CHAPTER 8

CONCLUSION AND FUTURE RESEARCH

8.1 CONCLUSION

The permanent magnet brushless dc motor has been designed and developed for the study of redundancy in the armature winding of the stator assembly. The requirement of armature winding functional redundancy for reliability improvement is accomplished by designing new quadruplex winding pattern to the stator assembly. With the above new design of winding pattern, the individual quadrant armature coils with permanent magnet rotor functions as a separate motor. Thus the single armature stator assembly and magnet rotor assembly has four individual motors. The analytical design has been carried out to calculate the electrical loading and magnetic loading for the required torque and speed output. Finite element based analysis software have been used to validate the airgap flux density used for the design. The tooth flux density, back iron flux density, cogging torque and torque output were simulated and plotted for the designed magnetic circuit. Based on the analytical and simulation results two prototype (integral slot and fractional slot) motors have been developed for performance comparison. The individual quadrant motor performances in both the configurations were measured using back-EMF and torque pick up and the results are tabulated. The experimental results have been investigated and found that the performances are same for all individual quadrant armature coils with common permanent magnet rotor.
Initially 24 slots stator and 8 poles rotor configuration has been designed and fabricated to test the armature quadruplex redundancy. While winding the armature coils, it was not possible to accommodate the number of conductors calculated per slot even though the slot space factor is less than 0.4. This was due to overhang length limitation for mechanical interface requirement. In order to overcome the overhang problem, the phase coils were distributed by increasing the number of slots and poles. This was achieved by increasing the number of slots to 48 and number of poles to 16 conforming to quadruplex winding design. High energy rare earth permanent magnets were used to increase the magnetic loading of the motor. The slots being integral, the stack has been skewed for one slot pitch to reduce the cogging torque. The electrical loading and magnetic loading were worked out and the design has been validated with the finite element analysis. The 60 slots stator and 16 poles rotor configuration has also designed for performance comparison with 48 slots motor configuration. The 60 slots stator assembly has been skewed for half slot pitch being a fractional slot configuration. Both the motor types were fabricated and tested for its performance in motor level, actuator level and system level. The motor level performances of individual quadrant coils for both motor types were measured. The individual quadrant performances are same but the over all performance of 60 slots motor is lower than the 48 slots motor. But the frequency response of 60 slots motor in actuator level and system level was better than 48 slots motor. Hence 60 slots armature stator and 16 poles magnet rotor was selected for further study.

The electrical loading has been increased in the 60 slots motor to increase the motor level performance. This was achieved by increasing the number of conductors per coil. Double wire strategy has been adopted for phase coils to reduce the line to line resistance. The improved 60 slots armature stator was fabricated and functional experiments were carried out. The performances of all quadrant coils were same and over all performance of
the motor have been improved. The 60 slots stator assembly with the same 16 poles rotor assembly performance was better in all motor level, actuator level and system level.

The magnetic core of the integral slot and fractional slot motor has been fabricated by stacking the M19, 29 gage silicon steel laminations. Further the performance of the motor with Cobalt Iron alloy lamination material for magnetic core has been analysed. The torque output of improved 60 slots motor configuration has been simulated with Cobalt Iron material as magnetic core instead of silicon steel lamination core. For the same electrical loading, magnetic loading and geometry, the motor with Cobalt Iron core has higher torque output compared to the motor with silicon steel lamination core. This was due to high permeability, high saturation flux density, rare earth alloy material for magnetic core.

Thus the quadruplex redundancy brushless dc motor has been designed and improvements were made based on the performance output of the motor. The functional redundancy was checked by ensuring equal performance in all four motors in the single unit. Integral slot stator and fractional slot stator were realised and finally improved 60 slots stator (fractional slot) and 16 poles rotor configuration has been suggested for the use in high critical electromagnetic actuator application in space mechanism.

8.2 FUTURE RESEARCH

1. Cobalt Iron alloy lamination for stator magnetic core

The non availability of cobalt iron alloy material in small quantity and very high cost of import restricted the work with the simulation. Certainly the high permeable Cobalt Iron alloy stator core will yield higher torque constant than the silicon steel material for same stator and rotor assembly
configurations. The fabrication and experimental testing shall be carried out to validate the performance.

2. **Tacho-generator signal for control of the motor**

Four separate six step commutation logic drive electronics is used to control the four quadrant redundancy motors. The current commutation in the armature coils is done based on the rotor position obtained from the sensor signals. In order to have a precise control of the motor, speed has to be measured separately by having a tacho-generator. This can be done by winding separate coils into the slots along with the main coils. The back-EMF of the secondary coils can be used by the drive electronics to control the speed of the motor. The tacho-generator design can be carried out as the further work.

3. **Protective sleeve design for permanent magnets**

The permanent magnet rotor is potted with epoxy compound to protect the magnets. The epoxy compound can not be used in chemical environment. Instead of potting, the magnets can be protected by metal sleeve over it. The performance of the motor can be tested with Aluminium alloy, Titanium, carbon fiber and non magnetic stainless steel material sleeves.

4. **Thermal analysis for temperature rise study**

The temperature rise in the motor during operation is due to ohmic loss, core loss and friction loss. The components and materials for the motors are selected based on the operating temperature of the motor. Exact prediction of rise in temperature can be obtained from thermal analysis. Also we assume that the high frequency PWM switching increases the core loss component by 30%. This can be studied effectively in thermal analysis.
5. **Environmental test**

The experimental test data are measured in Standard Room Condition for the developed motor. The performance of the motor can be simulated and experimentally tested with actual working environment. The temperature test, humidity and vacuum test shall be carried out. The sinusoidal vibration test and random vibration test of the motor shall be done to verify the mechanical stability.