Relative stability enhancement for brushed DC motor using a PLL interfaced with LabVIEW

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ABSTRACT

This work presents a fast response and stable computer based a brushed DC motor speed controller. The controller configured of gate drive circuits for H-Bridge accompanied with data acquisition unit DAQ-6211. These gate drive circuits include, phase comparator, current booster and wave forms cleaning circuits. An optical encoder is used for motor speed to frequency conversion. The CD4046 PLL chip compares phases of the encoder output frequency (motor speed) with a reference frequency (desired speed). The obtained phase difference (error) is used to allocate the suitable PWM duty cycles. An H-Bridge BJT switches driven by PWM is interfaced with the motor. The system hardware is provided with a simple and accurate data acquisition unit DAQ-6211 to be interfaced with the LabVIEW software Package. This allows monitoring and storing the different measured data of this platform. The system relative stability is determined and examined based on the Bode plot analysis and design. Then the relative stability criterion (Phase Margin) is measured the closed-loop stability of the system. This system considers the fast feedback response with indication of its stability state as well as the stable wide dynamic range. It compensates the changes in system parameters due to the environmental effects and other disturbances.

Keywords: DAQ-6211, DC motor, H-Bridge, LabVIEW, Phase margin, PLL, PWM, Relative stability

1. INTRODUCTION

The DC motors have been popular in the industry control area for a long time, because they have many good characteristics, for example: high start torque, fast response performance, easier to be linear control [1]. The different control approach depends on the different performance of motors. The DC motor control is then riper than other kinds of motors no matter in the theoretic study or in the research and development of the application technology. However, the technique of instrument design also moves forward the times of "virtual instrument", not only the designing time is shortened, but also the designing space is more elastic extension [2].

Usually control system does not remain constant throughout its life cycle, so there are always changes in system parameters because of environmental effects and other perturbations and disturbances. These changes and affections are called parameter variations (gain and stability, temperature, supply voltage variations and/or external disturbances) where can be studied using mathematical and physical term expressions to illustrate entire control system change. The more keeping prosperities control system with entire changes the lesser sensitivity of control system [1, 3].
This paper designs a control circuit to supervise and control the speed response of the DC motor with the virtual instrument graphic monitor software LabVIEW [4]. To control the speed and display the changes of rotational speed of the motor with assessment relative stability [17] by instantaneous monitoring phase difference angle (Φ) as the phase shift between desired and actual signals on PLL output, the better response of the system can be achieved by using the NI USB-6211 data acquisition (DAQ) [1, 5] that will read the data of the control circuit for transmitting the signal using in real time to PC. This does not require transfer functions, just experimental frequency response data of the (stable) open-loop system are necessary to judge the closed-loop stability [6, 7]. Because the DAQ card has the capability of the data storage, calculating, analysis, Analog to Digital Converter (ADC) and DAC conversion [19]

2. SYSTEM DESCRIPTION

The system configured of a permanent magnet DC motor, DC power supply, photo electric encoder B83609, motor control board, DAQ card NI USB-6211 accompanied with the NI-LabVIEW package [13] as shown in Figure 1. It is described and explained briefly as follows:

![](Figure 1. Block diagram of the system)

2.1. Hardware implementation

This circuit consists of phase locked loop (PLL - CD4046), passive low pass filter (LPF) [8], current amplifier, (regulator LM7805) and (Schmitt trigger 74HC14) as shown in Figure 2.

![](Figure 2. Voltage control circuit of permanent magnet brushed DC motor)

The system operation includes both hardware and software modules. Using the LabVIEW program, the system allows the user to monitor the actual motor speed in addition to take direct action when
the desired speed is out of the control range. This is accomplished with sampling rate of 2.5 kHz for each of
the four channels of the developed system [20]. The speed error leads to the average voltage adjustment
which will be applied to the driver of the motor after its filtering and amplification. The DC motor speed is
measured using (DAS) kit for the control system. The system master clock is internally generated in the PLL.
This PLL (CD4046) receives both the actual and the reference speeds. The PLL average voltage error is
smoothed and applied to motor drive circuits. Furthermore, the optimized LPF of an adjustable cut off
frequency that is according to the selected reference frequency makes two individual functions. The first
function is required for noise immunity and the second is working as a lead/lag compensator [23]. The LPF is
considered as essential stability issue and used for system final tuning [11]. For good driving of the motor,
single (2N2222) current booster has been used to reinforce the signal after noise rejection. Quad chopper of
four transistors (2N3055) is used to provide the rating current which is suitable to the DC motor and speed
redirection. On the other hand, the developed LabVIEW modules are used for monitoring the speed, stability,
and time response [21].

2.2. Software Implementation
The software of this work is configured of the following modules:

2.2.1. LabVIEW Programs
The LabVIEW is the most dominant package used for creating, testing and measurement, of the
equid data acquisition systems. The LabVIEW systems are broadly classified into, monitoring, logging, and
interactive or smart systems [12]. The control system of this work monitors the DC motor speed using the
LabVIEW program virtual instruments (VI) and reads the actual motor feedback and the reference speeds
[10]. The reading is performed as RPM and the analogue voltage output of the system in four test points
(reference signal, feedback signal, PLL output, current amplifier output) as shown in Figure 2. The front
panel and block diagram compile of LabVIEW on PC under windows 8.1 are showing in Figure 3 and
Figure 4.

![Figure 3. Front panel of the actual and reference speeds with time](image)

![Figure 4. Block diagram of actual and reference speed with time](image)
2.3. Flowchart of The Process

The System Algorithm Flowchart of The Process is shown in Figure 5.

![Flowchart Image](image)

Figure 5. The system algorithm

3. EXPERIMENTAL RESULTS

The practical system parameters are used for the system relative stability evolution [16, 18]. The system was built and tested using a DC motor with speed of 1200 rpm and voltage 12 Volt and current 0.8 Ampere. The rotary encoder has 20 pulses per revolution (ppr). The range of speed control is from 40 rpm to 600 rpm. Thus, the system block diagram and its gain \( K = 1.1 \) is shown in Figure 6, thus transfer function of loop transmission with VI LabVIEW program code as in Figure 7.

![Mathematical Model Image](image)

Figure 6. The condensed mathematical model of the system

The loop transmission state of the system at certain load:

\[
G(s)H(s) = \frac{1.1(1+0.000289s)}{(1+0.000318s)}
\]

(1)
3.1. Experimental results of the PLL.

The core of the system controller is the PLL designed to receive both the reference (desired) frequency and the feedback frequency that corresponding to the actual motor speed [24, 25]. An encoder has been coupled with the motor shaft in order to converge the speed to frequency. The PLL receives, both the motor actual and the reference frequencies [14]. According to the phase error of these two frequencies, the PLL provides a suitable duty cycle for driving the DC motor [15]. The variations in the PLL output due to the PLL input phase difference are displayed in Figure 8.

Figure 8. Reference frequency, Actual frequency, PLL output on LabVIEW software design program (VI).

The following figures are the experimental comparison explanation cases at different speeds related to the control circuit to follow up or monitoring it using four measuring points on circuit to be sure that the dynamic behavior of the control circuit of the system is in the normal case. There are four points pertaining to four channels on DAQ (CH1, CH2, CH3, CH4) as demonstrated in Figure 9 and Figure 10. All these channels are recorded simultaneously on DAQ channels (A10, A11, A12, A3). The channel CH1 assign to Reference signal (white color), CH2 to Feedback signal (red color), CH3 to comparator out from PLL (green color), CH4 to PWM input signal (blue color).
3.2. System response for different loads

The LabVIEW software modules are the speed control, stability, and time response on the system monitors [22]. Some of the PLL output-controlled phase difference angle ($\Phi$) that are corresponding to the different loads are listed in Table 1.

| Weight(gm) (Load) | 53.7 Hz Phase angle (Degree) $\Phi$ | 97.5 Hz Phase angle (Degree) $\Phi$ | 126Hz Phase angle (Degree) $\Phi$ | 155Hz Phase angle (Degree) $\Phi$ | 202Hz Phase angle (Degree) $\Phi$ |
|-------------------|-------------------------------------|-------------------------------------|----------------------------------|---------------------------------|----------------------------------|
| 0                 | Lockout / unstable system            | 56.2'                               | 72.72'                           | 111.6'                          | 145.4'                           |
| 100               | Lockout / unstable system            | 73.8'                               | 90.7'                            | 122.8'                          | 159.8'                           |
| 150               | 48.2'                               | 105.1'                              | 127.1'                           | 167.4'                          | Lockout / unstable system         |
| 280               | 67.7'                               | 122.8'                              | 176.8'                           | 195.5'                          | Lockout / unstable system         |
| 535               | 91.8'                               | 140'                                | 222.1'                           | Lockout / unstable system        | Lockout / unstable system         |

The motor operation modes according to the external load can be arranged through five different motor speed [9], which are:

- **161 RPM/ 53.7Hz**
  For no load up to the 100gm, the motor is still lockout and no effective duty cycle of the PLL that leads the motor speed to be lock-in. For a load of 150gm the motor starts the lock-in (stable operational range) and keep constant speed up to around 535gm as shown in Figure 11. One can see that the duties (2.5ms, 3.5ms and 4.75ms) cycles change according to the given loads 150gm, 280gm and 535gm respectively.

- **465 RPM/ 155Hz**
Locked-in motor speed range is located starting from the no load condition, up to 280gm with constant speed. The motor had locked-out at load of 535gm resulting in an unstable operation as shown in fig 12. However, the duties 2ms, 2.2ms, 3ms, 3.5ms cycle are due to the given no load, 100gm, 150gm, 280gm respectively, the load 535gm resulting in unknown duty outside the stable operational zone.

4. CONCLUSION

Digital control for the DC motor based on computer system has been designed, experimentally implemented and elaborated. The PLL is used as a phase and frequency comparator for measuring the speed drift w.r.t the desired reference speed. Simple and easy to use LabVIEW were has been used to achieve the suggested approach of the DC motor speed control. The system has been developed to include the graphical user interface using LabVIEW software as well as the DAQ-6211 module of national instruments. The system shows that the widest stable range is located at the measured speed range of (290 rpm to 378 rpm) for the all selected loads (100g up to 535g in 5 steps). The Bode plot of the system loop transmission shows that the system relative stability depends on both the load and the phase margin.

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