EVOLUTION OF AEROSPACE MOTOR TECHNOLOGIES

Starin Engineering, LLC

Timely Solutions Through Experience

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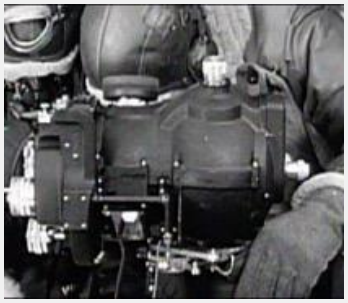
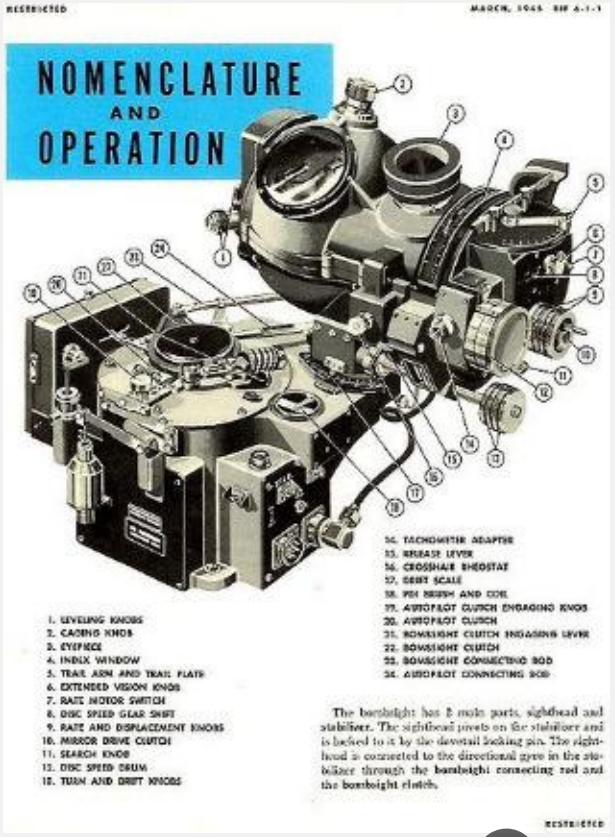
400 HZ AIRCRAFT GENERATORS / NORDEN BOMBSIGHT



- Any discussion of the evolution of motors used in Aerospace *must* start with the Norden Bombsight
- The Norden Bombsight was a mechanical analog computer using high speed gyros, motors, tachometers, clutches and gears to perform differential calculus
- The need for high-speed actuation resulted in the need for high frequency AC voltages



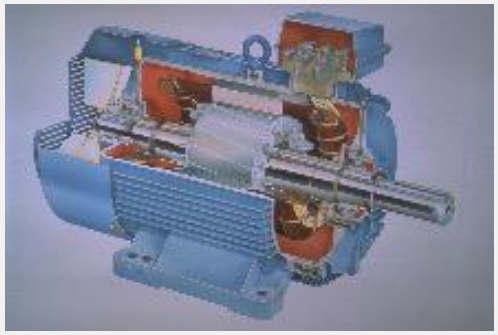
COMMERCIAL AEROSPACE / THE JET AGE

- Derivatives of the Norden Bombsight were used in commercial and military aviation for navigation, wind vector computation and cockpit instrumentation.
- Developed in the early 1950s the Boeing 707 revolutionized commercial aviation and ushered in the Jet Age.
- 400 Hz motors, resolvers, synchros and tachometers were produced by the tens of thousands
- Electric motors were limited to low to moderate power output applications

- In the 1950's the government felt it necessary to regulate the design of these components to assure public safety
- The government provided the design of these components and companies that excelled in manufacturing productivity received most of the business
- ***Innovation stagnated***

MOTORS DURING THE MOTOR DARK AGES

- As the design was regulated, there was very little development in the 1950s.
- A “Size 15” motor (1.5” in diameter) could only out out about 5 to 10 watts of mechanical power output
- Maximum operational temperature of 105º C was typical.
- High power output actuation was almost exclusively accomplished with hydraulics
- Used in electro-mechanical computers, there was still a large market for these products used in spares up to the mid 1980s
  - Aircraft Navigation
  - Disposable Ordinates
  - Commercial & Military Aviation Spares



Classic AC Induction Motor

Size 15 AC Motor

MOTORS DURING THE RENAISSANCE

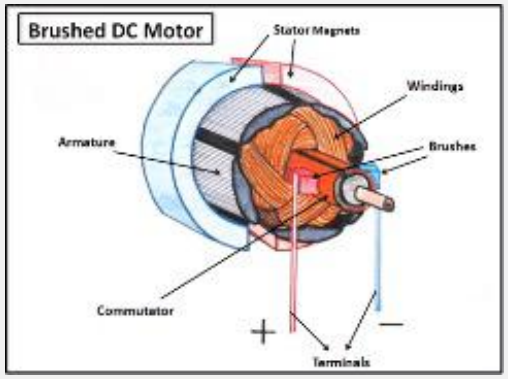
- By the 1960s the government decided to get out of component regulation. There were tremendous advances in the capabilities and control methods of AC motors in the late 60's and 1970s.
- Demand for higher performance motors resulted in advances in materials:
  - Vanadium Permendur (Hyperco 50)
    - Actually, invented in 1920s it was ahead of its time
  - Polyimide Insulation Systems rated over 200º C
  - Higher precision / more capable ball bearings
  - Alnico Magnets
- Companies that innovated, flourished. Motor suppliers that did not keep up withered away or were bought out.
- A Size 15 Motor during this period was capable of about 150 watts of intermittent mechanical power output. Unfortunately, thermal limitations and limitations in control electronics kept practical power output below 50 watts.

SOLID STATE REVOLUTION

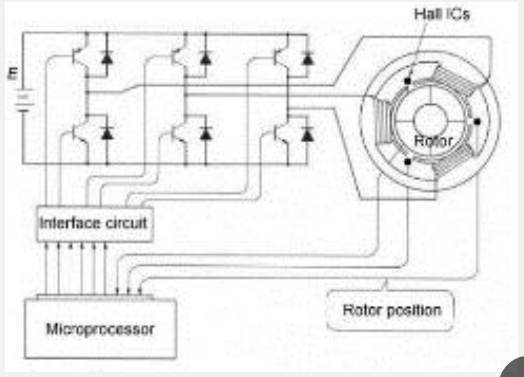
- As vacuum tubes made way for solid-state electronics, advances in motor control techniques significantly increased the capabilities for motors for higher power output applications.
- Higher power “Fixed-Control Phase” Techniques were implemented for more systems.
- By the late 1970s and early 1980s*, two-winding control* amplifiers were being implemented, significantly increasing power output capabilities for AC Induction Motors, with lower quiescent power losses.
- Two-winding control systems were a big advancement, but their usage was short-lived, due to the *Brushless DC Revolution*.

BRUSHLESS DC / PERMANENT MAGNET REVOLUTION

- By the late 1970s magnet materials made significant advances with rare earth materials (Sm-Co, N-Fe-Bn)
- This, coupled with advances in silicon-based electronics resulted in the Brushless DC Revolution of the 1980s
- At this time, a Size 15 Brushless DC Motor could produce about 350 watts of mechanical power (0.5 hp) output on an intermittent basis.
- Compared to a “Brush-Type” DC Motor, a Brushlesss is Commutated through electronic circuitry, rather than brushes.



Brush Motor Concept



Brushless Motor Concept

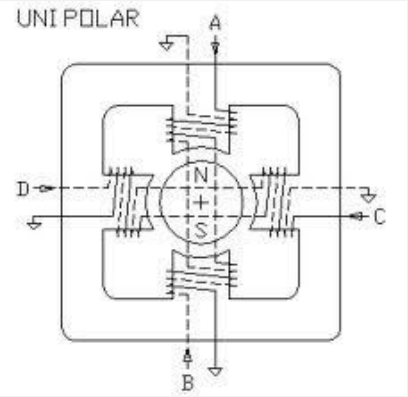
BRUSHLESS DC / PERMANENT MAGNET REVOLUTION

- Many Aerospace companies were reluctant to use Brushless DC Motors at this time, as the electronics to drive them were viewed as too complicated
  - Many felt that talking movies and engine powered motor coaches were a fad as well
  - Ferranti Ltd. In Edinburgh Scotland was the first company to use Brushless DC motors in an Aerospace application for a fire control radar for the Tornado Jet Fighter for the Royal Air Force (RAF)
  - The advantages of the DC servo-system over competitors hydraulic systems gave Ferranti a tremendous competitive advantage
  - US companies soon followed suit

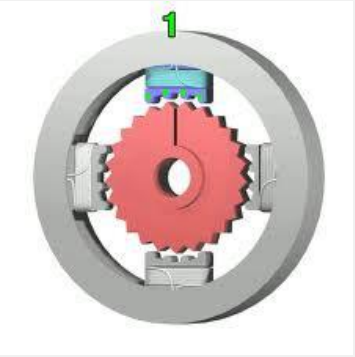
RAF Tornado

PERMANENT MAGNET STEPPER MOTORS

- Stepper Motors and Hybrid Stepper Motors evolved with the industry.
- Stepper Motors are desired due to simple control electronics, and easy ability to control position and average velocity.
- Very popular in space satellites and instrumentation



Stepper Motor Concept



Hybrid Stepper Motor

TODAY'S BRUSHLESS DC MOTORS

- Continued advances in machining techniques, magnet and insulation materials as well as control electronics have resulted in ever higher mechanical power output capabilities
- A size 15 motor can produce 1 hp (750 watts) of mechanical power output on an intermittent basis.
- A 3" diameter motor can reliably produce more than 5 hp of mechanical power output
- Continuous operational temperatures of 280º C and higher are available
- More and more systems are converting from hydraulics to Brushless DC and capabilities are increasing
- Aerospace Motors and Electro-Mechanical Actuation is over $1bn a year industry

Size 15 BLDC Motor

DIRECT DRIVE COG-LESS MOTORS

- A Cog-less Direct Drive motor utilizes high temperature non-magnetic materials to hold the motor windings in-place, rather that permeable soft-iron steels.
- This results in very low residual magnetism and uniform unpowered torque versus position, or cogging torque.
- Advantages include extremely smooth motor torque performance and low cross-section and large through hole construction.

- Applications include:
  - Radar Control Systems
  - Precision Optical Drive Systems
    - Drones
    - Surveillance Systems

TOMORROW'S INNOVATIONS

Advances in motor and control systems are tied closely to advances in supporting technologies

- Control Electronics
- Insulation Materials and High Temperature Capabilities
- Cryogenic Operation
- Control System Techniques and Algorithms
- Feedback Accuracy
- Machining Capabilities
- Ball Bearing Technologies

Developments Starin Engineering is working on:

- Stepper and Servo-Motor Control Techniques
- Gearing Technologies
- Force-Feel and Controlled Damping System
- Higher temperature capabilities / thermal management system
- Feedback Devices:
  - Rotary Accelerometers

CONTACT STARIN ENGINEERING FOR YOUR DEMANDING APPLICATIONS REVIEW

Starin Engineering LLC
www.StarinEngineering.net
Scott@StarinEngineering.net
(M) 303-882-0521
(O) 239-325-9994
2250 Imperial Golf Course Boulevard
Naples, Fl 34110

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