Identification of parameters for a DC-motor by LabVIEW
Abstract

In this bachelor thesis we focus on how the computer software LabVIEW test is used to a DC-motor through as a hardware incremental encoder and a USB-6009. By using LabVIEW, we can do pulse counting, voltage changing test, voltage signal acquiring and some other observing jobs.

This paper is a report of our mechanical operation and calculative work about the DC motor as well. The using DC motor's model number is E-660. Since we cannot find the official data of the DC motor we need, we tried to find some similar motor model to compare. Fortunately, we find some data. Even it is unofficial data from eBay website. However, these data can be seen as reference of our motor. Therefore we can compare the data from the laboratory and the theoretical ones.

For the other part of the thesis is about the incremental encoder, the model we used in project is DG 63 KA. We just can find a similar type and it as a reference. The model we find similar to the actual one is DG 60L and through the measurement and comparison, we manage to test the encoder pattern is the same as the reference.

Eventually, we can still do some calculations and analysis with the measured data. We also can summarize some content according to the referential data with the similar DC motor.

摘要

在此学士论文中我们主要将重点放在 LabVIEW 电脑软件测试如何通过硬件设备增量式编码器和 USB-6009 应用到直流电机上。通过使用 LabVIEW，我们可以进行脉冲计数，电压变化测试，电压信号采样和其它观测工作。

这份报告同时也包括对直流电机的机械操作和计算工作。我们使用的直流电机型号为 E-660。由于我们未能找到我们需要的直流电机的数据，我们尝试去找到一些相似的型号来比较。幸运的是，之后我们找到了一些数据。尽管数据是来自 eBay 的非官方数据。然而，这些数据可以作为我们电机的参考。因此我们可以使用这些理论数据和我们从实验得出的数据进行比较。

论文的另外部分是关于增量式编码器，我们在论文中使用的编码器型号是 DG 63 KA。我们只能找到一些类似型号作为参考。我们找到的和实际使用的类似编码器型号为 DG 60L 并且通过测量和比较，我们成功证实编码器的模式和参考中的相同。
最终，我们还对测量的数据进行了计算和分析。我们同时也根据类似的直流电机的参考数据进行总结。

**Keywords**

LabVIEW, DC-motor, incremental encoder, USB-6009

**关键词**

LabVIEW，直流电机，增量式编码器，USB-6009

**Contents**

Abstract .......................................................................................................................... 1
摘要 ................................................................................................................................. 2
Keywords ......................................................................................................................... 3
Contents .......................................................................................... 3

1 Introduction .................................................................................. 5

  1.1 Background ............................................................................. 5
  1.2 Purpose .................................................................................... 6
  1.3 Objectives .............................................................................. 6

2 Instruments .................................................................................. 6

  2.1 Introduction of LabVIEW ...................................................... 6
      2.1.1 The front panel ................................................................. 7
      2.1.2 The block diagram ........................................................ 8
  2.2 Instrument USB-6009 ............................................................ 9
      2.2.1 Hardware ....................................................................... 10
      2.2.2 I/O Connector ................................................................. 11
      2.2.3 Communication .............................................................. 12
  2.3 Measurement systems .......................................................... 14
      2.3.1 Pulse counting system .................................................. 14
      2.3.2 Voltage signal system ................................................... 15

3 DC-motor ..................................................................................... 16

  3.1 The used motor ...................................................................... 16
  3.2 Motor principles .................................................................... 17
  3.3 DC Motor Modeling ............................................................... 18
  3.4 Parameter Measurement ...................................................... 20
  3.5 Pulse counting ....................................................................... 22
  3.6 Counting system test ............................................................. 26
  3.7 DC-motor voltage changing test .......................................... 28
      3.7.1 Change from 0A to 20V ................................................ 28
      3.7.2 Change from 20V to 0A ................................................ 29
      3.7.3 Change from 10V to 0A ................................................ 30
      3.7.4 Change from 15V to 20V .............................................. 31
      3.7.5 Change from 20V-0V ................................................... 32
      3.7.6 Change from 10V-0V ................................................... 33
      3.7.7 Measurements .............................................................. 34
  3.8 Calculation ............................................................................. 35
      3.8.1 Density of the wheel ..................................................... 35
      3.8.2 Inertia of the wheel ....................................................... 35
      3.8.3 Parameters .................................................................... 36

4 Incremental encoder ................................................................. 38

  4.1 The used encoder .................................................................... 38
  4.2 Encoder principles .................................................................. 39
  4.3 Voltage signal acquiring ....................................................... 40
  4.4 Analysis ................................................................................. 44
1 Introduction

1.1 Background

Incremental encoder is a device which converts the rotation into periodic electrical signals. Then the electrical signals will be transferred into counting pulses. The number of the pulses presents the size of displacement. The incremental encoder will be described in chapter 4.

Incremental encoder takes the advantage of the principles of photoelectric convert ion directly to produce three pairs of square wave pulses A, B and M. While A and B pairs have a phase difference of 90 degrees, therefore, it is convenient to judge the rotation direction. The axis of the encoder rotates one circle will produces a certain number of pulses, while the pulses number is decided by the encoder grating lines. When it is needed to raise the resolution ratio, we can make the use of 90 degree phase difference signals A and B to double the frequency or change the higher resolution ratio encoder. M is defined as a pulse per circle which is used for datum point location. The merit of the incremental encoder is the simple structural principle, as well as the high anti-interference ability and a long mechanical life for
average more than ten thousands hours, high reliability which is suitable for long distance transportation. However, the drawback of it is that it cannot read the absolute position information when axis is rotating.

1.2 Purpose

The purpose of our work is to test and verify the parameters of DC motor to see if they are reasonable compared with theoretical calculation. At the same time, we also want to obtain the waveform graphs of cables and test the regulation form of incremental encoder. From the incremental encoder we are able to measure the rotation speed of the DC motor. We choose the USB-6009 to obtain the signals and LabVIEW to control this processing.

1.3 Objectives

1. Be familiar with most part of functions and the use of LabVIEW.
2. Find appropriate components to measure the waveform graphs of incremental encoder in the LabVIEW.
3. Compare the actual measured information to the theoretical parameter and summarize the characteristic of the actual measured information.
4. Put the measured data into the theoretical functions and calculate them.

2 Instruments

2.1 Introduction of LabVIEW

LabVIEW is short for Laboratory Virtual Instrumentation Engineering Workbench and it is a system design platform and development environment for a visual programming language produced by National Instruments. And its inventor is Jeff Kodosky, the program is initially announced on a MAC computer in 1986. The LabVIEW graphical development environment was built specifically for applications in engineering and science as well as built-in functionality designed to reduce development time for design and simulation in signal processing, control, communications, electronics and more. LabVIEW first introduce the concept of virtual instruments, the user can control the instruments they designed themselves through the man-machine interface. Besides, the function library of LabVIEW includes: signal acquiring, signal analysis, machine vision, math arithmetical, logical arithmetical, sound vibration analysis, and information storage as so on. LabVIEW can support Windows, UNIX, Linux, Mac OS operating systems. For the sake of LabVIEW has the special graph program and simple, easy research interface, it can promote the efficiency of research and shorten the software service time, which is
gradually fond of by many system researchers. Nowadays, LabVIEW is widely used in industry automatic control field. A LabVIEW program consists of two parts: the Front panel and the Block Diagram.

In our project work, we mainly use the DAQ assistant unit as a tool to acquire signals from the incremental encoder and the DC-motor. A time unit is also used to counting for the time has left as well as several indicators to record the data we need. We get used to majority functions of the LabVIEW through the thesis.

2.1.1 The front panel

As illustrated in Figure 2.1, the front panel window is the interface to your VI code that comprises a virtual instrument. Front panel contain various types of controls and indicators, in other words, inputs and outputs. When you right click on the blank space of front panel, a Controls palette will appear. The Controls palette consists of top-level icons representing sub palettes that contain a full range of available objects that you can use to create front panels.
FIGURE 2.1
LabVIEW front panel (screen shot from National Instrument example)

As we can see from Figure 2.1, this is an example from “Calculation on Dynamic Data.vi”. In this example, we can get to know the switch as a button named “STOP”, an indicator named “Offset”, a waveform graph named “Result”. These components consists the front panel of the example.

2.1.2 The block diagram

As illustrated in Figure 2.2, the block diagram window contains program code that exists in a graphical from which is so called G programing elements. Block diagrams contain terminals corresponding to front panel controls and indicators, as well as constants, functions, subVls, structures, and wires that transfer data from one element to another. When you right click on the black space of the block diagram, an Express palette will show up. The Express palette presents the more
commonly utilized controls in a more compact viewing pane.

![LabVIEW block diagram](image)

**FIGURE 2.2**
LabVIEW block diagram (screen shot from National Instrument example)

### 2.2 Instrument USB-6009

One of the main instruments that we used in our project is the National Instruments USB-6009. The National Instruments USB-6009 is a low cost multifunction data acquisition device (DAQ) provides basic data acquisition functionality for applications such as simple data logging, portable measurements and the laboratory experiment from academic institutions. As illustrated in Figure 2.3, it has 8 analog inputs (14-bit, 48 kS/s) and 2 analog outputs (12-bit, 150 S/s) and 12 digital I/O as well as 32-bit counter. It has bus-powered for high mobility and was
built-in signal connectivity. OEM version available means that it is cheap for students to purchase. It is also compatible with LabVIEW, LabWindows/CVI, and Measurement Studio for Visual Studio .NET while in our project, the laboratory uses software of LabVIEW.

![USB-6009 outlook (National Instrument website picture)](image)

**FIGURE 2.3**
USB-6009 outlook (National Instrument website picture)

2.2.1 Hardware

The figure 2.4 shows the key functional components of the NI USB-6009.
2.2.2 I/O Connector

Figure 2.5 shows the ports of NI USB-6009. Analog input signal names are listed as single-ended analog input name, AI x while the differential ones are named, (AI x+/−)

Figure 2.6 indicates a detailed description of each signal. In the project, the counting system mainly uses the PFI 0 pin, this pin is configurable as either a digital trigger or an event counter input. Through this pin, we can easily read the number of pulses for the calculation of rotating speed.
2.2.3 Communication

Figure 2.7 shows the basic procedure how physical phenomena are converted into signals are received and then filtered by the signal conditioner to the suitable signal we needed. In the next step, signals will be obtained by DAQ hardware, for example, in our case, that should be USB-6009. Finally, the signals acquired by the
computer are processed by the control software, in our case, the LabVIEW.

**FIGURE 2.7**
Communication diagram

Picture is from website “http://www.data-acquisition.us/”
2.3 Measurement systems

2.3.1 Pulse counting system

We can obtain from Figure 2.8. Pulse counting system consists of three parts: the DC motor, incremental encoder and USB-6009. In this system, DC motor is internally connected to the incremental encoder, when incremental encoder connected to the USB-6009, we choose one of the pulses signal, for example, here we choose white, that is, K1 signal connected to PFI0, the pulses counting channel. Then connect the red to +5V to provide the voltage supply for the device.
2.3.2 Voltage signal system

Figure 2.9 shows the voltage signal system also consists of three parts: the DC motor, incremental encoder and USB-6009. In this system, DC motor is internally connected to the incremental encoder, when incremental encoder connected to the USB-6009 while the differences between the two systems are the connections. Lilac cable is connected to AI0 and yellow cable is connected to AI4 to make a comparison. White cable is connected to AI1 and brown cable is connected to AI5 to make a pair. Pink cable is connected to AI2 and black cable is connected to AI6 to see the result. While red is +5V and blue link to ground to make sure the power supply for the device. Grey and green are internally connected to +5V and ground.
3 DC-motor

3.1 The used motor

Figure 3.1 indicates the picture of the motor used in project. We can easily read some information from its brand. It was produced by ElectroCraft. The model number is written to be E-660. “ElectroCraft, Inc. specializes in dependable, application-engineered specialty fractional-horsepower motor and motion products.

The ElectroCraft Powering Innovation custom manufacturing services cover the following products: AC motors, DC motors, brushless motors, machine transaxle drives, gearboxes, servo motors, AC gear motors, DC gear motors, brushless gear motors, stepping motors, linear actuators, integrated motor drives, motor generators, motor speed controls, servo drives, stepping drives, electric circuits for the control and regulation of electric motors, electric controls for electric motors, amplifiers for electric motors, position controls for electric motors, stepping controls for electric motors and electric motor speed sensors.

ElectroCraft is headquartered in the United States in Dover, New Hampshire and support the needs of our global customers with operations in Europe and Asia, as well.” (From the website page “about the ElectroCraft”)

This DC motor we used in this project is produced by ElectroCarft and we tried to find data about the motor as we can see the model is E-660. However, we only find the unofficial data about the motor to compare as reference.
3.2 Motor principles

A common actuator based on these principles and used in control systems is the DC motor to provide rotary motion. A sketch of the basic components of a DC motor is given in Figure 3.2. In addition to housing and bearings, the nonturning part (stator) has magnets, which establish a field across the rotor. The magnets may be electromagnets or, for small motors, permanent magnets. The brushes contact the rotating commutator, which causes the current always to be in the proper conductor windings so as to produce maximum torque. If the direction of the current is reversed, the direction of the torque is reversed.

![DC Motor Diagram](image)

**FIGURE 3.2**
Sketch of a DC motor

The motor equations give the torque $T$ on the rotor in terms of the armature current $i_a$ and express the back EMF voltage $e$ in terms of the shaft rotational velocity $\dot{\theta}_m$.

Thus

$$T = K_t i_a \text{ [Nm]}$$  \hfill (3.1)

$$e = K_e \dot{\theta}_m \text{ [V]}$$  \hfill (3.2)

In consistent units, the torque constant $K_t$ equals the electric constant $K_e$, but in some cases the torque constant will be given in other units, such as ounce-inches per ampere, and the electric constant may be expressed in units of volts per 1000 rpm. In such cases the engineer must make the necessary translations to be certain the equations are correct.
3.3 DC Motor Modeling

Acquire the equations of a DC motor by virtue of the Figure 3.3(a). Let us suppose that the rotor has inertia $J_m$ and viscous friction coefficient $b$.

![Image](image.png)

**FIGURE 3.3**
DC motor: (a) electric circuit of the armature; (b) free-body diagram of the rotor

Figure 3.3(b) is a free-body diagram about the rotor. The figure gives the positive direction a definition and reveals the two torques, $T$ and $b\dot{\theta}_m$. We can get the following equation by Newton’s laws yields.

$$J_m\ddot{\theta}_m + b\dot{\theta}_m = K_t i_a \text{ [Nm]}$$ (3.3)

When studying the electric circuit which contains the back EMF voltage, we can get the electrical equation like

$$L_a \frac{di_a}{dt} + R_a i_a = v_a - K_e \dot{\theta}_m \text{ [V]}$$ (3.4)

When $s$ displaced for $d/d\tau$ in Equations (3.3) and (3.4), and $L_a \to 0$,

$$\frac{R_a J_m \theta_m s^2 + b \theta_m s}{K_t} = v_a - s \theta_m K_e$$

$$\frac{\theta_m [R_a J_m s^2 + b s] + s K_e K_t}{K_t} = v_a$$
\[
\frac{\theta_m(s)}{V_a(s)} = \frac{K_t}{s(J_m s R_a + b R_a + K_t K_e)}
\]

The transfer function of the motor will become

\[
\frac{\theta_m(s)}{V_a(s)} = \frac{K_t}{s[(J_m s + b)(L_a s + R_a) + K_t K_e]} \text{ [rad/V]}
\]

(3.5)

In most conditions, the relevant influence for the inductance is inappreciable contrast with the mechanical motion and can be ignored in Equation (3.4). If so, we can associate Equations (3.3) and (3.4) then we can get

\[J_m \dot{\theta}_m + \left(b + \frac{K_t K_e}{R_a}\right) \dot{\theta}_m = \frac{K_t}{R_a} v_a \text{ [Nm]}\]

(3.6)

From Equation (3.6), it is obvious that in this condition the influence for the back emf is difficult to distinguish by virtue of the friction, and the transfer function is

\[
\frac{\theta_m(s)}{V_a(s)} = \frac{K_t / R_a}{J_m s^2 + \left(b + \frac{K_t K_e}{R_a}\right) s} = \frac{K}{s(\tau s + 1)} \text{ [rad/V]}
\]

(3.7)

Where

\[
K = \frac{K_t}{b R_a + K_t K_e} \text{ [rad/V/s]} \]

(3.8)

\[
\tau = \frac{R_a J_m}{b R_a + K_t K_e} \text{ [s]} \]

(3.9)

In most conditions, a transfer function between the motor input and the output speed (\(\omega=\dot{\theta}_m\)) is necessary. In such cases, the transfer function will become

\[
\frac{\Omega(s)}{V_a(s)} = s \frac{\theta_m(s)}{V_a(s)} = \frac{K}{\tau s + 1} \text{ [rad/s]} \]
3.4 Parameter Measurement

FIGURE 3.4
Pictures of the used wheel

FIGURE 3.5
Structure pictures of the used wheel
Parameters of the wheel are obtained below:

Weight of the wheel \( M = 1209.77 \text{g} \)

Height of external wheel \( H_e = 12.26 \text{mm} \)

Height of internal wheel \( H_i = 27.50 \text{mm} \)

Radius of the middle \( r_m = 6.6 \text{mm} \)

Radius of the internal wheel \( r_i = 22.3 \text{mm} \)

Average radius of the external wheel \( r_e = 60 \text{mm} \)

---

**FIGURE 3.6**

Picture of the torque test

The length of the whole ruler \( d = 100 \text{cm} \)

The radius of the wheel take away \( r = 6 \text{cm} \)

The length from the wheel to the center of gravity \( l_1 = 44 \text{cm} \)

The length from the center of gravity to the end point \( l_2 = 50 \text{cm} \)

The distance from the bottom position movement \( d_2 = 39 \text{cm} \)

Weight of the ruler \( m = 330 \text{g} \)
3.5 Pulse counting

For the pulses counting system, this part we need to use the unit DAQ assistant. The DAQ Assistant is a graphical interface that we can use to configure measurement tasks and channels. As illustrated in Figure 3.7, DAQ Assistant is located on the Functions>>Express>>Inputs palette. As illustrated in Figure, right click on the blank space, one can easily find the unit. To launch the DAQ Assistant, place it on the block diagram.

![Figure 3.7](image)

**FIGURE 3.7**
DAQ Assistant unit interface (screen shot from National Instrument LabVIEW)

When the DAQ Assistant is placed on the block diagram, as showed in Figure 3.8, a DAQ Assistant dialog box will automatically show up. In this part, we need to first choose Acquire signals.

![Figure 3.8](image)

**FIGURE 3.8**
DAQ Assistant dialog box (screen shot from National Instrument LabVIEW)
After that, for the sake of our pulses counting system, we select the Counter Input. Then choose the Edge Count option which is illustrated in Figure 3.9

![Image](signal_acquiring_box.png)

**FIGURE 3.9**
Signal acquiring box (screen shot from National Instrument LabVIEW)

Figure 3.10 indicates that the dialog box then displays a list of devices and channels which are connected with the computer. In this case, there is only one USB-6009 unit is connected with the computer while there is only one counting channel in USB-6009-PFI0, so we select it and continue.

![Image](device_channel_choosing.png)

**FIGURE 3.10**
Device and channel choosing (screen shot from National Instrument LabVIEW)
At this point, the DAQ assistant opens a new window, shown in Figure 3.11, which displays the options for configuring the selected channels. In the Edge Count Setup>>setting section, we can change the active edge, the number of initial counting as well as counting direction. In our case, we remain the default value since we just need to count the number of pulses, there is no need to consider about the up or down edge even direction. For the Timing Settings>>Acquisition Mode part, we choose 1 Sample which is on demand.

![Figure 3.11](image)

**FIGURE 3.11**

Counting edges setting (screen shot from National Instrument LabVIEW)

After the parameter setting section, we click on the Run Button, shown in 3.12, and then the counting system is running. We can obtain the number of pulses signal transferred into computer by looking at the indicator block-Measured Value(s). We can see, at the moment we take the picture, there are 4994 pulses of the DC motor has produced while the DC motor is 1000 pulses per revolution which indicates the DC motor has rotated nearly 5 circles during the measure time.

![Figure 3.12](image)

**FIGURE 3.12**

Counting edges running (screen shot from National Instrument LabVIEW)
When finish the DAQ Assistant part, we begin to structure the pluses counting block diagram which is demonstrated in Figure 3.13. Second to none, we put a stop switch to control the DAQ Assistant to decide when to reset the number of receive the signals. After that, a time counting unit is added into the system to record the time has elapsed. Then we use arithmetical unit divide the number of pulses with the time record to obtain the figure which is call pulses per second by the division. Three kinds of indicators are added also into the block diagram to figure out the information we wanted in Gauge, Numeric and Waveform Chart.

![Pluses counting block diagram](image1)

**FIGURE 3.13**
Pluses counting block diagram (screen shot from National Instrument LabVIEW)

Then we focus on pulses counting front panel as shown in Figure 3.14, the front panel consists of four components which are related with the block diagram system. A switch controls whether to reset the DAQ Assistant number as well as three kinds of instrument to obtain information in different respects.

![Pluses counting front panel](image2)

**FIGURE 3.14**
Pluses counting front panel
3.6 Counting system test

After we complete the counting system, ahead of all, we need to test the system to see whether the system can work properly. The figure 3.15 shows the signal generator produces a square wave which has a 2 kHz frequency.

![Signal generator](image)

**FIGURE 3.15**
Signal generator

Figure 3.16 demonstrates the picture obtained by the oscillator to monitor the square wave is working properly.

![Oscillator picture](image)

**FIGURE 3.16**
Oscillator picture
Figure 3.17 shows the connection of the test signals. Red one is for the square wave produced by the signal generator.

![Figure 3.17 Test signals connection](image)

Then we can run the system and observe the front panel data which is illustrated in Figure 3.18. From the data it is not difficult to find out the system is functioning well. The Numeric number of the pulse is 1996, almost the same with the number we set in signal generator. Besides, the Gauge and Waveform Chart also get the reasonable information.

![Figure 3.18 Front panel data](image)
3.7 DC-motor voltage changing test

3.7.1 Change from 0A to 20V

a. Test with the wheel

![Waveform Chart](image1)

FIGURE 3.19
0A-20V with the wheel

b. Test without the wheel

![Waveform Chart](image2)

FIGURE 3.20
0A-20V without the wheel
3.7.2 Change from 20V to 0A

a. Test with the wheel

![Waveform Chart](image1)

**FIGURE 3.21**
20V-0A with the wheel

b. Test without the wheel

![Waveform Chart](image2)

**FIGURE 3.22**
20V-0A without the wheel
3.7.3 Change from 10V to 0A

a. Test with the wheel

![Waveform Chart](image1.png)

*FIGURE 3.23*

10V-0A with the wheel

b. Test without the wheel

![Waveform Chart](image2.png)

*FIGURE 3.24*

10V-0A without the wheel
3.7.4 Change from 15V to 20V

a. Test with the wheel

FIGURE 3.25
15V-20V with the wheel

b. Test without the wheel

FIGURE 3.26
15V-20V without the wheel
3.7.5 Change from 20V-0V

a. Test with the wheel

![Waveform Chart](image)

**FIGURE 3.27**
20V-0V with the wheel

b. Test without the wheel

![Waveform Chart](image)

**FIGURE 3.28**
20V-0V without the wheel
3.7.6 Change from 10V-0V

a. Test with the wheel

![Waveform Chart](image1.png)

**FIGURE 3.29**
10V-0V with the wheel

b. Test without the wheel

![Waveform Chart](image2.png)

**FIGURE 3.30**
10V-0V without the wheel
3.7.7 Measurements

<table>
<thead>
<tr>
<th>Number</th>
<th>Voltage and current change</th>
<th>Time constant $\tau$ [s]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>With wheel</td>
</tr>
<tr>
<td>1</td>
<td>0A-20V</td>
<td>9</td>
</tr>
<tr>
<td>2</td>
<td>20V-0A</td>
<td>9</td>
</tr>
<tr>
<td>3</td>
<td>10V-0A</td>
<td>9</td>
</tr>
<tr>
<td>Average (123)</td>
<td></td>
<td>9</td>
</tr>
<tr>
<td>4</td>
<td>15V-20V</td>
<td>4</td>
</tr>
<tr>
<td>5</td>
<td>20V-0V</td>
<td>4</td>
</tr>
<tr>
<td>6</td>
<td>10V-0V</td>
<td>4</td>
</tr>
<tr>
<td>Average (456)</td>
<td></td>
<td>4</td>
</tr>
</tbody>
</table>

**TABLE 3.1**
Time constant

From Table 3.1 we can easily compare the time constant with or without the wheel. Time constant only depends on the wheel and has no relation with the voltage changing. However, in the beginning, we made a mistake when we doing the time constant measurement. Since our initial idea is to take 0V-20V, 20V-0V and 10V-0V, but we just make the open circuit not the shorted ones. Then we get the wrong pictures and time constant. Therefore, we continue the measurements to get the correct constants.

<table>
<thead>
<tr>
<th>Number</th>
<th>Voltage [V]</th>
<th>Current I [A]</th>
<th>Pulses per second</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>With wheel</td>
<td>Without wheel</td>
</tr>
<tr>
<td>1</td>
<td>10</td>
<td>0.185</td>
<td>0.183</td>
</tr>
<tr>
<td>2</td>
<td>15</td>
<td>0.200</td>
<td>0.198</td>
</tr>
<tr>
<td>3</td>
<td>20</td>
<td>0.216</td>
<td>0.213</td>
</tr>
<tr>
<td>4</td>
<td>30</td>
<td>0.246</td>
<td>0.234</td>
</tr>
</tbody>
</table>

**TABLE 3.2**
Current and pulses number

Table 3.2 shows the current and pulses number when the voltage is changing. We can see the current is not varying linearly as the voltage grows while the pulses normally do within the range of allowable error.
3.8 Calculation

3.8.1 Density of the wheel

First of all, we calculate the volume of the wheel.

\[ V = V_e + V_i \ [m^3] \]

The volume of the wheel consists of two parts the external and internal parts.

\[ V = S_e H_e + S_i H_i \ [m^3] \]

The volume should be the area time height respectively.

\[ V = \pi (r_e^2 - r_i^2) H_e + \pi (r_i^2 - r_m^2) H_i \ [m^3] \]

\[ V = \frac{1}{4} \pi (0.12^2 - 0.045^2) * 0.012 + \frac{1}{4} \pi (0.045^2 - 0.013^2) * 0.027 \ [m^3] \]

\[ V = 1.56 * 10^{-4} \ [m^3] \]

\( V \) represents the volume of the wheel
\( V_e \) and \( V_i \) represents the external and internal part volume
\( S_e \) and \( S_i \) represents the external and internal part area
\( H_e \) and \( H_i \) represents the external and internal part height/thickness
\( r_e, r_i \) and \( r_m \) represents the external, internal and middle part radius

The second step is to calculate the density of the wheel

\[ \rho = \frac{M}{V} = \frac{1.210}{1.56 * 10^{-4}} = 7758 \ [kg/m^3] \]

\( \rho \) represents the density of the wheel
\( M \) represents the mass of the wheel

We can get density of the wheel \( \rho=7758 \ [kg/m^3] \) and compare to the normal data of the steel \( \rho=7800 \ [kg/m^3] \), it is quite reasonable about the density of the wheel.

3.8.2 Inertia of the wheel

Then we focus on the inertia of the wheel.
The inertia of the wheel can be approximately equal to the integral of the formula below

\[ J = \sum_{n=1}^{N} r^2 \rho dV \]

\[ J \approx \int_{0}^{R} r^2 \rho 2\pi hr \, dr = 2\pi \rho \int_{0}^{R} r^3 \, dr = 2\pi \rho [r^4/4]_{0}^{R} \]

\[ J_w = J_e + J_i \quad [Nms^2] \]

\[ J_w = 2\pi \rho H_e [r_e^4/4] r_e^i + 2\pi \rho H_i [r_i^4/4] r_i^h \]

\[ J_w = 0.031 \quad [Nms^2] \]

\( J_w, J_e \) and \( J_i \) represents the inertia of the wheel, external part and internal part \( r_e, r_i \) and \( r_m \) represents the external, internal and middle part radius

### 3.8.3 Parameters

We can obtain the time constant \( \tau \) from Table 3.1

Time constant with the wheel \( \tau_w = 9s \)

And time constant without the wheel \( \tau = 3s \)

From the Formula 3.3, we can obtain the following equations

\[ \frac{J_m + J_w}{b} = \tau_w [s] \]

\[ \frac{J_m}{b} = \tau [s] \]

Then

\[ J_m = 0.0155 \quad [Nms^2] \]

\[ b = 0.00517 \quad [Ns/m] \]

\( J_m \) and \( J_w \) represents the inertia of the motor and wheel

The next step, from section 3.7.7

\[ d1 = \frac{44}{44 + 50} \ast 39 = 0.183m \]

\[ T = mgd = 0.33 \ast 9.81 \ast 0.183 = 0.592Nm \]
From the formula

\[ T = K_t \times I \]

Then

\[ K_t = 0.197 \text{ [Nm/A]} \]

From the formula 3.3 and Table 3.2

\[ b = \frac{K_t i_a}{\theta_m} = \frac{0.197 \times 0.216}{\frac{16879}{1000} \times 2\pi} = 4.01 \times 10^{-4} \text{ [Nms]} \]

From the Table 3.2, and the formula

Motor constant

\[ K = \frac{\text{pulses number per second} \times 2\pi}{\text{pulses number per revolution} \times \text{voltage}} \]

We can get the pulses number of the DC-motor, after that we can obtain

\[ K = \frac{8213 \times 2\pi}{1000 \times 10} = 5.15 \text{ [rad/V_s]} \]

Then

\[ K_t = K_e = \frac{1}{K} = 0.197 \text{ [Nm/A] or [V_s/rad]} \]
4 Incremental encoder

4.1 The used encoder

Figure 4.1 shows the incremental encoder produced by Germany Company STEGMANN, and we can obtain some parameters on its brand easily. The model for this encoder is D6 63 KA and the resolution for the encoder is 1000 pulses per revolution. The power supply is read to be +5V.

“True to the motto, "we produce quality from the very beginning", SICK | STEGMANN encoders are designed and developed with the aid of the most modern CAD equipment. Before and during manufacture, they are subjected to the most stringent quality controls, using high precision, modern measuring devices.

In order to ensure that we meet our own high standards, almost all the component parts needed for the various finished products are made in our own factory. Our customers have come to value our consistent quality, thereby establishing confidence and leading to long-term business relationships.

SICK | STEGMANN encoders have an extremely wide range of applications. They are used for positioning and control purposes on machine tools, cranes, presses, printing machines, office machines, robots, servo drives and similar equipment where reliability is the highest priority. Our highly motivated development engineers are continually seeking to enhance our product range.” (From the website page “Introduction of SICK | STEGMANN”)
4.2 Encoder principles

The incremental encoder sometimes called a relative encoder. It consists of two tracks and two sensors whose outputs are called channels A and B. As the shaft rotates, pulse trains occur on these channels at a frequency proportional to the shaft speed, and the phase relationship between the signals yields the direction of rotation. The code disk pattern and output signals A and B are illustrated in Figure 4.2. By counting the number of pulses and knowing the resolution of the disk, the angular motion can be measured. The A and B channels are used to determine the direction of rotation by assessing which channels "leads" the other. The signals from the two channels are a 1/4 cycle out of phase with each other and are known as quadrature signals. Often a third output channel, called INDEX, yields one pulse per revolution, which is useful in counting full revolutions. It is also useful as a reference to define a home base or zero position.

![Encoder diagram]

**Figure 4.2**
Encoder principles
4.3 Voltage signal acquiring

In this section, the processing of the voltage signal acquiring is similar to the processing of pulses counting. As the Figure 4.3 shows, after you place the DAQ Assistant Unit on the block diagram, the DAQ Assistant dialog box will appear automatically.

FIGURE 4.3
DAQ Assistant dialog box (screen shot from National Instrument LabVIEW)

Then, shown in Figure 4.4, there is a need for choosing the devices and channels. Unlike the pulses counting part, each USB-6009 has 8 analog channels to obtain the signals at the same time.

FIGURE 4.4
Devices and channels choosing (screen shot from National Instrument LabVIEW)
Figure 4.5 demonstrates an example of a voltage signal graph that we can see the waveform graph from the indicator.

![Figure 4.5 Voltage signal graph (screen shot from National Instrument LabVIEW)](image1)

Figure 4.6 shows the images of voltage signals obtained from Ai0 and Ai4. Ai0 is connected to Lilac cable which means K0, the M output while Ai4 is connected to Yellow cable which means $\overline{K0}$, the $\overline{M}$ output.

![Figure 4.6 Signals Ai0 and Ai4 (screen shot from National Instrument LabVIEW)](image2)
Figure 4.7 shows the images of voltage signals obtained from Ai1 and Ai5. Ai1 is connected to White cable which means K1, the A output while Ai5 is connected to Brown cable which means $\overline{K1}$, the $\overline{A}$ output. We can easily to judge the two signals are a suitable pair.

![FIGURE 4.7](image1)

**FIGURE 4.7**

Signals Ai1 and Ai5 (screen shot from National Instrument LabVIEW)

Figure 4.8 shows the images of voltage signals obtained from Ai2 and Ai6. Ai2 is connected to Pink cable which means K2, the B output while Ai6 is connected to Black cable which means $\overline{K2}$, the $\overline{B}$ output. We can easily to judge the two signals are also a suitable pair.

![FIGURE 4.8](image2)

**FIGURE 4.8**

Signals Ai2 and Ai6 (screen shot from National Instrument LabVIEW)
Figure 4.9 shows the images of voltage signals obtained from Ai3 and Ai7. Ai3 is connected to Grey cable which means Sense+, internally connected to $U_s$, while Ai7 is connected to Green cable which means Sense-, internally connected to ground.

![Figure 4.9](image)

**FIGURE 4.9**
Signals Ai3 and Ai7 (screen shot from National Instrument LabVIEW)

Figure 4.10 shows the images of voltage signals obtained from Ai1 and Ai2. We can see through the graph to obtain the fact that there is a phase shift of 90 degree between Ai1 and Ai2 signals. In that way, the exclusive or of K1 and K2 can provides four times increase in resolution.

![Figure 4.10](image)

**FIGURE 4.10**
Signals Ai1 and Ai2 (screen shot from National Instrument LabVIEW)
4.4 Analysis

Compare to the result of the data we obtained in LabVIEW and the Figure 4.11 and Figure 4.12, we can verify the pattern of the incremental encoder is working properly and get a better understanding of the principle of the encoder.

**Output Wave Forms**

![Output Wave Forms Diagram]

**FIGURE 4.11**
Output wave forms (from STEGMANN DG 60 L PDF page4)

We can see clearly the signal K1 and K2 has a 90 degree shift. And the patterns can be recognized as four kinds: A1 B0, A1 B1, A0 B1, and A0 B0 while the A exclusive or provide the time.

**FIGURE 4.12**
Description of the cables (from STEGMANN DG 60 L PDF page4)
5 Result

For the inertia of the wheel $J_m = 0.031 \,[Nms^2]$ compare to the unofficial data “Motor Inertia: 0.0320 Oz-in-SEC” is nearly the same and while $R_a = 2.2\Omega$ is acceptable compared to “Motor Terminal Resistance” found in reference [8].

Then we can compare the $K$ measured with the $K$ calculated from formula 3.7

$$K = \frac{0.197}{4.01 \times 10^{-4} \times 2.2 + 0.197^2} = 4.96 \,[rad/Vs]$$

Formula 3.8.3 gives $K = 5.15 \,[rad/Vs]$. From 3.8.3, both with and without wheel, the small difference is acceptable result.

The test from table 3.2 and formula 3.4

$$R_a i_a = 2.2 \times 0.183 = 0.4V$$

And

$$v_a - K_e \dot{\theta}_m = 10 - 0.197 \times \frac{8213}{1000} \times 2\pi = 0.16V$$

The difference 0.4V and 0.16V are acceptable.

From formula 3.9, the time constant $\tau$ is given without wheel

$$\tau = \frac{2.2 \times 0.0155}{4.01 \times 10^{-4} \times 2.2 + 0.197^2} = 1.72s$$

Compare to the table 3.1 that gives the value 2.00s

The time constant $\tau$ with the wheel is calculated to

$$\tau = \frac{2.2 \times 0.031}{4.01 \times 10^{-4} \times 2.2 + 0.197^2} = 3.42s$$

Compared to the value 4.00s, that is an acceptable result.

Also we testify the encoder pattern from the analysis 4.4.

We conclude the color of different cables match well and the encoder pattern can be observed from the graph of voltage signals clearly.

Therefore, we complete the objectives in the beginning. We have been familiar with most part of functions and the use of LabVIEW. We find appropriate components to measure the waveform graphs of incremental encoder in the LabVIEW. We compared the actual measured information to the theoretical parameter and summarize the characteristic of the actual measured information, as well as put the measured data into the theoretical functions and calculate them.
Reference

[1] USER GUIDE AND SPECIFICATIONS NI USB-6008/6009 [online]  
[Accessed 30 May 2012]


[3] Introduction for LabVIEW [online]  
http://en.wikipedia.org/wiki/LabVIEW  
[Accessed 30 May 2012]

[4] Data Acquisition Systems (DAQ) and Equipment [online]  
http://www.data-acquisition.us/  
[Accessed 30 May 2012]

[5] Company Profile [online]  
http://www.electrocraft.com/company/  
[Accessed 30 May 2012]

[6] Introduction of SICK | STEGMANN [online]  
http://www.stegmann.com/intro/index.html  
[Accessed 30 May 2012]

[7] Parameterizing DC motor performance [online]  
http://www.solarbotics.net/starting/200111_dcmotor/200111_dcmotor4.html  
[Accessed 30 May 2012]

[Accessed 30 May 2012]

[9] NI USB-6009 introduction [online]  
[Accessed 30 May 2012]

[10] DG 60 L Incremental Encoder (PDF) [online]  
[Accessed 30 May 2012]
http://hades.mech.northwestern.edu/index.php/Brushed_DC_Motor_Theory
[Accessed 30 May 2012]
