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# Automatic Speed Controller of a DC Motor Using Arduino, for Laboratory Applications

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## Abstract

*This work presents a simple speed control application for a DC motor in laboratory use. The purpose of this application is to maintain the desired speed on a generator operating on the same axis to the motor.*

*Two small laboratory DC machines of 1kw and 300W nominal power have been used for testing the controller. Close loop control has been applied by using appropriate speed encoder. The controller functions as a DC chopper and PWM signal is produced by an Arduino UNO controller. The nominal input voltage was 200Volt, so igt switching devices were used.*

*There are over voltage and over current protections and, moreover, a mode without speed metering is available (open loop control scheme).*

*A detailed analysis is provided on the equipment and the techniques that have been used for the control of the power electronic device. The scope of this work was to plan and test the controller, in terms of energy efficiency and economical operation.*

*This study presents the critical results of the tests focusing on the best operational point and discusses the related conclusions. The controller's operation was efficient in both low and high speeds that were tested.*

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## **Keywords**

DC motor controller; DC chopper; energy efficiency in motors

## **I. Introduction**

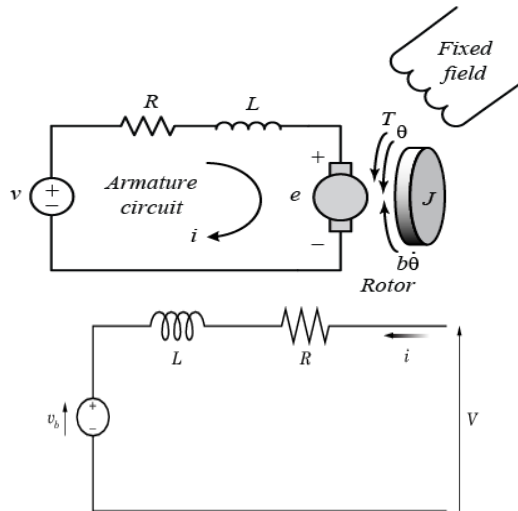
DC motors have many applications in many fields of industrial, commercial and other activities, such as robotics, automobiles, servomechanisms etc. The electric drive systems used in many industrial applications require higher performance, reliability, variable speed due to their ease of controllability. The speed control of a DC motor is crucial in applications where precision and protection are essential. The purpose of a motor speed controller is to take a signal representing the required speed and to drive a motor at that speed. Microcontrollers can provide easy control of a DC motor. A microcontroller-based speed control system consists of an electronic component and a microcontroller. There are many applications of DC motor drives that use power electronics to control the voltage and consequently the speed or position of the motor. For large motors it is highly economical to use power electronics, in order to minimize the power loss and the size of the motor. DC choppers are easily implemented.

In this paper, an Arduino UNO system (microcontroller) was used for the control signal. The DC motor fed by a DC chopper that was driven by the Arduino UNO microcontroller. The chopper is driven by a high frequency PWM signal. Controlling the PWM duty cycle is equivalent to controlling the motor terminal voltage, which in turn directly adjusts the motor speed. This work is a practical one and highly feasible from an economic and accuracy point of view. The desired objective is to achieve a system running on a desired constant speed at any load condition. That means the motor will run on a fixed speed instead of varying with the amount of load. [1]

## **II. Mathematical Model**

DC motor consists of two sub-processes: electrical and mechanical.

The DC Motor represents the electrical and torque characteristics of a DC motor using the following equivalent circuit model:



**Fig. 1. The electrical equivalent circuit of a DC motor**

In order to specify the equivalent circuit parameters for this model it is necessary to set the Model parameterization parameter to By equivalent circuit parameters. The resistor  $R$  corresponds to the resistance you specify in the Armature resistance parameter. The inductor  $L$  corresponds to the inductance you specify in the Armature inductance parameter. The permanent magnets in the motor induce the following back emf  $v_b$  in the armature:

$$v_b = k_v \omega$$

where  $k_v$  is the Back-emf constant and  $\omega$  is the angular velocity. The motor produces the following torque, which is proportional to the motor current  $i$ :

$$T_e = k_t i$$

where  $k_t$  is the Torque constant. The DC Motor model assumes that there are no electromagnetic losses. This means that mechanical power is equal to the electrical power dissipated by the back emf in the armature. Equating these two terms gives:

$$T_e \omega = v_b i$$

$$k_t i \omega = k_v \omega i$$

$$k_v = k_t$$

The electrical subprocess consists of armature inductance ( $L_a$ ), armature resistance ( $R_a$ ) and magnetic flux of the stator ( $\Psi$ ). Armature current ( $I_a$ ) is caused by armature voltage ( $U_a$ ) on the coil ( $L_a$ ). Because the motor is rotating, there is an opposite induced voltage on inductance proportional to the speed of

the motor ( $\omega$ ) and magnetic flux ( $\Psi$ ). Armature current through inductance is therefore:

$$I_a(t) = \frac{1}{L_a} \int_0^t (U_a(t) - R_a I_a(t) - \Psi \omega(t)) dt + I_a(0)$$

The second sub-process in the motor is a mechanical one. It consists of the inertia of the motor and a load ( $J$ ). The difference in motor speed is caused by the electromagnetic moment ( $M_{em}$ ), the load ( $M_l$ ) and the friction of the motor ( $M_f$ ):

$$\omega(t) = \frac{1}{J} \int_0^t (M_{em} - M_l - M_f) dt + \omega(0),$$

where  $M_{em}$  is a function of armature current and  $M_f$  is a function of speed. As a load ( $M_l$ ), we used an electric brake. It has a non-linear characteristic between output torque ( $M_l$ ) and input control voltage and is also speed-dependant.

### III. Modeling of Motor Dynamics

$$T = J \frac{d^2 \theta}{dt^2} = J \frac{d\omega}{dt}$$

The torque is given by:

Also:

$$K_t i_a = J_m \frac{d^2 \theta}{dt^2}$$

$$I_a(s) = \frac{J_m s^2 \theta(s)}{K_t}$$

$$(L_a s + R_a) \frac{J_m s^2 \theta(s)}{K_t} = V_{in}(s) - K_b s \theta(s)$$

$$\left( L_a s \frac{J_m s^2 \theta(s)}{K_t} + R_a \frac{J_m s^2 \theta(s)}{K_t} \right) + K_b s \theta(s) = V_{in}(s)$$

$$G_{angle}(s) = \frac{\theta(s)}{V_{in}(s)} = \frac{K_t}{[L_a J_m s^3 + R_a J_m s^2 + K_t K_b s]}$$

#### IV. DC chopper drive

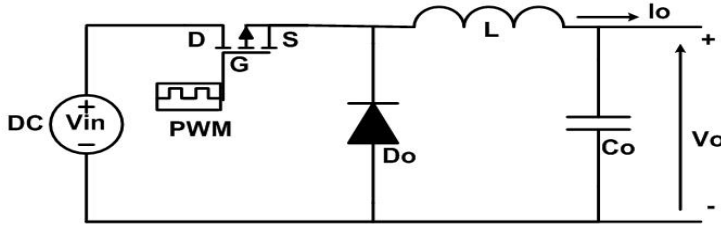


Fig. 2. DC chopper electric circuit

When the semiconductor element (mosfet) is in a conducting state (switch closed), the diode of Fig reverse biased and the input provides energy both to the load both in coil linearly charging. As the semiconductor element is in a cutoff state, the stored energy flows through the passageway.

The above analysis relates to resistive loads, such as small power supplies. In fact we very rarely resistive loads and if we talk about drives the buck converter can be used consists of a coil and capacitor.

There is continuous conduction and discontinuous conduction. The criterion is

$$I_{min} = \frac{V_d - V_o}{L_o} * D * \frac{T}{2} = \frac{D * (1 - D)}{2} * \frac{V_d * T}{L_o}$$

Where:

$I_o$ : the current at the inverter output

$V_o$ : voltage at the inverter output

$V_d$ : the output voltage

$I_l$ : the current in the coil

For continuous current:

$$V_o = D \cdot V_d$$

$$I_o = \frac{I_{lmax} + I_{lmin}}{2}$$

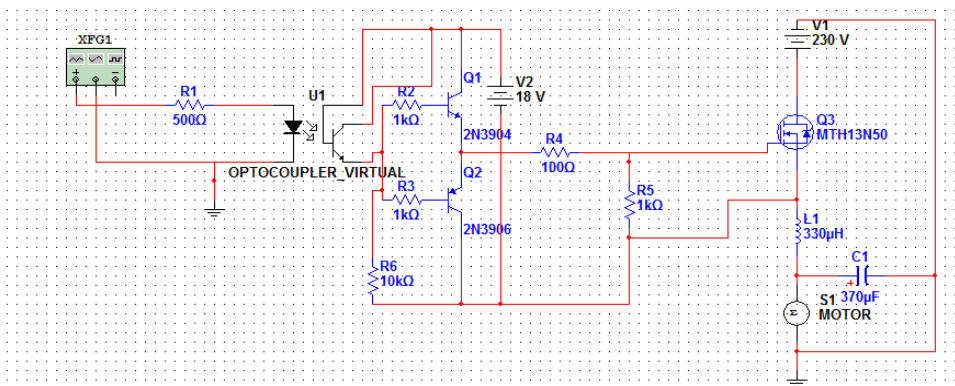
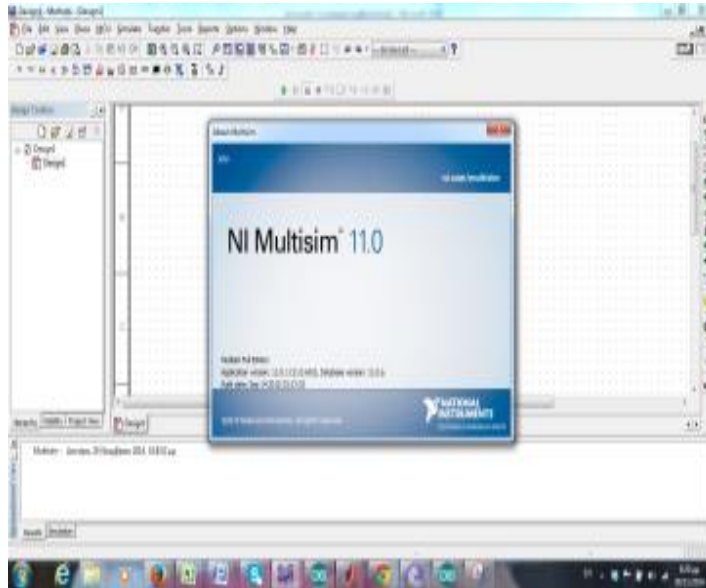
$$I_{lmax} - I_{lmin} = \frac{V_d - V_o}{L_o} * D * T = \frac{V_o}{L_o} * (1 - D) * T$$

For discontinuous current:

$$V_o = V_d * \frac{D^2}{2} * \frac{1}{\frac{D^2}{2} + I_o \frac{L_o}{V_d * T}} \Rightarrow \frac{V_o}{V_d} = \frac{D^2}{D^2 + \frac{1}{4} * (\frac{I_o}{I_{omin}})}$$

## V. Methods and Testing

For the purposes of our project in electronic circuits planing, a multsim software was used:



**Fig. 3. The Multisim software and the relevant circuit simulated**

For the control of the DC chopper, an arduino UNO chipset was used. Below there is sample algorithm - code that is used to control the switch. We used an

analog input ( A0 ) , depending on the value of which is formed the width of the pulse to the digital output ( No. 9) . Set the sampling rate to communicate with the computer as 9600.

```
#include <PWM.h>
#include <FreqCount.h>

int i=0;
int a[4];
int n_ref=200;
int incomingByte = 0; // for incoming serial data
int pinout=10;
longint Va=0;
int n_max=2500;

void setup()

    Serial.begin(9600); // opens serial port, sets data rate to
    9600 bps
    FreqCount.begin(1000);

void loop()

    • Δίνω στροφές → μεταβλητή n_ref

        // send data only when you receive data:
        for (i=0;i<4;++i) {
            if (Serial.available() > 0) {
                // read the incoming byte:
                incomingByte = Serial.read();
                a[i]=incomingByte-48;

                // say what you got:
                Serial.print("I received: ");
                Serial.println(incomingByte,DEC);
            }
        }
        if (incomingByte>0) n_ref
        =1000*a[0]+100*a[1]+10*a[2]+a[3];
        Serial.println(n_ref,DEC);
    }

    •

        • Reading speed by tacho ( serial and
        conversion ) ⇄ variable n_rot if
        (FreqCount.available()) {

            unsigned long count = FreqCount.read();
```

```

Serial.println(count);

N_rot = (count / 60);

Serial.println(N_rot);

// I check speed adj = (n_ref - n_rot) o If (adj-10 > 0 and Va < 65535) Va = Va
+ (adj / n_max) * 6553; delay(200); // To maximum 10 % step // o If (adj-10
< 0 and Va > 0) Va = Va - (adj / n_max) * 6553;    pwmWriteHR(led, Va);

Serial.println(Va);

Serial.println(Va);

Serial.println(n_rot);

    delay(200);    }    }

```

In order to test our drive system, two DC motors separately excited were used, one of 0.8kW(~1hp) nominal power (ELWE) and the other of 250W(1/3hp) nominal power (hampden). For loading the motor, a DC generator was used on the same axis.



**Fig. 4. Hampden motor system**

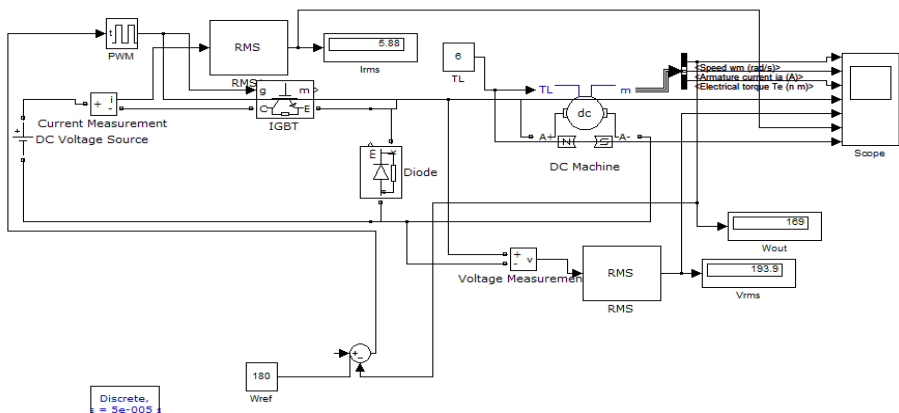




**Fig. 5. ELWE motor system**

The whole idea was to change the load of the motor, trying to maintain the speed of the motor, by controlling the duty cycle electronically.

Besides, as part of an integrated and comprehensive study on the system developed for the needs of the labor was used Matlab and Simulink software simulations. Used existing mathematical models of the library of MATLAB Simulink ( Version 7.12.0 ) and in the picture below summarizes the model developed.



**Fig. 6. Matlab Simulink model**

Through appropriate models on Matlab Simulink, specific measurements recorded torque, power and speed. There are both instantaneous measurements and oscillograms.

Note that these data do not correspond to the experimental data, which the system established in the laboratory. This was a theoretical approach of the

system in order to extract critical information about the operation of our developed system.

## VI. Results and Discussing

Towards to establish speed control, many tested have been taken place. Below in summary charts Torque to duty cycle are presented in the cases (scenarios) examined in two laboratory DC machines and the simulation model in matlab. Notice that the slope of the curve changes depending on the machime power. For the ELWE motor which has quite higher power, there was more adjustment range for duty\_cycle stabilizer speed. It is reasonable because we have a greater range of load we can serve.

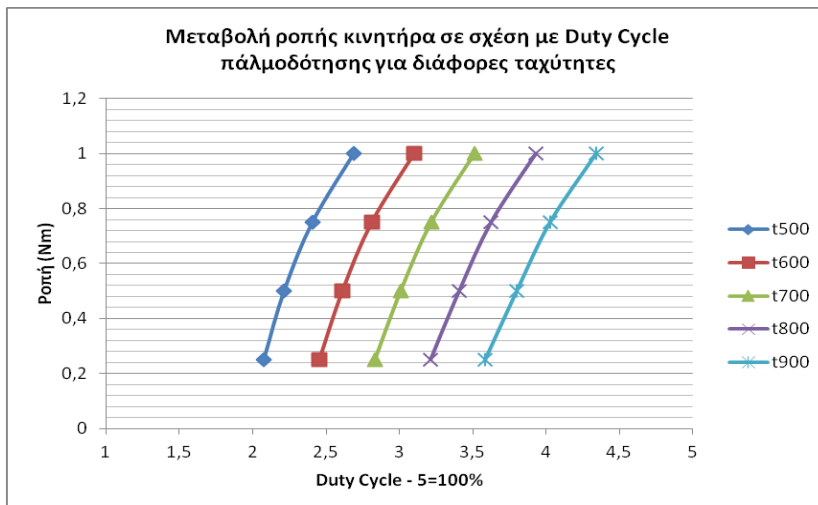


Fig. 7. Hampden motor system(Torque-Duty Cycle)

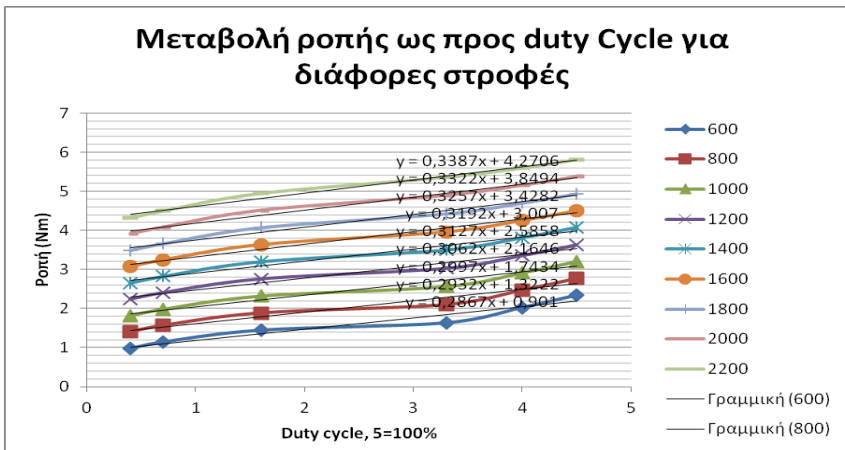
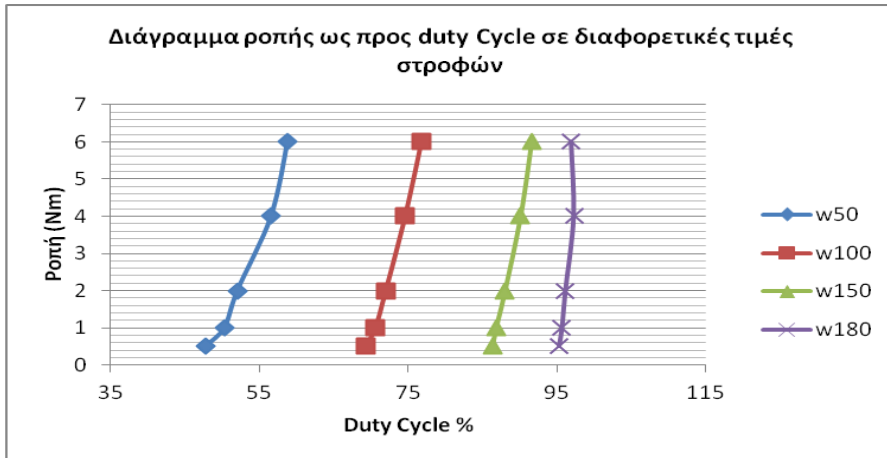
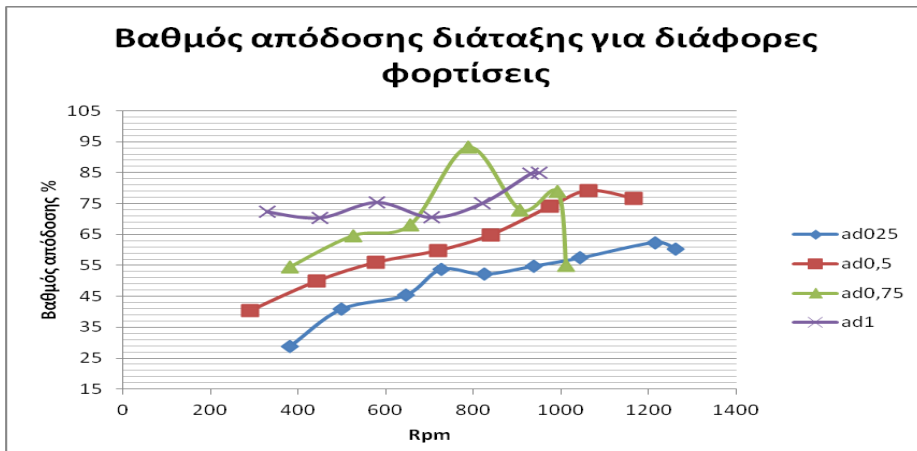


Fig. 8. ELWE motor system(Torque-Duty Cycle)

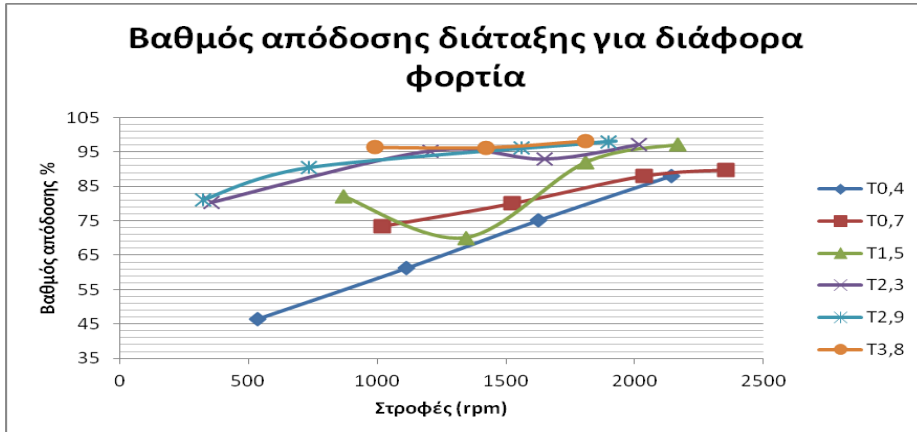


**Fig. 9. Matlab simulation tests(Torque-Duty Cycle)**

Also what can be presented as a conclusion is the variation in efficiency, of their power provision. Overall efficiency is quite high, especially in the larger loads.

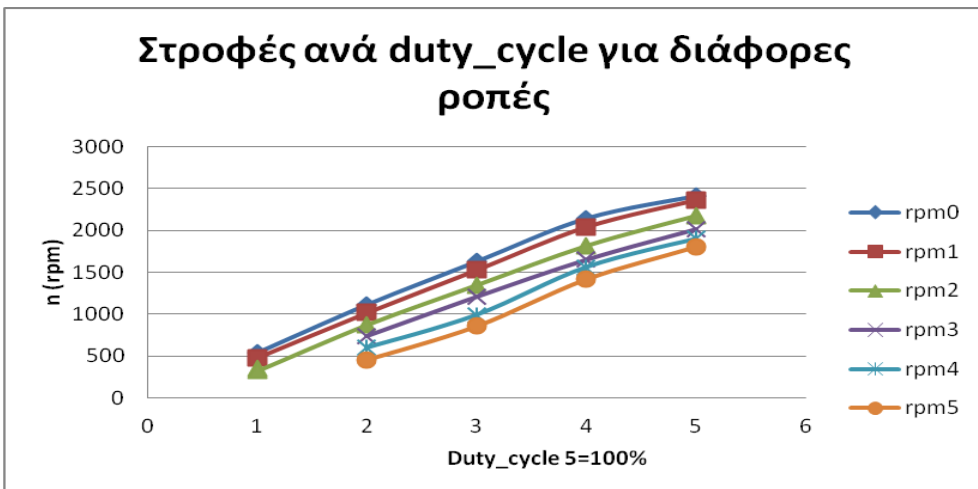


**Fig. 10. Hampden motor system (efficiency%-rpm)**



**Fig. 11. ELWE motor system (efficiency%-rpm)**

Also of interest is the comparison of experimental measurements in relation to measurements in MATLAB as shown in the two graphs below, and to the change of the speed in relation to the duty cycle for various constant loads. The curve skai their inclinations are equivalent.



**Fig. 12. ELWE motor system(rpm-Duty cycle)**

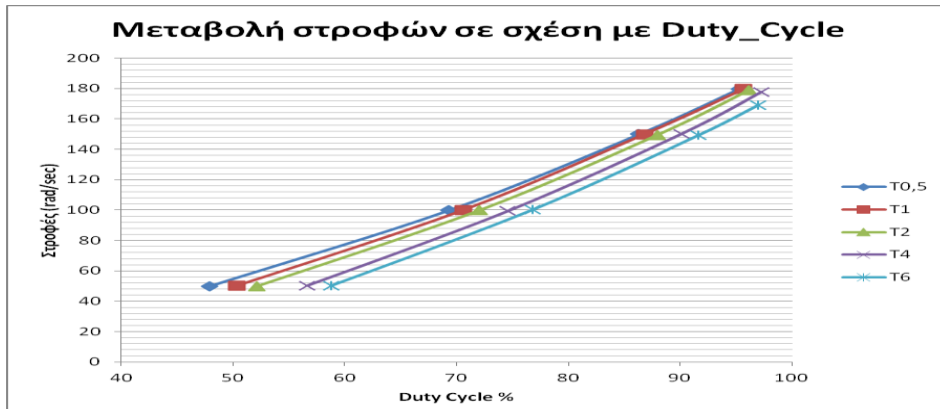


Fig. 13. Matlab simulation tests(Rpm-Duty Cycle)

## VII. Conclusions

From all the measurements for the experimental devices implemented in the electrical machinery workshop , can be exported appropriate modeling for each engine in order to measure the drum power to determine the duty\_cycle for the desired constant speed. This contributes to the linearity of the operation of the DC motor , with constant agitation.

First, it was the automatic feedback speed control using tacho signal from the machine shaft. When performing experiments but found that the speed measuring device was defective, and not having any other option we turned to open-loop control, with potential for expansion in a closed loop, or using tacho, or drum current measuring device.

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