

# New Labs for Control Courses DC Motor Control

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## Abstract:

A number of labs have been developed using small scale dc motors that demonstrate the PID algorithm for speed and position control. These labs are very inexpensive and complement the PLC equipment presently in most automation labs. The labs will demonstrate the basic concepts of PID and the concept of loop-in-loop control. These labs are currently under development and will be shared in their early state complete with PLC program and HMI screen. They are extremely low cost and can be used to augment other labs using feedback control.

## DC Motor Position Control Lab

This lab has a history from a number of previous developers. One was the original lab for the Auto Controls course manufactured by a former instructor in EET, John Rich. Its purpose was to control speed and then position using PID loops. The motor at right can be run both forward and reverse and to a position. The lab was the highlight of the AutoControl course by Mr. Rich during his tenure.

Prof. Rich's design is shown here (Fig. 1a):

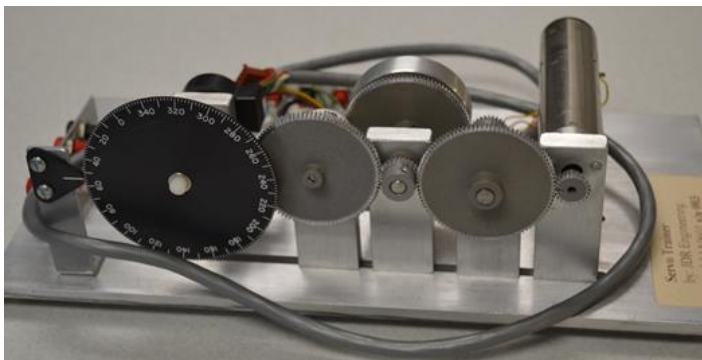


Fig. 1a  
Speed and Position  
Control of DC Motor

and here (Fig. 1b)

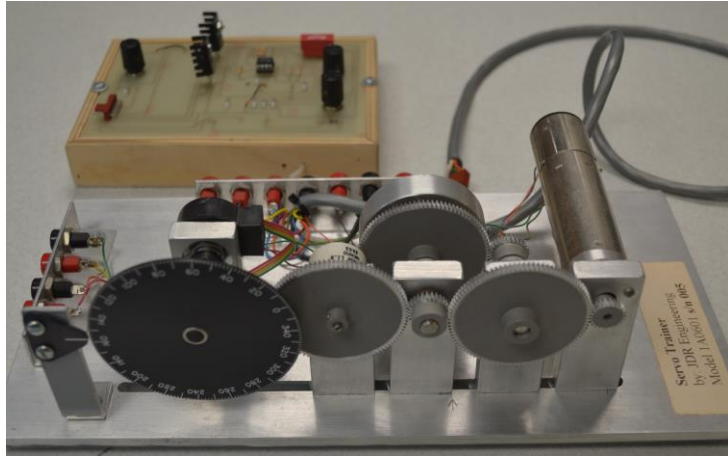


Fig. 1b  
Speed and Position Control of  
DC Motor with Control Board

The equipment whose diagram is shown below was used but only by demonstration since the school owned only two of these units. This equipment was purchased from the company Feedback. Again, the DC motor was controlled by a PID loop for speed control and a second PID loop for position.

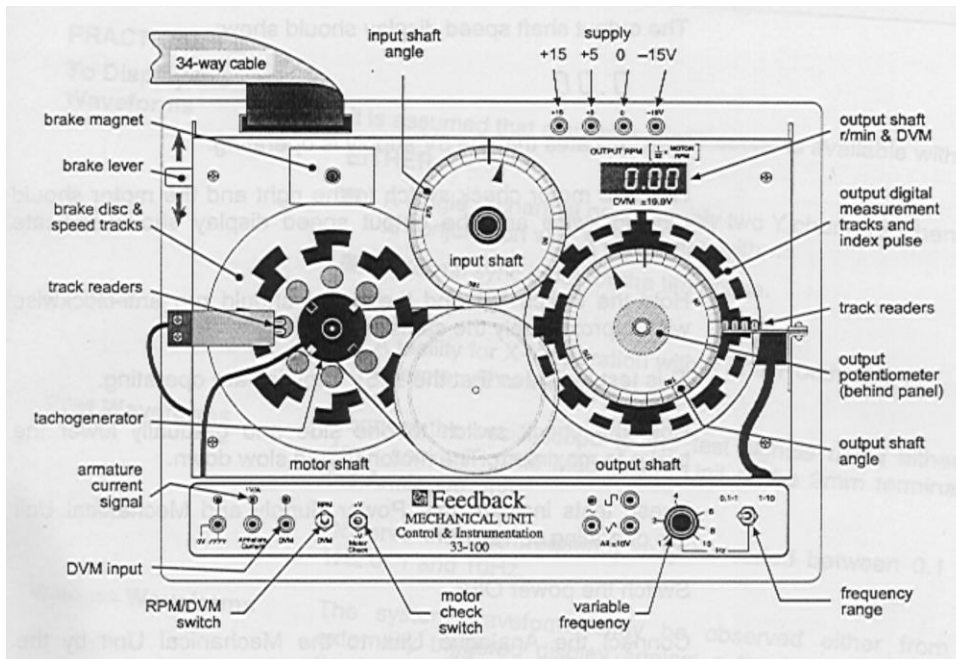


Fig. 2  
Speed and Position  
Control of DC Motor  
from 'Feedback'

Another was from a paper “A Low-Cost Control System Experiment for Engineering Technology Students” by Dr. Curtis Cohenour Ph.D., P.E. P.E., Ohio University<sup>[1]</sup>. Dr. Cohenour’s implementation is shown below in Fig. 3. This design was attempted with limited success.

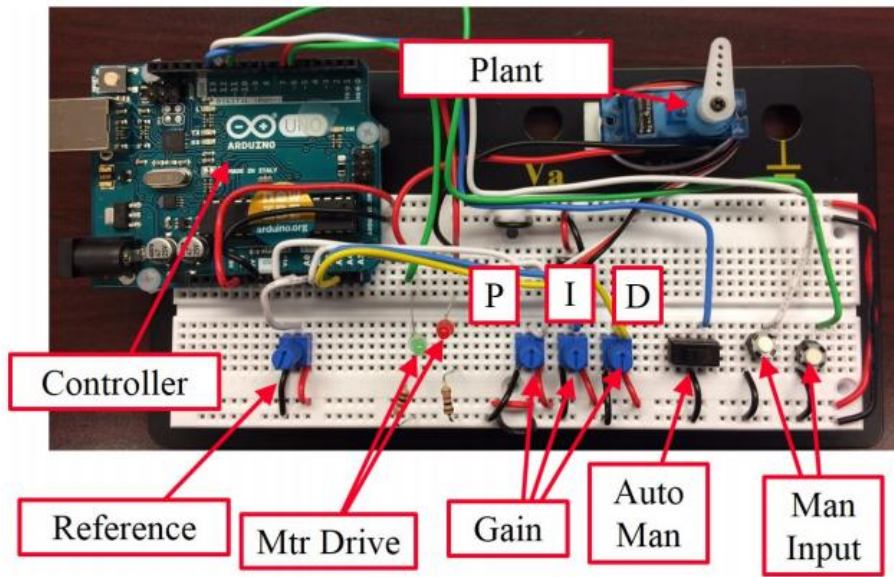


Fig. 3  
Speed and Position Control of  
DC Motor using Arduino

### Speed Control with PLC Controller

What is being proposed is using PID block controlling a dc gear motor for controlling a DC motor. The control loop is to control the speed of the motor to a setpoint. The controller is a Siemens S7-1200 with encoder inputs and PWM output.

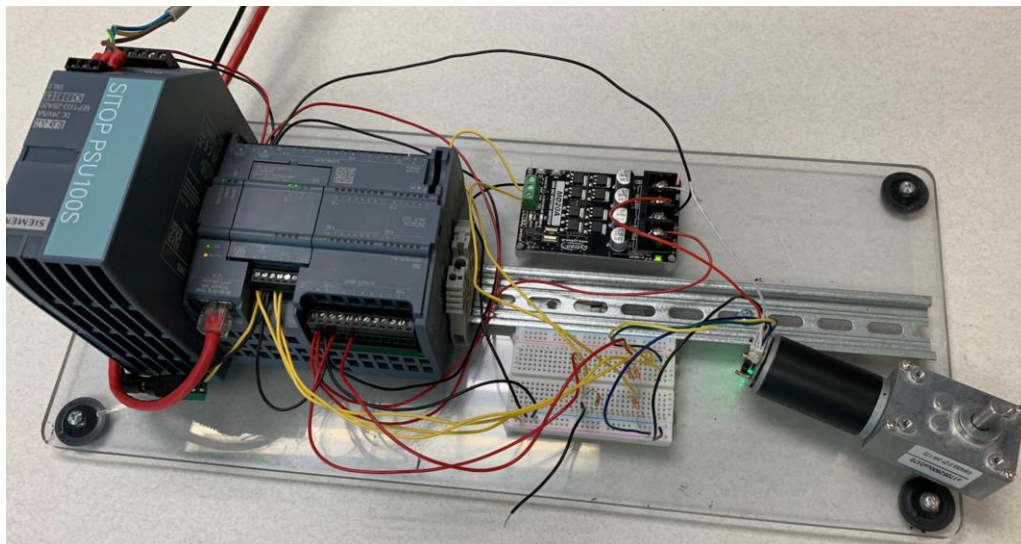


Fig. 4  
Speed and Position  
Control of DC Motor  
using PLC

This lab would consist of building this motor and controller. To continue, a second PID block will be added to control to a position. This successfully emulates the original purpose of the lab from Prof. Rich as well as the other designs of Figs 2-3. Additions to the lab would include

building a ramp block to successfully ramp from setpoint to setpoint at a set acceleration/deceleration rate.

## **Planning the Lab**

This design incorporates a dc motor with pwm speed control board and PLC for programming. Appendix I gives a wiring diagram for the lab. Appendix II gives a partial program for use in implementing the lab. The lab has not been implemented in the classroom except as a demonstration. It is being planned for the present term as a general lab for students. The lab will closely follow the program of Appendix II. A second PID loop for position control will be implemented in future semesters.

The lab is planned around the idea that a student would be given the basic wired PLC that was configured but without any program. The student would determine the various settings such as how long to set the OB's timed interrupt. The program in Appendix II gives 100 msec but students might choose another setting. If the student were to choose 100 msec, then the maximum number of counts per period could be observed by running the output full on. Then the scaling could be determined for 100% of the process variable. Each decision would be seen having an affect on other decisions.

The tuning program in the Siemens software was not capable of effectively providing good tuning parameters for this application. The output went unstable with the tuning parameters automatically generated. The derivative parameter had to be changed to zero to stabilize the motor. This can be observed as a necessary part of proper tuning of PID loops. Auto tuning programs are not necessarily always best. And there are a number of variables determining best parameters for these loops.

## **Summary**

The motor provides a good low cost PID lab experience if the PLC is already part of the controls lab. In this case, the Siemens S7-1200 is available and suitable for this application. The tuning of the motor is the only problem in that stability issues arise which must be dealt with. The output of the PID block can be observed in a graphical form and various setpoints can be entered. The ramping from setpoint to setpoint can be implemented with a small program to provide ramping of the setpoint. In all, this lab experience should provide a meaningful experience for students in an auto controls class. The lab should be robust enough to allow students to experiment with various parameters without destroying the equipment. It should be a good lab for many years to come.

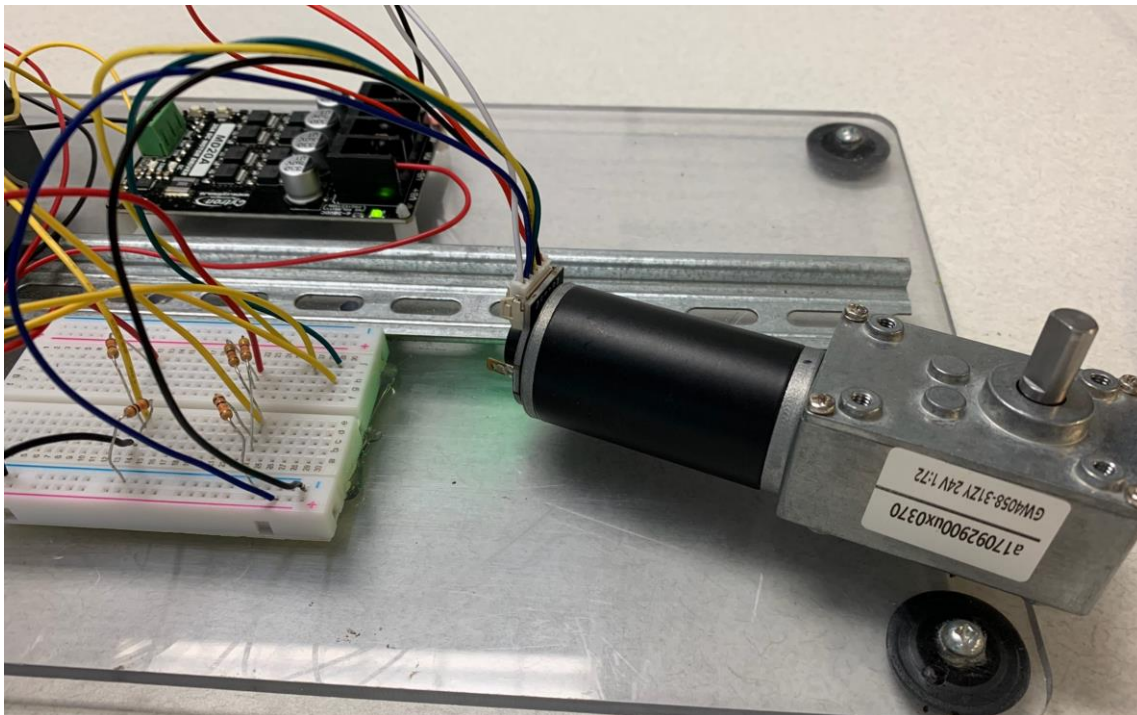
## Appendix I

Parts for this lab include:

1. S7-1214 or 1215 DCDCDC Siemens PLC
2. DI4 5 VDC signal board
3. Cytron Technologies MD 20A - 20 A 6V-30 V DC Motor Driver
4. ALITOVE 5V 3A 15W AC 100V~240V to DC Power Supply Adapter Converter
5. Uxcell DC 24V 111RPM 16Kg.cm Self-Locking Worm Gear Motor with Encoder/Cable or equal

Breadboard, resistors

Connections are seen in these figures. The motor connects its encoder logic through the breadboard. The power to the motor is furnished through the controller at top. The power is provided by the 24 V supply at left and a 5 V supply which is not shown.



The motor can be seen here. It is rated at 24 V dc and has a gear reduction of 1:72.

### Wiring from Motor and Encoder Connection:

- Red Wire - positive power supply of motor(+)
- White Wire - negative power supply of motor(-)
- Black Wire - negative power supply of encoder(-) (positive and negative power supply of encoder do not allow connect wrong; voltage is 3.3 -5V)
- Blue Wire - positive power supply of encoder(+) (positive and negative power supply of encoder do not allow connect wrong; voltage is 3.3 -5V)
- Yellow Wire - signal feedback (11 signals per motor turns a circle)
- Green Wire - signal feedback (11 signals per motor turns a circle)

The S7 1200 v2.2 CPU in relation to the Quadrature encoder:

The 1200 with 24V DC inputs support up to six High Speed Counters.

- a. Up to 3 of the addresses Ia.0 to Ia.5 can be used for Quadrature Mode at 80Khz.
- b. Up to 3 of the addresses Ia.6 to Ib.5 can be used for Quadrature Mode at 20Khz.

The DI4 5 VDC signal board with part number 6ES7 221-3AD30-0XB0 is used in this example since the encoder pulse signals are 5V. It supports 160 KHz for Quadrature Mode. The input is "source" type. So, the encoder must support this which means that it is NPN or Open Collector type. The encoder and card work together in this example.

For the S7 1200 v2.2 when configuring the HSC, please select the Input Source as "signal board input". Please note that the option is only available if the signal board has been added in the hardware configuration. Please note that the addresses of the HSC will be the address of signal board (default 4.x). In v4.x S7 1200's, the user selects the address rather than the Input Source.

Cost of the signal board is shown in the quote below. Prices may change but should be close to this price:

001	5.00	0.00	5.00 EA	6ES72213AD300XB0	EA	88.0000	440.00
			1.0	S7-1200 SIGNAL BOARD 4 DI 5VDC 200KHZ	1.0		
				lead time 23 days			

The dc motor controller is shown below. We used either 12 V for power to the motor or 24 V depending on the rating of the DC motor. This controller is very inexpensive and can accommodate either the 12 V or 24 V varieties. It is also used in the tank-over-tank lab in Hybrid Text Ch. 25. It works well with the cheap power supplies (MeanWell or equivalent) for most applications.

# Cytron Technologies MD 20A 20 A 6V-30 V DC Motor Driver

## 1. BOARD LAYOUT & FUNCTION

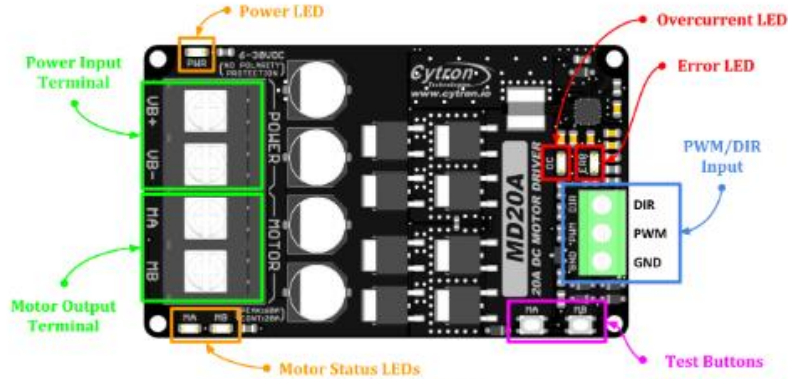
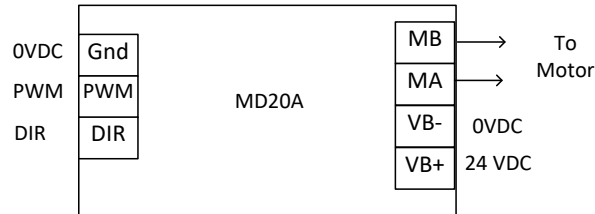


Figure 1: MD20A Board Functions

The wiring diagram shown below gives the complete wiring diagram for the motor shown in the figures above:

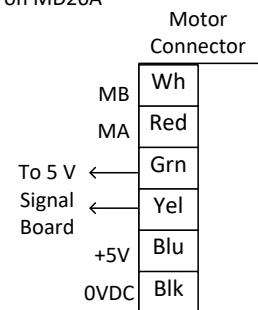
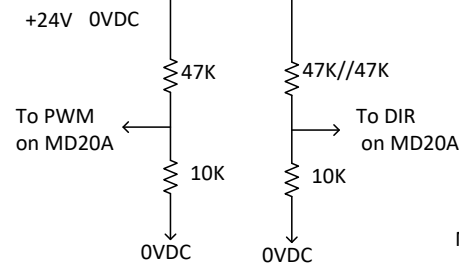


Onboard Signal Board 5 V DI4x5VDC					
L	M	0	1		

+5V 0VDC Yel Grn

Jumper 24 V Com to 5 V Com

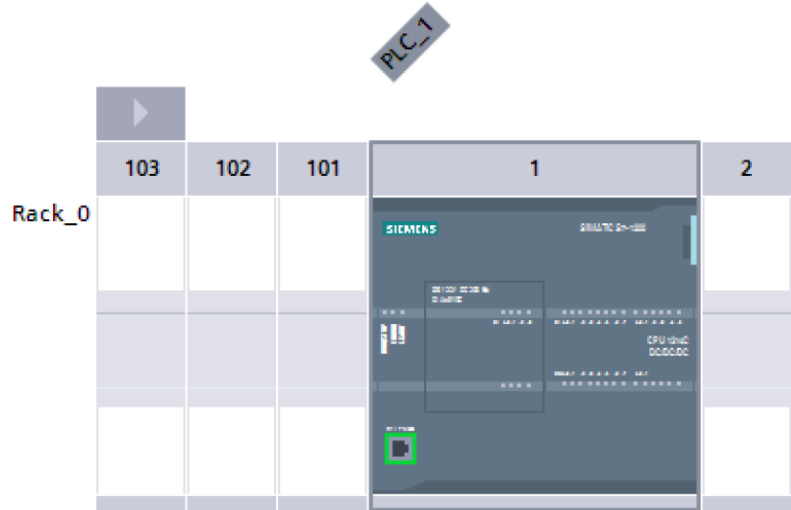
DC 24 V Outputs						
L	M	0	1	2	3	



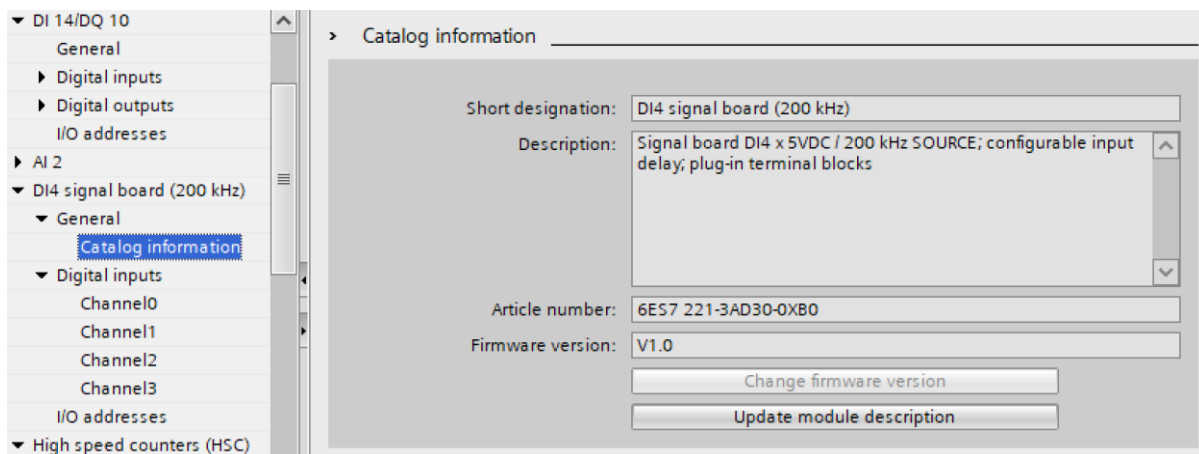
## Appendix II

### Programming the Siemens

The diagram below shows the Siemens PLC:

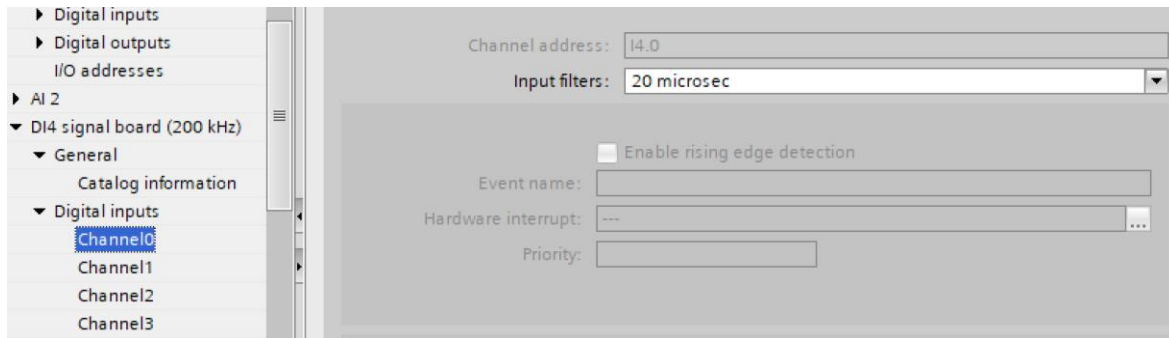


Configuration of the PLC is given in the following configuration tabs:

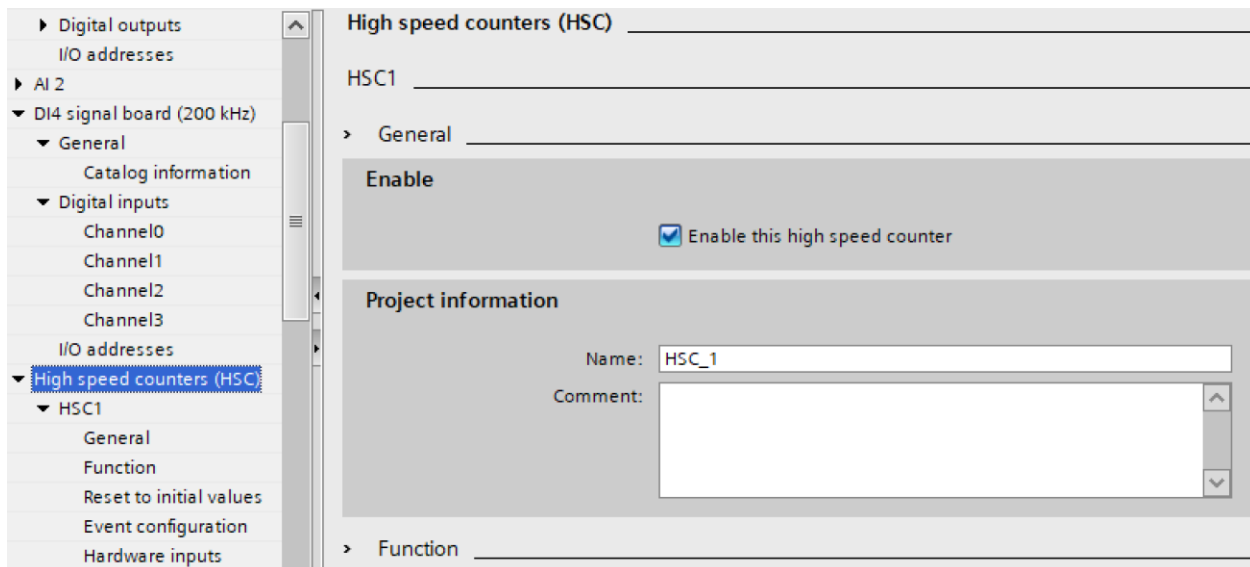
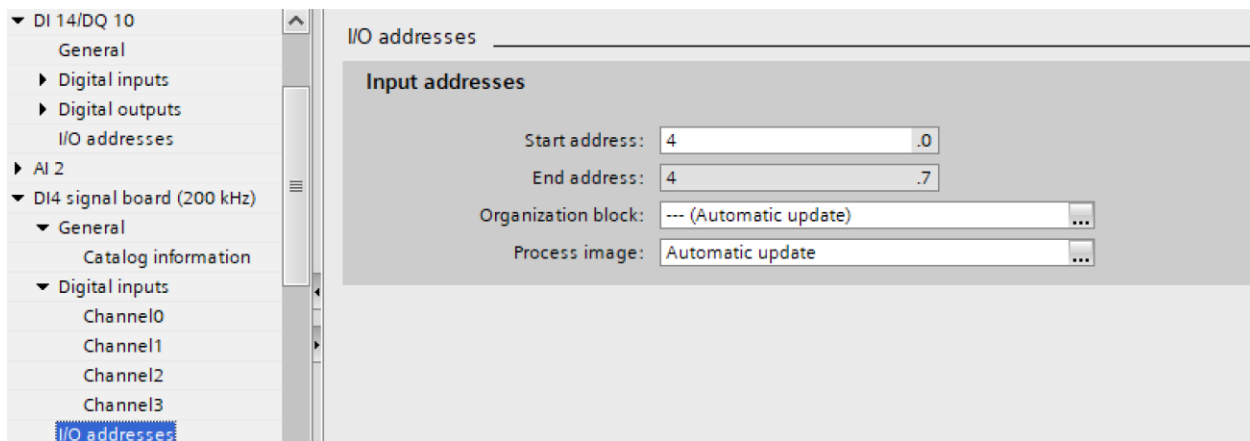


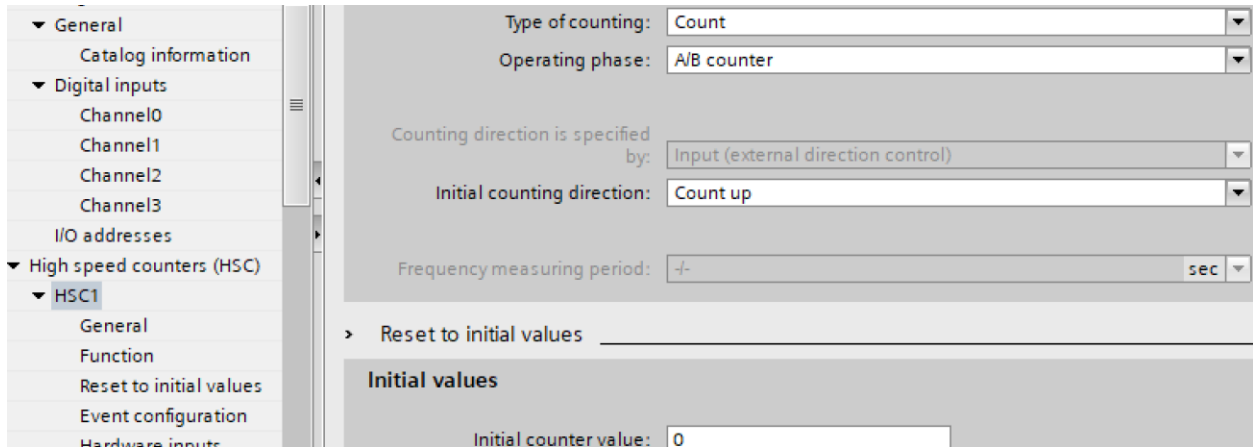
The Signal Board must be changed to allow for the fast pulse inputs:



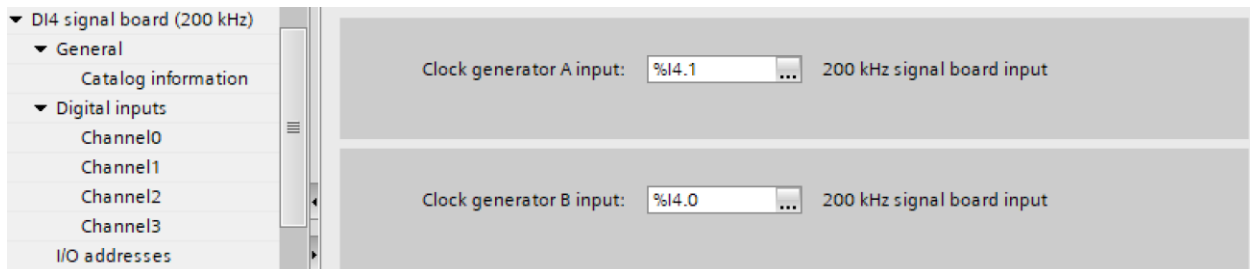


Addressing of the Digital Inputs for the encoder from the Signal Board are shown here:

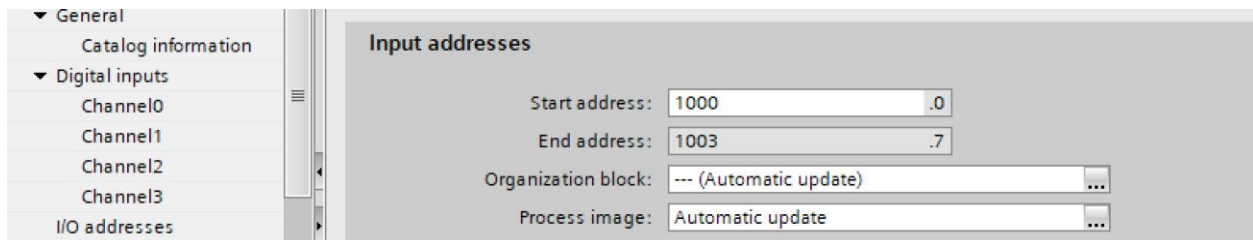




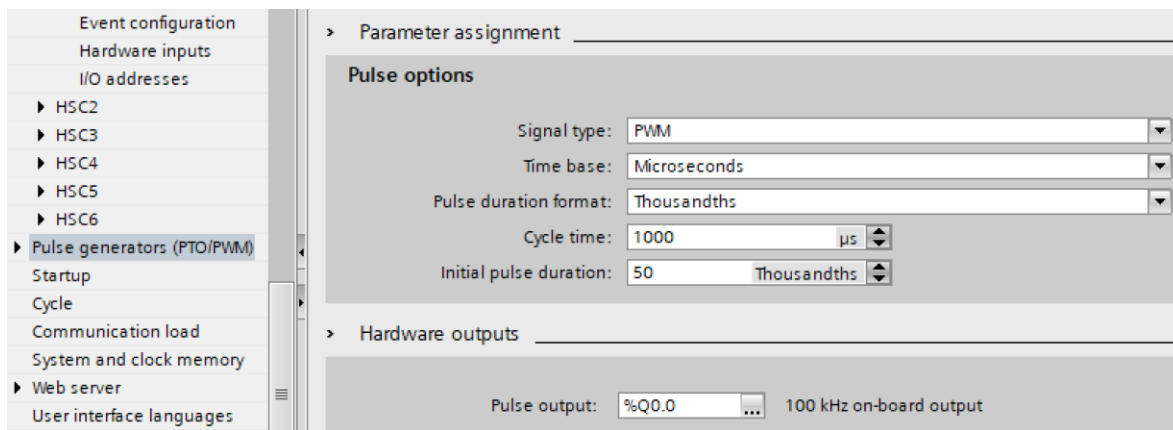
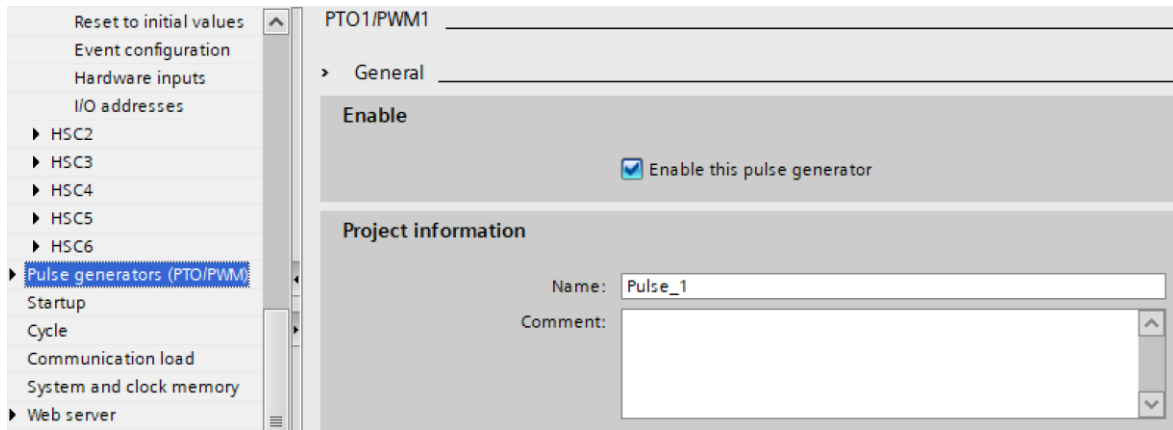
The address of the encoder is configured below:



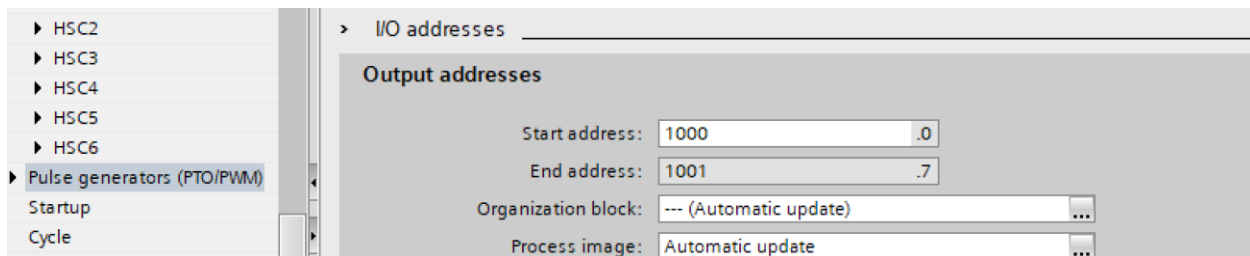
The high-speed input enters the PLC as a pulse in ID1000. This is the address used to calculate the pulses received in the last 100 msec.



The output PWM is shown here:



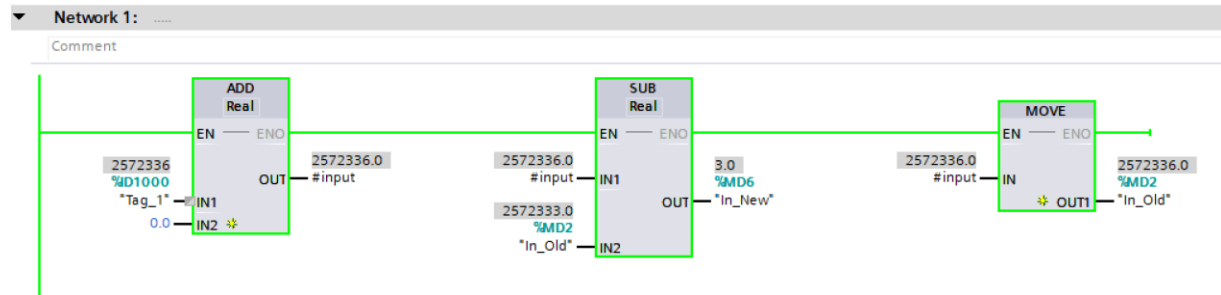
The output configured is a PWM signal that varies from 1 to 1000 microseconds and repeats each millisecond.



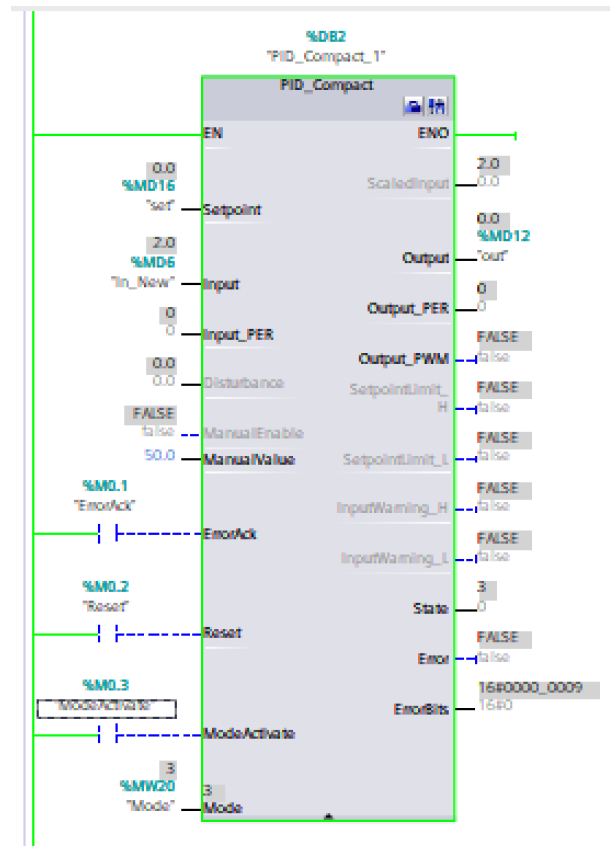
The program is in a cyclic interrupt program that is executed each 100 ms. It consists of a rung to get the input count for the last 100 msec followed by the PID block and finally the output to the PWM block.

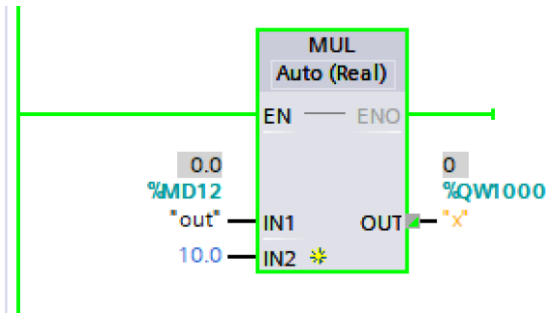
The choice of 100 ms is chosen due to the observation that with 11 pulses per revolution of the motor, we only receive about 125 pulses in 100 ms. If we were to choose 10 ms as our cycle time, we would only expect 12 pulses per scan at full speed. We need more accuracy than 1/12.

If one were to spend more for a more sophisticated motor, more pulses would give greater accuracy and the scan could be reduced.

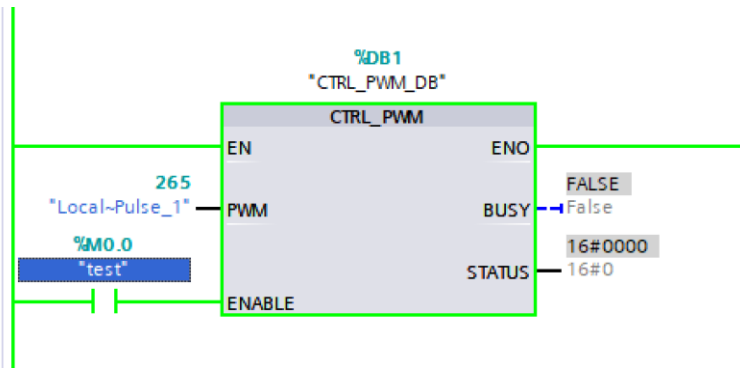


The PID block is shown next. The values for the numeric inputs are found in the Watch Table. Boolean variables can be set directly by modifying the input in online mode.





OB1: The OB1 block contains only the PWM input block. The 'test' bit is to be set before the PWM is allowed.



Link to S7-1200/1500 PID Manual:

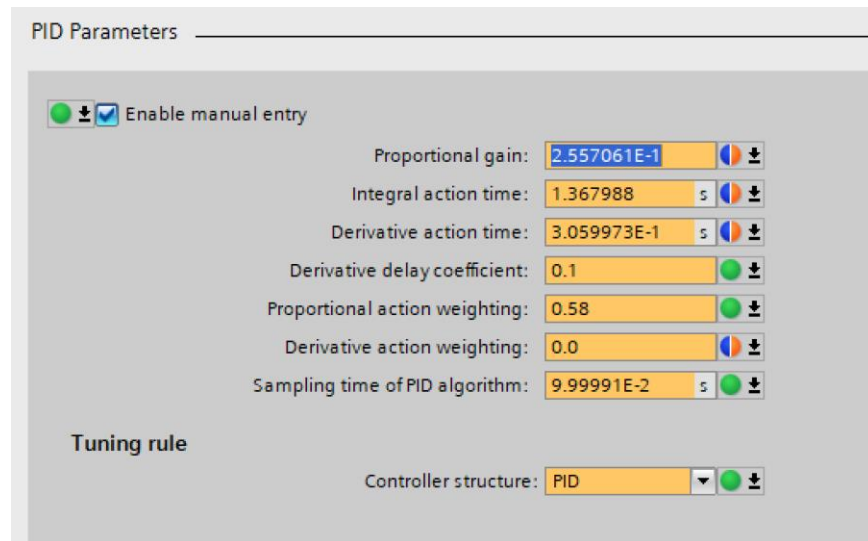
<https://support.industry.siemens.com/cs/us/en/view/108210036>

The tuning rules are found on pgs. 265 - 266 under the descriptions of operating modes "Pretuning" and "Fine tuning" in the 1200.

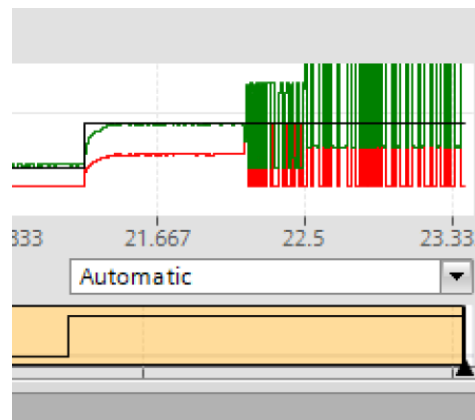
The following is a watch table built to display the variables for the PID block. The video gives additional detail of the PID block and uses this watch table to vary the speed.. Set the setpoint via the input 'set'.

Project10 ▸ PLC_1 [CPU 1214C DC/DC/DC] ▸ Watch and force tables ▸ Watch table_1								
	i	Name	Address	Display format	Monitor value	Modify value		Comment
1		"X"	%QW1000	DEC+/-	743	100	<input checked="" type="checkbox"/>	
2		"Tag_1"	%ID1000	DEC+/-	1189089		<input type="checkbox"/>	
3		"Q0.2"	%Q0.2	Bool	<input checked="" type="checkbox"/> FALSE	FALSE	<input checked="" type="checkbox"/>	
4		"set"	%MD16	Floating-poin...	125.0	125.0	<input checked="" type="checkbox"/>	
5		"Mode"	%MW20	DEC+/-	3	3	<input checked="" type="checkbox"/>	
6		<Add new>					<input type="checkbox"/>	

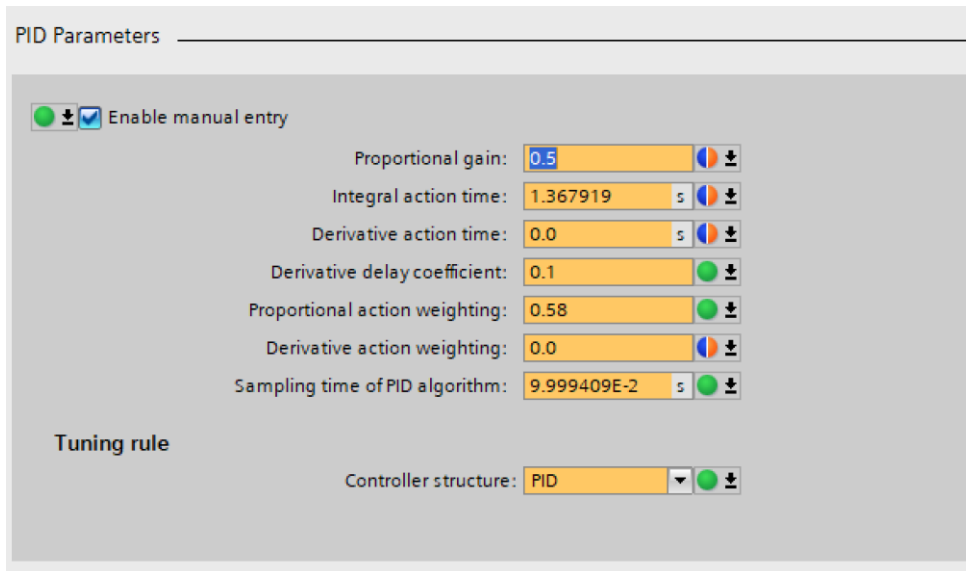
The commission of the PID block allows the auto tuning of the PID variables. With this option, the following PID parameters are generated and the output below.



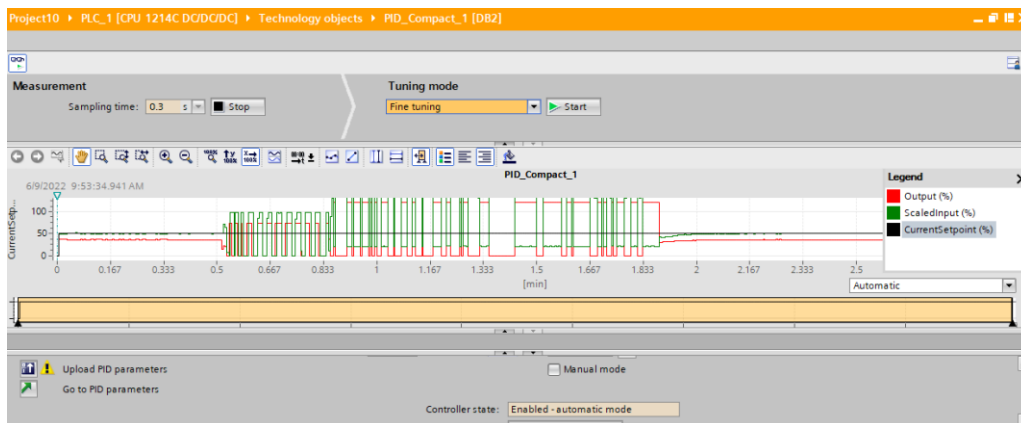
The motor oscillates. This demonstrates the instability of the tuning process. This is a good example of instability.



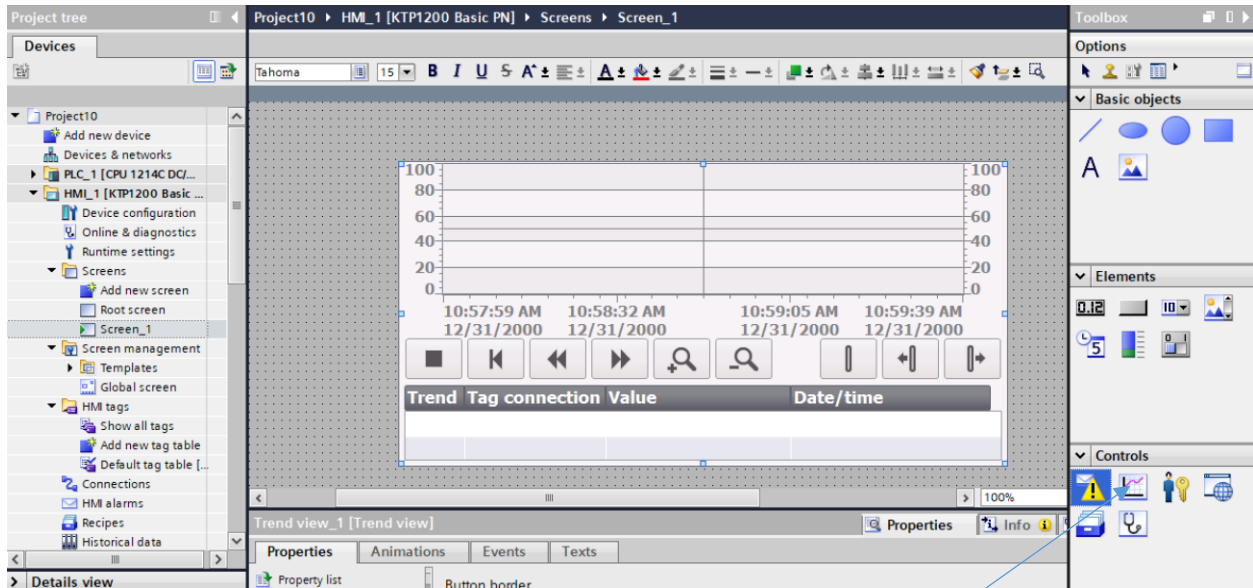
With the change shown below, instability is gone. Move a '0' into the Derivative action time variable and stability.



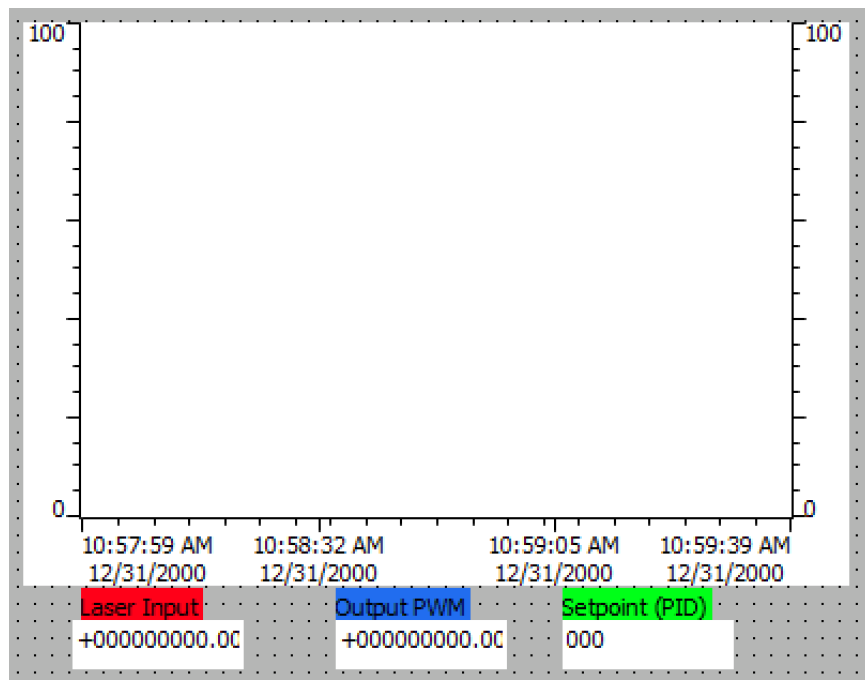
Now, the process of finding the best P, I, and D for a best response is required.



The best display of the response to the PID loop is not the chart above but rather the display below on a screen of an HMI display. Following is a step-by-step set of instructions to configure the display similar to the Ball-in-Tube and other PID labs. These instructions give a complete set of instructions for configuration of a historical data trend.



The Trend View under Controls is chosen. The picture above is very different than what is configured below. Commissioning of the graphic display can be achieved by proper configuration of the Trend View screen.





## Bibliography

[1] Dr. Curtis Cohenour, A Low-Cost Control System Experiment for Engineering Technology Students Ohio University, Proceedings of the ASEE's 125rd Annual Conference, Columbus, Ohio, 2017.

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