Design Kit

DC Motor Speed Control Circuit
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Key simulation models

**DC Motor Model**
⇒ The model features on transient characteristics of the motor.

**LM555 Timer IC Model**
⇒ The model features on functions of the IC.
2.1 Manufacturer Specification

MABUCHI MOTOR RS-380PH

- Voltage Range......................... 12.0 V
- Normal Voltage........................ 7.2 V
- Normal Load............................ 9.8 mN\cdot m
- Speed at No Load..................... 16,400 rpm
- At Normal Load
  - Speed................................. 14,200 rpm
  - Current.............................. 2.9A
2.2 Torque Constant and Back EMF Constant

- The Torque Constant $K_T$ is obtained as:

\[ \text{Torque} = K_T \cdot I_1 \quad (1) \]

RS-380PH at Normal Load:
- Torque = 9.8 mN\cdot m
- $I_{\text{Normal Load}}$ = 2.9 A
- $K_T = \frac{9.8}{2.9} = 3.379$ mN\cdot m/A

- The Back EMF Constant $K_E$ is obtained as:

\[ V_{\text{EMF}} = K_E \cdot \text{Speed} \quad (2) \]

RS-380PH at No Load:
- Speed = 16,400 rpm
- $V_{\text{EMF}} = V_{\text{Normal}} - R_M \cdot I_{\text{No Load}} = 7.2 - 0.3456 = 6.8544$ V
- $R_M = 0.576 \Omega$ and $I_{\text{No Load}} = 0.6$ A (measurement data)
- $K_E = \frac{6.8544}{16,400} = 0.41795$ mV/rpm
2.3 The Armature Inductance and Resistance

- The Armature Inductance and Resistance are obtained with a Precision Impedance Analyzer (Agilent 4294A)
- \( L_S = 165 \, \text{uH} \) and \( R_S = 575.977 \, \text{m}\Omega \)

Precision Impedance Analyzer |\( |Z| \) vs. Frequency measured data.

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2.4 The DC Motor Equivalent Circuit

- The Back EMF Voltage is the voltage generated across the motor's terminals as the windings move through the motor's magnetic field.
- The Back EMF voltage is linearly proportional to the motor's velocity in the Mechanical Part.

This figure shows the equivalent circuit of DC motor model that includes the $|Z|$-frequency part, Back EMF Voltage part, and Mechanical part.
2.5 Transient Response at No Load

- The test setup includes 12Vdc source, series resistor, and the motor.
- The result is used to obtain the start-up current and the steady state current.
- The time constant of the current response will be used to determine the parameters that model the motor shaft’s inertia.

This figure is the motor current and voltage at start-up transient (oscilloscope screen captured).
2.6 Transient Response at No Load (Model)

- This figure shows the result of the start-up transient simulation with RS-380PH motor model at condition 12V, no load.
This figure shows the simulated speed at no load (16,400rpm). To monitor the speed, trace "I(X_U1.V_rpm)" inside the model .SUBCKT.

Note: for OrCAD 16.0 set "All" for the Currents of the Data Collection Options of the Simulation Settings.
2.8 The Motor Steady-State Current Condition Setting (1/2)

This figure shows the current waveforms of the motor with the different rated torque load, that result as the different steady-state current.

Since the simulations are focused on the electrical world, the RS-380PH spice model is directly conditioned by input the steady-state current.
Steady-state current simulated result will match the model input value “IL” only when the condition Vcc is 12Vdc. In the other case, “IL” value is changed until the desired steady-state current condition is met.

- This figure shows the unmatched value of the steady-state current condition when Vcc condition is 7.2Vdc (not a 12Vdc).
2.9 Transient Response at Load 3.8A (Measurement vs. Simulation)

The test setup include 12Vdc source, 0.8Ω series resistor and the RS-380PH motor with fan.

- This figure shows the result of the start-up transient simulation with RS-380PH motor model at condition 12V, 3.8A load.
- The result is compared to the voltage and current waveforms obtained by the oscilloscope.
3. LM555 DC Motor Speed Control Circuit (No Load)

- The circuit is simulated and compared with the measured waveforms from oscilloscope (Tektronix: TDS3054B) to verify the simulation using the RS-380PH model.

Analysis directives:
.TRAN 0 1.5s 0 4u SKIPBP
.OPTIONS ABSTOL = 1.0u
.OPTIONS GMIN = 1.0E-8
.OPTIONS ITL4 = 15
.OPTIONS RELTOL = 0.01
.OPTIONS VNTOL = 1.0m
3.1 Rectified dc voltage with ripple

Rectified dc voltage with ripple
3.1 Rectified dc voltage with ripple

Measurement

Simulation

Rectified dc voltage with ripple

IC555 Output pulse voltage
IC 555 Output Pulse Voltage
3.2 IC 555 Output Pulse Voltage

Measurement

Simulation

IC 555 Output Pulse Voltage
3.3 Transistor Q2: VCE

Transistor Q2: VCE

PARAMETERS:
vr1 = 250K
3.3 Transistor Q2: VCE

Measurement

Simulation

Transistor Q2: VCE
3.4 Transistor Q1: VCE, IC
3.4 Transistor Q1: VCE, IC

Measurement

Simulation

Transistor Q1: VCE, IC
3.5 Motor Voltage and Current

Motor Voltage and Current

PARAMETERS:
vr1 = 250K

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3.5 Motor Voltage and Current

**Measurement**

**Simulation**

**Motor Voltage and Current**

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4. LM555 DC Motor Speed Control Circuit (Fan Load)

- The circuit is simulated and compared with the measured waveforms from oscilloscope (Tektronix: TDS3054B) to verify the simulation using the RS-380PH model under the different load condition.

Analysis directives:
.TRAN 0 1.5s 0 4u SKIPBP
.OPTIONS ABSTOL = 1.0u
.OPTIONS GMIN = 1.0E-8
.OPTIONS ITL4 = 15
.OPTIONS RELTOL = 0.01
.OPTIONS VNTOL = 1.0m
4.1 Rectified dc voltage with ripple
4.1 Rectified dc voltage with ripple

Measurement

Simulation

Rectified dc voltage with ripple

IC555 Output pulse voltage

Rectified dc voltage with ripple

IC555 Output pulse voltage

Rectified dc voltage with ripple
4.2 IC 555 Output Pulse Voltage

PARAMETERS:
vr1 = 250K

OUT
GND
IN

V1

Reg

U3
uPC7812A

D3
D4001

D4
D4001

D7
D4001

D6
D4001

D5
D4001

C3
c1000u

R3
30k

R2
5k

RV1

R1
10k

D1
D1N4148

D2
D1N4148

C2
1nf

IC = 0

Q1
Q2SC1061

Q2
QBC547

R4
10k

R4
10k

C1
1nf

IC = 0

U1
LM555

U1
LM555

U2
RS-380PH

IL = 1.5

Vsense

D5
D4001

D6
D4001

D7
D4001

D4
D4001

D3
D4001

VOFF = 0

VAMPL = 13.5

FREQ = 50

IC 555 Output Pulse Voltage
4.2 IC 555 Output Pulse Voltage

**Measurement**

![Measurement Graph]

**Simulation**

![Simulation Graph]

IC 555 Output Pulse Voltage

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4.3 Transistor Q2: VCE
4.3 Transistor Q2: VCE

**Measurement**

**Simulation**

Transistor Q2: VCE

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4.4 Transistor Q1: VCE, IC

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4.4 Transistor Q1: VCE, IC

**Measurement**

**Simulation**

Transistor Q1: VCE

Transistor Q1: IC

Transistor Q1: VCE

Transistor Q1: IC

Transistor Q1: VCE, IC
4.5 Motor Voltage and Current

Motor Voltage and Current

PARAMETERS:

vr1 = 250K

VOFF = 0
VAMPL = 13.5
FREQ = 50

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4.5 Motor Voltage and Current

Measurement

Simulation

Motor Voltage and Current
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<th>Folder name</th>
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<td>¥Simulations¥Transient¥Trans_NoLoa</td>
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<td>2. Speed at No Load (Model)</td>
<td>¥Simulations¥Transient¥Speed_NoLoa</td>
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<td>3. The Motor Steady-State Current Condition Setting (1/2)</td>
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<td>7. LM555 DC Motor Speed Control Circuit (Fan Load)</td>
<td>¥Simulations¥Trans_NoLoad</td>
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<td></td>
<td>¥Simulations¥Trans_FanLoad</td>
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Analysis directives:

```verbatim
.TRAN 0 1.5s 0 4u SKIPBP
.OPTIONS ABSTOL = 1.0u
.OPTIONS GMIN = 1.0E-8
.OPTIONS ITL4 = 15
.OPTIONS RELTOL = 0.01
.OPTIONS VNTOL = 1.0m
```