MEC 411 Lab #1

Digital PID Speed Control of a Turntable

1. Objective

The objective of this project is to implement a PID turntable speed control system that satisfies certain performance specifications. The PID controller will be implemented using software with a Data Acquisition (DAQ) interface, and the results obtained experimentally will be compared to theoretical results obtained using MATLAB, and to experimental results from the previous investigation.

2. PID Turntable Speed Control System

The turntable is controlled by a DC motor with a tachometer whose parameters are listed in Table 1.

Table 1: DC Motor and Tachometer.

Performance Parameters	Value	Units	Tolerance
Rated voltage D.C.	@12.0	Volts	-
Rated current	0.944	AMPS	-
Rated continuous torque	14	OZ-IN	-
Peak (momentary) torque	70	OZ-IN	-
Rated speed	800	RPM	± 15%
Rated continuous power out	8.3	Watts	± 15%
No load speed	1000	RPM	MAX
No load current	0.340	AMPS	MAX
Back EMF constant (K_b)	12.0	V/KRPM	± 10%
Torque constant (K_m)	16.2	OZ-IN/A	± 10%
DC armature resistance (R_a)	11.5	OHMS	± 15%
DC armature inductance (L_a)	3.16	mH	± 15%
Armature temperature	155	DEG. C	MAX
Unit weight	12	OZ	MAX
Tachometer voltage gradient	0.52	V/KRPM	

The block diagram for the digital PID turntable speed control system is shown in Figure 1. The closed loop transfer function is:

$$T(s) = \frac{\omega(s)}{V(s)} = \frac{G_c(s)G(s)}{1 + K_t G_c(s)G(s)} \tag{1}$$

where

$$G(s) = \frac{K_m}{(L_a s + R_a)(Js + b) + K_b K_m} \approx \frac{K_m}{R_a(Js + b) + K_b K_m} \tag{2}$$

$$G_c(s) = K_c\left(1 + \frac{1}{T_i s} + T_d s\right) \tag{3}$$

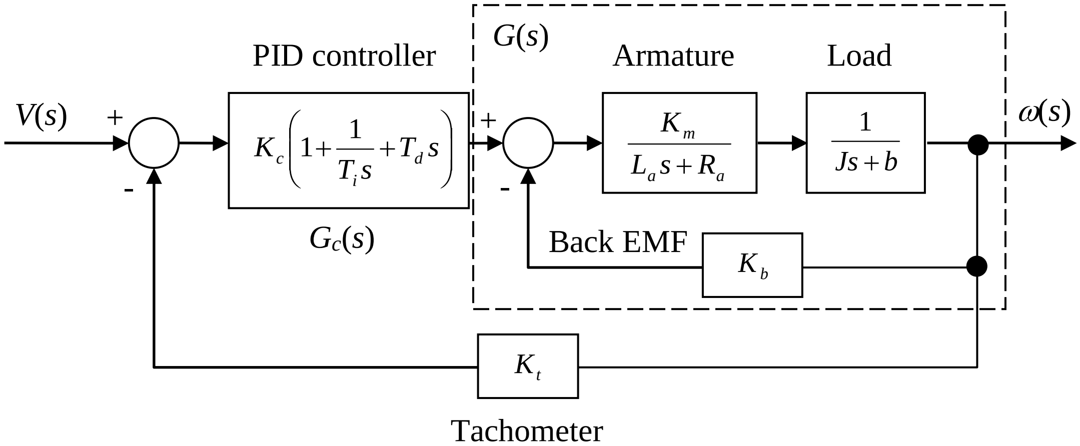


Figure 1: Block diagram of a PID turntable speed control system.

Assume the parameters of the DC motor, the tachometer, and the load to be as follows:

K_m = 16.2 OZ-IN/A
R_a = 11.5 Ω
L_a = 0
J = 2.5 OZ-IN^2
b = 0
K_b = 12V/KRPM
K_t = 12V/KRPM

Note that the integration time (T_i) and the derivative time (T_d) are in minutes.

3. Design Specifications

Design a PID controller for the turntable speed control system by selecting appropriate values for the system parameters within the computer program so that the system output satisfies the following performance specifications when subjected to a unit step input:

1) Percentage overshoot is to be less than 10%
2) Settling time to within 2% of the final value is to be less than 500ms.
3) Rise time is to be less than 200ms

4. Experimental Procedure

1) Build the proposed turntable speed PID control system as shown in Figure 2. Note that if you require any information on any of the components to be used during this experiment (hint:

you do), you are expected to look up the datasheets yourself – this information will not be provided; this is part of the exercise.

2) Connect the input *V* to the function generator with a square wave with a frequency of 1Hz and an amplitude of 1V.
3) Connect Channel 1 of the oscilloscope to the input *V* and Channel 2 to point ω, which is the feedback voltage indicating the actual speed of the turntable measured by the tachometer. You don't strictly speaking need the oscilloscope since the control software can record the waveforms directly, but you may find it helpful.
4) Set the integration time (T_i) and the derivative time (T_d) to zero. This is now feedback control with a P (Proportional) controller. Adjust K_c so that the turntable output speed is as close to the input as possible while keeping the system stable – record all system parameters, along with input and output waveforms using the computer software.
5) Set the derivative time (T_d) to zero. Now the system is a PI (Proportional-Integral) controller. Adjust K_c and T_i to make the turntable output speed as close to the input as possible while keeping the system stable – record all system parameters, along with input and output waveforms using the computer software.
6) Adjust the three parameters (K_c, T_i, T_d) to make the system perform as required by the given specifications. Now the system becomes a PID (Proportional-Integral-Derivative) controller. Record the design values of K_c, T_i, and T_d along with input and output waveforms using the computer software. To tune the controller you may either utilize the Ziegler-Nichols method, or you may tune by trial and error.

5. Lab Report

1) The lab report ***must*** include the followings: cover page with title, group number, names of the group members, and date, table of contents, abstract, introduction, experimental procedure, results, discussion, conclusions, and ***references***.

2) The abstract must be a concise summary of the work that has been done that clearly informs the reader of all essential facts associated with the project. i.e. who, what, when, where, why.

3) The introduction must include any relevant background information that the reader will require in order to understand the report, and must include all necessary derivations associated with the theory involved with the experiment. This will include derivations of the transfer functions for each component of the system as well as the overall transfer function for the system.

4) The experimental procedure will outline the steps required to complete the investigation in sufficient detail such that they could be used by the reader to successfully repeat the results reported by the authors.

5) In the results section you will report the findings of the experimental procedure. You will also use MATLAB to simulate the output response in each step of the experimental procedure based on the recorded parameters.

6) In the discussion section you will compare the theoretical results calculated using MATLAB with the corresponding experimental results. You will determine whether the experimental results agree with the theoretical model and with the previous experimental results to within relevant experimental uncertainty, and if not, you will explain and suggest corrections for future investigations, including a mathematical analysis justifying your explanation.

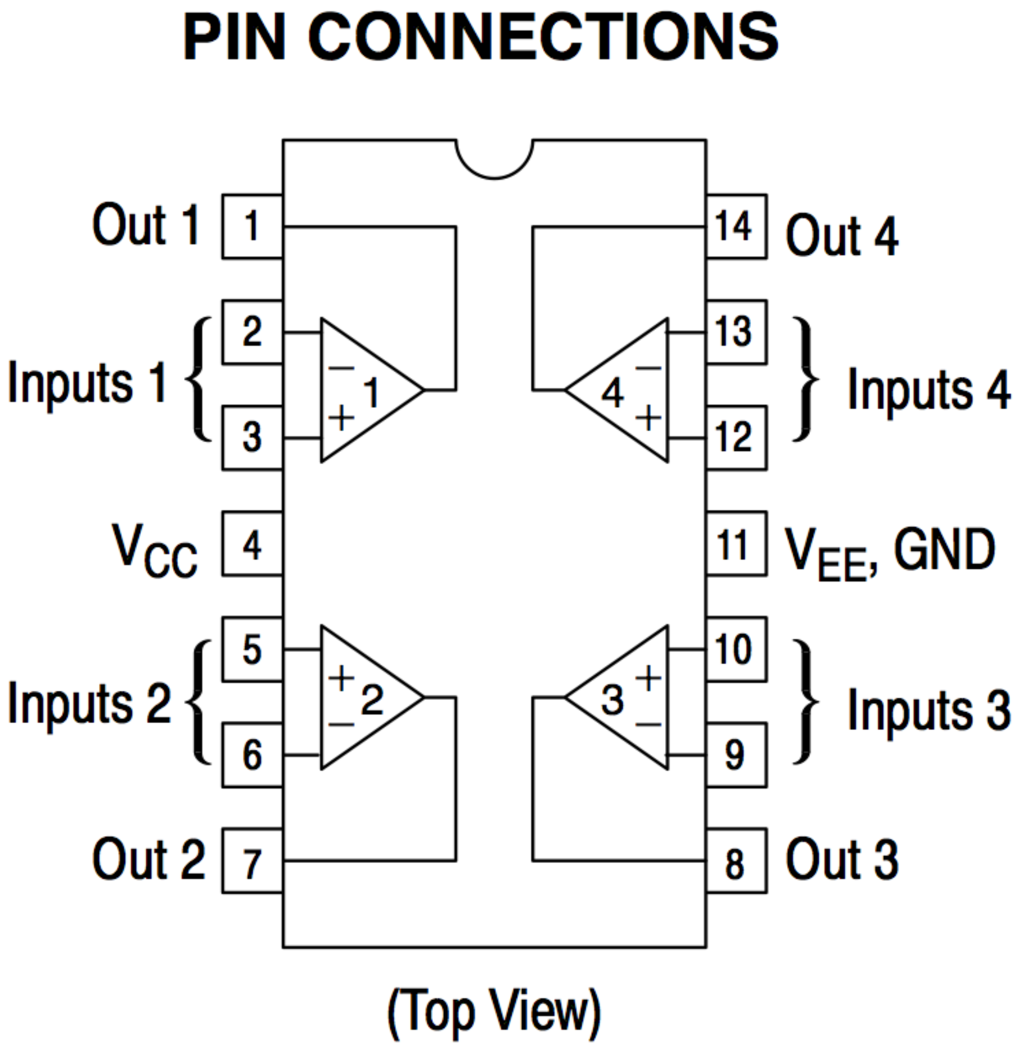
7) The conclusions section will clearly identify what you have learned from the lab as simple statements in bullet point format, i.e.:

- The experimental results showed . . .
- The relevant values were found to be . . .
- The experimental results did/didn't agree with the theoretical results
- The experimental results did/didn't agree with the previous results
- The discrepancy, if any, is attributed to . . .
- In future investigations, this/that should be considered to correct, if necessary.
- Etc.

8) Additional details on required lab report content and format will be distributed separately and must be followed.

How to use the computer software:

1. Run the computer software.
2. The program will start up in the active state.
3. Adjust the PID gain parameters to your liking, as instructed, observing the input and output (i.e. motor speed, not the controller output) waveforms in the on-screen graph.
4. Set the path to the name of the file you wish to use to store your data. Use a .csv (comma separated variable) file extension.
5. Click on the "record" button – the program will begin recording the input and system output. It will continue to record until you click the button again.
6. Open the .csv file in Excel and proceed with whatever it is you would like to do with your data.



Op Amp connection Diagram: LM324/D, Rev. 15, Semiconductor Components Industries, LLC, 2004

Resistor Color Code:

Band 1 & 2	Value	Band 3	Multiplier
Black	0	Black	X1
Brown	1	Brown	X10
Red	2	Red	X100
Orange	3	Orange	X1k
Yellow	4	Yellow	X10k
Green	5	Green	X100k
Blue	6	Blue	X1M
Violet	7	Silver	/100
Gray	8	Gold	/10
White	9		

Band 4: Tolerance: Gold 5%, Silver 10%, None 20%

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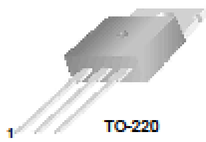
October 2008

TIP120/TIP121/TIP122
NPN Epitaxial Darlington Transistor

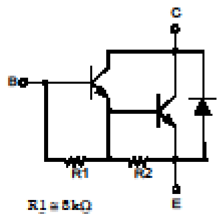
- Medium Power Linear Switching Applications
- Complementary to TIP125/126/127



TO-220

1.Base 2.Collector 3.Emitter

Equivalent Circuit



$R1 \cong 8k\Omega$
$R2 \cong 0.12k\Omega$

Absolute Maximum Ratings* T_a = 25°C unless otherwise noted

Symbol	Parameter	Ratings	Units
V_{CBO}	Collector-Base Voltage : TIP120 : TIP121 : TIP122	60 80 100	V V V
V_{CEO}	Collector-Emitter Voltage : TIP120 : TIP121 : TIP122	60 80 100	V V V
V_{EBO}	Emitter-Base Voltage	5	V
I_C	Collector Current (DC)	5	A
I_{CP}	Collector Current (Pulse)	8	A
I_B	Base Current (DC)	120	mA
P_C	Collector Dissipation (T_a=25°C)	2	W
	Collector Dissipation (T_C=25°C)	65	W
T_J	Junction Temperature	150	°C
T_{STG}	Storage Temperature	- 65 ~ 150	°C

* These ratings are limiting values above which the serviceability of any semiconductor device may be impaired.

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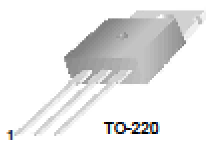
TIP125/TIP126/TIP127
PNP Epitaxial Darlington Transistor

- Medium Power Linear Switching Applications
- Complementary to TIP120/121/122



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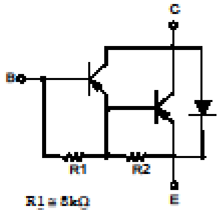

R1 ≈ 8kΩ
R2 ≈ 0.12kΩ

Absolute Maximum Ratings* T_a = 25°C unless otherwise noted

Symbol	Parameter	Ratings	Units
V_{CBO}	Collector-Base Voltage : TIP125	- 60	V
	: TIP126	- 80	V
	: TIP127	- 100	V
V_{CEO}	Collector-Emitter Voltage : TIP125	- 60	V
	: TIP126	- 80	V
	: TIP127	- 100	V
V_{EBO}	Emitter-Base Voltage	- 5	V
I_C	Collector Current (DC)	- 5	A
I_{CP}	Collector Current (Pulse)	- 8	A
I_B	Base Current (DC)	- 120	mA
P_C	Collector Dissipation (T_a=25°C)	2	W
	Collector Dissipation (T_C=25°C)	65	W
T_J	Junction Temperature	150	°C
T_{STG}	Storage Temperature	- 65 ~ 150	°C

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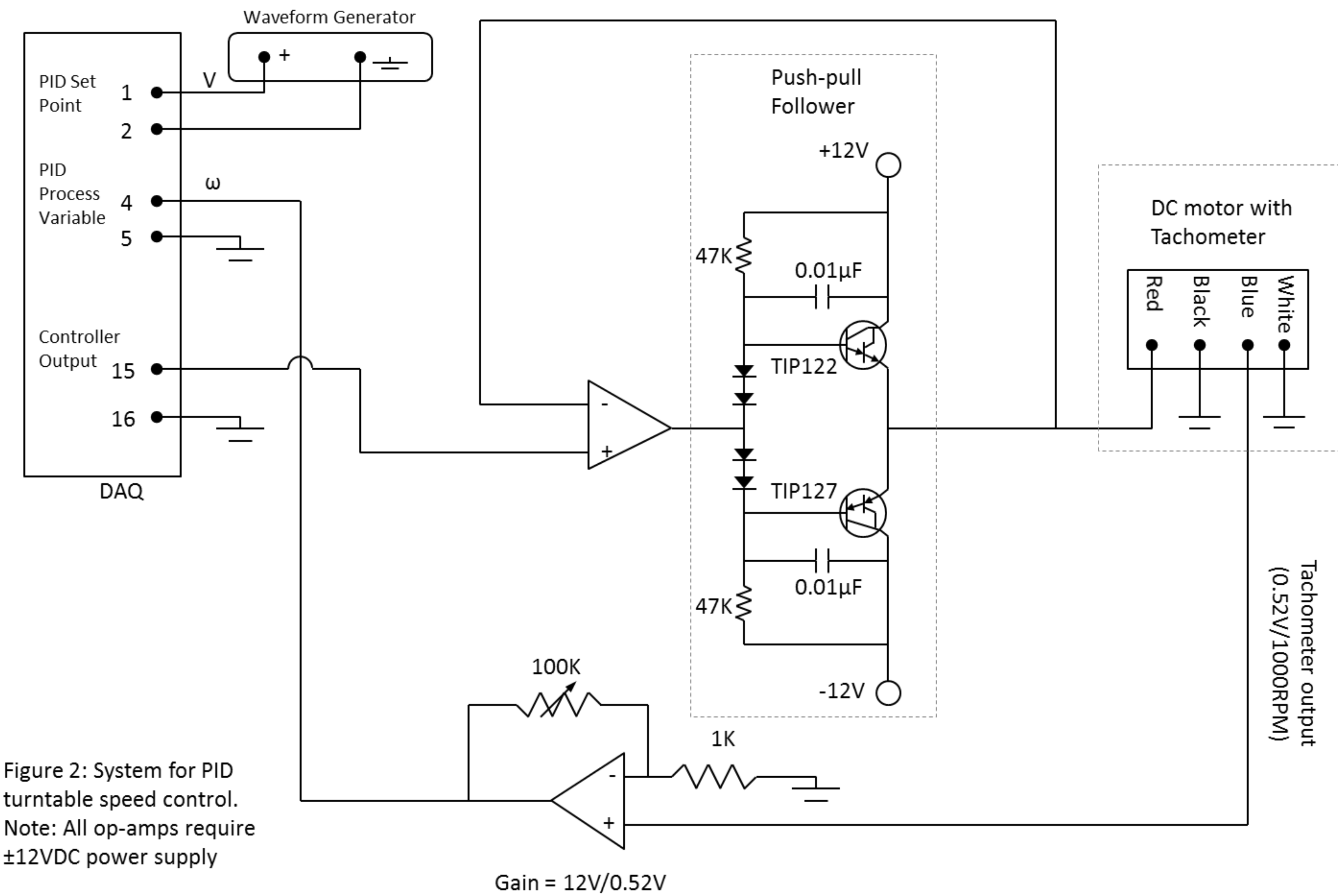

Figure 2: System for PID turntable speed control.
Note: All op-amps require ±12VDC power supply