AN APPRAISAL OF THE TRANSIENT RESPONSE OF A D.C. SHUMT MOTOR USING MATLAB/SIMULINK UNDER NO LOADING AND FULL LOADING CONDITIONS

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ABSTRACT: Electric machines are used to generate electrical power in power plants and provide mechanical work in industries.

This paper describes the MATLAB/SIMULINK realization of the performance of a D.C. shunt motor and introduces model power components to use computer simulation as a tool for conducting transient by using Simulink and SimPower System. These simulation models were employed to calculate the speed \(N\), torque \(T\), armature current \(I_a\), input and output power \((P_{in} and P_{out})\), losses \((P_{losses})\) and efficiency \(\eta\) for the motor at no load and load conditions. The results obtained using MATLAB were compared with the practical results, the ratio of error is about \((1-2)\%\) was found. The SIMULINK was written in MATLAB languages version (6.5).

Keywords: D.C. Shunt Motor, MATLAB/SIMULINK, Controller Model, SimPower System.

1-INTRODUCTION

The theory of electrical circuits represents one of the most important parts of any electrical engineering education. The aim of this paper is analysis circuit and to experience the actual behavior of a D.C. shunt motor, this requires a powerful software mathematical tool \([1]\).

MATLAB is a good software package for high performance numerical combination of analysis and visualization. It makes the combination of analysis capabilities more flexibility, more reliability, and powerful graphics \([2, 3]\). The modeling and simulation of this paper helped to generate expected outcomes of the project design, simulation software MATLAB is used to provide simulation design and results for evaluation the speed, torque and the armature current for a D.C. shunt motor. Simulink which is a sub program of matlab was used to complete the modeling and simulation \([4]\). Simulations are interactive, so user can change parameter on the spot and immediately see what happens \([5]\).

These can be achieved by changing the setting in Matlab/ Simulink to investigate a D.C. motor responds to these changes.

The Simulink program will help the students without returning to the laboratory to use the actual D.C. motor.

Many researches dealt with this subject. Saffet Ayasun and Gultekin Karbeyaz (2007)," in their paper describes the matlab simulink realization of the D.C. motor speed control methods". Karung Berkunci’s (2006) work," presents shunt connected direct current motor analysis using matlab laboratory". Tan Kiong Howe’s (2003), evaluate the transient response
of a D.C. motor by variation of terminal voltage, armature resistance, and field resistance using MATLAB/Simulink.

2- PRINCIPLES OF OPERATION OF D.C MOTOR

An electric motor operation is based on simple electromagnetism. Motor is a machine which converts electrical energy into mechanical energy that when a current-carrying conductors is placed in an external magnetic field, it experience a mechanical force proportional to the current in the conductor and to the strength of the external magnetic field and between them generate rotational motion [6].

The effect of flux distribution is very important, because the limits of successful commutation are directly influenced by the flux, also both the generated voltage and torque of armature current are influenced thereby [7].

The brushes, commutator contacts and rotor windings are such that when power is applied, the polarities of the energized winding and the stator magnets are misaligned, and the rotor will rotate until it is almost aligned with the stator’s field magnets. As the rotor reaches alignment, the brushes move to the next commutator contacts and energize the next windings [8].

In the field resistance control, a series resistance is inserted in the shunt-field circuit of the motor in order to change the flux by controlling the field current. It is theoretically expected that an increase in the field resistance will result in an increase in the no-load speed of the motor and in the slope of the torque-speed curve [9].

The field current may be varied by placing a variable resistance in series with the field windings. Since the current in the field circuit is low, a low-wattage rheostat may be used to vary the speed of the motor due to the variation in field resistance. A decrease in field current reduces the strength of the electromagnetic field. When the field flux is decreased, the armature will rotate faster, due to reduced magnetic field interaction. Thus the speed of a D.C. shunt motor may be easily varied by using a field rheostat [10].

3 -MOTOR MODELING SIMULATION AND MATHEMATICAL REPRESENTATIONS

The system contains a D.C. shunt motor, a model based on the motor specifications needs to be obtained, as shown in Fig(1).

The basic motor equations are:-

\[ E_b = V_t - I_a R_a \quad \text{(1)} \]
\[ E_b = K_m W_m \quad \text{(2)} \]
\[ T = K_m I_a = K_f f I_a \quad \text{(3)} \]
where: \( K_m = K_f f \), \( K_a = K_f f \), at separately excited
\( K_m = E_b / W_m \) at shunt excited

Applying Kirchhoff's Voltage Law:
\[ V_t = E_b + I_a R_a + L_a \frac{dI_a}{dt} \quad \text{(4)} \]
\[ V_t = I_f R_f + L_f \frac{dI_f}{dt} \quad \text{(5)} \]
From equation (2)
\[ V_t = K_m I_f W_m + I_a R_a + L_a \frac{dI_a}{dt} \quad \text{(6)} \]
The Laplace transform of equations (5, 6)
\[ V_t(s) = K_m I_f W_m(s) + I_a R_a + L_a I_a(s) \]
\[ V_t(s) - E_b = I_a(s) [L_a(s) + R_a] \]
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\[ I_a(s) = \frac{V_t(s) - E_b}{L_a(s) + R} \quad \text{(7)} \]
\[ V_t = I_f R_f + L_f I_f(s) \quad \text{(7)} \]
\[ I_f(s) = \frac{V_t(s)}{L_f(s) + R_f} \quad \text{(8)} \]

Or equation (7):
\[ V_t(s) = K_a I_f W_m(s) + I_a R_a (1 + s \tau_a) \quad \text{Where: } \tau_a = \frac{L_a}{R_a} \text{ is the electrical time constant of the armature.} \]

The dynamic equation for the mechanical system:
\[ T = K_a I_f I_a = J \frac{dW_m}{dt} + B W_m + T_L \quad \text{(9)} \]

\[ B W_m = \text{is the rotational loss torque of the System.} \]

The Laplace transform of equations:
\[ T(s) = K_a I_f I_a(s) \]
\[ = J s W_m(s) + B W_m(s) + T_L(s) \]
\[ T(s) - T_L(s) = W_m(s) \times \left[ J s. + B \right] \quad \text{……. (10)} \]

From (3) and (10)
\[ T(s) = J s W_m(s) + B W_m(s) + T_L(s) \]
\[ = W_m(s) / \left[ J s. + B \right] + T_L(s) \]
\[ : W_m(s) = T(s) - TL(s) / [B \left[ 1 + \tau_m s \right]] \quad \text{…… (11)} \]

Where \( \tau_m = J / B \) is the mechanical time constant of the system.

From (2) and (8)
\[ V_t(s) = E_b(s) + I_a(s) R (1+s \tau_a) \]
\[ \therefore I_a(s) = \frac{V_t(s) - E_b(s)}{R (1+s \tau_a)} \quad \text{…… (12)} \]

The values of Pin, Pout, Plosses, and (\( \eta \)) can be calculated by:
\[ \text{Output power } = P_{out} = W_m \times T \quad \text{[KW]} \]
\[ P_{out} = 2 \pi N / 60 \quad \text{…… (13)} \]
\[ \text{Input power } = V_t \times I_{in} \quad \text{[KW]} \]
\[ P_{in} = V_t \times (I_a + I_f) \quad \text{…… (14)} \]
\[ \text{Losses power } = P_{in} - P_{out} \quad \text{…… (15)} \]
\[ \text{Efficiency } (\eta) = \frac{P_{out}}{P_{in}} \times 100 \% \quad \text{… (16)} \]

A block diagram which represents the equations (7), (8) and (10) is shown in fig. (2).

4- MODELING RESULT AND DISCUSSIONS

In this paper, the specifications of D.C. shunt motor were obtained from the engraving on the metal tag attached onto the motor, shown in table (1).

To produce a good model design, there needs to be some amount of simulations, to avoid aimless trial and error techniques with the actual equipment of a D.C. shunt motor.

From the specification of the D.C. motor and the equations; Calculate the constant torque (\( K_f \)) or (\( K_a \)), at no-load;
\[ V_t = 220 \text{ volt, } I_f = 0.75 \text{ ampere, from the equation (2); then the torque constant:} \]
\[ (K_f) = \frac{E_b}{I_f W_m} \]

As the speed in terms of (N) (r.p.m.), \( N = 1800 \text{ r.p.m.}, \) to convert to (rad / s), then the speed \( W_m = 2\pi N / 60, \) \( W_m = 2 \times 3.14 \times 1800 / 60 = 188.4 \text{ rad/s,} \)

And
\[ K_f = 220 / 0.71 \times 188.4 = 1.644 = K_a \]

The value of B obtains from calculates the mechanical equation as follows:-
From equation (9) and when \( T_L = 0 \) (no-load), at steady state, \( I_a \) and \( W_m \), stabilized then:
\[
\frac{dW_m}{dt} = 0.
\]
\[
K_f I_f I_a = J \frac{dW_m}{dt} + BW_m + T_L.
\]
\[
\therefore \frac{dW_m}{dt} = K_f I_f I_a - BW_m = 0, \quad T_L = 0.
\]
\[
\therefore K_f I_f I_a = BW_m.
\]
\[
B = 1.644 \times 0.71 \times 1.8 / 188.4, \quad B = 0.01115.
\]
\[
I_a = 1.8 \text{ ampere from the measurements of experiment at no-load.}
\]
\[
J = 0.117 \text{ Kg}^*m^2 \text{ the value of the armature (rotor) inertia.}
\]

After the measuring of the values of resistance and inductance (Ra, La) of the armature windings and the shunt field windings (Rf, Lf) for the D.C. shunt motor in electrical machines laboratory (D.C. Machines laboratory), their values were:-

\[
Ra = 2 \Omega, \quad La = 16.2 \text{ mh}, \quad Rf = 210 \Omega, \quad Lf = 5.47 \text{ H}.
\]

And varies resistance connected in series with shunt field windings to obtain speed about (1800 r.p.m.) at no-load, the varies resistance shown in table (2).

The average of the constant torque, \( K_f = K_a = 1.607 \). And
\[
I_L = 0, 2, 3, 5, 6, 8, 9, 10, 12, 13, 14, 15. \text{ Ampere.}
\]

Where the field current (If) is constant If = 0.71 ampere. Take \( K_a \) at no load when the speed is (1800 r.p.m.) and \( E_b = V_t, IaRa \) is neglected because the voltage drop (IaRa) is very small.

\[
K_a = K_m = \frac{E_b}{I_f W_m}, \quad K_a = 220 / 0.71 \times 188.4 = 1.644.
\]

Comparing the results of table (3) and table (4), the values of (If) is kept constant of a (0.71 amp.) while this value was (0.698 amp.) at simulation technique. This slight difference may be of recording the direct data obtained from the devices.

The same observations were recorded for the \( I_a \) (amp.) \( T \) (N.M.) and \( W_m \) (rad/s). This difference was calculated and it was found to be about (1-2) %

The D.C. shunt motor was modeled using characteristics transfer function of electrical and mechanical of the motor as shown in fig. (3).

5- SIMULATION RESULTS AND DISCUSSIONS

D.C. motors are used to drive mechanical loads, some applications require that the speed remain constant as the mechanical load is applied to the motor changes.

A: Simulation Results At no-load:

At speed \( (W_o) \) on no-load, the produced no-load current is small and not enough to carry the load so the motor starts to slow down. And the e.m.f. becomes smaller, resulting in a higher current and higher torque.

At no-load to obtain the speed (1800 r.p.m.) connect variable resistance in series with the shunt field circuit, its shown in table (2), increase the resistance, the speed increase until to obtain (N= 1800 r.p.m.), the relation between them linearity, the results of simulations for the D.C. shunt motor model at no load is shown in Fig. (4).

A series resistance is inserted in the shunt-field circuit of the motor in order to change the flux by controlling the field current. It is theoretically expected that an increase in the field resistance will result in an increase in the no-load speed of the motor; this method is one of the most common speed control methods for dc shunt motor.

Fig.(5), shows the output waveform of the starting torque which has a high value in the beginning, after that it drops to an approximate torque equal to the torque imposed (2.1 N.M.), the output waveform armature current shows a large increasing, at starting, after that it drops to reach the approximate armature current (Ia) (1.8 amp.), and the output waveform of the speed
in (rad/s), it is very clear that there is a large increase in the speed at the beginning but at steady state the speed remains constant at (188.4 rad/s)(1800r.p.m.) at no load.

B: Simulation Results At load:

At load (change in the mechanical load), when the mechanical load applied to the shaft vary, the armature current rises and the speed drops. The mechanical load torque reaches (21 N.M.).

From the simulation results shown in Fig. (6) the armature current rises, from no-load at (1.8 amp.) to the full load current (19.8amp.) at steady state, shows the variation of torque from (21 N.M.) at no-load to the value (21 N.M.) at full load at steady state and Te =22.7 N.M., and the reduction of speed in (rad/s) of the shunt motor from no-load at (188.4 rad/s)(1800r.p.m.) to ( 157 rad/s)(1500r.p.m.) at full load, this cause to diminish e.m.f., resulting in higher current and a corresponding higher torque, leads to slow down the speed.

The simulation results for calculating Pout, Pin, Plosses, and η, from the equations (13, 14, 15, and 16) are shown as; fig. (7) and fig. (8).

Fig (7) Shows the output power versus time at full load, \( P_{out} = 3.564\, \text{KW} \), the input power versus time at full load, \( P_{in} = 4.5\, \text{KW} \). And shows the curve of the losses in power versus time at full load, \( P_{losses} = 0.9365\, \text{KW} \).

Since the power losses =0.9365KW, then power is dissipated in:-
1- Power losses converted directly to heat in the resistances of the current paths.
2- Mechanical energy developed within the device is absorbed in friction and windage converted to heat.
3- The energy absorbed by coupling field is converted to heat in magnetic core loss for magnetic coupling or loss for electric coupling.

Fig. (8) Shows the efficiency versus time at full load, the efficiency of the motor, \( \eta = 80\% \).

8- CONCLUSION

** In this paper, the block diagram of a D.C. shunt motor was developed by using matlab / Simulink, the exact simulated with expected waveform output were obtained, for example the armature current, torque, speed and output power characteristic of the d.c. shunt motor.

** High protection, increases complexity in operation of the protection equipments by increasing the supply voltage drop and transient torque which can damage the mechanical drive, one of the advantages of having simulink is, increasing the simplicity of the operation of protection equipments and low cost.

** From the obtained results, it was very clear that simulation can be very helpful tool to study the dynamic behavior of D.C. shunt motor and its interaction, with reading experiment.

** Simulation model of D.C. shunt motor and feedback control system for D.C. motor drives have been developed using MATLAB/SIMULINK and it has been shown that proposed simulation model correctly predict the effect of the field resistance on the torque-speed characteristic of the D.C. shunt motor.

9- REFERENCES


Table(1): Specifications of a D.C. Shunt Motor

<table>
<thead>
<tr>
<th>D.C. motor specification</th>
<th>Tipo</th>
<th>160L</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model Number</td>
<td>61.575F</td>
<td></td>
</tr>
<tr>
<td>Power</td>
<td>2.94KW</td>
<td></td>
</tr>
<tr>
<td>Horse Power</td>
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<td></td>
</tr>
<tr>
<td>Voltage</td>
<td>220 V</td>
<td></td>
</tr>
<tr>
<td>Current</td>
<td>15.4 A</td>
<td></td>
</tr>
<tr>
<td>Field Voltage</td>
<td>220 V</td>
<td></td>
</tr>
<tr>
<td>Field Current</td>
<td>1.06 A</td>
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</tr>
<tr>
<td>Speed</td>
<td>1500 r.p.m.</td>
<td></td>
</tr>
<tr>
<td>Wd</td>
<td>Compound</td>
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</tr>
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</table>

Table (2): Simulation results at no load condition.

<table>
<thead>
<tr>
<th>Eb = Vt-IaRa</th>
<th>Wm (rad/s)</th>
<th>N (p.m.)</th>
<th>T (N.M.)</th>
<th>Ia (Amp.)</th>
<th>Km=Ka =Eb/IaWm</th>
</tr>
</thead>
<tbody>
<tr>
<td>216.4</td>
<td>88.4</td>
<td>800</td>
<td>0.22</td>
<td>1.8</td>
<td>1.618</td>
</tr>
<tr>
<td>213.2</td>
<td>85.78</td>
<td>775</td>
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<td>211.2</td>
<td>83.17</td>
<td>750</td>
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<td>4.4</td>
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<td>206.6</td>
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<td>0.63</td>
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<td>204.4</td>
<td>77.93</td>
<td>700</td>
<td>0.37</td>
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<tr>
<td>198.8</td>
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<td>665</td>
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<td>10.6</td>
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<tr>
<td>196.4</td>
<td>72.7</td>
<td>650</td>
<td>4.1</td>
<td>1.8</td>
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<td>194</td>
<td>70.61</td>
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<td>5.5</td>
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<tr>
<td>188</td>
<td>67.47</td>
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<td>9.6</td>
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<tr>
<td>185.6</td>
<td>64.85</td>
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<td>183</td>
<td>62.23</td>
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<td>2.9</td>
<td>8.5</td>
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<tr>
<td>180</td>
<td>157</td>
<td>500</td>
<td>3.8</td>
<td>20</td>
<td>1.615</td>
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Table (3): The experimental results at load.

<table>
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<tr>
<th>Rf +Rser. (Ω)</th>
<th>Wm (rad/s)</th>
<th>N (r.p.m.)</th>
<th>If (Amp.)</th>
<th>Ia (Amp.)</th>
<th>T (N.M.)</th>
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<td>1800</td>
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<td>1.797</td>
<td>2.063</td>
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Table (4): The simulation results at load.

<table>
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<tr>
<th>N (r.p.m.)</th>
<th>Wm (rad/s)</th>
<th>TL (N.M.)</th>
<th>Te (N.M.)</th>
<th>Ia (Amp.)</th>
<th>If (Amp.)</th>
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<td>22.68</td>
<td>19.8</td>
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**Fig.(1):** Schematic Diagram of D.C. Shunt Motor.

**Fig.(2):** Simulink Model of D.C. Shunt Motor.
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Fig.(3): Simulink Model for D.C. Shunt Motor with the Constant Values.

Fig.(4): Rotor Speed (Wm) Versus Field resistance (Rf +Rser.)(Ω) At no load.

Fig.(5): Simulated Output Ia, Te, and Wm Versus Time (Sec.) at no load.
Fig. (6): Simulated Output $I_a$, $T_e$, and $W_m$ Versus Time (Sec.) at full load.

Fig. (7): Simulated $P_{out}$, $P_{in}$, and losses Versus Time (Sec.).

Fig. (8): Simulated Efficiency ($\eta$) % Versus Time (Sec.).
AN APPRAISAL OF THE TRANSIENT RESPONSE OF A D.C. SHUMT MOTOR USING MATLAB/SIMULINK UNDER NO LOADING AND FULL LOADING CONDITIONS

Tقييم الحالة العابرة لمحرك تيار مستمر ذو أثارة متوازية باستخدام ماتلاب / سيمولينك تحت ظروف حالات اللاحمض والحمض الكامل

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الخلاصة

تستخدم المكائن الكهربائية لتوليد الطاقة الكهربائية في محطات الطاقة الكهربائية وتزويد العمل الميكانيكي في الصناعات.

يفصل البحث عملية ادرك الماتلاب / سيمولينك لداء محرك تيار مستمر ذو أثارة متوازية ويقدم نموذج للمكونات الالكترونية لاستعمال المحاكاة بالكمبيوتر كأداة لأجراة الحالة العابرة باستخدام نظام Simulink و SImpower هذا النموذج استخدمت لحساب كل من السرعة (N) والموم (T) وتيار المنتج (Ia) والقدرة الداخلية والخارجية (Pin and Pout) وكمية المحرك (η) تحت ظروف حالات اللاحمض والحمض الكامل. تم مقارنة نتائج المحاكاة مع النتائج العملية وكانت نسبة الخطأ فيها بمعنوي % (2-1) والتي حصلنا عليها من استخدام الماتلاب. المحاكاة كتبت في نظام الماتلاب / سيمولينك، بلغة النسخة (6.5).