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Improving the Response of Electromagnetic Servo Relay Drives (ESRD) Using PID Comp. and Multi-level Voltages

Dr. Eng. Saad A-R. Makki
Almustansiriah University
College of Education
Computer Science Dep.

Abstract

Electromagnetic Servo Relay Drive (ESRD) devices are small, simple and reliable devices. Special types of ESRD Utilizing Pulse Width Modulation (PWM) technique to input driving voltage are used in guidance and control systems.

In this Paper a simulation, using MATLAB and Simulink were performed. To improve the rising time and time response of the mechanical armature angular position, the input voltage has been selected to do that. Two techniques have been proposed, first is the PID compensator and second is the reshaping / reforming the input pulse voltage.

The effects on the different system parameters has been declared and discussed in addition to the comparison between the two used methods. Results show that the 2nd method is more effective and give an improvement in star sting and rising time by about 20% compared with 6% improvement in 1st method. The second method shows an increment in power consumption which lead in heat dissipation.

Key Words: Electromagnetic Relays, Pulse width Modulation, Servo Relay, PID Controller, PWM

الخلاصة

ان ادوات القيادة السرفوية ذات مبدأ الرلي الكهرومغناطيسي (ESRD) هي ادوات صغيرة و بسيطة وذات معولية (اعتمادية). هنالك نوع خاص من الـ (ESRD) يستخدم مبدأ التحميل بعرض النبضة (PWM) يجد له تطبيق في منظومات السيطرة والتوجيه.

تم استخدام برامج محاكات ماثلاب والسميلنك MATLAB and Simulink.

لأجل تحسين زمن الصعود وزمن الاستجابة للخرج الزاوي للذراع المتحرك وان الدخل الفولتي قد اختير لتحقيق ذلك. لقد تم أستخدام اسلوبين, الاسلوب الاول تم عن طريق استخدام معوض نوع PID والاسلوب الثاني هو باعادة تشكيل / تغيير شكل دخل الفولتية النبضية.

تم مناقشة وايجاد التأثيرات على معالم المنظومة المختلفة بالاضافة الى ايجاد مقارنة بين الطريقتين المستخدمتين. اظهرت النتائج بان الطريقة الثانية اكثر فعالية وتعطي تحسين في زمن البدء وزمن الصعود مقداره 20% مقارنة مع 6% تحسين في الطريقة الاولى. اظهرت الطريقة الثانية مساوئ في زيادة القدرة المستهلكة وبالتالي زيادة الحرارة المتبددة.

Introduction

Electromagnetic relay composes of two parts, electromagnetic mechanism and actuating mechanism. Electromagnetic mechanism produces pick-up force that makes armature iron move, and it changes the input excitation (electric input) to mechanical work. Actuating mechanism includes contact system and return mechanism. Its performance represents the relay output characteristics.[1]

Electromagnetic Servo Relay Drives (ESRD) are a special type of relays used in control systems for example in controlling the aerodynamic surfaces in small flying objects or controlling the flow of fluid in pipes. [2]

As shown in Fig.(1), the relay consists of two sides each side contains a coil for producing magnetic field. Under the un-excited condition, armature iron was in initial position because of the effect of reaction of plate spring. When power was on in one coil, the coil produced magnetic field and the electromagnetic pick-up force in the operation gap between armature iron and yoke iron. Then, the pick-up force made armature iron rotated and pusher arm began to move say right side. Through an idle distance, pusher arm contact with movable spring and push the movable spring apart from normally closed spring. After armature iron passed the free distance, movable spring contacted with normally open spring. Armature iron continued to move until passed over-travel distance and contact with yoke iron. In this way, the relay completed one contact transfer to right side. When power was off, armature iron returned because of the reaction spring restoring force and the contact transfer in release process was completed. Similarly when energizing the left coil with DC power and the armature iron move to left side.

The actuator of a relay is a kind of a linear electromagnetic solenoid, especially push/pull type. Due to its simplicity, high reliability, and low cost, the solenoid actuator is widely used as industrial apparatus for automobile application, pneumatic valves, electric relay, and switches. [3].

For control purposes the movement of the armature controlled by supplying the left and right coils with DC voltage utilizing the Pulse Width Modulation (PWM). The PWM technique for linear control systems. The cycle of the output period divided into *equal switching intervals* (regular sampling) of width. As shown in Fig.(2), voltages of left and right coils width are modulated according to control signal, this will lead to a result that the left and right positioning intervals will be proportional to the control signal.[4]

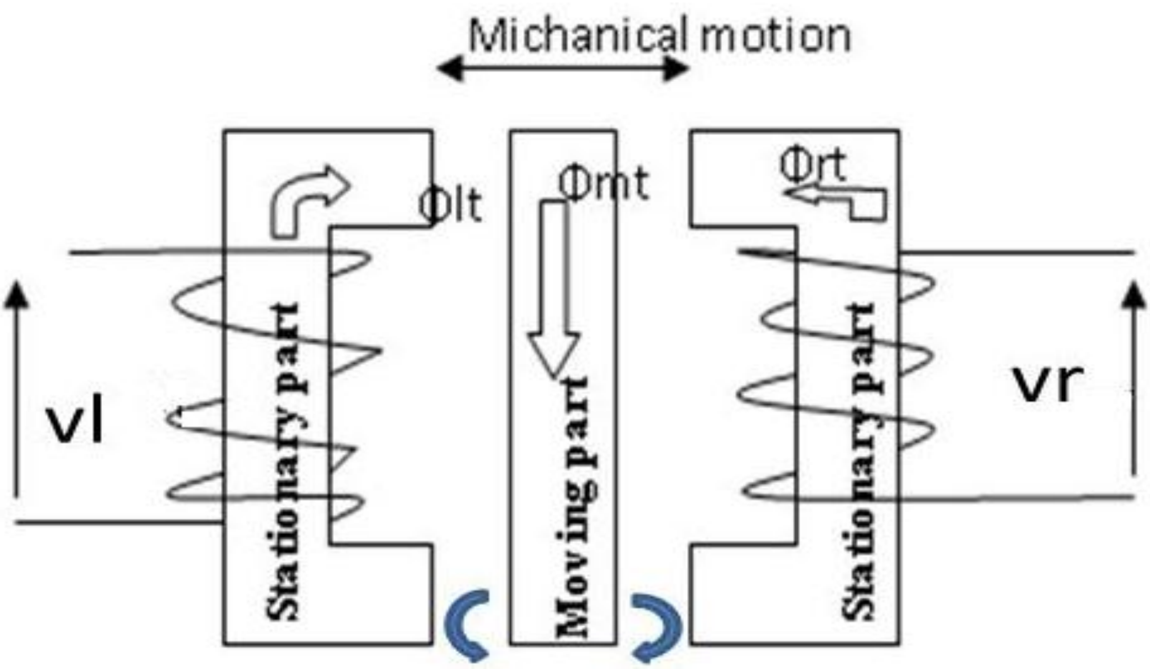

Fig.(1) Electromagnetic Servo Relay

System Modeling

Simulation, using MATLAB ver. 7.10.0(R2010a) and Simulink, were performed.
The system (left and right sides) consists of three blocks.

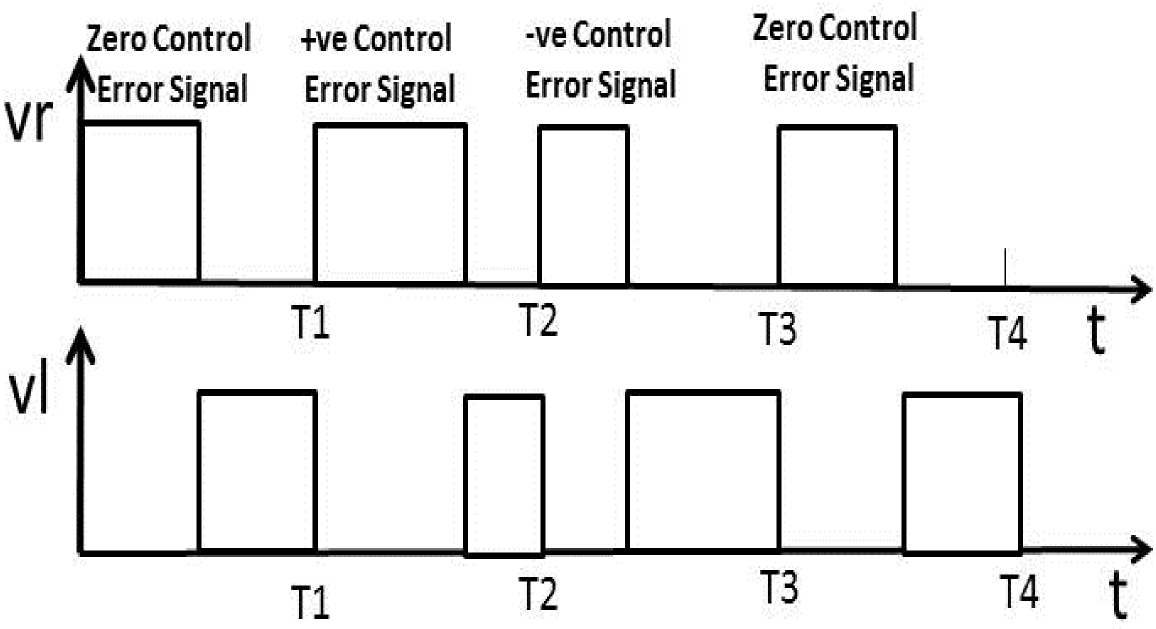

Fig.(2) Pulse Width Modulation

The first block is the electric power supplies which consist of voltage supplies Vl and Vr (10 V DC each), coils resistance R (20 Ohm), and Coils reluctance L (10 mH). The reluctance considered here constant value, actually it is nonlinear value, its value depends mainly on magnetic material of cores, magnetic value, and moving armature position.[5]

$$\frac{I(s)}{V(s)} = \frac{Kv}{TvS+1} \qquad (1)$$

Equation (1) is the transfer function of the electric circuits, where Kv= 1/R and Tv=L /R

The second block is the two side magnetic circuits in which the magnetic strength (Nl) depend on the number of coils tern and the magnetic circuit length (l). The main parameters are magnetic flux density (B), total flux (Φ) and the attraction force (or torque) of moving the armature (Tg) which they are functions of electric current(I), magnetic material(μr) and the moving armature position (α).

The third block is the dynamic block. The attraction force and torque (Tg), viscosity torque (Tv), and stiffness torques (Ts) are calculated. The main parameters are the angular acceleration $\ddot{\alpha}$ of the moving parts, magnetic torque generated (Tg) moving parts inertia (J) and the time response of the armature translation from side to side. The movement is limited mechanically by an angle equal to 13 degrees around the mid position. [5],[6],[7]

System and Simulation

The results have been presented according to the following parameters:

For Electric Circuit: Vl=Vr=10 V pulse/squer voltage with 10 Hz, Rcl=Rcr=25Ω, Ll=Lr=10mH, Nl=Nr=1500,
For Magnetic Circuit: Left and Right parts are identical with a length=5cm, Moving part length=3 cm, cross section area of all magnetic parts including the air-gap= 4*10^-5m, leakage factor of coils=0.9, air-gap length=o.5 cm, isolated sheet thickness=50 μm. The material is a Stalloy type. Its B-H carve shown in Fig.(3).
Mechanical Parameters: J=0.000003 Kgm^2, αmax= ±13deg., Stiffness= 0.0014 N/deg., Viscosity= 0.001 N/(Deg/Sec).
The main parameters of the dynamic control system are the generated torque, rising time constant, and the moving part (armature) acceleration.
The nominal input voltage is a pulse variable duration with a constant peak value equal to 10 V for both coils. Fig.(3-8) show the nominal system parameters behavior.
Fig.(3) and Fig.(4) show the voltage and current of the core windings respectively.

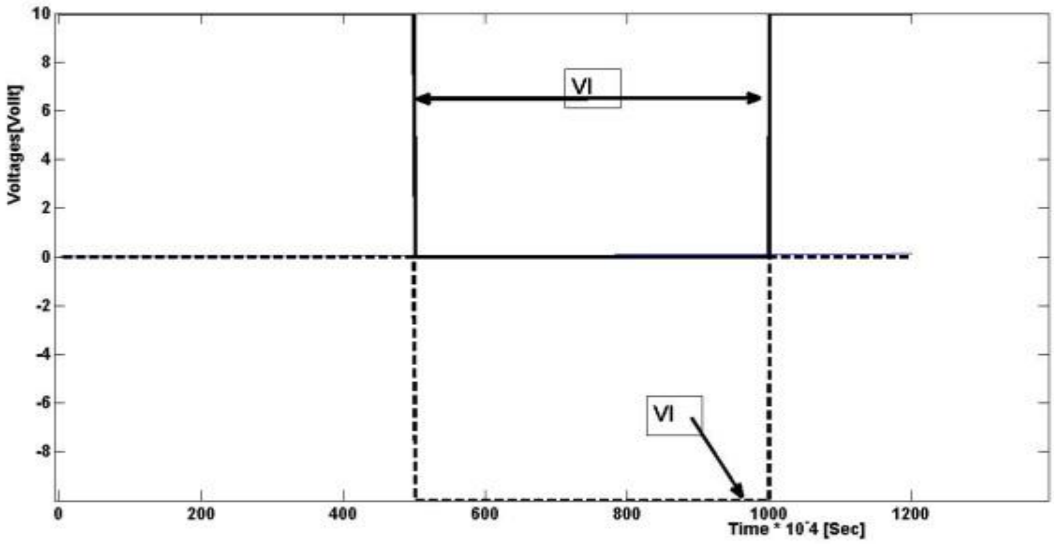

Fig.(3) Nominal Voltage input Shape

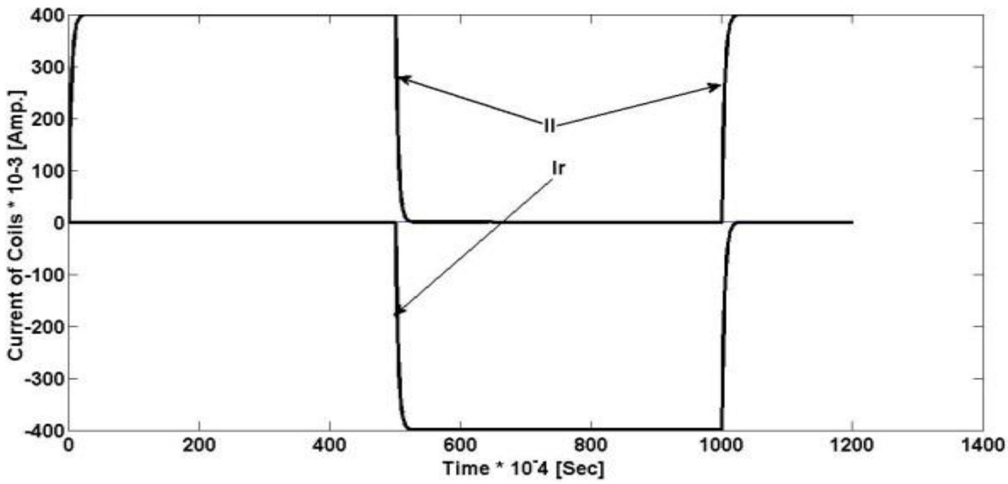

Fig.(4) Nominal Current shape

Fig.(5) show the armature angular position movement and the mechanical limitation of the angle to ±13 degrees. Fig.(6) show the behavior of the magnetic generated torque which cause the armature to move.

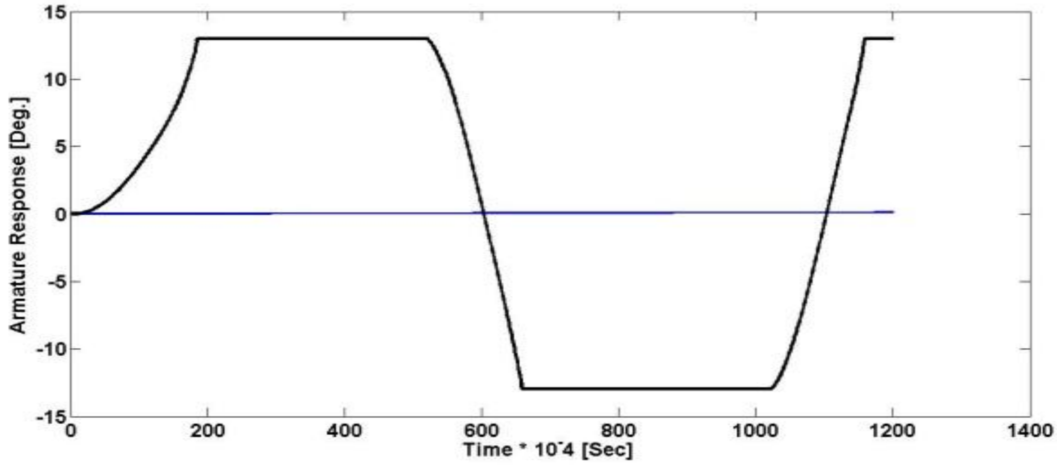

Fig.(5) Nominal Armature Response Angle

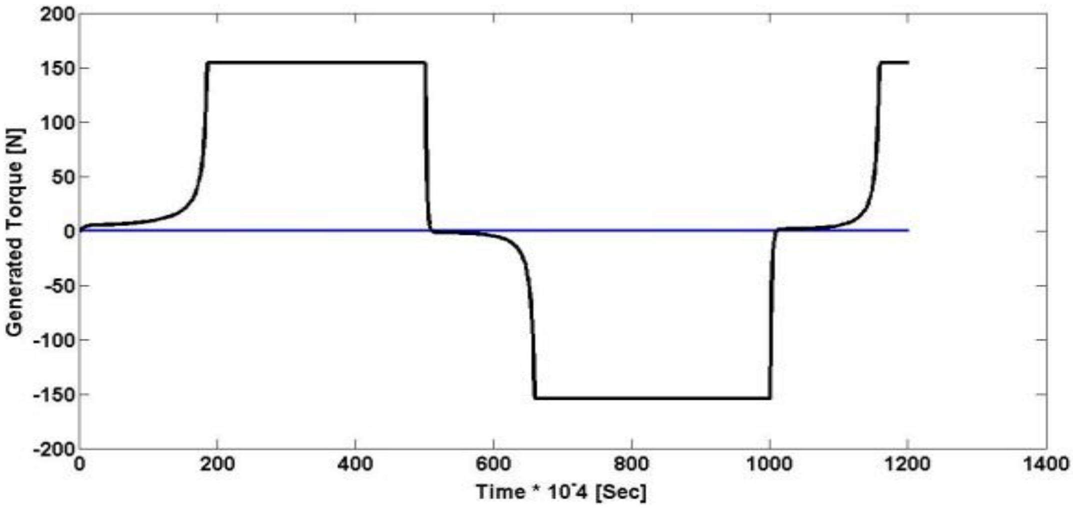

Fig.(6) Nominal Developed Torque

Fig.(7) and Fig.(8) show the armature angular rate (speed) and acceleration respectively.

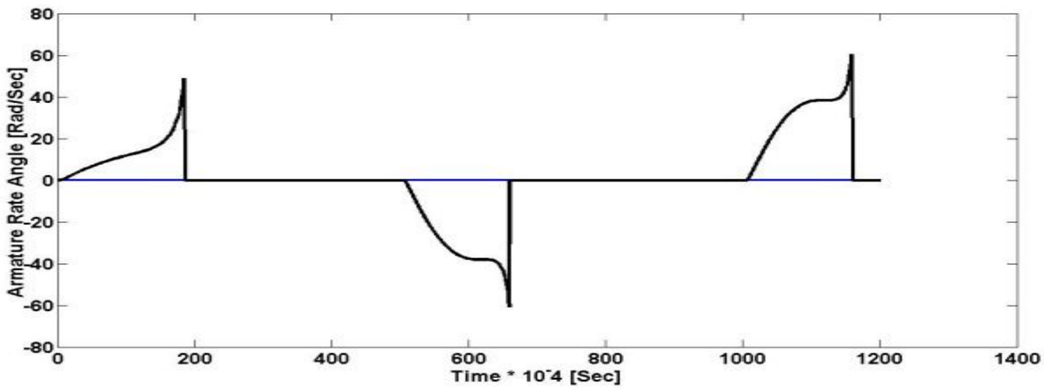

Fig.(7) Nominal Armature Angle Rate

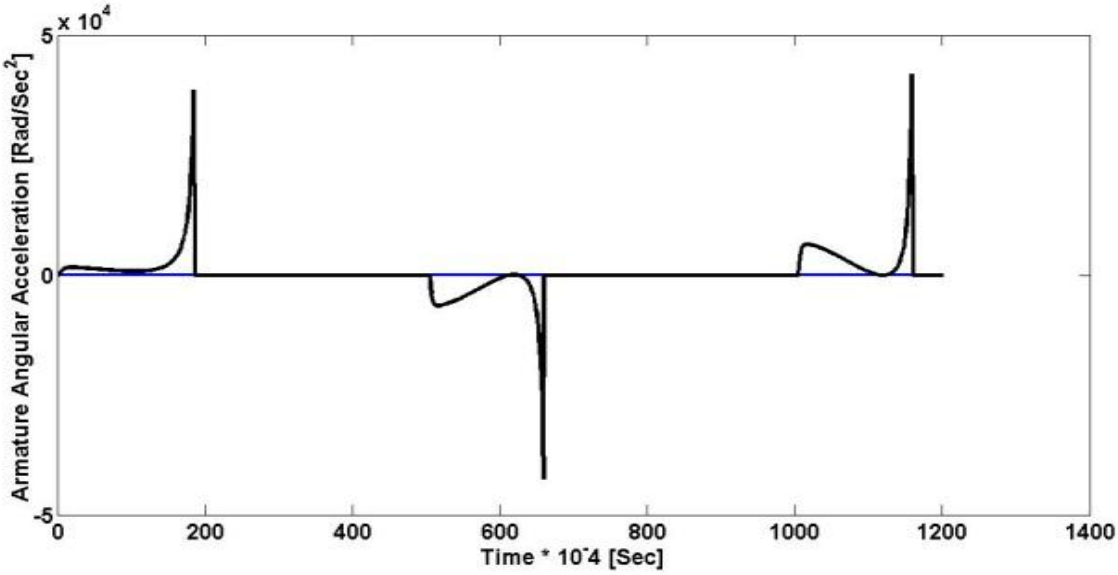

Fig.(8) Nominal Armature Angle Acceleration

Improvement Using Input Current Compensation

The electric circuit is a simple one. It consists of resistance and inductance of coil. Actually the inductance has a nonlinear characteristics depending on the Current value, the B-H carve of the magnetic material and the armature position. The inductance has been considered constant for this paper.

A PID compensator has been used in the forward circuit with tuned coefficients p=35.5, I=126000, and D=-0.004. Fig.(9) A and B show the winding current response for the nominal uncompensated current, compensated current using PID forward compensator, and the Ideal case when the input is a step input. The ideal case is just for comparison of the output parameters. The rising time of uncompensated current is time constant is 2.5msec. The rising time of compensated one is about 0.5msec. The improvement in response is clear.

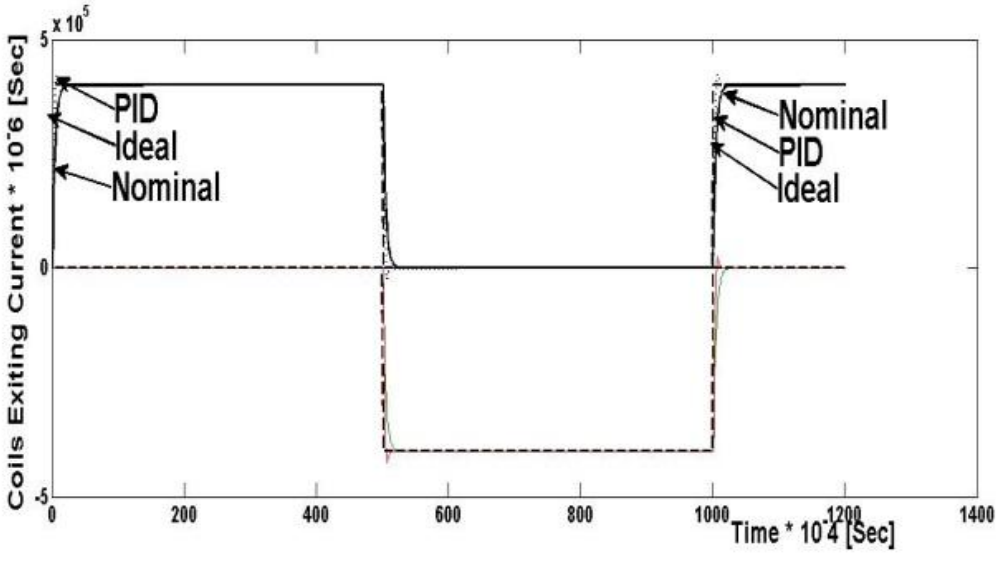

Fig.(9) Winding Exiting Current

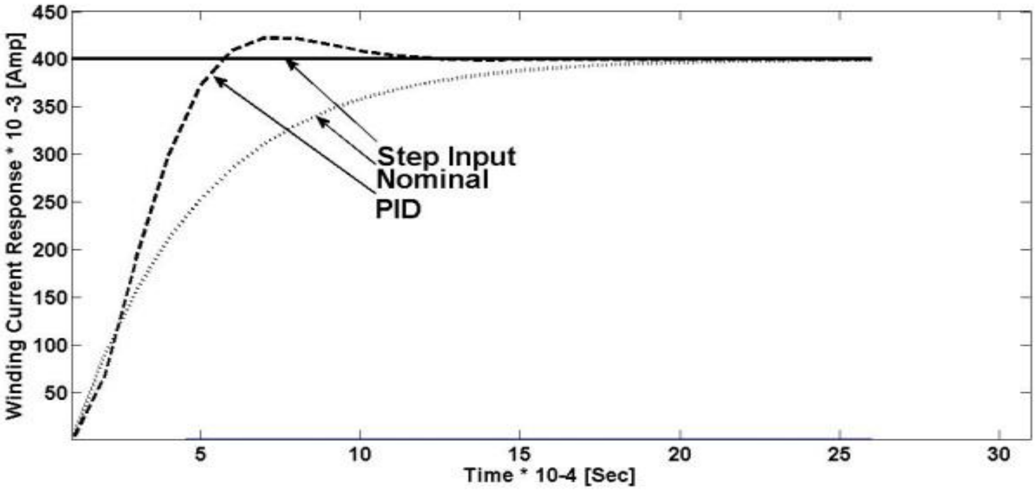

Fig.(10) Detailed Current response for the three cases

Fig.(11) and Fig.(12) show the behavior of the armature position angle α. The angle is limited to ±13 degrees by mechanical limits.

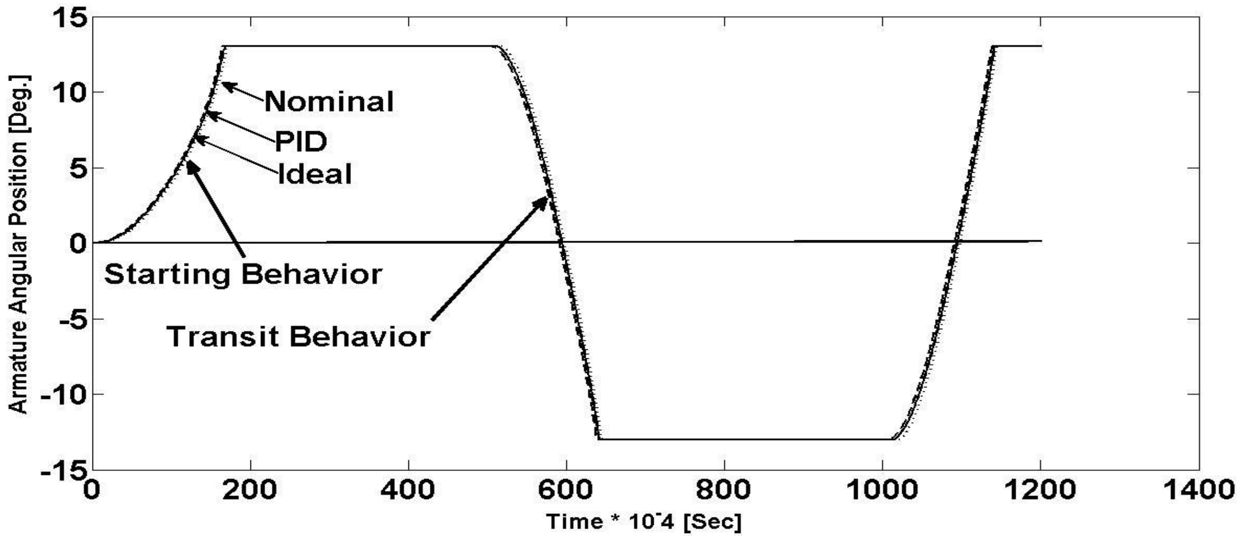

Fig.(11) Armature Position Response

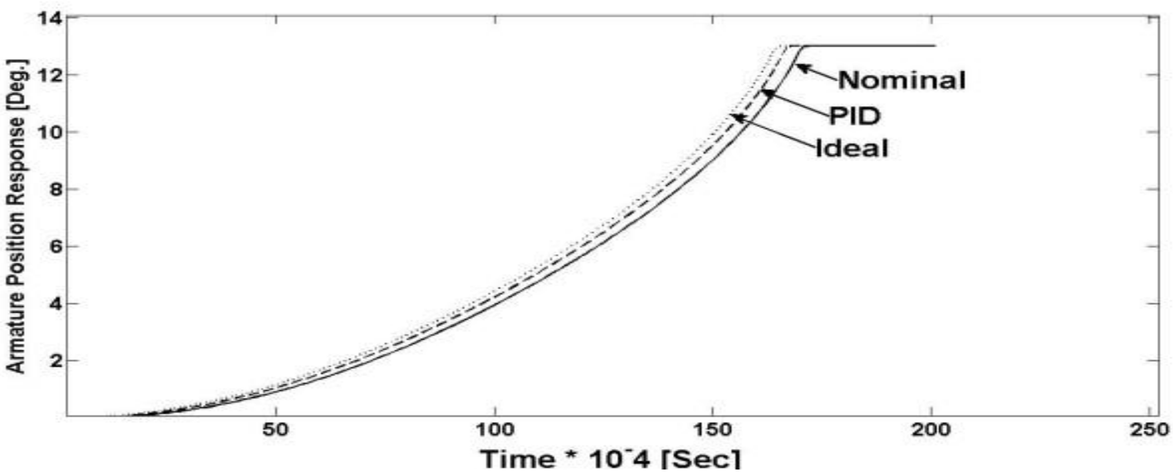

Fig.(12) Armature Starting Behavior

Fig.(13) and Fig.(14) show the behavior of the generated magnetic torque and force. The behavior of generated torque depends mainly on the position of the armature **α** (on air gap length).

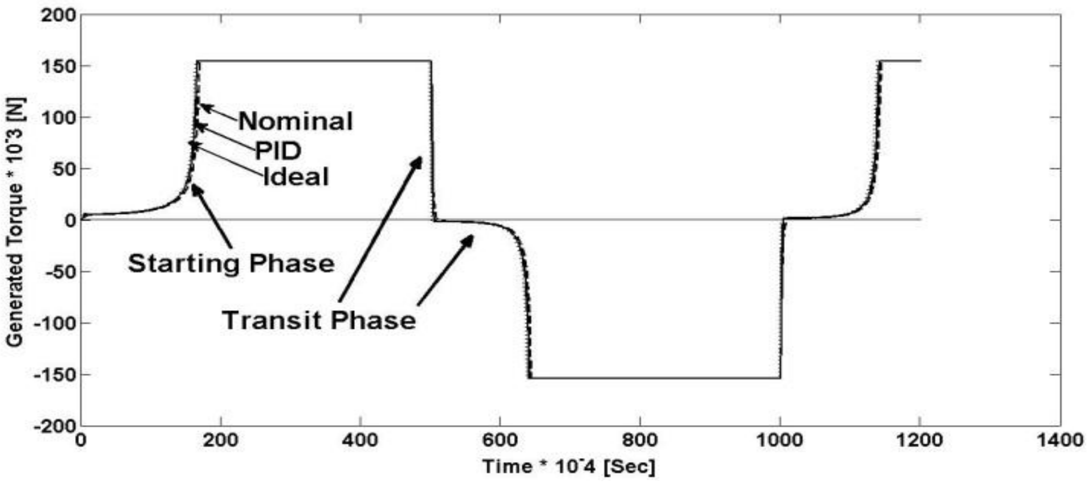

Fig.(13) Generated Torque

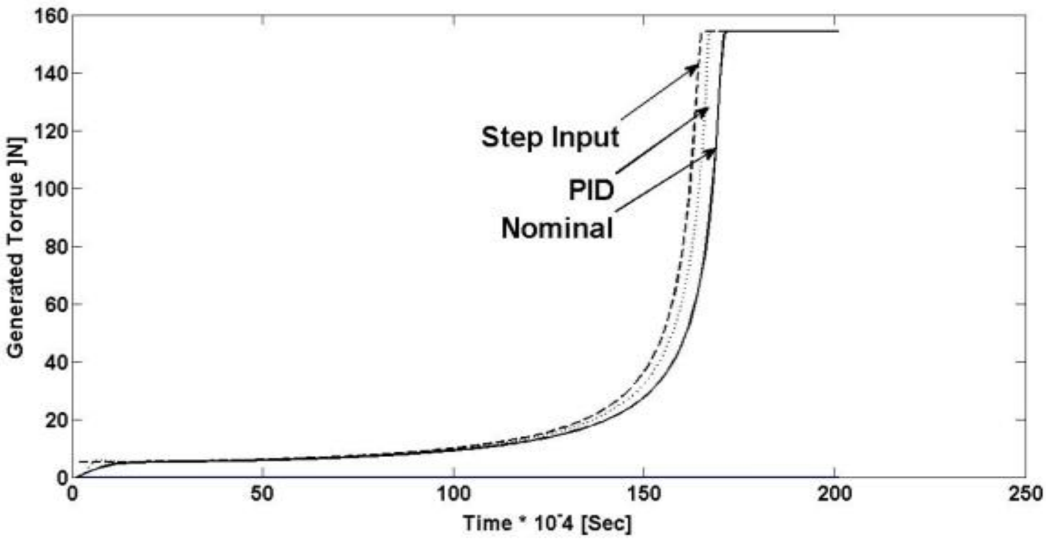

Fig.(14) Starting Generated Torque

The starting of the movement of the armature at the beginning (when the armature move from zero α position to say +13 degrees) has initial conditions equal to zero for position rate **ά** and angular acceleration **ᾰ** in which differs from the transit motion in which the armature moves from say +13 degree to -13 degrees. See Fig.(15) and Fig.(16).

The rising time for the starting motion is 16.5msec, 16.6msec, and 17.7msec for Ideal, PID, and nominal cases respectively. The transit time is about 13msec. The differences between different cases are within about 1msec. For transit case the time is about 13msec. Remember the periodic cycle of the PWM is 100msec (10 Hz).

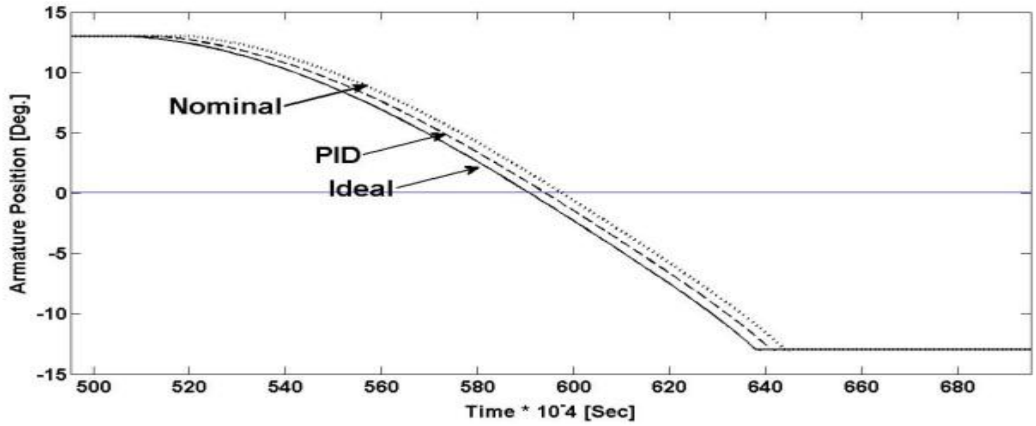

Fig.(15) Armature Transit Behavior

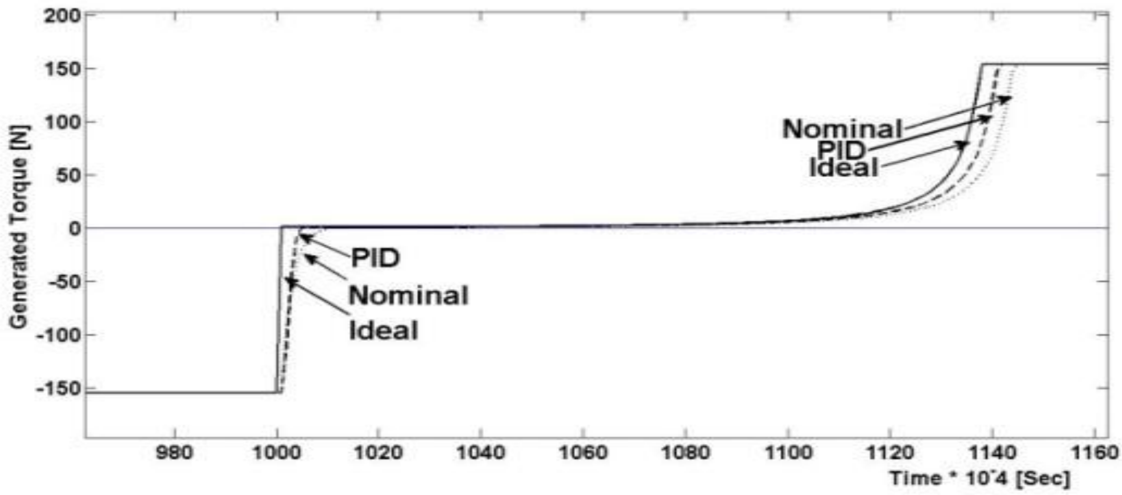

Fig.(16) Generated Torque Transit Behavior

Improvement using input voltage Reshaping

The second proposal to improve the armature position response will depend on the minimizing of mechanical time response of the moving armature. This proposal depends on modifying the shape of the input voltage by increasing the value of the voltage of variable width pulse in the beginning of the pulse by interval of (Ʈ) as in Fig.(17). This technique will lead to increase the generated motive torque and accelerate the armature and then decreasing the time response of the moving armature. Fig.(17-21) show the behavior of the main system parameters, which are the armature position, generated torque, armature angular rate and armature angular acceleration.

The disadvantage of this method is the increase of the power and energy consumption. This problem can be avoided or mitigated by reshaping the input voltage and decreasing the nominal voltage to quarter of this value. This can be done due to fact that when the armature has been accelerated and reached the final destination (13 Deg.) it will be stopped mechanically and need no high force to be kept and stick at the final position. This problem is out of the scope of this paper.

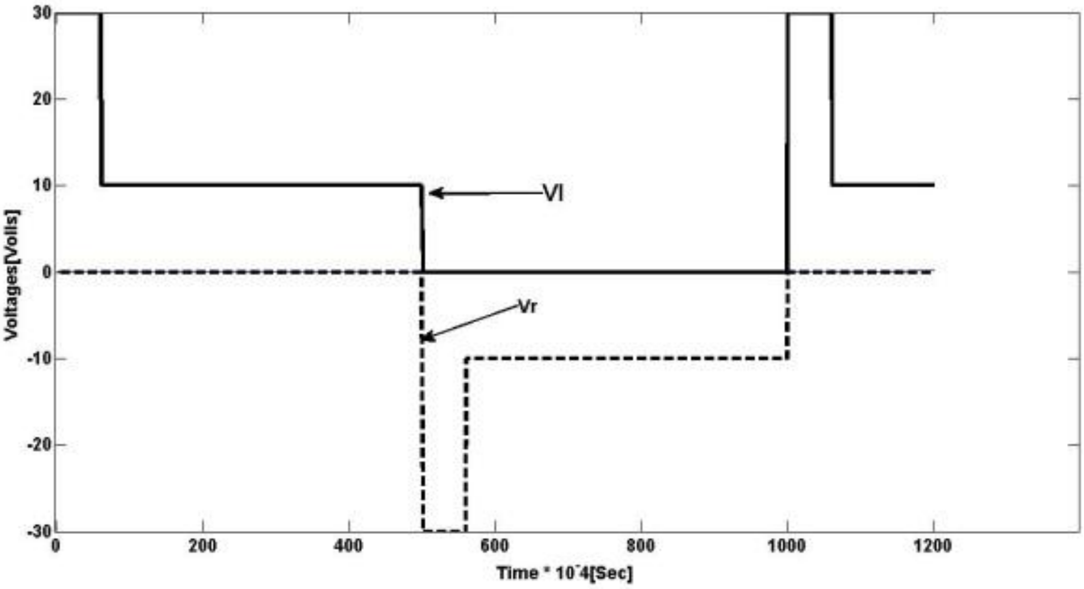

Fig.(17) Reshaped Input Voltages

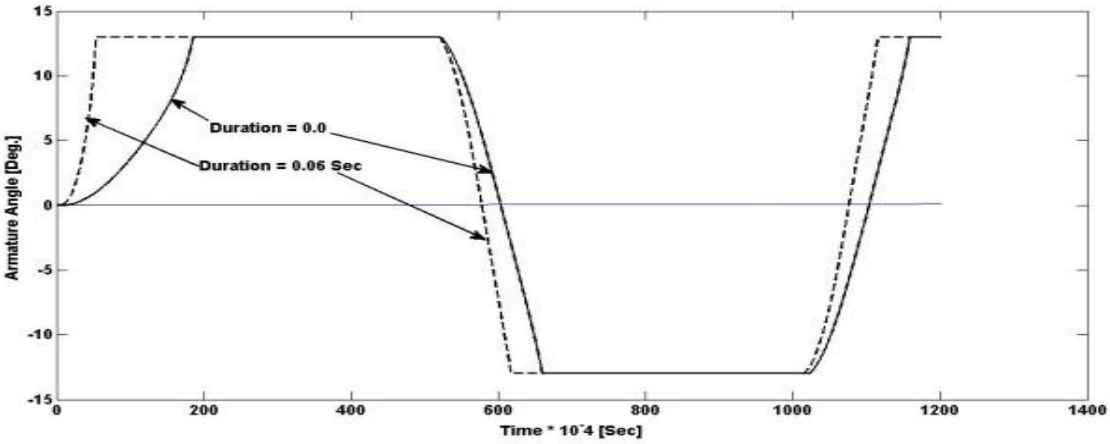

Fig.(18) Armature Position Response α

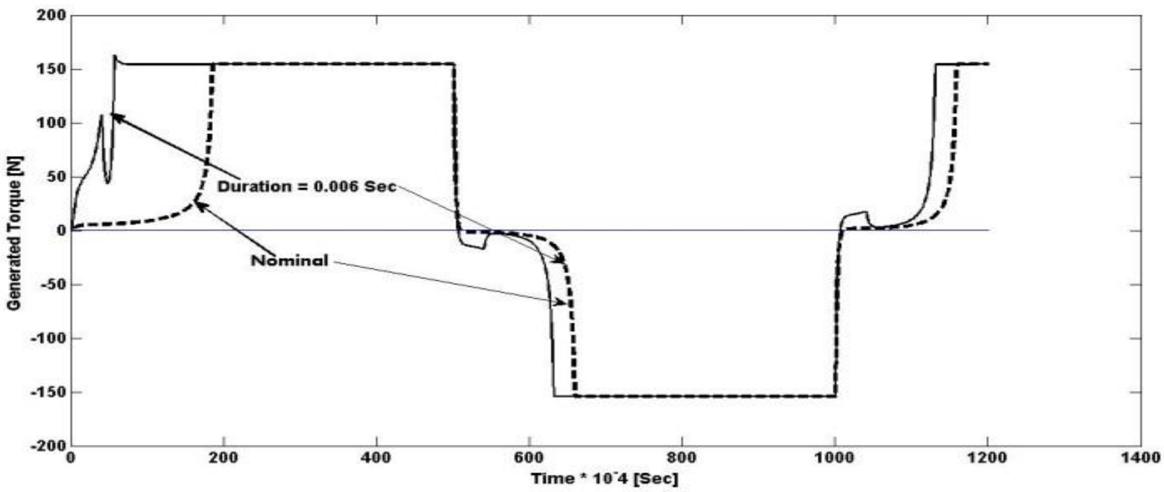

Fig.(19) Magnetic Torque Generated

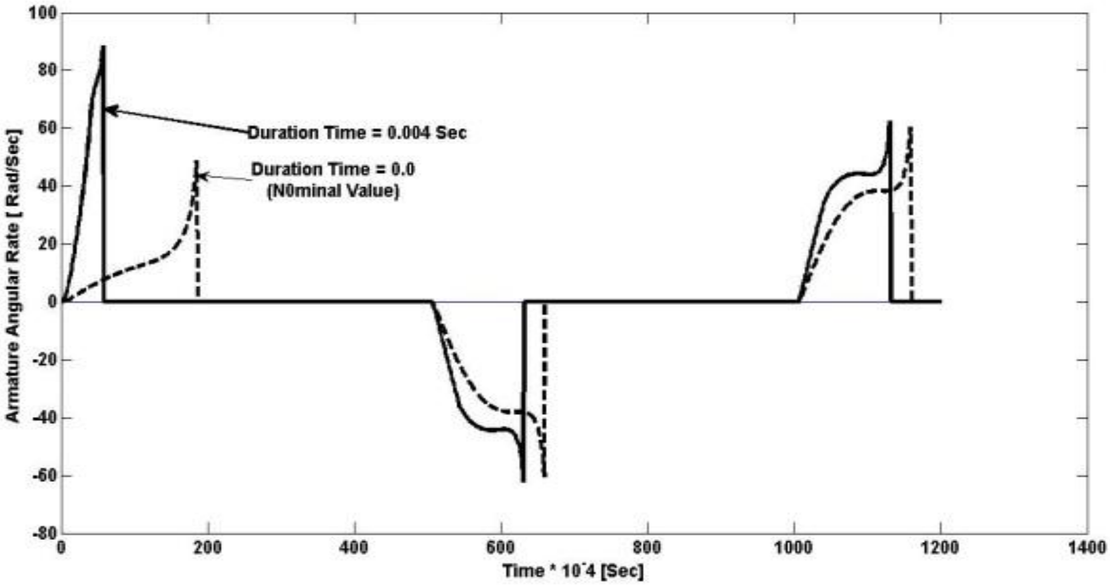

Fig.(20) Armature Angular Rates ά

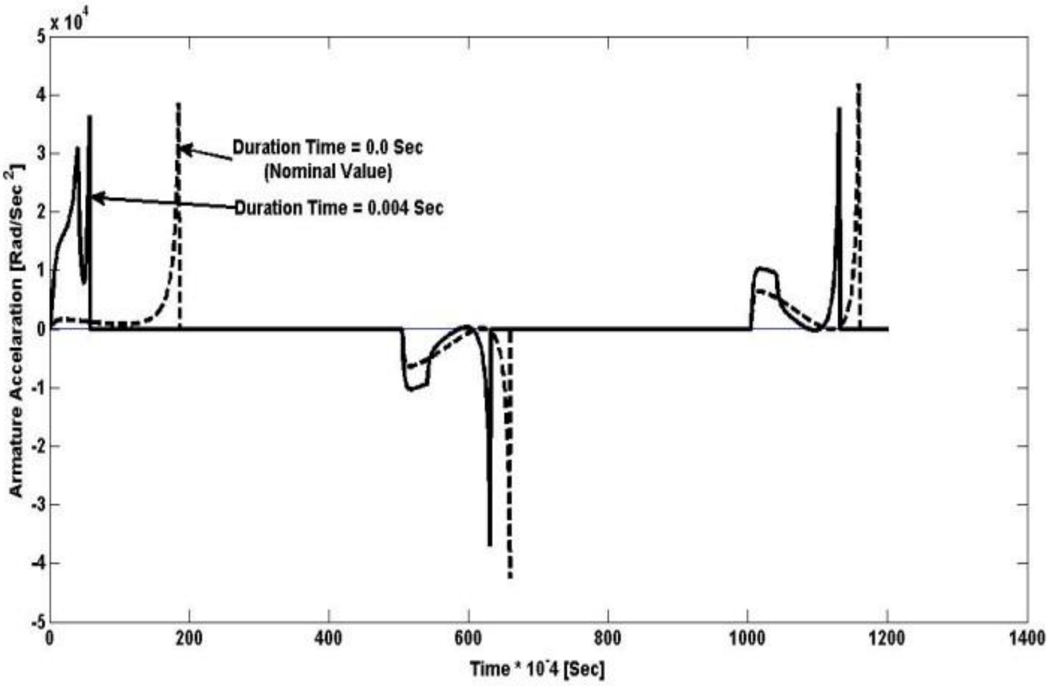

Fig.(21) Armature Accelerations ᾰ

Table (1) shows some important result for deferent pulse deformation pulse of 30 volt amplitude.

Table (1) some important parameter values with deformation duration time Ʈ

Pulse Deformation Duration Ʈ [mSec]	ά max [Rad/Sec]	ᾰ max 10^4 [Rad/Sec^2]	Energy For periodic time [Joules]	Energy Difference [Joule]	Transit Time [mSec]	Decrease in Transit Time [mSec]	Difference in Transit Steps [mSec]
00	51.40	4.355	0.396	0.0000	12.8	0.0	0.0
01	52.60	4.455	0.441	0.0450	12.4	0.4	0.4
02	68.70	4.170	0.505	0.1090	11.7	1.1	0.7
03	70.03	4.154	0.569	0.1730	11.1	1.7	0.7
04	72.30	4.053	0.633	0.2390	10.3	2.5	0.8
05	74.36	3.508	0.697	0.3010	09.3	3.5	1.0
06	80.56	3.663	0.761	0.3650	09.0	3.8	0.6
07	89.90	3.402	0.825	0.4290	08.5	4.3	0.5
08	112.00	4.500	0.889	0.4930	08.2	4.5	0.5
09	169.40	13.30	0.953	0.5570	07.7	5.0	0.5
10	187.00	25.10	1.017	0.6210	07.7	5.0	0.0

Fig.(22) show the behavior of maximum armature angular (άmax.) and maximum armature angular (ᾰmax.) values(with pulse deformation duration. Really the (ᾰmax.) didn't say much about the system. It seen that (άmax.) increases with (Ʈ). Fig.(23) show that the energy and energy increment increasers with (Ʈ) by a significant value.

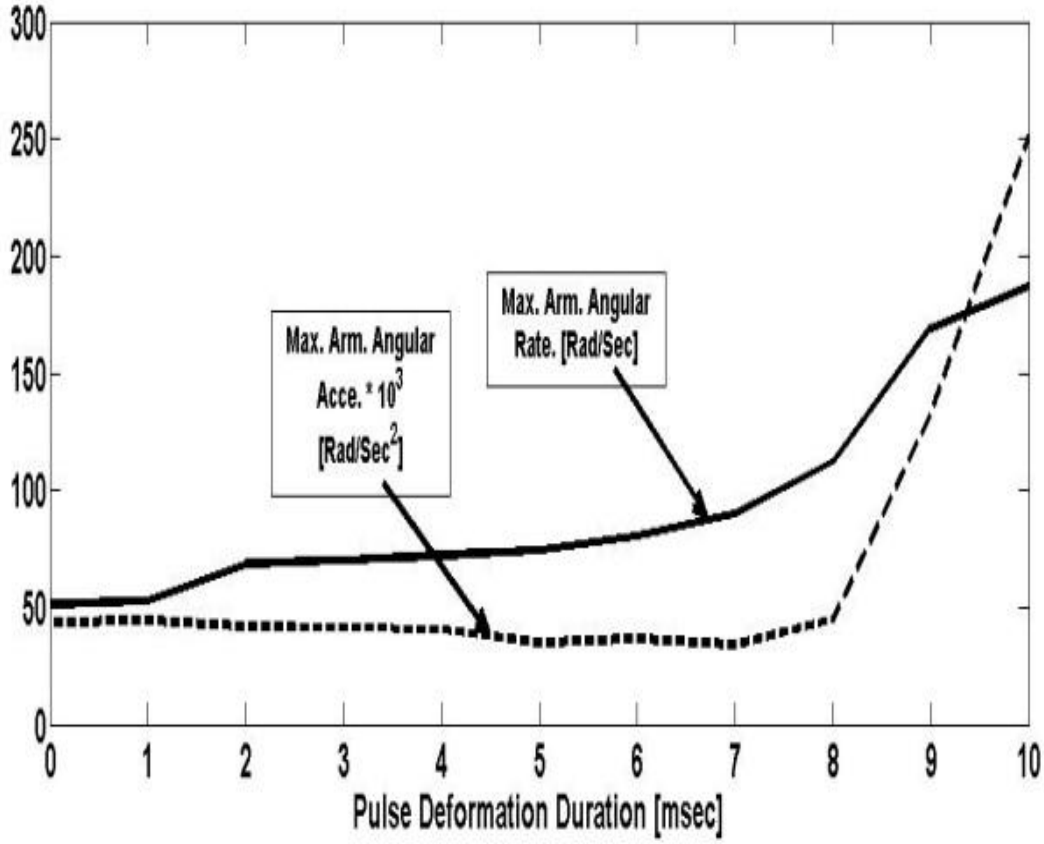

Fig.(22) άmax and ᾰmax behavior

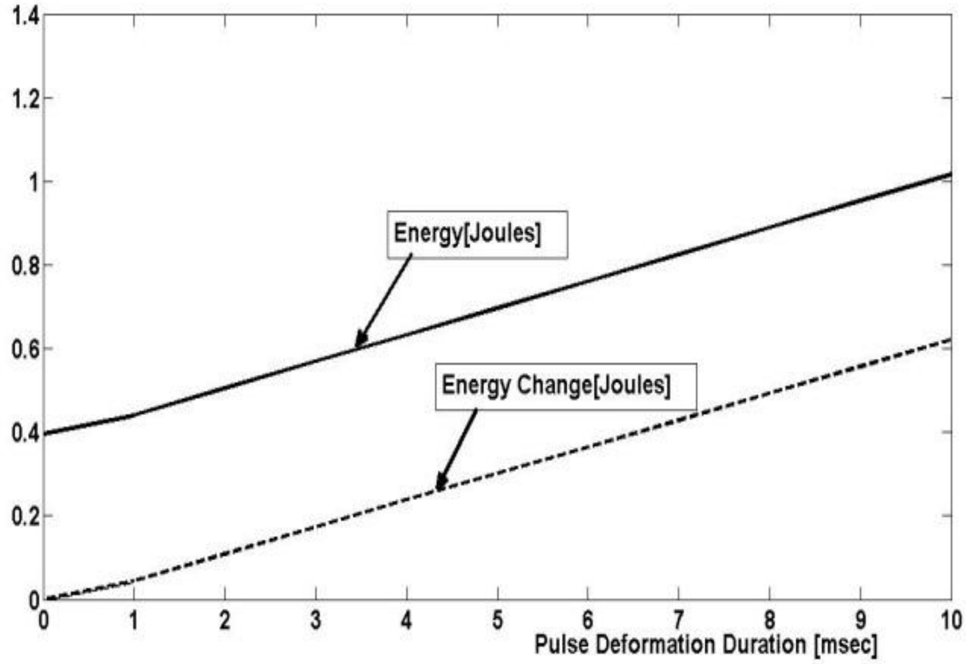

Fig.(23) Energy and it's increment behavior

Fig.(24) show the transit time, time decrement and the decrement transit time between steps of changing (Ʈ). It is seen that the best effective value for (Ʈ) is between 3msec to 6msec.

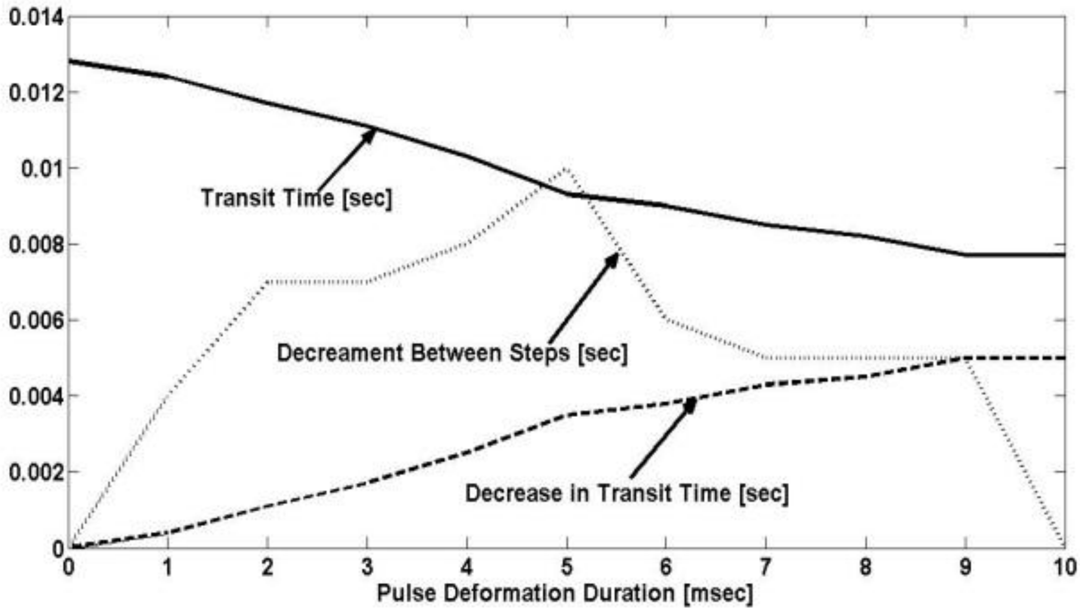

Fig.(24) Transit time behavior

It is seen that this way is very effective to shorten the rise and response time of the armature angular motion. The pulse deformation of one millisecond is effective as that of the PID compensator. The deformation of 5msec resulted in about 3.5msec shortening in time response.

Conclusion

- Two technics have been used to improve the response of the motion of the mechanical armature angular motion. First is the compensating the input electric drive voltages. Second is the deformation of the input driving current.
- Results show that the second technique is more effective and flexible in selecting the quantity of deformation in input voltage.
- There is an increase in the maximum output angular rates and increase in the input despaired power. These problems should be mitigated as a future work.
- Results show that the second method of using multi-level voltages is more effective than the PID method. PID method give about 6% improvement in starting and rising times while the multi-level voltage method give about 20% improvement in starting and rising time. There for 2^{nd} method is recommended to be used.
- Results show that the best time of duration to be used in the 2^{nd} method is between 3 to 6 msec.
- The disadvantage of the second method is the increase in power consumption for example when using 3 msec duration and 30 V input, the increase in power is about 50%.

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