Universidade do Minho

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Integrator Project

Integrated Master´s in Engineering

Industrial Electronics and Computers

Conveyor Belt velocity control: laboratory guide

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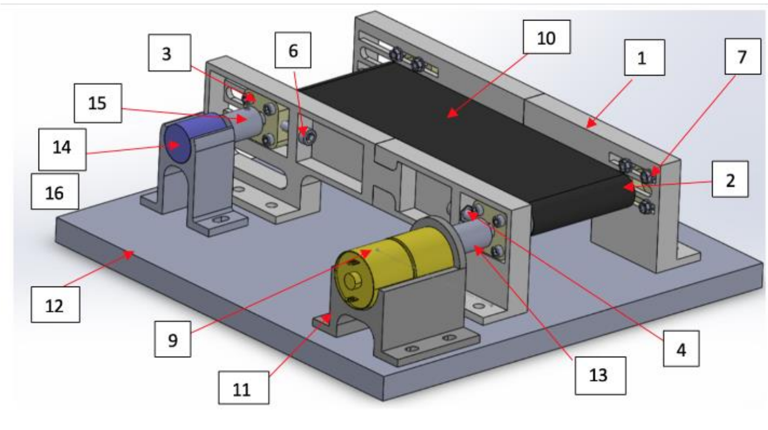
1.Introduction

This laboratory practice focuses on the control of the velocity of a conveyor belt considering all types of control on the curriculum of the UC Automatic Control + Proportional-Integral.

Specifically, an electronic system will control a laboratorial model of a conveyor belt, which allows the simulation of all characteristics of the merchandised version, represented Figure 1.



Kit's mechanics assembly

Kit's mechanical components

Nr	Description	Quantity
1	Support frame components	4
2	Shafts	4
3	Tensioners	4
4	Nuts M6	4
5	Washers M4	16
6	Screws M6x30	4
7	Screws M4x20	16
8	Nuts M4	16
9	Motor	1
10	Belt	1
11	Motor support	1
12	Base 300x300 mm	1
13	Motor coupler	1
14	Motor feedback (generator)	1
15	Generator coupler	1
16	Generator support	1
17	Base screws M4	18
18	Base nuts M4	18
19	Base feet supports	4

Figure 1- Laboratorial Model of Conveyor Belt

The motor is fed a voltage causing it to start rotating. The generator, acting as a sensor, will then apply a voltage to its terminals, based on the conveyor belt's speed, thus providing a feedback path for the control.

The control system will require a sensor, a controller and an actuator.
As mentioned before, in this model of the conveyor belt, the generator will act as the sensor, supplying a "variable to control".

The controller has several duties:

- Establishing a reference variable, or more accurately, an electrical representation of it.
- Establishing the electrical representation of the error.
- Establishing a command voltage, using the reference and measured variables previously mentioned and a control rule.

In this model, there will be several controllers, each employing a different control rule, present in this document on Figure 3 and Figure 6.

The actuator serves as the connector between motor and controller, it will apply the command variable on the motor, permitting that the controller's changes to the system be shown.

The control rules to be applied can be succinctly described as follows:

- On-Off Control – It applies the maximum value of the command variable or the minimum (in this case 0). In this specific case, the motor will either be rotating at full speed or not rotating at all.
- Proportional Control – It applies a command variable between its maximum and minimum value, proportional to the error.
- Proportional-Integral Control – Serves the same purpose as proportional control, control-wise, but allows for better system performance, specifically by reducing the steady-state's error.

Due to the motor's characteristics the actuator needs to be an H-bridge, represented by Figure 5.

All control rules require simulation, to implement a control rule without a clear idea of its consequences to the system, can be disastrous both for the model as well for a future career in engineering. In order to simulate, the system's mathematical model and physical constant values must be obtained.

In all that follows consider +Vcc=12V and -Vcc=-12V. The opamps to be used are LM304 or equivalents.

2. Mathematical model

This prototype uses a DC motor and a reduction box with a reduction ratio of G:1 to move a cylinder that will in turn move the conveyor. Another DC motor, working as a generator is at the end of the conveyor, the latter moves a cylinder that will in turn move the generator.

Definitions:

J1: Motorized Cylinder's Moment of Inertia

J2: Generator Cylinder's Moment of Inertia

M: Conveyor's Mass

w: Cylinder's Angular Velocity

B: System's Supposedly Linear Coefficient of Friction

The conveyor's velocity (Control Variable) will be obtained by $v = w * r$, r being the cylinder's radius. With this equality in mind we can obtain the system's Lagrangian function:

$$L \quad = \frac{1}{2}(J1 + J2 + Mr^2)w^2$$

With the Lagrangian, the system's equation based on the torque is obtainable:

$$(J1 + J2 + Mr^2)\frac{dw}{dt} = \mathcal{T} - Bw \ (2)$$

Considering that the motor is of the DC variant and using the following definitions:

Ka: Motor's Electromechanical Constant

I: Motor's Current

Ua: Motor's Voltage

R: Rotor's Resistance

wm: Motor's Angular Velocity

This relation is obtained:

$$\mathcal{T} = G * Ka * I$$

$$I = \frac{1}{R}(Ua - Ka * wm)$$

Considering that:

$$wm = G * w$$

The expression above can be simplified further:

$$\mathcal{T} = Km * I, Km = Ka * G$$

$$I = \frac{1}{R}Ua - \frac{Km}{R}w$$

In conclusion, the following model is obtained:

$$(J1 + J2 + Mr^2)\frac{dw}{dt} + (B + \frac{(Km)^2}{R})w = \frac{Km}{R}Ua$$

A first-degree model with one control variable resulting in a single feedback gain.

2.1 – Obtain the physical constants of the system

Before drafting any kind of control diagram, the system's physical constants are required for an accurate simulation. Following the mathematical module, the following constants are required:

- M – Conveyor's mass
- m – Cylinder's mass
- r – Radius of the cylinder's base
- J1 – Moment of inertia of the motor's cylinder
- J2 – Moment of inertia of the generator's cylinder
- B – Supposedly linear coefficient of friction
- Km – Motor's electromechanical constant (with reduction box)
- R – Rotor's resistance

2.1.1- Measure M, m and r with appropriate measuring instruments and calculate J1 and J2 with those values.

2.1.2 – Run a series of tests to obtain physical constants.

Consider the following equations:

$$\mathrm{Km} = \frac{\mathcal{T}}{\mathrm{I}} \qquad \mathrm{B} = \frac{\mathcal{T}}{\mathrm{w}} \qquad \begin{aligned} \mathrm{Un} &= \mathrm{R} * \mathrm{ia} + \mathrm{Ka} * \mathrm{w} \\ \equiv \mathrm{R} &= \mathrm{Un}/\mathrm{Ia} + 0, \mathrm{w} = 0 \end{aligned}$$

$\mathcal{T}$ – Torque obtained when the motor is rotating at a constant angular velocity.
I – Nominal current.
w – The constant angular velocity of the motor.
Un – Nominal voltage of the motor.
Ia – Start-up current of the motor.

2.1.2.1- Build a simple circuit with a DC power source (+Vcc) in series with a 1-ohm resistor and the motor. Measure, with an amperemeter, the current that passes through the motor when it rotates with constant velocity. Calculate the motor's potency.

2.1.2.2- With the motor's potency, calculate the torque and with it Km and B.

2.1.2.3- With the same circuit as in **1.2.1**, using an oscilloscope measure the motor's startup-current and calculate R.

3 – On-Off Control Simulation

Before implementing any electronic circuit with the purpose of controlling a system, the method of control must be chosen and its suitability towards the system analyzed. Following the Automatic Control UC's curriculum, on-off control will be considered first:

3.1- Using the provided mathematical module and system's physical constants develop a simulation draft implementing on-off control.

3.2- Draw conclusions considering the physical consequences of the system's behavior with on-off control. Can it be implemented? Should it be implemented? Justify your answers adequately.

4- Proportional Control Simulation

Once again before considering implementing a circuit, the control rule's compatibility towards the system must be tested through simulation.

4.1- Develop a simulation draft using proportional control. Obtain an appropriate gain, that is physically possible to use for proportional control.

4.2- Draw conclusions. Does the system do what its supposed to? Does it reach the level of control desired? Why?

4.3- Compare to the results of the on-off simulation. Is it better? Why?

5-Measure the voltage of generator

As the belt moves, a voltage in the terminals of the generator appears in the mV range. This voltage is crucial to control the velocity of the belt, it is the feedback signal that informs the controller of the value of the velocity of the belt. This value will be compared to the reference voltage, which varies between 0 and 5V so the voltage of the generator needs to be betwixt 0 and 5 V as well.

To do so, the first thing is to make a motor and generator test, where one varies the voltage in the motor and reads the voltage in the terminals of the generator. Inputting the values in an excel sheet and drawing the tendency line, the result must be an almost linear slope. This slope defines the gain necessary to use in a non-inverting opamp montage.

Furthermore, the generator voltage must pass throw a low pass filter for the ripple oscillations to disappear.

After the non-inverting opamp montage, it must pass through a full-wave rectifier (R4=R5). Should the motor be rotating counter-clockwise, the voltage at the generator's terminals will be negative, which must not happen for our actuator is an H-Bridge.

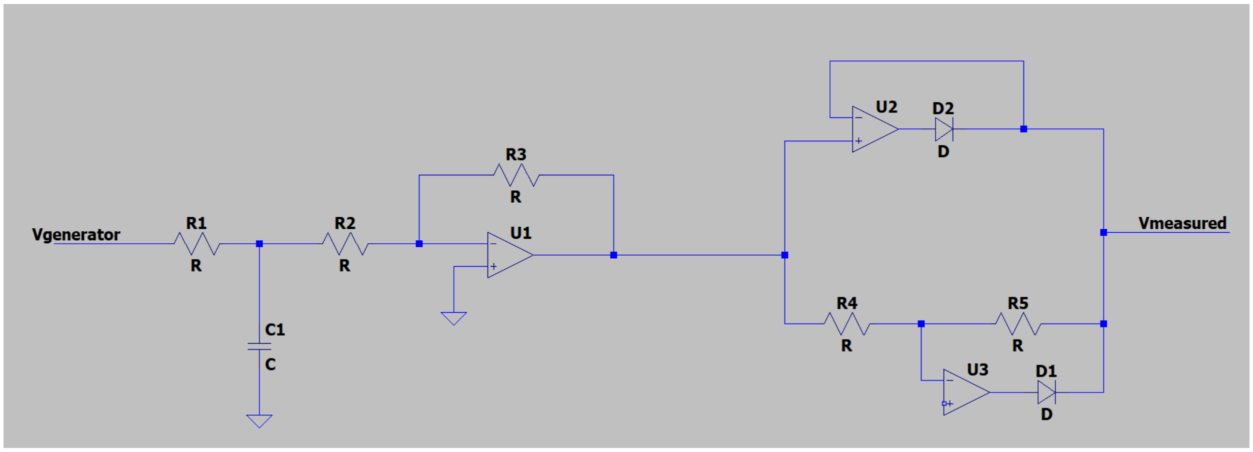


Figure 2 – Vmeasured Circuit

5.1 – Make the motor/generator test and draw the tendency line in excel.

5.2- Dimension R1 and C1 for the cutoff frequency to be 1 Hz.

5.3- Dimension R2 and R3 for Vmeasured to vary between 0 and 5V

6-Proportional Control Circuit

The implementation of proportional control can be obtained by the circuit in Figure 3.

The circuit using +Vstat, the RV1 potentiometer and 100-ohm resistor serves allows the generation of a Vreference voltage, the electrical representation of the conveyor's desired velocity. The A2 opamp with the R3 and R4 resistors implement a subtractor resulting in:

$$Vcommand = \frac{R3}{R4}(Vreference - Vmeasured)$$

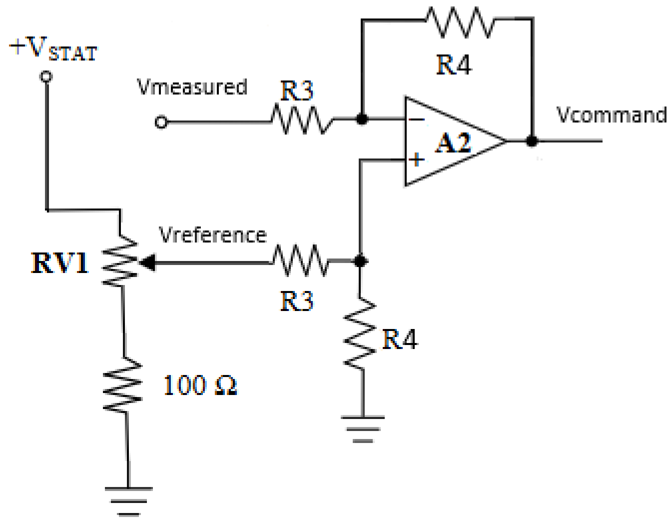


Figure 3- Circuit Implementing Proportional Control Rule

6.1-Study the behaviour of the circuit in Figure 3.

6.2- Calculate adequate values for R3 and R4 in order to obtain the gain that was deemed adequate in the simulation.

6.3- Assemble the circuit and test its behaviour. Make sure the opamp is behaving correctly.

6A-PWM based actuator

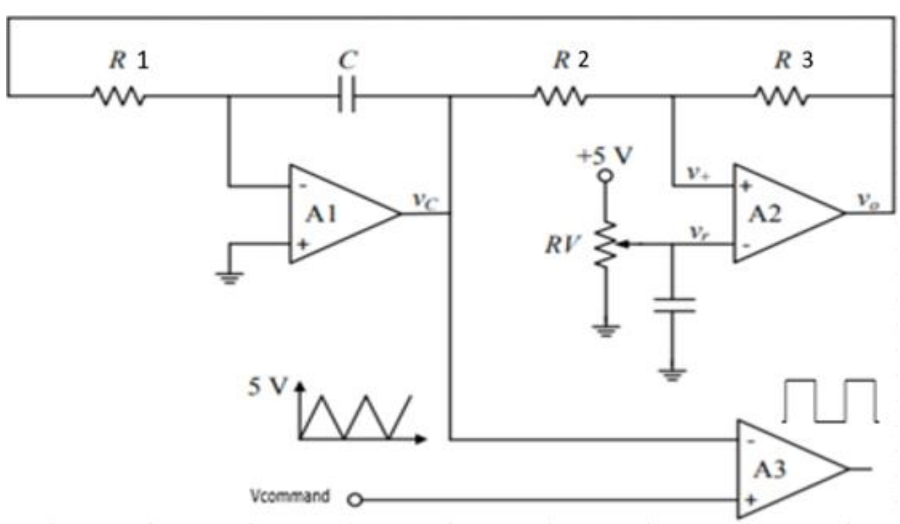


Figure 4- PWM signal generated by PWM modulator

Amplifier A1 is used in an inverter integrating assembly. Amplifier A2 is used in a non-inverting comparator assembly with hysteresis. Together, they generate a triangular wave between 0 and 5 V. The A3 amplifier performs a simple comparator, generating the PWM wave whose duty cycle is modified as the command tension varies.

The output wave, is high when the command voltage is higher than the triangular wave produced in the feedback loop, see Figure 4. Otherwise, it stays at 0V.

The PWM wave generated in the A3 interchanges between two values: 0V and 5V. However, when the duty cycle is changed (the time when it is 5V is changing) the medium voltage modifies, which is the product of the duty-cycle times high voltage (5V). That can be done, modifying the command voltage.

6.1A- Calculate the value of the components in the triangular wave:

a) Obtain the Vc expression in function of R1, C and Vo.

b) Determine R1 and C such that Vc takes 20ms from 0V to 5V.

c) Determine R2, R3 and Vr so that the comparator changes between 0V and 5V when Vo is +Vsat or -Vsat. Measure +Vsat and -Vsat.

6.2A- Draw Vo and Vc from 0ms to 40 ms.

6.3A- Draw Vcommand graph in function of Duty-cycle.

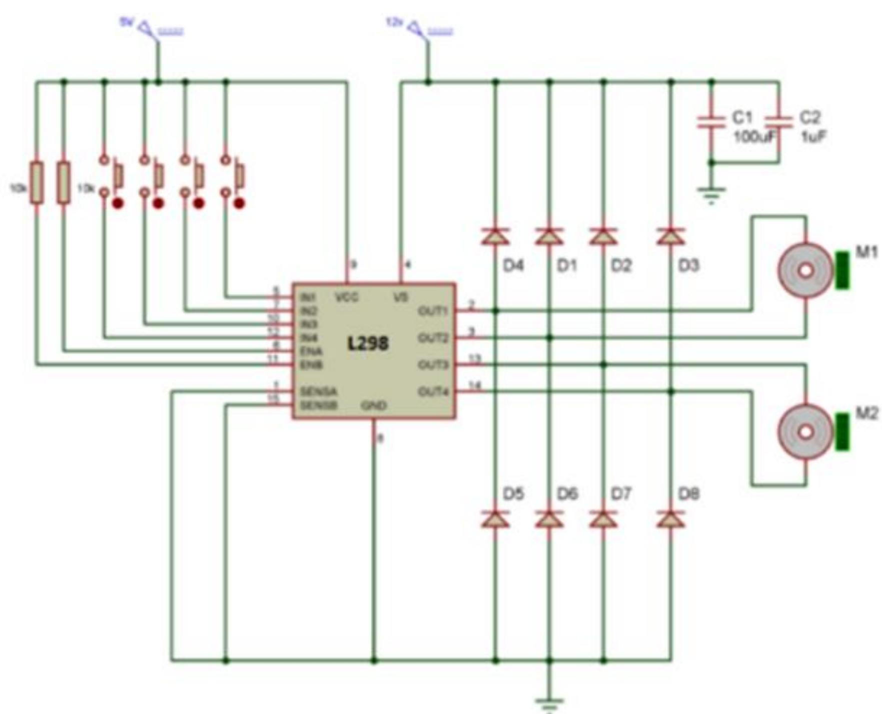


Figure 5- Actuator Circuit with the actuator part

6.4A- Which terminal should the A3 output be connected to? Assemble the following circuit, above in **Erro! A origem da referência não foi encontrada.**. Hint: The Enable terminal enables L298 internal H-Bridge.

a) Does the motor spin? Since only one motor will be used, which components are not useful for controlling motor M1?

b) Try pressing different buttons and adjust Vcommand so that the motor spins half the nominal value. Measure OUT1 and OUT2 tension.

c) Make the motor tension/velocity test and draw the tendency line in excel.

6.5A- Join the actuator's exit to the motor's terminals and observe the results. Does the system achieve the desired control?

7-PI Control

PI control is needed for non-integrating processes, in other words, any process that returns the same output given the same set of inputs and disturbances, one such example is a system whose control is not capable of reaching the desired level of control, normally due to physical limitations, more specifically once a certain point in the system's response is reached, no matter how much the input or disturbance is changed (within physical reason of course) the system's response will not change. In other words, **a constant steady-state error** is present!

The integrator will calculate the integer of the error and add it to Vcommand, therefore slowly reducing the steady-state error. The higher the integral gain, the faster the system's steady-state error will decrease.

$$Vcommand = Kp * Error + Ki * \int Error$$

$$Integrator\ Output = -\frac{1}{R11 * C} \int Error$$

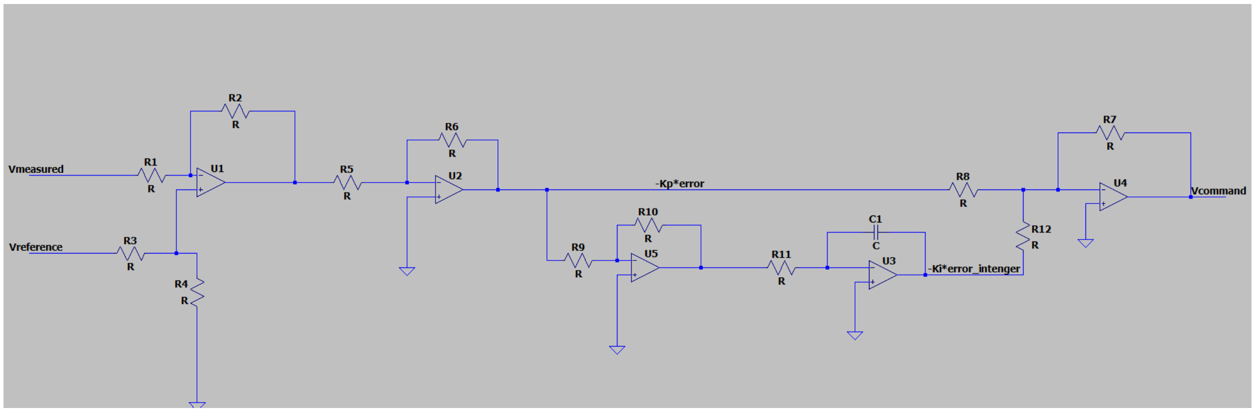


Figure 6- Circuit Implementing PI Control rule, R5=R6=R9=R10=R8=R7=R12=R7

7.1- Using the simulation diagram for **3.1**, add integral control and comment on the result. Obtain a value for the integrator's gain.

7.2- Study the circuit in Figure 6. What is the purpose of amplifiers U2, U3 and U5?

7.3- Use the PWM actuator to test the PI control on the motor. Measure the conveyor's velocity and see if it reaches the value its supposed to. Compare to the results of the proportional gain.

7.4- Could PID control be used for this model? Why/Why not? What would be the consequences of forcing a derivative control?