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Simulation and Development of Stepper Motor for Badminton Playing Robot

Rupesh Borkar[1], Tanveer Aga[2]
[1]*Electrical Department, Govt. College of Engineering, Aurangabad, MH, India*
[2]*Mechanical Department, Govt. College of Engineering, Aurangabad, MH, India*

ABSTRACT: *The development of digital electronics and microprocessor systems has the advantage to the development of electric motor capable to be digitally controlled. In this paper stepper motor is used to control position of the shuttle disc. When the shuttle is release at the same time racket hits for servicing. The simulation and hardware has been developed and it shows the variation of stepper motor parameters for no load and for rated load using Matlab Simulink.*
Keywords:*stepper motor, bipolar drive, shuttle disc.*

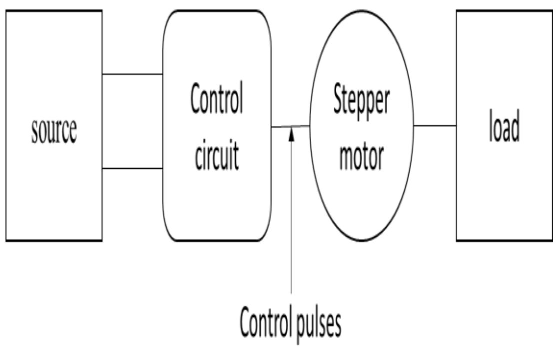
I. Introduction

The stepper motor has a wide popularity in the digitally control system means with changing the input pulses the position of the rotor can be controlled. Stepper motor widely used in numerical control of machine tools, tape drives, floppy disk drives, printers, robotics, X-Y plotters, textile industry, integrated circuit fabrication, electric watches etc. In badminton playing robot introduction of stepper motor is very important and becomes easy to move shuttle loaded disc at the desired position within a specified interval and vibration free. This operation will be automatic or manually as per the requirement. Application of simulation packages has considerably improved electrical machines analysis replacing the expensive laboratory equipment and enabling performing of different experiments easy and with no cost.

As the stepper motor exhibits advantages like open loop capability, high torque density and lower cost with respect to other brushless servo alternatives. Hence to satisfy complex requirement regarding motor torque, speed and angular displacement. The stepper motor is suitable to fulfil the requirement as we need with a reliable and cheap control circuit. In this way chapter II will explains system description, III is simulation of stepper motor for rated load and no load using Matlab Simulink library, IV hardware implementation.

II. System Description

The system we are using can be represented by following block diagram as shown in figure.1. It consist of dc supply batteries are rated of 12V, 24V, 48V and may be higher as per the requirement, control or drive circuit to control the pulses, stepper motor and load. Load will be the angular movement of an object or translational. Control circuit is consisting of semiconductor switches and hysteresis comparator to achieve the sequential energization and de-energization of the phase winding.



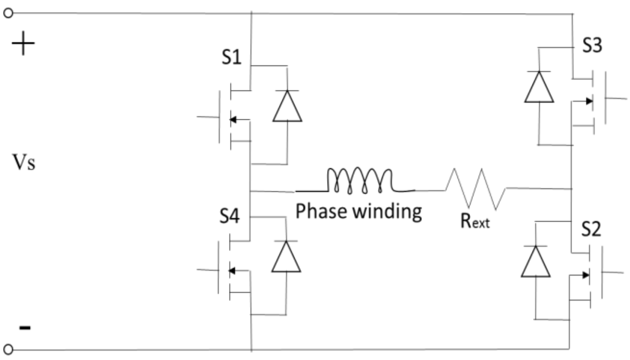


Fig.1 Block diagram of the systemFig.2 One phase of a Bi-polar drive circuit for hybrid stepper motor

1. Stepper Motor

The stepper motor is an electromechanical converter that converts convert pulses applied to the motor phases during a rotation. These control pulses consist of discrete angular displacements of equal size, and they represent the step of the motor. The angle by which the rotor of the stepper motor moves when one pulse is applied to the input (stator) is called step angle. To achieve a smoother movement of rotor, we have to increase the resolution or step number of a motor. Higher the resolution, greater the accuracy of the positioning of objects by the motor. In stepper motor step angle can be achieve up to 0.36^o, it will have 1000 steps in one revolution and greater resolution. Small step angles obtained by the use of slotted pole pieces to increase the number of effective saliencies (now referred to as teeth) together with multistack assemblies. Basically there are three most popular types of rotor arrangements

- Variable reluctance (VR) type
- Permanent magnet (PM) type
- Hybrid type, a combination of VR & PM

A variable reluctance stepper motor is based on the property of flux lines to occupy low reluctance path. The stator and rotor therefore get aligned such that the magnetic reluctance is minimum. The variable reluctance stepper motor will be a single stack and multi stack type. Single stack type has the advantage of high torque to inertia ratio. The reduced inertia enables the VR motor to accelerate the load faster.

Permanent magnet stepper motor are similar in construction but the rotor consist of permanent magnet poles made of high retentivity steel. There feature of PM stepper motor is higher inertia & therefore lower acceleration than VR stepper motor.

Hybrid stepper motor combines the features of VR & PM stepper motor, an axial permanent magnet is provided in the middle of the rotor. It is operating due to the electronically commutated magnetic field which enables the rotor movement. Electrical windings are placed on stator while rotor is made of permanent magnet. The major advantage of the hybrid stepper motor is that if the motor excitation is removed, the rotor remains locked due to the dent torque produced by the permanent magnet.

2. Drive Circuit

It response to each individual control pulse and direction signal, the control circuit applies power to the motor windings to cause the rotor to take step forward, a step in reverse, or lock in position. Consider motor has two phases, when both the phases are energised with the DC current, the motor will stop rotating and hold in position. In this case maximum motor torque is equal to holding torque. If the current in one phase is reversed, the motor will have a one step in known direction and if the current in other phase had been reversed, the motor would move one step in the other direction. As illustrated in figure.2 each phase winding of the motor is controlled by drive circuit with MOSFET as its controllable power switch. Each two MOSFET switch of each phase winding are turned ON simultaneously as per position and direction required. The bipolar circuit has the features are high efficiency, fast decaying of freewheeling current, no freewheeling resistance, expensive etc.

3. Mathematical Modeling

For hybrid stepper motor the equivalent circuit for one phase is shown in fig.3

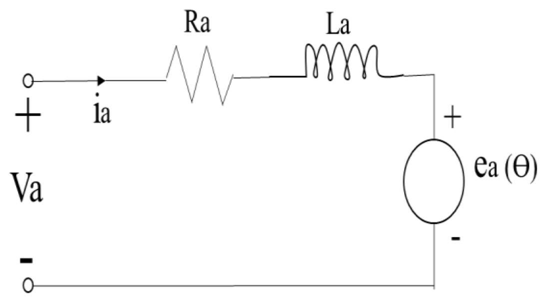


Fig.3 Equivalent circuit of one phase of hybrid stepper motor

Where, Ra and La are resistance and inductance of A-phase winding. The phase voltage equation is given by equation (1) where, XL is the Inductive reactance and ia is the phase current.

$$Va = (Ra + X_L)i_a - e_a(\theta) \quad \ldots \ldots (1)$$

The voltage source e_a (Θ) represents the motor back E.M.F.electromotive force) which is a sinusoidal function of the rotor position:

$$e_a(\theta) = -p\Psi \sin(p\theta)\frac{d\theta}{dt} \quad \ldots \ldots (2)$$

Where, p is the number of pole pairs and **Ψ**m is the motor maximum magnetic flux. If Θ=0, the North Pole on the rotor is fully aligned with A-axis pole so that the A-phase back E.M.F. is then zero. The electromagnetic torque produced by hybrid stepper motor is equal to the sum of the torque resulting from the interaction of the phase currents and magnetic fluxes created by the magnets and the detent torque, which results from the saliency of the rotor.

$$T_e = -p\Psi_m i_a \sin(p\theta) - p\Psi_m i_b \sin\left(p\theta - \frac{\pi}{2}\right) - Td_m \sin(2p\theta) \ldots\ldots (3)$$

From above equations the phase current, electromagnetic torque, rotor speed, rotor angle for the values maximum magnetic flux **Ψ**m=0.05 wb, detent torque Td_m =0.008 N-m, number of pole pairs p=50 and Ra=8ohm.

III. Simulation And Results

The Simulink model of the hybrid stepper motor drive system from Simulink demo library is presented in fig.4. It is consisted of two sections: electrical and mechanical. According to Simulink model motor input parameters are: phase voltage (A^+, A^-, B^+ and B^-) and mechanical load T_L. Output parameters from motor model are: phase current Iph, electromagnetic torque Te, rotor speed w_m and rotor position theta.

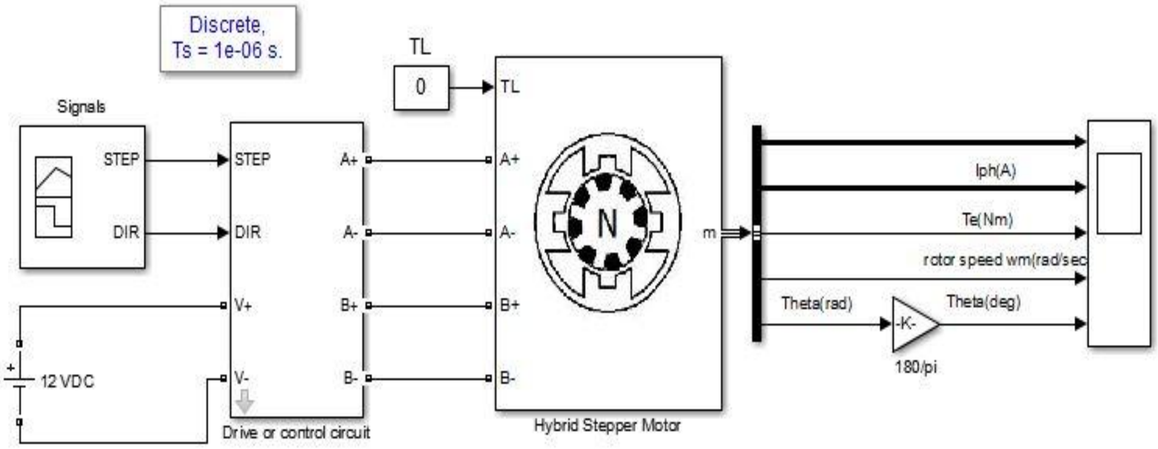


Fig.4 Simulink model of the hybrid stepper motor

Drive or control circuit is consisted of three functional block are control block, hysteresis comparator and MOSFET PWM converter (fig.5). Motor movement is controlled by two signals STEP and DIR which are output signals from signals from the signal builder block as shown in fig.6. Positive value means '1' of step signal enables motor rotation and '0' stops the rotation. DIR signal controls the direction of rotation value '1' enables one direction and '0' enables the direction opposite to that of '1'.

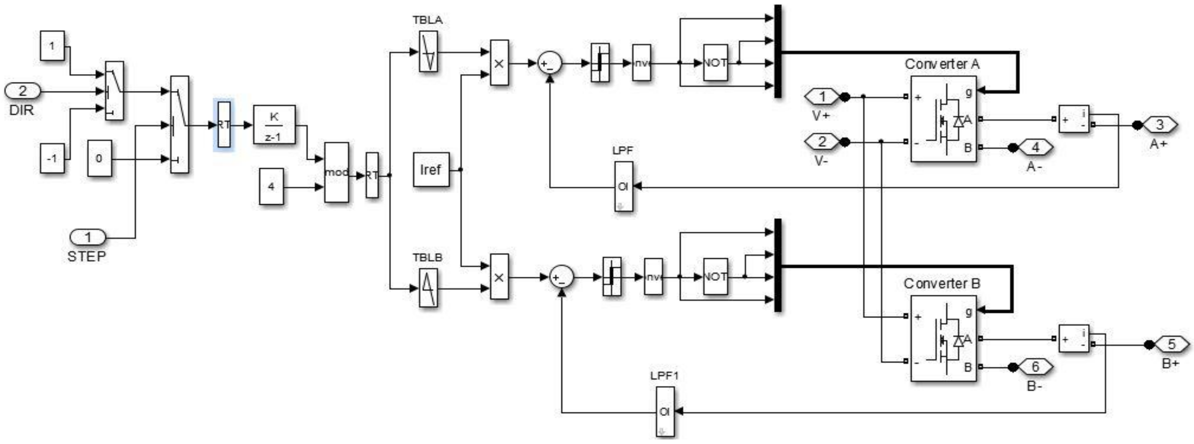


Fig.5 Simulink model of drive circuit

Converter 'A' and 'B' are consist of for MOSFET 'H' bridge configuration. Bridges are supplied by 12V dc and their outputs supply the motor windings with the excitation current and moves the rotor. We have simulated the Simulink model for no-load and for load 0.1 N-m to reach the position of 0^o to 54^o with a speed of 200 (rad/sec) within a 0.15 sec as shown in fig.7&8 respectively.

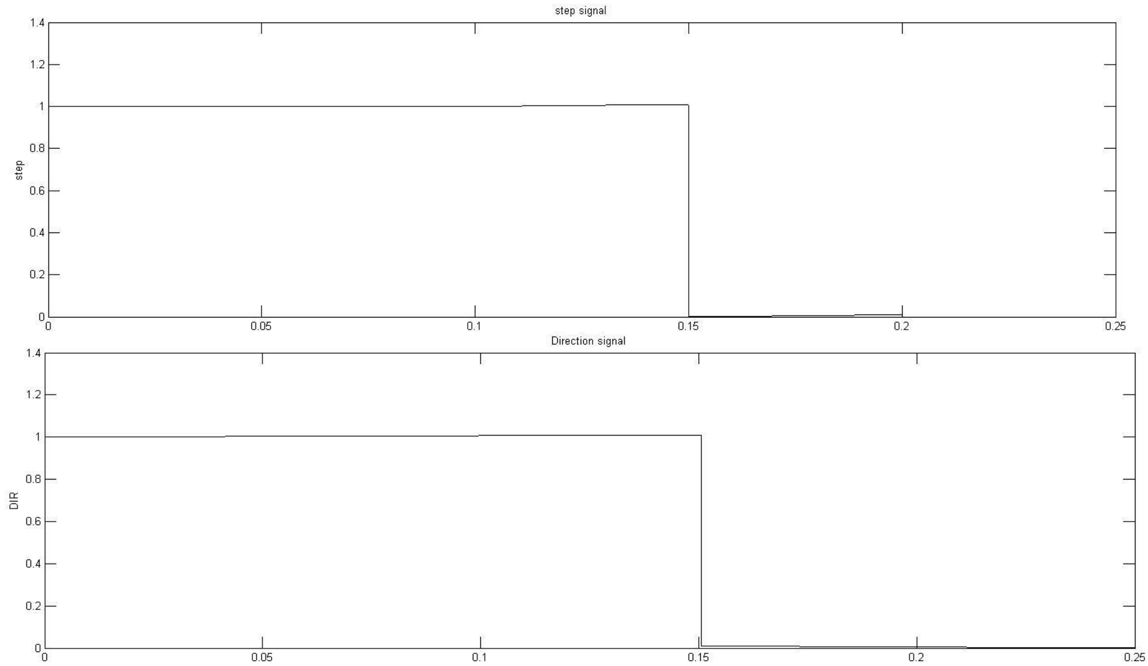
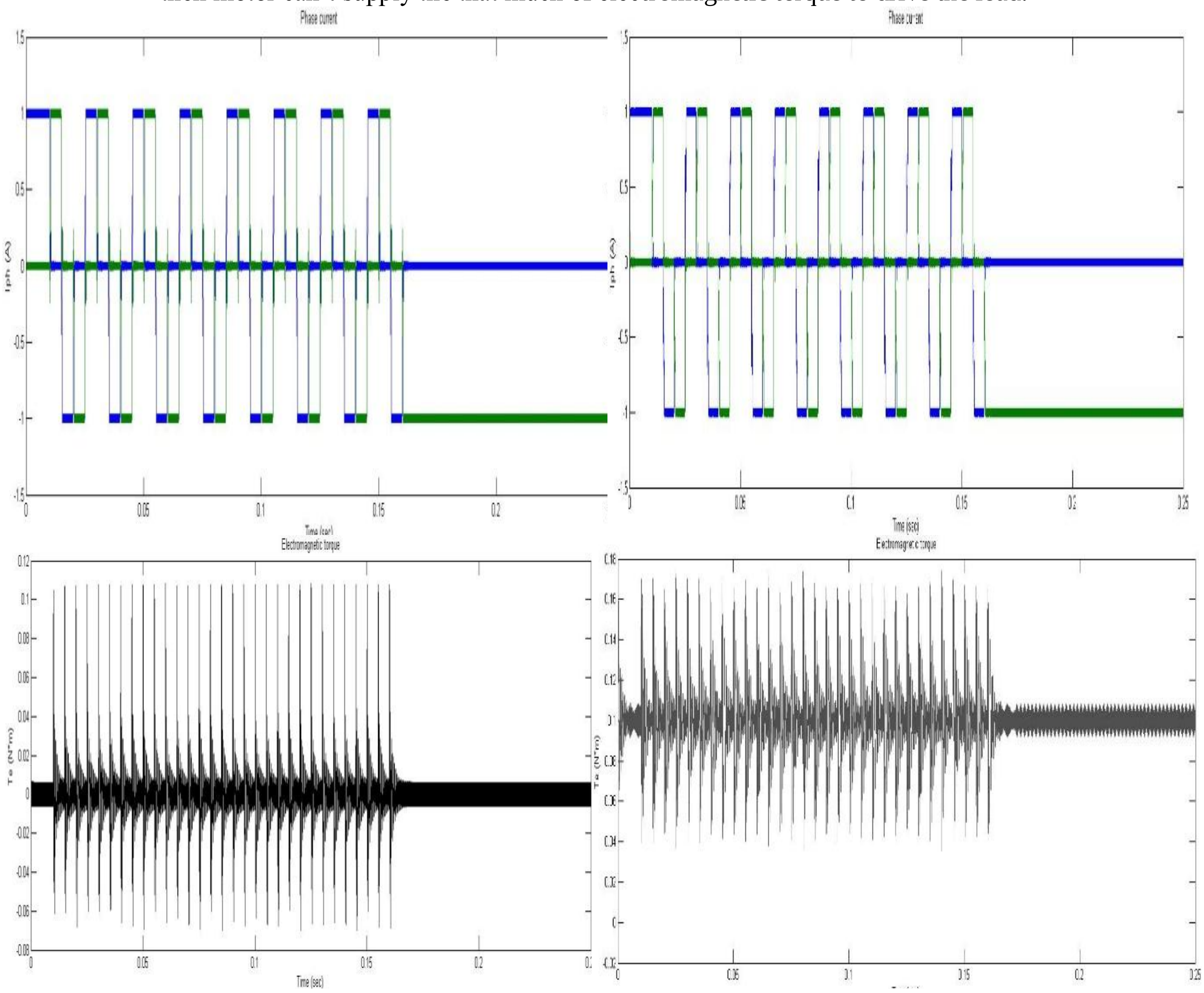
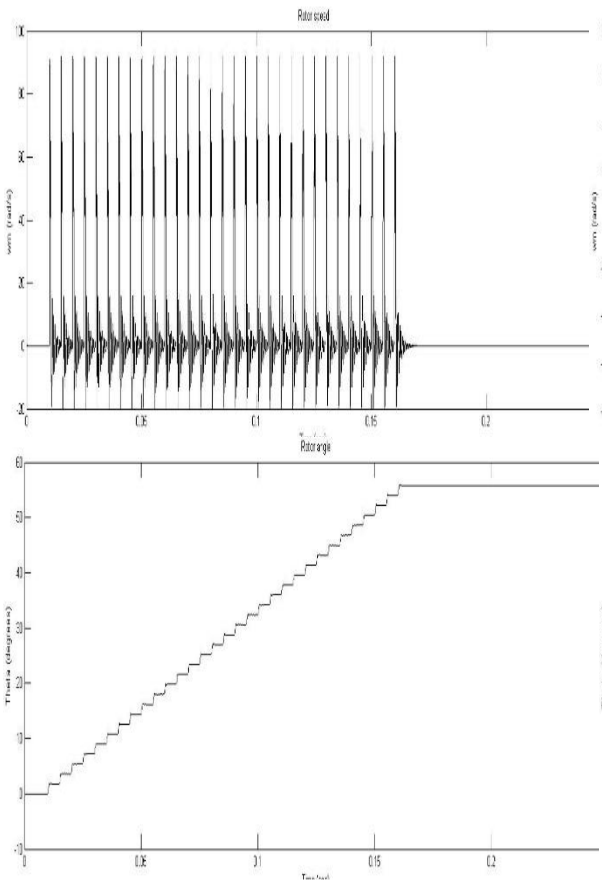


Fig.6Signals of STEP and DIR from signal builder block

After achieving a 54^o position of the rotor there is a hold position of the rotor. From the results we can say that electromagnetic torque is near to 0.1 N-m in order to drive the load torque, if there is a increment of load torque then motor can't supply the that much of electromagnetic torque to drive the load.





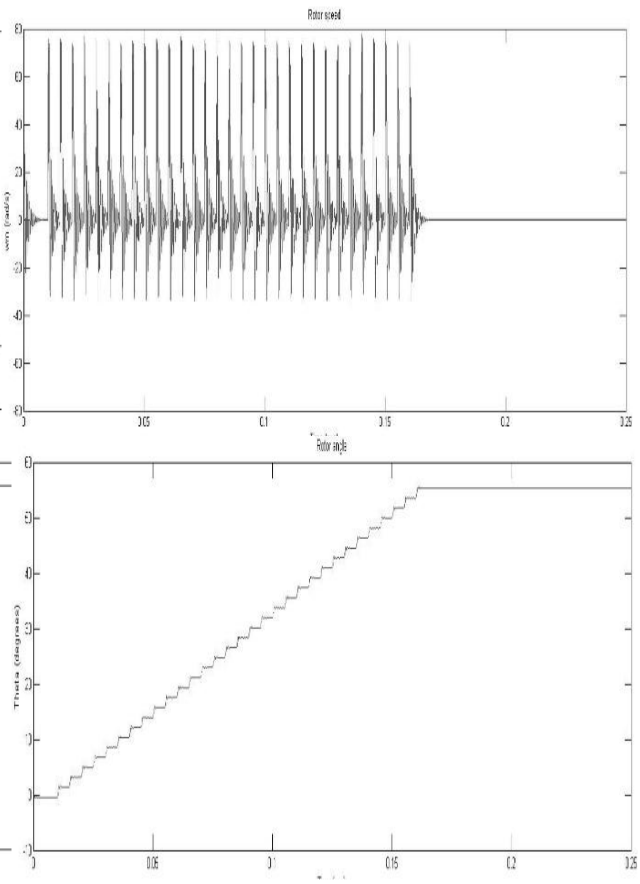


Fig.7 Motor transient performance at no-loadFig.8 Motor transient performance for load 0.1 N-m

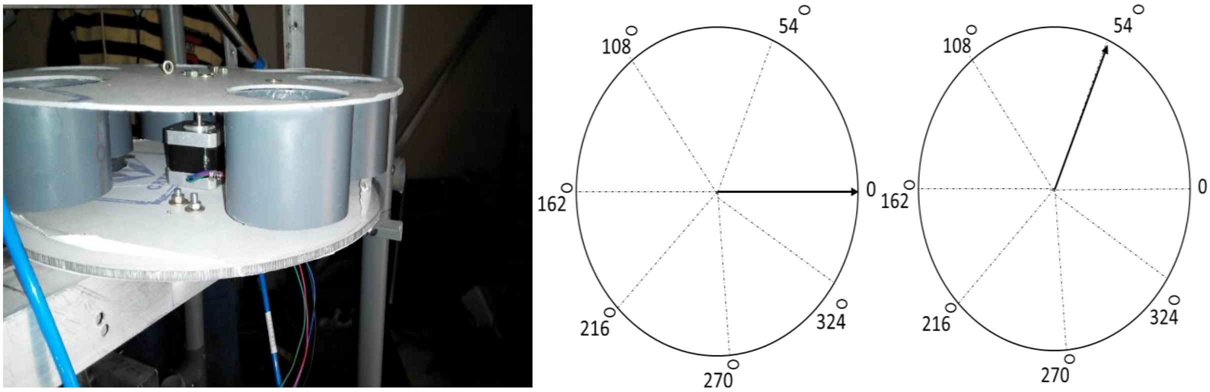
From the simulation and mathematical analysis the motor parameters for no-load and for load 0.1 N-m is shown table.1 for the values maximum magnetic flux **Ψ**m=0.05 wb, detent torque Td_m =0.008 N-m, number of pole pairs p=50 and Ra=8ohm. From the simulation and actual test result the error for the particular angle achievement is at load 0.1N-m is 0.10%.

Table.1 Analysis results of simulation and mathematical modeling

Motor Parameters	Simulation Analysis		Mathematical Analysis		Test set up analysis	
	For No-load	For 0.1 N-m load	For No-load	For 0.1 N-m load	For No-load	For 0.1 N-m load
Phase current Iph(A)	1	1.1	1.04	0.829	1	0.98
Electromagnetic torque Te (N-m)	0.1027	0.17	0.1027	0.1027	0.1027	0.99
Rotor speed wm(rad/sec)	92	90	94	92	91	89.5
Rotor angle ϴ (degree)	54	53.995	54	54	54	53.985

IV. Hardware Implementation

Fig.9 (a) shows the arrangement of shuttle disc drive system rotated by stepper motor. The upper disc is shuttle disc attached to the stepper motor of type 17HA0403-32N, W01205 44 MOONS. Lower disc is fixed with having one hole to drop down the shuttle when servicing by racket is desired. The upper disc move with a 54^o on the lower disc.Actually hole of the lower disc in closed position when servicing is done and if there is a foul in game then this closed position is opened with pneumatic cylinder connected to it. The micro-stepping drive is used to control the pulses of motor is RMCS-1102 V2.0 with enable and has the features like smooth and quiet operation, input supply voltage from 12VDC to 50VDC and peak current 0.5A to 5A. We select the speed 200 steps/rev for the movement of rotor from 0^o to 54^o.As shown in fig.9 (b&c) the thick arrow line indicates the moving position of shuttle disc. At standstill position six shuttles are loaded in the upper disc and if foul in game, the racket mechanism is actuating and shuttle drop down though a movement of 54^o of the rotor for servicing.



a) b) c)

Fig.9 Shuttle disc position: a) Shuttle disc arrangement using hybrid stepper motor b) at standstill and c) when one control pulse is applied

For supplying the drive circuit we used lithium polymer battery of 11.1V, 5000mAh 22C. In this way we carried out the rotation of shuttle disc with a slight deficiency in the angle of 0.02 degree when the shuttles are loaded.

V. Conclusion

In this paper analysis of transient performance of hybrid stepper motor for no-load and rated load is carried out. Simulation results proved that the motor is running in forward, backward direction and hold on position according to the applied signals from PWM converter to the excitation windings and only in case when the applied load is smaller than motor electromagnetic torque. With the advantage of hybrid stepper motor the performance of hardware is improved with a deficiency of 0.02 degree when the shuttles are loaded.

REFERENCES

[1] Moussa Bendjedia, Youcef Ait-Amirat, *Member, IEEE*, Bernard Walther, and Alain Berthon, *Member, IEEE"Position Control of a Sensor less Stepper Motor"* IEEE Transactions On Power Electronics, Vol. 27, No. 2, February 2012

[2] N. Greenough, C.C. Kung *"A New High-Efficiency Stepper Motor Driver For Old Technology Stepper Motors"*978-1-4799-0171-5/13/$31.00 ©2013 IEEE

[3] Andrea Antonioli, Michele Antonioli,SandroCalligaro, Roberto Petrella*"A Low Cost Sensor less Drive for Hybrid Stepper Motors Based on Back-EMF Observer and d-Axis Current Injection for Industrial Labelling Machines"*978-1-4799-2325-0/14/$31.00 2014 IEEE

[4] GhineaMihalache, AvramCezara, DobrescuTiberiu, Balan Emilia *"The Simulation of The Stepper Motor With Variable Reluctance By Matlab-Simulink"* Recent Advances in Robotics, Aeronautical and Mechanical Engineering

[5] VasilijaSarac,Slobodan Pesic "*Application of Matlab/Simulink in hybrid stepper motor modeling*" Faculty of Mathematics & Natural Science – FMNS 2013

[6] Ashfaq Husain "*Electric Machines*" book, Second Edition, Dhanpatrai Co. (Pvt.) Ltd.