

A Brief Analysis of Torque Ripple Formation In Different Motor Drives And Minimizing Strategies

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Abstract

High precision electric drives must have high efficiency, high robustness, high torque profile, high integration, precise performance and especially stable running. This Paper mainly focus on the various factors affecting the regularized torque characteristics of various drive and the predominant method to overcome the ethical dilemma. If a machine is indulged in Precise work, the operation of drive must be highly sensitive with null error. In this paper a keen knowledge on operation and drawbacks of different drives, if drawback persists on machine list of various methodology to be implemented and finding out a feasible easy method to overcome the drawback. Cogging torque, back emf due to non-uniform magnetic distribution, Slot Harmonics, manufacturing imperfection are some of the factors influencing torque disturbance in drive and this periodic torque variation arises results in Torque ripple. Torque ripple causes major flaws imperfection in Performance of machine so it must be mitigated with suitable control strategy technique. This Paper clearly give a brief knowledge of selecting suitable technique for mitigation of Torque ripple to an acceptable level of smooth functioning of drive.

Keywords: Precision electric drives, torque ripple, cogging torque, back EMF, slot harmonics, control strategies, torque disturbance, drive performance, magnetic non-uniformity, stable operation.

Introduction

Torque ripple in PMSM (Permanent Magnet Synchronous Motor)

PMSM is featured with compact design, high power density, high efficiency due to its three-phase static stator design incorporates slotted lamination core winded with sinusoidal winding to lessen the eddy current loss and a rare earth permanent magnet rotor with constant magnetic field without excitation current correspondingly eliminates copper loss. For commutation process an electronic inverter is required to control stator winding current.

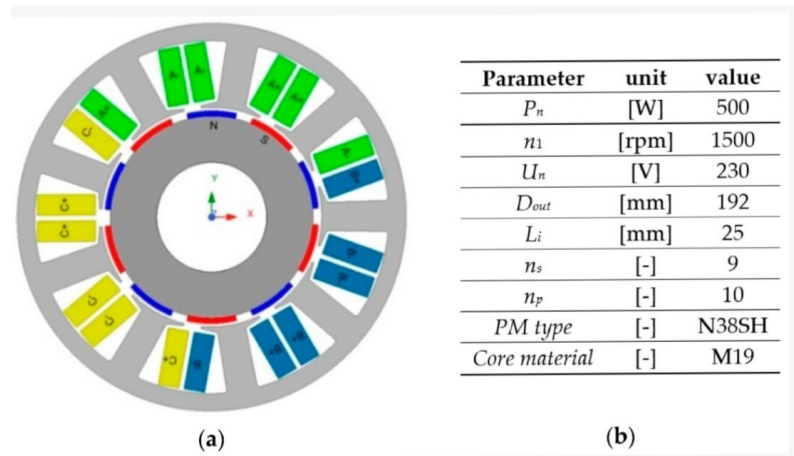


Fig.1 a. Structure of PMSM

b. Basic Parameters of PMSM

PMSM drive mainly deals with microelectronic works, a minor disturbance will affect performance of machine up to high extent, the minor disturbance is meant as cogging torque which in turn is framed as torque ripple. Torque ripple in drive causes vibration and strange sound, increase machine temperature, attrition in drive components these factors will affect the machine performance so the ripple produced must be mitigated for better functionality of machine drive.

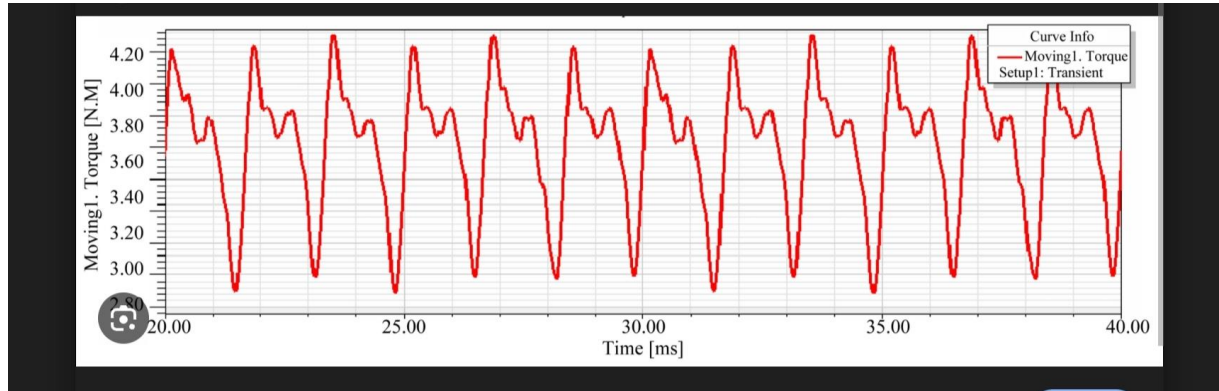


Fig. 2 Curve representation of Torque ripple Vs Time

Torque ripple is a highly considerable factor affecting the functionality of drive, on analyzing the factors that are responsible for generation of ripple content are electromagnetic flux irregularity and lag in neutralizing back emf. The previously said problems are mitigated by two common strategies first, feasibly changing the field energizing switching characteristics of poles and the second, by skewing the physical pole structure optimization, thereby the air gap gets altered and in turn reduces the cogging torque. Torque ripple mitigation converts the drive into an effective PMSM machine for precise sensitive applications.

Torque ripple in BLDC Motor

Brush Less Direct current motor is a stationary elementary stator structure that includes laminated sheet core coil wounded in a three-phase configuration, the coil is energized to generate a magnetic field that drives the permanent magnet rotor. This drive eliminating brushes since the coil are not connected to rotor, no rotating coil condition no brushes or commutator needed. Commutation is done by electronic switching and usage of suitable sensor. Sensor identifies the initial position of rotor and play a key role in electronic switching task to energize the stator slot for the subsequent rotation of rotor.

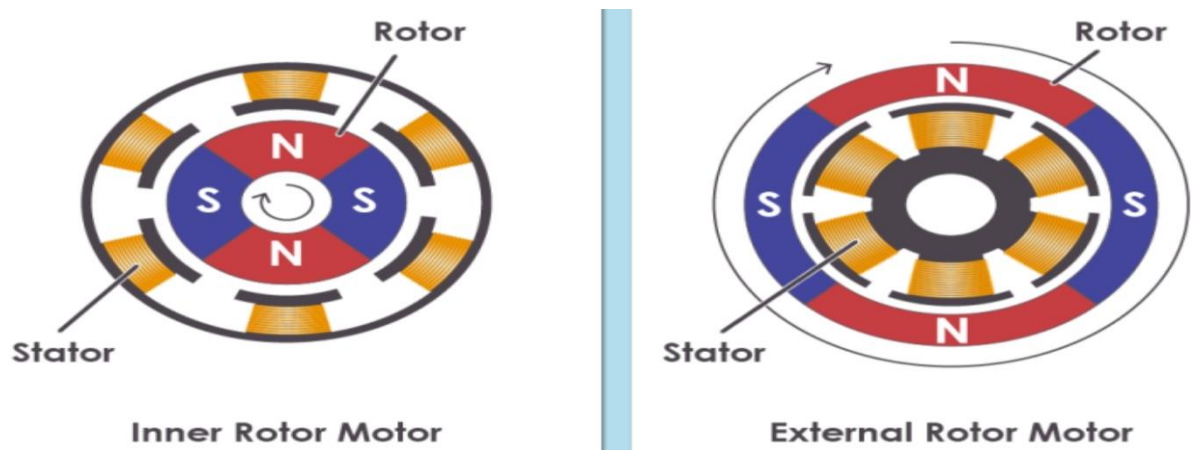


Fig.3 Schematic diagram of BLDC inner rotor and External rotor structured motor

BLDC motor are widely used in soft reacting sensitive electric applications such as EVs, computer accessories like hard disc drive, cooling fan and cd drives, customer usage devices like air conditioner, washing machine industrial applications like CNC, robots, drones and especially in medical equipment. High torque ratio and stable smooth running of the drive are significantly needed for BLDC motor drive to run as high proficiency machine drive. The working of BLDC motor is established by a suitable energy switching device and a fast-acting sensor to know the position of rotor. Even though a levelheaded switching device and multiple coil charging technique for energizing the coil are used still it possess an improper magnetic field variation between the air gap of stator and rotor during commutation process.

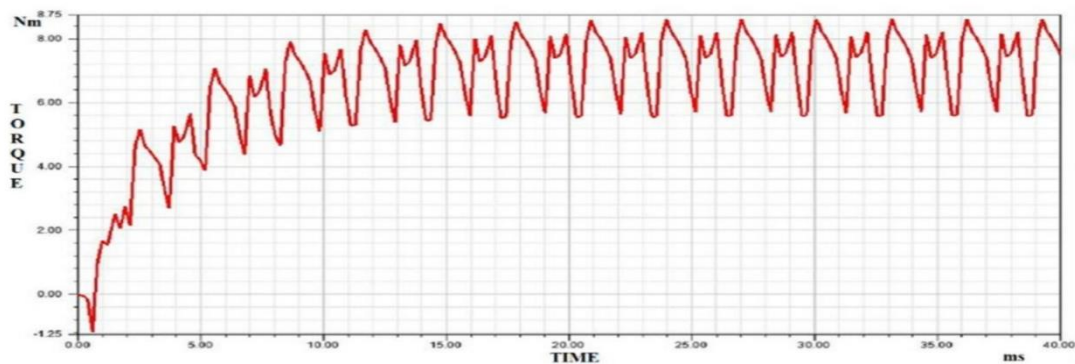


Fig. 4 characteristic curve of torque ripple Vs Time in BLDC motor

Torque ripple in Stepper motor

Stepper motor constitute of an immobilized stator with field electromagnetic winding and soft steel permanent magnet toothed rotor, which converts electrical pulses in to pinpoint discrete mechanical movement. The movement is purely fixed steps without position encoding sensors in turns reducing the complexity of the machine if a stator coil is energized sequentially the motor will rotate from the position firmly when stopped.

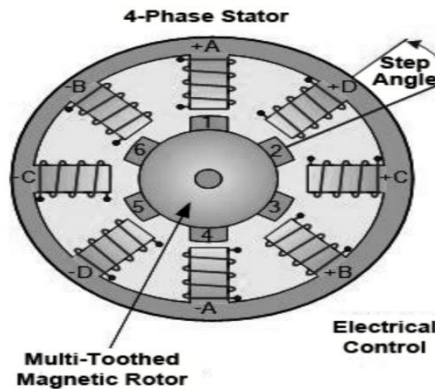


Fig.5 Cross sectional diagram of stepper motor drive

Stepper motor drive predominantly used where the accuracy matters such as industrial robots, 3D printers, CNC machines, camera platforms and different fields where high torque, closed loop applications and application where precise dynamic control required more than raw speed. Stepper motor drive is practiced in meticulous dynamic close loop sensitive applications since the performance of the drive must highly stable, but due to non-sinusoidal magnetic flux imperfection occurs between stator and rotor leads to the rise of 20 times the torque value which makes the machine to vibrate and switching delays results in creation of cogging torque.

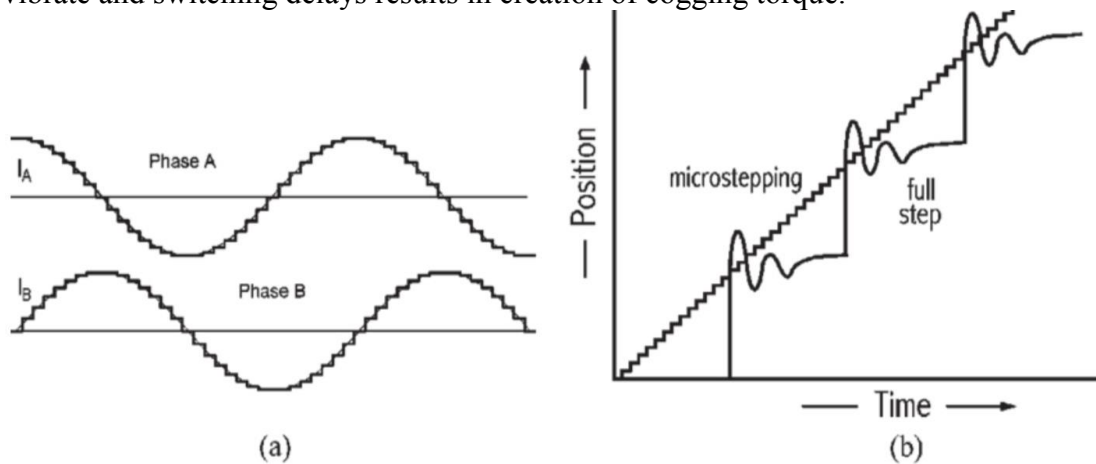


Fig.6 a. Current waveform (micro stepping) b. Ripple produced by unbalanced torque

The disturbance created in torque leads to torque ripple with noise, vibration and geometric attrition in machine components. For normal machine this torque disturbance is considered to be negligible, it doesn't affect the performance of drive but sensitive running machine like stepper motor this disturbance can't be neglected, it affects the effectiveness of machine. Stepper motor is a high-profile meticulous running machine, so torque ripple occurred must be reduced by implementing efficacious switching strategy and skewing machine structure thereby altering air gap between rotor and stator for mitigating non sinusoidal magnetic flux which in turn reduces the ripple component in torque.

Torque ripple in SERVO MOTOR

Servo motor is a special Machine that performs a vital role in Industrial applications and robotics. The drive exhibits smooth performance, controllability and unique characteristics that makes the machine a net worthy drive. Servo motor is a closed loop high precision actuator with gear system, position Sensor and Control circuit The feedback Signal is compared with the actual input signal chosen and work accordingly, the drive has a high accuracy Sensor to intimate the position of rotor, the speed of motor can be regulated using gear arrangement and control circuit manages the rotation of drive. Drive has a capability of error deletion by associating the actual position from feedback signal and desired position, if error Persists the drive rotates to the position rotor shaft where there is null error. The Presence of closed loop system helps the drive to identify the error position and helps the machine rotates precise to the defined target.

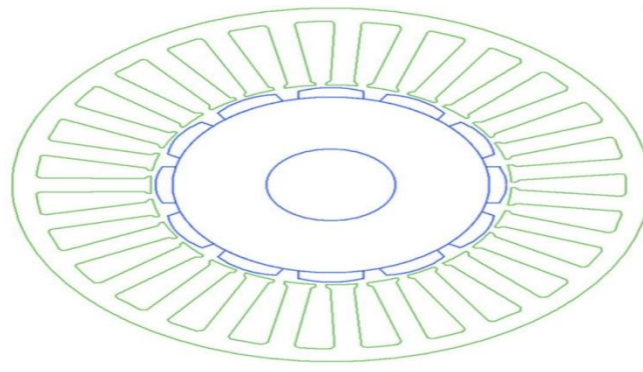


Fig. 7. Design of Servo motor drive

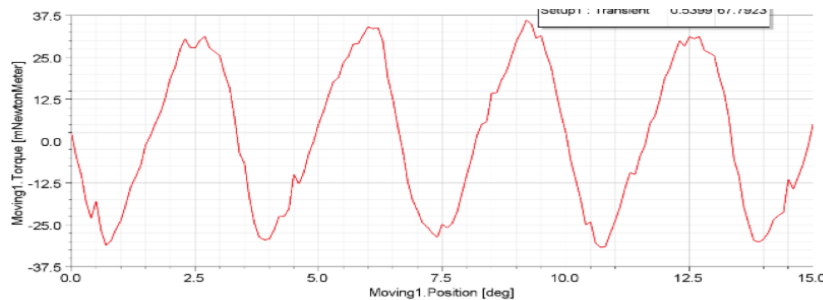


Fig. 8. Torque ripple curve of servo motor

Servo motor exhibits a Permanent magnet rotor that has its own distinctive property of creating cogging torque due to non-sinusoidal magnetic flux developed in air gap between rotor and stator. The formation of cogging torque and irregular magnetic flux disturbs the Linear torque characteristics of the drive which in turn disturb the torque profile, that consecutively generates torque ripple. Torque ripple formation will distract the preceptive function of machine, so for the sensible machine-like Servo motor the disturbance caused due to torque ripple cannot be derelict. The ripple in torque must be attenuated by changing the switching characteristic sequence of drive or by altering the structure of machine.

Torque ripple in Switched reluctance motor

SRM has Salient pole Structured Stator with field windings and salient pole rotor fabricated from stack of Laminated Iron Sheets, the rotation principle based on variable reluctance and the rotor is free to rotate on minimum reluctance path. The qualities like rigid structure, robustness, simple design, durability and magnet free design permits the machine to be utilized for many Precise applications like Robotics, traction motor for electrical vehicles, mining equipment, industrial applications and the place where we require high speed instantaneous torque profile.

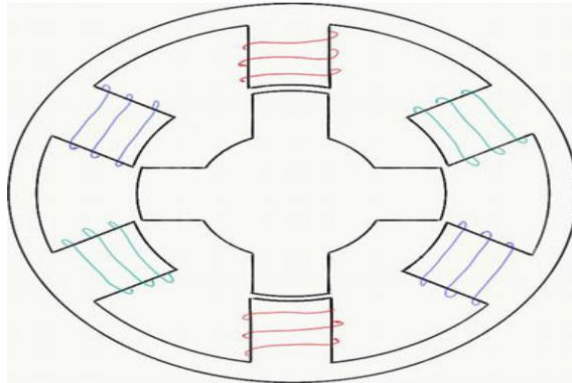


Fig. 9 Cross sectional view of 6 X 4 Stepper Motor

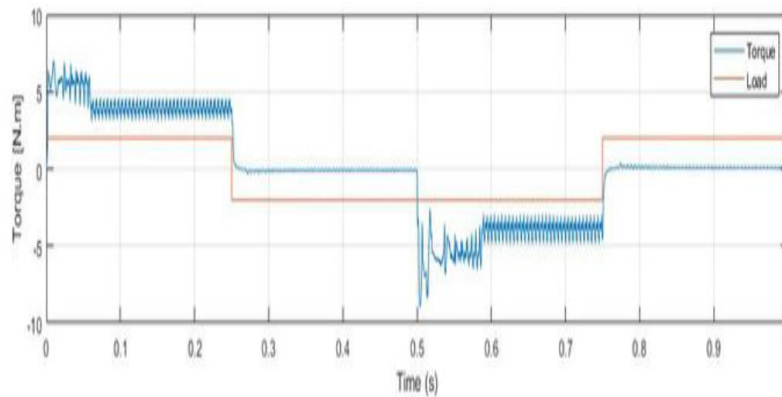


Fig. 10 Torque ripple characteristic curve with respect to time

The switching sequence of stator field is considered to be a valuable important reason for effective running of motor drive. Despite to its smooth running of SRM drive, there are some remarkable drawbacks appear on machine due to its irregular current Profile. When the stator pole is energized an electromagnetic field produced that tries to travel in minimum reluctance path i.e through rotor tends to align the position of rotor to low reluctance path and makes the drive rotate. The consecutive pole of Stator is energized, the previous field must be deenergized fully but due to residual magnetism there will be generation of back emf, which affects the rotor pole movement freely to next position this causes torque disturbance that in turn creates torque ripple. For a steady smooth-running application this torque disturbance will become a major issue and it must be clear off using proper Switching sequence or by altering the design Structure of drive.

Ripple control strategy:

Torque ripple is a crucial factor that hindering the performance of drive so torque ripple minimization is immensely need for steady and smooth operation of Machine. Mitigation of Torque ripple can be done in two ways: one is related to the electromagnetic structure refinement and the other one improving control strategy. Even though successful new researches were done to minimize the torque ripple based on structural design refinement such as skewing the rotor and stator, increasing the magnetic flux air gap, altering shape of rotor, changing pole curve shape gives fabulous outcome of Torque ripple mitigation. This geometric change can be carried out at the time of drive manufacturing, but will not be done when practicing a machine on application. Apart from design modification the most commonly used feasible method is digital Control technique such as field-oriented control, improved Commutation Technique, Predictive Control algorithm, Power electronic optimization, high resolution sensors can be applied as per the requirement and nature of machine and its hazard barrier. No hardware changes were implemented in digital control technique, the selection of different controller purely depends on ripple nature, producing factors, nature of machine and load handling. If a suitable controlled is applied to drive, then the performance will be immensely ripple reduced and the machine must be greater performance machine. Most commonly used control strategies are advanced direct instantaneous torque control system, Torque sharing functions, model predictive control, Sliding Mode control, Fuzzy and Neural based intelligent control, Average Torque control etc.

The choosing of switching techniques may vary with motor characteristics, region of application, control parameters, and nature of torque ripple.

Torque sharing function - maintaining standardized torque on phases by comparing with reference torque and avoid torque disturbance during commutation process.

Direct Instantaneous Torque control - an adaptive turn on angle control technique is followed to cut down the Peak torque arises during Commutation within a specified band width.

Model Predictive Controller - A mathematical calculations were priorly set to Predict the future torque behavior and torque variation was controlled by selecting

optimal. This MPC is widely used and found to be precise Control method in torque ripple minimization.

Field oriented Control / Vector Control - Selecting optional Stator field Current control technique to get a smooth torque characteristic align the current Vector of Stator to rotor field to get effective result than normal commercial control Technique.

Intelligent / adaptive Control - This Scheme uses neural network, fuzzy logic to control Current non linearity, speed control, Load control to avoid pulsation in torque production.

Optimization control Technique - with the reference of Drive characteristics offline and online calculations are made on current profiles to obtain torque optimization.

Controller techniques

Torque sharing function-based controller is effective when the controller receives an accurate data on Various values of nonlinear Magnetic characteristics which are responsible for torque disturbance of the Machine and it is widely used in non-magnetic rotor drives. Direct Instantaneous Torque Control technique provides high Switching frequency at the time of commutation. This high Switching frequency gives a transient response in smaller machines but for turbo machines this controller delivers higher Losses and less efficiency. In Model predictive Control method, the design of controller requires a huge rate of prior analyzed data on different Stage of operation in machine. This controller technique can be used only for Constantly operating machineries if there is any change on Load user has to modify the Controller design again by making the prior Calculations. Intelligent and adaptive type of controller practices to follow fuzzy logic, neural network and reinforced Learning methodology for computing the values to handle nonlinear complex complications arisen in drive.

Conclusion

Power electronics controllers are widely use to mitigate the torque ripple value to a greater extent. Even though structural skewing gives an appropriate Torque ripple reduction, the drive structure has to be modified at the stage of manufacturing and it is difficult while employed in applications. Structurally altered drives are used only for the specified process. It is resolved that implementation of correctly designed controller for torque ripple mitigation is a better method for devolving the drive-in various applications.

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