

## TO STUDY RECENT ADVANCES IN PERMANENT MAGNET BRUSHLESS DC MOTORS

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### ABSTRACT

This paper deals with the latest developments in Permanent Magnet Brushless DC (PMBLDC) motor drives. A comprehensive account of the state-of-the-art on types of construction of the motor, closed loop controllers in position, speed and current/torque control and recent trends in inverters, sensors etc. are given. Techniques for mechanical sensors elimination are discussed in detail. Special efforts made to reduce torque ripples, noise and vibrations are described. The impact of microelectronics through integrated chips used in the control of PMBLDC motor drives is given. The increasing applications of this drive due to improved performance and its cost reduction are also enlisted.

**Keywords.** *PMBLDC motor; sensors; controllers; sensorless operation; torque pulsations.*

### INTRODUCTION

Permanent Magnet Brushless DC (PMBLDC) motors are increasingly being used in a wide spectrum of applications such as domestic equipments, automobiles, information technology equipment, industries, public life appliances, transportation, aerospace, defence equipment, power tools, toys, vision and sound equipment and medical and health care equipment ranging from microwatts to megawatts [1-24]. It has become possible because of their superior performance in terms of high efficiency, fast response, light weight, precise and accurate control, high reliability, maintenance free operation, brushless construction, high power density and reduced size. Recent developments in PMBLDC motor technology in terms of availability of high performance rare earth PM materials, varying motor constructions such as axial field, radial field, package type, rectangular fed, sine fed motors, improved sensor technology, fast semiconductor modules, low cost high performance microelectronics devices, new control philosophy such as robust, adaptive, fuzzy, neural AI based controllers, have been a boon to their widespread use in the large speed ranges from few revolutions to several thousand revolutions per minute (rpm). They have been proven most suitable for position control in machine tools, robotics and high precision servos, speed control and torque control in various industry and process control applications [7, 8, 21-24]. In spite of being one of the best, the PMBLDC motor has faced many hurdles to come to its present stage in terms of cost, torque ripples, noise, vibrations, reduced reliability due to the large number of components, operational constraints such as temperature rise etc. Continuous efforts have been made to overcome these problems on different aspects of this drive. The PMBLDC motor drive is undoubtedly quite a big mission in itself; this paper concentrates on the recent advances in PMBLDC motors in terms of motor construction, closed loop controllers, semiconductor power modules, sensors and their reduction, torque ripple minimization, impact of microelectronics, cost reduction and potential applications.

### LATEST DEVELOPMENTS IN THE PMBLDC MOTORS

PMBLDC motors may be classified into different categories such as number of phases, radial or axial field, cageless or with cage bars, surface mounted PMs or buried magnets, sinusoidal or rectangular fed motors etc. Some of them are briefly discussed in this section.

### 1. Number of phases

PMBLDC motors are developed in single phase in low power ( $< 50W$ ) for tube axial fans to cool electronics equipments 25. They are manufactured in two phase construction for home appliances such as solar PV fed refrigeration system, servo control etc. Most of the medium and high power rating motors are designed in three-phase construction similar to conventional ac motors. In some electric vehicles 22-24 and megawatt rating motors for submarine propulsion etc., designers have compelling reasons to increase the number of phases to five, six or more in order to reduce the per phase power handling requirements.

### 2. Radial and axial field motors

Most of the motors in the market are radial field type (cylindrical or salient pole construction). However, the axial field motors have some advantages over the conventional radial field construction in terms of power density, torque to inertia ratio, peak torque, less magnet weight, low inductance, short winding turns, compact design etc. 6,8. Axial field motors are designed in package, disk and sandwich type construction and have no iron in the rotor, resulting in low inertia. Axially directed magnetic field from rotor magnet interacts with radially directed currents in these axial field motors. The magnets are encapsulated in resin or plastic. Because of their construction, they are considered most suitable for robotics, computer equipments, machine tools etc. 8. Radial field motors are also designed with varying desired flux linkage waveforms such as sinusoidal or trapezoidal, different shapes and positions of magnets in the rotor such as buried or surface mounted etc. They are widely used since stator design is similar to conventional ac synchronous or induction motors

### 3. Shape and location of PM in rotors

. They are also designed to achieve sinusoidal or trapezoidal back emfs depending upon applications. Permanent magnets are placed in the rotor in PMBLDC motors 6, 8. In axial field type of motors, the magnets are encapsulated in resin or plastic in disc form as shown in figure 1a. These magnets are placed in such a manner that induced back emf are either sinusoidal trapezoidal waveforms. In radial field motors, the magnets are placed in different form such as surface mounted for low speed motors and interior radially oriented or interior tangentially oriented in high speed PMBLDC motors. shows such rotor geometries

### 4. Sinusoidal and rectangular fed motors

PMBLDC motors are designed to have either sinusoidal or trapezoidal (excited) induced back emfs 8,26-32. Sinusoidal excited motors are fed with sinusoidal polyphase currents similar to conventional synchronous motors for ripple-free torque with unity power factor for constant torque operation below base speed with frequency control and having leading currents to affect field weakening for constant power operation. Maximum speed of operation is restricted with demagnetization caused by armature reaction and mechanical construction. Magnetic saliency on rotor with reluctance torque helps to achieve wide speed range of constant power operation. Trapezoidal excited motors need polyphase balanced rectangular currents with 120 electrical degree width and adjustable magnitude and direction. Constant flux interaction with constant amplitude polyphase currents develops ripple free torque similar to conventional dc motor with electronic commutation

### Back EMF based position estimation

The most common methods of rotor flux position sensing is based on deriving the back emf signals. There are many methods for rotor position estimation based on the back emf and are briefly discussed below.

#### 1. Direct back EMF detection:

This method is quite popular for rectangular fed PMBLDC motors. In these PM motors, particular phase winding is excited for  $2/3$  of each electrical period and ideally there is always one phase which is not excited.

The direct sensing of back emf of unexcited phases in sequence is used to generate discrete rotor position signal for current synchronization with rotor flux. It has been applied to many industrial applications including disk drives 46, compact stereo players 41,42 and room air conditioners 43

#### **Estimation of back EMF:**

This method is applied to both sinusoidal fed and rectangular fed PMLDC motors. This method is based on the reconstruction of the back emf by using voltage equation of the motor ( $e = v - iR - Ldi/dt$ ). Reconstruction of the back emf involves either simulating this equation with operational amplifier 46 or solving this equation in on-line digital processor normally used for control. In this method, the terminal voltage and line current are measured directly and the above equation is used to achieve back emf and rotor position.

#### **3. Third harmonic voltage detection based position estimation**

In star-connected PMLDC motors, the third harmonic voltage is measured between the star point and an artificial star point created by three high-value resistors which are connected to the motor terminals. Such a voltage gives six zero crossings in the 3-phase motor and results in rotor position for current synchronization with rotor flux.

### **CONCLUSIONS**

The latest trend and present status of PMLDC motor drives have revealed that this drive has great potential for use in a number of applications. The use of new PM materials, latest motor construction technology, intelligent closed-loop control, new types of inverters, sensorless operation, and field weakening have resulted in potential applications and provided a broad prospective to drive-design and application engineers. The methods of torque pulsation reduction have been explored to design PMLDCM drives to suit highly position-sensitive applications. In view of these new developments, these drives are expected to enjoy a bright future in a larger number of applications of adjustable speed applications requiring high efficiencies and fast dynamic responses such as blowers, compressors, automobiles, vehicle propulsion systems and traction drives.

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