlling the high tensions in the strip. These occur in the straightening section of the line in Fig. 2.

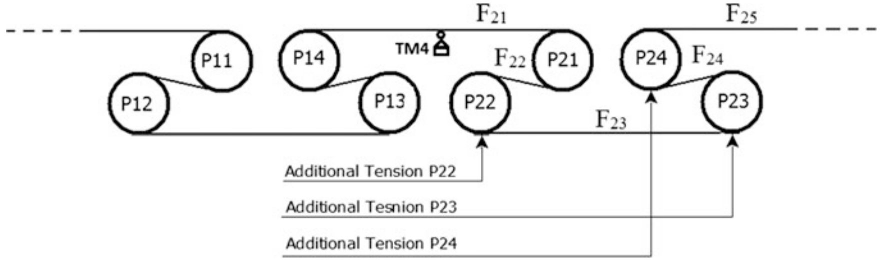



**Fig. 2** Scheme of arrangement of the drives in central part of the analysed continuous strip processing line

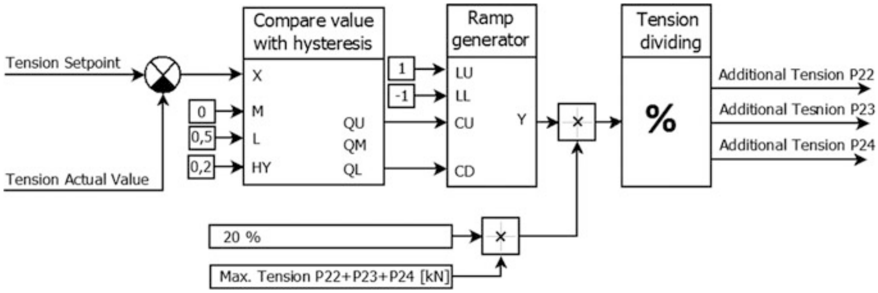
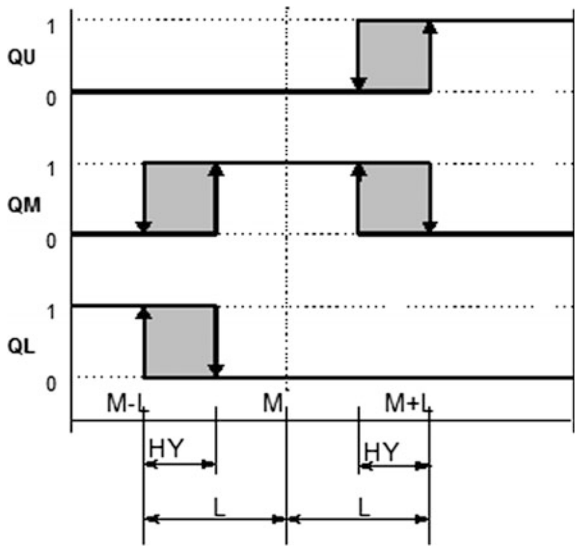



**Fig. 3** Tension controller equipped by a ramp generator

**Fig. 4** Comparator principle




The notation P11, P12 … P31 presents drive bridles (the tension rolls). The tensions in the strip between these drives reach high values. Satisfactory control results can be obtained with a controller that gradually changes the required value of the tension in the line section (smoothly or by slow changes) in time instants, when the actual value tension reaches the set point value within a band of hysteresis (set up by the programmer). The smoothly changed value is generated by a ramp generator. In our tension levelling line, it is allowed that the preset tension can vary within the boundaries of ±1%, what means that a controller having a constant control deviation can be also used.

The controller scheme is shown in Fig. 3. We have named the presented structure as a tension controller with ramp. The control deviation *X* is compared to the value *M* which is set to zero in order to keep the control deviation at zero value.

Figure 4 shows the function of the block comparing the value with hysteresis.

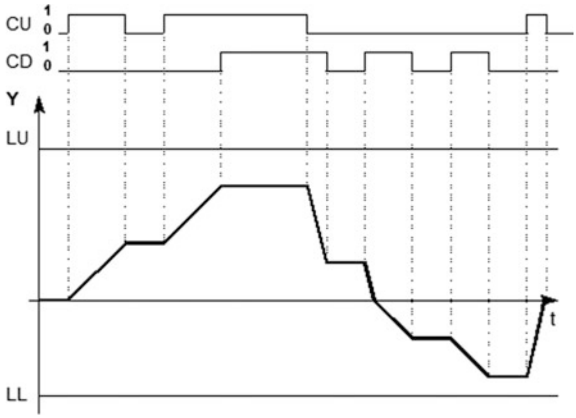



**Fig. 5** Ramp generator principle

The ramp generator principle of operation is shown in Fig. 5. If the signal CU = 1, the output of ramp generator is raised; if CU = 0 and CD = 0, the output of the ramp generator does not change.

The ramp generator output is multiplied by the tension, and the signal is divided among the drives to compensate arose control deviation. In our control system, the output from the ramp generator is multiplied by a constant presenting 20% of the sum of all maximal possible tensions for the drives P22, P23 and P24. This constant corresponds to the maximum actuating controller intervention. It also depends on precise measurement of mechanical loses in the line equipment and correct estimation of the inertia of rotating parts. The value of 20% has been estimated empirically for the given line having certain parameters.

The entire controller structure is designed for a four-drive system, as shown in Fig. 2. One of the drives works as a lead one—the master drive (drive P21 in Fig. 2). It is a speed-controlled drive without torque limitation, i.e. the torque limiter is set to maximum. Its function is to keep strip elongation on a required value according to the preset speed value.

The signal from the tension controller presents an additional tension signal for the drives P22, P23 and P24. The block *Tension dividing* divides the actuating intervention of the controller among the adjacent drives.

Based on the production technology, partition of the tension among the drives can be done by operator/programmer himself in time of commissioning the line. Two conditions to be considered are to take in the consideration the power rating of the drives and to ensure that the tensions in the line satisfy the condition (3):

$$F_{21} > F_{22} > F_{23} > F_{24} \tag{3}$$

i.e. the master drive should develop the highest tension, and thus, it has the highest torque.

The experimental results from a real line are shown in Fig. 6. It can be observed that the initial transport speed of the strip $v$ = 5 m/min was changed by the operator

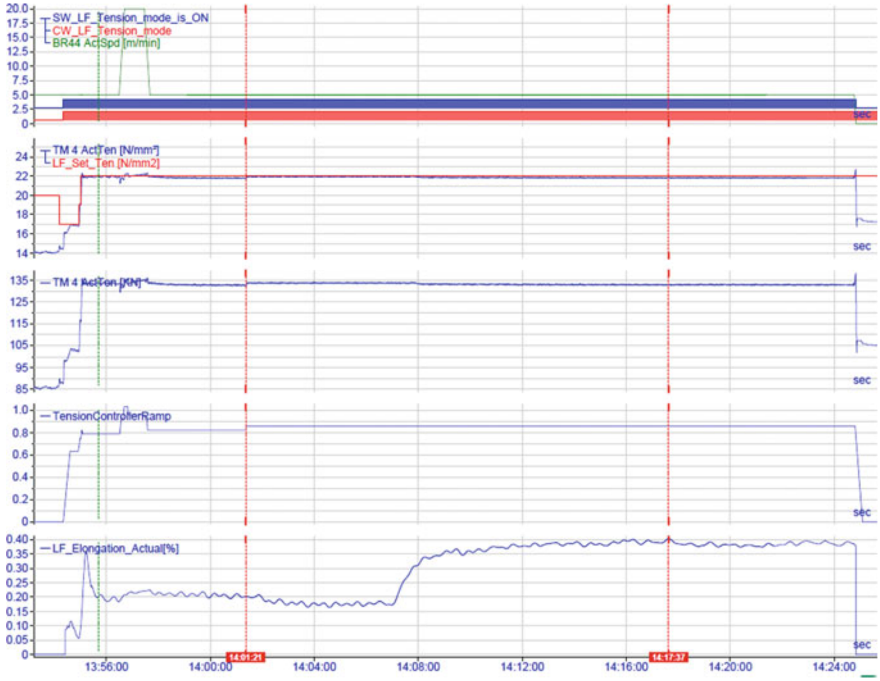



**Fig. 6** Time responses of the variables in line with the ramp tension controller (for the labeling of the curves see Table 1).

to the value of $v = 20$ m/min within a short-time interval. In the time instant, when the tension mode was switched on, the output signal from the controller has increased (the trace *Tension Controller Ramp*). The reference value of the tension was set to the value of $\sigma = 22$ N/mm$^2$ by the superimposed control loop. During the tension mode, the tension in the line was kept on approximately constant value (the trace *TM4 ActTen*).

During the first measurement on the real line, the deviation from the set value was $\Delta\sigma = 0.24$ N/mm$^2$ and during the second measurement it was $\Delta\sigma = 0.18$ N/mm$^2$. Note that the relative elongation during a run at the constant speed is not constant. We suppose this is caused by changes of the material properties.

### *3.3 Stepper Tension Controller*

In case a low tension in the strip is required, we have designed another solution. As an example for such a case, an annealing oven for the aluminium strips serves here. The length of the strip in the oven is 100 m. The mechanical arrangement of the

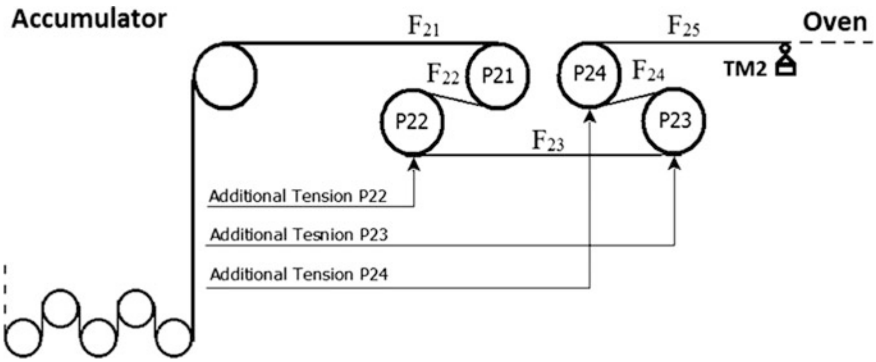



**Fig. 7** Scheme of arrangement of drives in the oven section

**Table 1** Labelling of the curves in Fig. 6

| | |
|---|---|
| BR44_ActSpd (m/min) | Actual speed one of the drives in Levelflex |
| SW_LF_Tension_mode_is_on | Tension mode is on if value is log 1 |
| CW_LF_Tension_mode_is_on | Tension mode is active if value is log 1 |
| LF_Set_Ten ($N/mm^2$) | Set value of tension in Levelflex |
| TM4 ActTen ($N/mm^2$) | Actual value of tension in Levelflex |
| Tension Controller Ramp | Tension controller output |
| LF_Elongation_Actual (%) | Elongation actual value |

drives in the input part of the oven is shown in Fig. 7. The tension in the strip coming out from the accumulator is high, and it is decreased by a tension section consisting of four drives working in the generator mode.

The value of the tension $F_{25}$ in the oven is as follows:

$$F_{25} = F_{21} - T_{21} - T_{22} - T_{23} - T_{24} \tag{4}$$

where the variable $T_{ij}$ presents a tension corresponding to the developed torque by the drive $P_{ij}$. It consists of two components: the calculated contribution of the torque (a portion of the total required torque for four drives) and signal corresponding to the additional tension from the tension controller. The variable $F_{21}$ presents the strip tension in the output from the accumulator.

For such an arrangement of the section, *a stepper tension controller* was developed as shown in Fig. 8. Its operation is based on increasing or decreasing of the set tension value in steps: the controller works until the control deviation is lower than the preset range. If any difference between the set and actual number of impulses occurs, the controller increases or decreases its output. The output from the counter is multiplied by the tension, and then, it is divided among the drives which control the arisen control deviation.

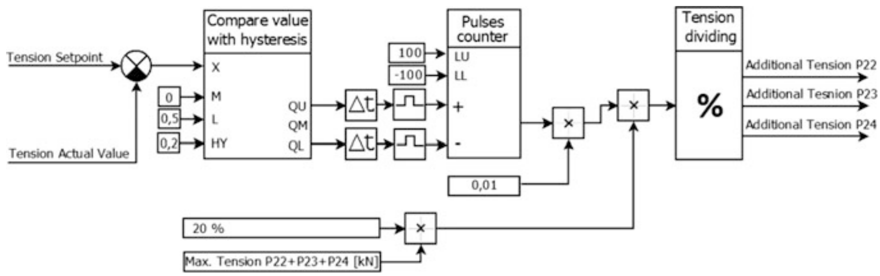



**Fig. 8** Internal structure of the stepper tension controller (for the line sections with low level of the tension)

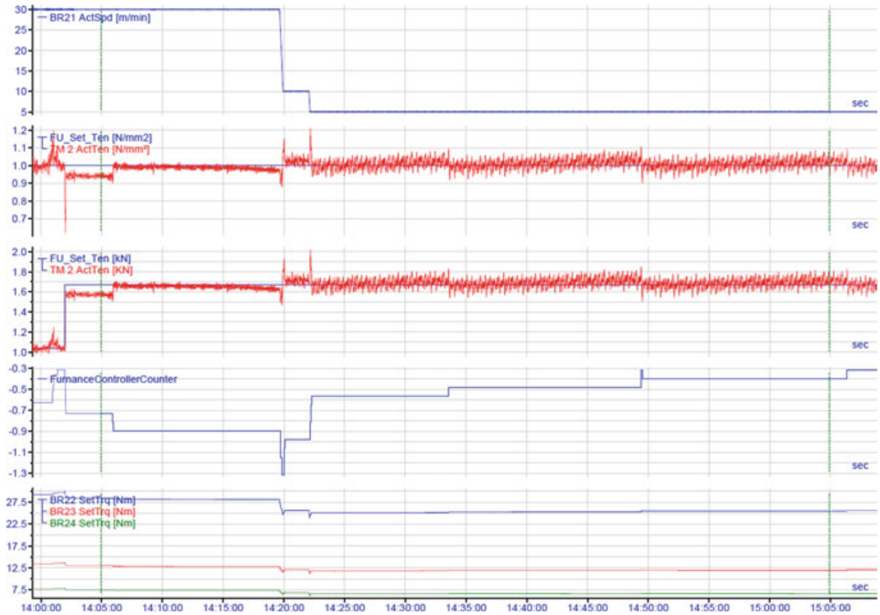



**Fig. 9** Time courses of tensions in the strip in annealing oven with the stepper tension controller

The described low-tension controller was applied in the control system of the drives in the annealing oven, and the main variables were recorded in Fig. 9, where labeling of the curves is listed in Table 2. During measurement, the set value of tension in the strip was adjusted to the value 1 N/mm$^2$ and the tension was controlled with the maximum control deviation of ±0.1 N/mm$^2$.

It can be observed in Fig. 9 that the control deviation between reference tension *FU_Set_Ten* and the actual tension in the oven *TM2_ActTen* really does not exceed value of ±0.1 N/mm$^2$. The step value of the tension controller output is led into

**Table 2** Labelling of the curves in Fig. 9

| | |
|---|---|
| BR21_ActSpd[m/min] | Actual speed of the drive in front of furnace |
| TM 2_ActTen[N/mm$^2$] | Actual tension in furnace |
| TM 2_ActTen[kN] | Actual tension in furnace |
| FU_Set_Ten[N/mm$^2$] | Set value of tension in furnace |
| FU_Set_Ten[kN] | Set value of tension in furnace |
| FurnanceControllerCounter | Output from controller |
| BR24_SetTrq[Nm] | Set torque for drive BR24 |
| BR23_SetTrq[Nm] | Set torque for drive BR23 |
| BR22_SetTrq[Nm] | Set torque for drive BR22 |
| BR21_SetTrq[Nm] | Set torque for drive BR21 |

control circuits of the drives changing the motor torques, and thus, the tension in the strip is also changed.

It is advantageous to use the described stepper controller in cases when operational intervention of the controller allows a slow change of the controlled variable or when the time of the system response is not known or when this time depends on various other parameters (temperature in the oven, the strip speed, strip cross section).

## 4 Conclusion

This paper deals with the design and description of two developed tension controllers for a continuous strip straightening section of the strip processing line. Two special tension controllers were developed based on practical experiences. The first one is a tension controller with ramp, which is advisable to use for the control of high tensions. The second controller is a stepper controller, which can be advantageously used for the control of low tensions in a very long section. The controllers were successfully applied during commissioning of a continuous levelling line for aluminium strips and they work reliable. They consist of basic programming blocks that are involved in the basic libraries of digital control systems.

**Acknowledgements** The research was supported by the project of the Slovak Grant Agency VEGA No 1/0464/15 titled “Research of New Principles and Methods for Design of Electrotechnical Systems”.

## References

1. Dechuan, C., Hao, Z., Meifang, W.: An intelligent tension control system in strip unwinding process. In: IEEE International Conference on Control and Automation, ICCA’07, pp. 342–345 (2007)

2. Nevaranta, N., Niemelä, M., Pyrhönen, J., Pyrhönen, O., Lindh, T.: Indirect tension control method for an intermittent strip transport system. In: International Power Electronics and Motion Control Conference, ECCE-EPE-PEMC'12, Novi Sad, Serbia, pp. DS2a.2 1–6 (2012)
3. He, F., Wang, Q.: Compensation and fuzzy control of tension in strip winding control system. In: IEEE International Conference Industrial Electronics and Applications, IEEE-ICIEA'12, Singapore (2012)
4. Sakamoto, T., Izumihara, Y.: Decentralized control strategies for strip tension control system. In: IEEE International Symposium on Industrial Electronics, pp. 1086–1089 (1997)
5. Valenzuela, M., Bentley, J., Lorenz, R.: Sensorless tension control in paper machines. IEEE Trans. Ind. Appl. **39**, 294–304 (2002)
6. Lynch, A.F., Bortoff, S., Röbenack, K.: Nonlinear tension observers for strip machines. Automatica **40**, 1517–1524 (2004)
7. Perduková, D., Fedor, P., Timko, J.: The multi-motor drive model for teaching in the motion and process control engineering. Acta Electrotechnica et Informatica. Košice, Elfa, pp. 19–25 (2002)
8. Theis, E.: Levelling in detail. Everything you need to know about flatteners and levellers for coil processing, Parts 1–4. Available online: http://apdesign.co.za/levelling.html
9. Tension Leveler: Printmetal Technologies Japan, Lt. Available online: http://www.primetals.co.jp/products/pro3_4_1.html
10. Magura, D., Fedák, V., Kyslan, K.: Modeling and analysis of multi-motor drive properties in a strip processing continuous line. Modelling of Mechanical and Mechatronic Systems—MMaMS'14. The High Tatras, Elsevier, pp. 281–288 (2014)