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# Aerospace Induction Motor Actuators Driven From a 20-kHz Power Link

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ACTUATORS DRIVEN FROM A 20-KHZ POWER LINK  
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## AEROSPACE INDUCTION MOTOR ACTUATORS DRIVEN FROM A 20-KHZ POWER LINK

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Aerospace electromechanical actuators utilizing induction motors are under development in sizes up to 40 kW. While these actuators have immediate application to the Advanced Launch System (ALS) program, several potential applications are currently under study including the Advanced Civil Aircraft program.

Several recent technology advances developed for the Space Station Freedom have allowed induction motors to be selected as a first choice for such applications. Among these technologies are bi-directional electronics and high frequency power distribution techniques. Each of these technologies will be discussed with emphasis on their impact upon induction motor operation.

### BACKGROUND

For over a decade NASA Lewis Research Center has been evaluating, and defining power components and system characteristics as part of our OAST charter. This work provided a foundation for the Advanced Aircraft Secondary Power System Study in 1985 which concluded that a 20 kHz ac system had great advantages particularly when multikilowatt, multiply redundant, distribution was involved (1). This study also recognized the advantage of high frequency power for motor operation. In the intervening years, the technology has been reduced to practice and evaluated with several full power testbeds. The initially baselined 20 kHz power distribution for Space Station is shown in the diagram (Fig. 1). The system comprised two independently powered feeders (left and right) similar to conventional aircraft practice. All loads had current limiting remote power controllers (RPC's) and could draw power from either feeder subject to power management.

Differential protection was provided between nodes to monitor soft and hard faults. In this system the RPC's were programmable for: off, on, trip level, monitors indicated switch status, the current flowing, and produced a flag when over current trips occurred. Similar instrumentation, but no current limiting or tripping, was provided by the node switches or remote bus isolators (RBI's) located on the feeder lines. This system was assembled at NASA Lewis and operated with complete success for over a year (2,3).

It is the confidence gained from the Space Station Testbeds, advanced components, and operating experience that forms the foundation for advanced electrical power, distribution, and control. These advances in power control and newly demonstrated capabilities for control of a larger class of inherently rugged, induction motors using pulse-population-modulation with field-oriented control powered from a high frequency source makes this approach even more attractive. For example, selective steering of high frequency, low energy pulses and switching at

zero crossing significantly reduces the size and weight of the electronics while greatly reducing EMI/EMC effects.

### WHY HIGH FREQUENCY POWER DISTRIBUTION

Electrical system reliability is, in reality, the probability of suitable electrical power being available to user loads. Long term availability is most efficiently achieved by parallel redundant elements in a single distribution block consisting of a source, storage (if required), and a distribution system all under active control and management. Uninterruptible, or secure power, for critical loads may be implemented by an additional block, or blocks, depending upon the requirements. Within a single block, fault limiting, fault isolation, and fault recovery through reconfiguration are implemented to maintain as much post fault capability as possible. This capability (fault tolerance) involves status sensing, intelligence, current limiting, and active switching. When all available technologies are fully reviewed, it becomes obvious that these requirements may be much more easily met by utilizing a distributed, alternating current (ac) system. The system physics, the system fault recoverability, and the overwhelming terrestrial experience support this conclusion. Given an ac system several engineering decisions remain as regards the distribution voltage, waveform, and frequencies. While each specific application must be evaluated, point designs and operating experience to date support the selection of ultrasonic, sinusoidal power systems operated at the highest voltage appropriate to the situation. Both the proposed advanced secondary power system (1), and the Space Station Freedom power system involved multi-redundant systems delivering multikilowatts of power over distances of many yards. For these applications, a single phase, 20 kHz, 440 V distribution system was selected. In the case of the Space Station, the distribution voltage within pressurized elements was reduced to 220 V out of consideration of reduced pressure breakdown. Similar arc over conditions would also exist on a transatmospheric vehicle. This 20 kHz, single phase, high voltage, high frequency distribution system is the source used to supply the four quadrant induction motor drive circuitry.

### WHY INDUCTION MOTORS

Induction motors possess very desirable characteristics for aerospace applications. They are very rugged, will operate at high temperature, and due to their lack of permanent field excitation they tend to fail gracefully. Until recently, however, they have also displayed low efficiency and required complex controls. The induction motor in its simplest form (Fig. 2) is that of a transformer with its secondary free to move. Two currents are involved in the motor action, the primary (stator) current (proportional to the

applied voltage divided by the applied frequency) which establishes the magnetic flux density, and a secondary (rotor) current proportional to both the magnetic flux density and the rate at which the magnet lines are cut (slip frequency).

As the slip frequency results from the spacial differences between the stator field and the rotor conductors, at least one of them must be "moving." Reviewed in its simplest form then an induction motor has a magnetic field which is; capable of rotation, and proportional to the ratio of applied voltage to frequency and a rotor current proportional to the difference in rotation between the magnetic field and the rotor itself.

The point to be made is that when an induction motor is operated from a multi-phase controller whose voltage and frequency are independently variable, both the rotor and the stator currents are independently controllable, and furthermore, the rotor current is "instantly" variable. As is usually the case these simplistic concepts have their limitations, but nonetheless, they provide an excellent first order explanation.

PULSE POPULATION MODULATION

Independently variable voltage and frequency waveforms are easily synthesized from a high frequency power source (Fig. 3). With zero voltage switching, the output consists of a series of half sinusoids. The frequency is controlled by the waveform, and the voltage is controlled by the number of pulses (population) within the envelope. What has occurred, not unlike radio transmission, is that all switching and energy control is done at the carrier frequency and not at the machine frequency. A three phase set of synthesized 400 Hz waveforms is shown in Figure 4. This frequency translation results in greatly reduced component sizes particularly as regards electromagnetic filtering. Also loss generating waveform distortions are much reduced as compared with conventional (PDM) control.

FIELD ORIENTED (VECTOR) CONTROL

Although pulse population synthesis has advantages for driving any ac machine, it has

marked advantage as regards field oriented control of induction machines. In vector control each stator current is controlled relative to the rotor field and consists of a flux producing current, and a orthogonal torque producing current.

These required flux and torque producing currents bear obvious relation to the voltage and frequency synthesis described earlier. Figure 5 shows an induction motor under vector control with output torque as the control parameter. Two points are of interest; the torque is "instantly" variable, and is held constant over a speed range including reversal through zero speed.

CONCLUSION

Electrical actuators driven from a high frequency link, and using induction motors have many advantages. They provide high efficiency over a wide operating range, high peak torque, and rapid response. From a systems standpoint, their rugged construction, and soft failure characteristics are particularly attractive.

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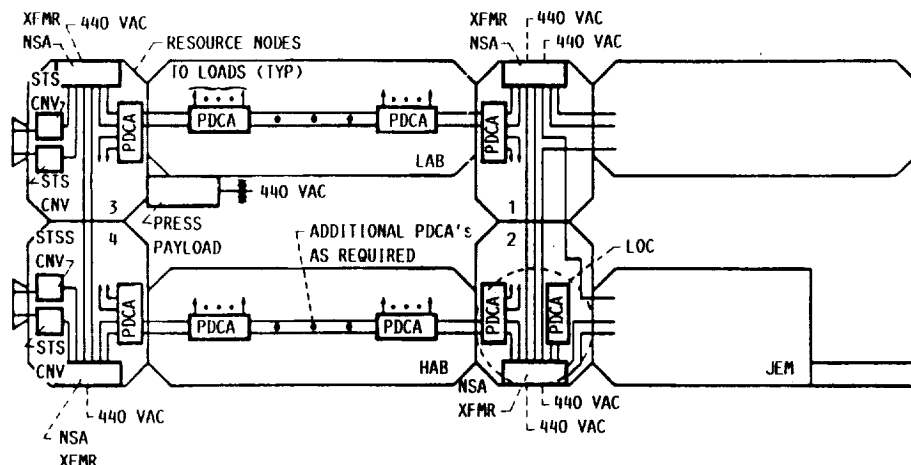


FIGURE 1. - MODULE PRIMARY DISTRIBUTION ARCHITECTURE.

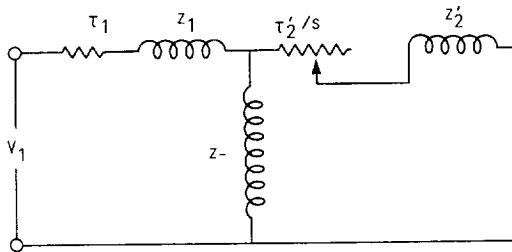
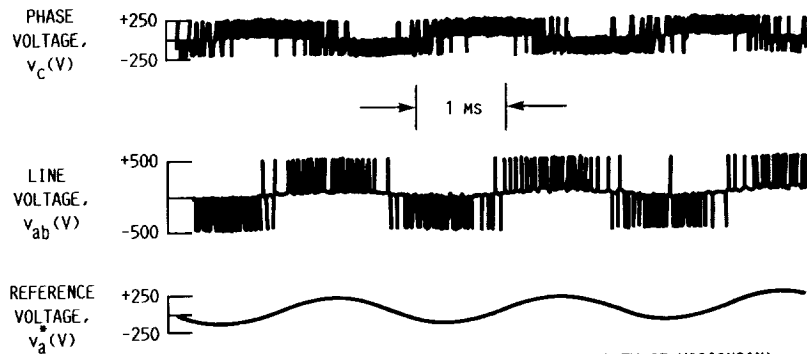
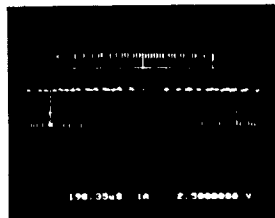


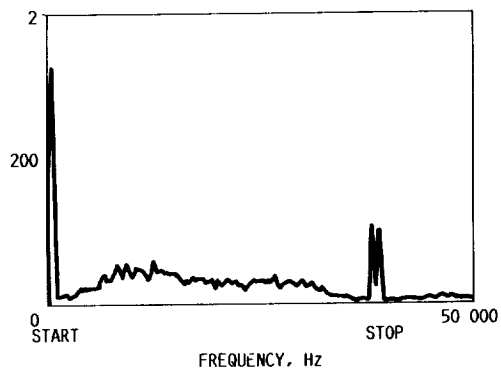
FIGURE 2. - EQUIVALENT CIRCUIT OF THE POLYPHASE MOTOR.  
IRON LOSSES DUE TO THE MAIN FLUX NEGLECTED.



(A) COMPUTER SIMULATION OF LOW FREQUENCY SYNTHESIS (UNIVERSITY OF WISCONSIN).



(B) OUTPUT OF BREADBOARD SYNTHESIZER (UNIVERSITY OF WISCONSIN).



(C) SPECTRUM OF BREADBOARD SYNTHESIZER (UNIVERSITY OF WISCONSIN) (1ST SIDEBAND SET).

FIGURE 3. - WAVEFORM SYNTHESIS.

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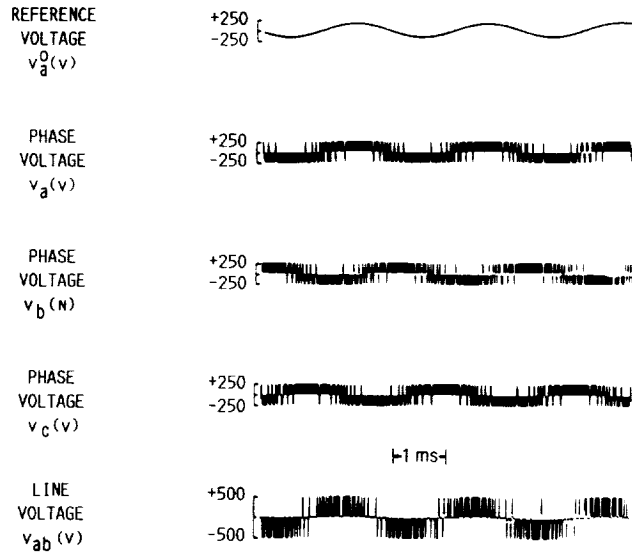
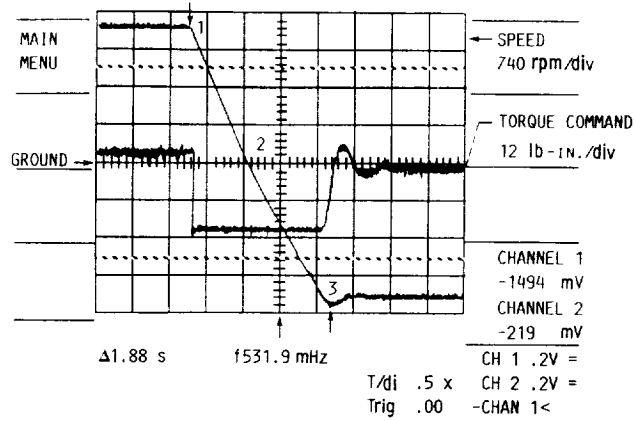
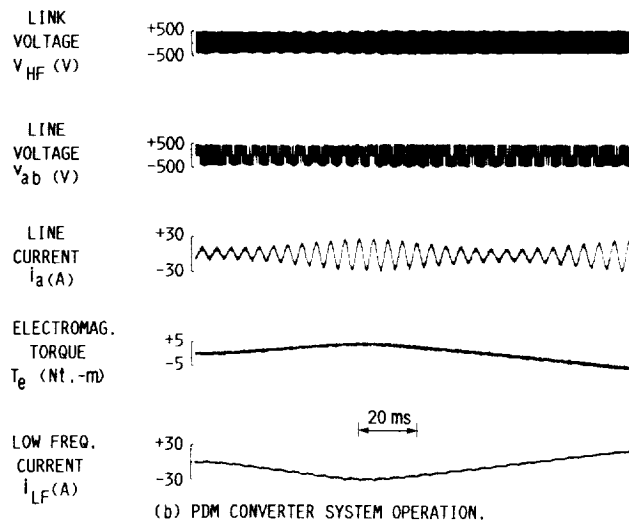


FIGURE 4. - SYNTHESIS OF A BALANCED SET OF VOLTAGES HAVING SINUSOIDAL FUNDAMENTAL FREQUENCY IS 400 HZ WITH A MODULATION INDEX OF 0.9.



(a) SPEED REVERSAL OF 2-hp MACHINE.



(b) PDM CONVERTER SYSTEM OPERATION.

FIGURE 5. - INDUCTION MACHINE UNDER BOTH MOTORING AND GENERATION.

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