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N85 13853

ELECTRICAL/ELECTRONICS WORKING GROUP SUMMARY

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INTRODUCTION

This panel considered the electrical/electronics technology area. The major conclusion arising from the discussions held by this group is that there are no foreseeable circuit or component problems (Figure 1) to hinder the implementation of the flywheel energy storage concept. Therefore, the membership of this panel addressed itself to the definition of the major component or technology developments required to permit a technology ready date of 1987. There were 13 participants in these panel discussions. Their names and affiliations are included in Table 1 at the end of this summary.

CONCLUSIONS AND RECOMMENDATIONS

The committee recommendations deal with the following items: motor/generators, suspension electronics, power transfer, power conditioning and distribution, and modeling. In addition, an introduction to the area of system engineering is also included.

1. System Engineering

Before proceeding with a technology development program, it is essential to define critical requirements and interfaces. A list of design considerations for this area will necessarily be quite long. Therefore, only the more critical aspects will be discussed here (Figure 2). One of these issues is peak power and energy reserves. A paper by Giudici, contained in these proceedings, addressed that topic earlier. In utilizing inertial energy storage systems at a 75 percent depth of discharge, the reserve margin for satisfying peak power demands is limited. Such topics must be addressed in system studies in order to define the peak power and energy reserve margin requirements for the spacecraft under consideration. Some concern has been expressed that too much emphasis is being placed on achieving higher energy density in this concept at the sacrifice of other possibly more important parameters such as life-affecting design factors. Next to life, the characteristic considered of extreme importance, because of its impact on other systems, is system efficiency. The system studies must also define modularity, redundancy, and resupply requirements. Module sizes in the range of 10-30 kilowatts were discussed, but final sizing should result from the specific spacecraft application studies.

As part of the overall system requirements definition, rotor balance and dynamic characteristics must be defined because of their major impact on suspension system stiffness and attitude control system effectiveness.

One of the potentially restrictive characteristics of this energy storage concept is the lack of available power during the deployment phase. Therefore, consideration must be given to a hybrid energy storage approach in which batteries may be used to provide power during deployment and to satisfy short-duration peak power needs.

2. Motor/Generator Electronics

The motor/generator electronics, or charge-discharge electronics, must be optimized for efficiency (Figure 3). The cooling of these circuits will become a problem, since dense packaging will be employed, possibly inside the rotor. Therefore, thermal control must be addressed early in the development phase.

Selection of the number of motor/generator poles must be made in concert with the selection of the electronics switching frequency. There is a certain relationship between the output frequency of the generator and the electronics which process and control that power output. Coordination of these selections is essential to insure that they are high enough to provide for high energy density, but not so high as to present a problem to the electronics and result in unacceptable operating efficiencies.

The required and achievable speed/momentum control accuracy of counterrotating MG's must be analyzed and properly specified. This is of special concern if the flywheels are used for storage only rather than integrated with the attitude control system. The specification of momentum control accuracy in counterrotating units, in addition to speed control accuracy, is necessary, since momentum is not a function of only rotational speed.

3. Suspension System Electronics

It is concluded that no critical electronics technology issues exist in this area. It is primarily a sensor and feedback control problem (Figure 4), which is covered by a separate working group.

4. Power Conditioning and Distribution

The input and output voltage of the inertial storage device should be high voltage dc. Direct current interfaces are easy to define. In addition, dc systems can readily be paralleled in redundant modules. For high-power applications, a value of 200+ volts is felt to be in the appropriate range. In addition to the charge-discharge electronics (Figure 5), there is a need for solar array voltage-limiting or voltage-regulating circuitry. The Space Station will have variable demands placed on its power system by the changing payloads, with the predictable loads being primarily those of the spacecraft housekeeping systems. Therefore, there will be conditions when the withdrawal of energy from the storage units will be considerably smaller than the anticipated average. In such a condition, there will be more energy in the arrays than can be absorbed by the inertia wheels without operating them at speeds above their design limits. Thus, if no control is placed on the array, an overvoltage condition will result which will adversely affect the electronics associated with the energy storage and power distribution systems.

Another protection measure which must be incorporated in the electronics or be an inherent feature of the energy storage system design is a means of surviving the failure of a paralleled energy storage module. Of particular concern is the output of a higher than allowable voltage under such failure conditions.

5. Power Transfer Across Rotating Interfaces

A dc rotary power transfer interface is recommended between the solar array and the energy storage system (Figure 6), and it appears that the required technology is well in hand. The rotating wheel energy storage device by itself does not require rotary power transfer interfaces, since the power is collected from the stationary element of the unit. Approaches for effecting power transfer across rotating interfaces, such as presented by gimbals, include slip rings and roll rings. A paper was presented on the roll ring concept at this symposium.

6. Analytical Modeling and Simulation

Since it is unlikely that it will be possible to perform all the desired or even necessary testing, it will be essential to produce well-documented and well-analyzed designs. Therefore, it is recommended that, in parallel with the development of the hardware, modeling and simulation of the energy storage system be addressed (Figure 7). The total electrical power system shall be modeled and analyzed to include the static and dynamic behavior of the motor/generator and its electronics, the magnetic suspension system, the interfacing solar array, and the power distribution and conditioning systems. This modeling must incorporate the proper scaling factors for extrapolation and correlation of scaled-down hardware test results to full-scale storage modules.

The model(s) generated as a part of this effort will be instrumental in developing energy storage system management strategies for normal and abnormal operations. Since a Space-Station-type power system will have independent power buses with significant redundancy requirements, parallel modules are going to be necessary. Therefore, an energy management system is essential.

7. Technology Development Program

To demonstrate technology readiness (Figure 8), it is necessary to establish a data base derived from analytical studies, as well as performance and life testing. The requirements of the system must be defined, and a configuration must be selected as early as possible in order to meet a 1987 technology ready date attendant to the Space Station mission. The high efficiency of the motor/generator and associated electronics and the quality of the power produced by this storage system, as well as its dynamic performance capability, must be demonstrated. The integrated energy storage unit, i.e. the rotor, motor/generator, magnetic suspension, and electronics, must be tested, and its performance as an individual device, as well as an element of paralleled storage modules, must be evaluated. An output of such testing will be the demonstration of the storage system energy balance, redundancy, and failure recovery management capability. An integral part of the system evaluation is life testing to establish the credibility of this concept as a long life storage system capable of essentially unlimited operational cycles.

CONCLUDING REMARKS

It was felt unanimously by the members of this working group that this is a viable technology. It is a promising technology for low Earth orbit energy storage, which should be pursued, regardless of whether it can programmatically satisfy the needs of the early Space Station or whether it will be integrated with the attitude control functions or be used as an energy storage approach only. Integration of these functions into one system is preferred, but the question as to its implementation was left to be resolved by the system studies.

TABLE 1

ELECTRICAL/ELECTRONICS WORKING GROUP

PANEL MEMBERSHIP

NAME	ORGANIZATION	PHONE
A. D. Schoenfeld	TRW	(213)536-1972
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SUMMARY

- THERE ARE NO IDENTIFIABLE CIRCUIT OR COMPONENT SHOWSTOPPERS
- 1987 TECHNOLOGY READINESS REQUIRES DEMONSTRATION OF PROGRAM OBJECTIVES BY ANALYSIS AND PROTOTYPE TESTING OF AN INTEGRATED FLYWHEEL SYSTEM CONFIGURATION
- THERE ARE NO INHERENT TECHNICAL REASONS TO DEMONSTRATE VIABILITY THROUGH FLIGHT TESTING

Figure 1

SYSTEM ENGINEERING

BASED ON SPACE STATION REQUIREMENTS AND TECHNOLOGY TRADE STUDIES, DEFINE FLYWHEEL SYSTEM AND COMPONENTS REQUIREMENTS AND INTERFACES. SOME OF THE MORE CRITICAL DESIGN CONSIDERATIONS ARE

- PEAK POWER AND ENERGY RESERVE MARGINS
- FULL LOAD CHARGE/DISCHARGE EFFICIENCY AND STANDBY LOSSES
- MODULARITY, REDUNDANCY, AND RESUPPLY
- BALANCE AND DYNAMIC STABILITY CHARACTERISTICS
- SUSPENSION STIFFNESS CHARACTERISTICS
- DEPLOYMENT PHASE POWER/ENERGY REQUIREMENTS

Figure 2

MOTOR/GENERATOR ELECTRONICS

- M-G AND ELECTRONICS OPTIMIZED FOR EFFICIENCY
- PROPER COOLING OF THE ELECTRONIC COMPONENTS MAY REQUIRE HEAT PIPES
- THE SELECTION OF THE NUMBER OF POLES SHALL BE COORDINATED WITH THE SELECTION OF THE ELECTRONICS SWITCHING FREQUENCY
- THE REQUIRED AND ACHIEVABLE SPEED/MOMENTUM CONTROL ACCURACY OF TWO COUNTERROTATING M-G'S SHALL BE ANALYZED AND PROPERLY DEFINED

Figure 3

SUSPENSION SYSTEM ELECTRONICS

- NO ISSUES. IT IS PRIMARILY A SENSOR AND FEEDBACK CONTROL PROBLEM

Figure 4

POWER CONDITIONING AND DISTRIBUTION

- THE INPUT TO AND THE OUTPUT FROM THE INERTIAL ENERGY STORAGE SHALL BE HIGH VOLTAGE DC
- IN ADDITION TO THE ENERGY STORAGE CHARGE AND DISCHARGE ELECTRONICS THERE IS A NEED FOR A SOLAR ARRAY VOLTAGE LIMITER OR VOLTAGE REGULATOR
- THE FAILURE OF A PARALLELED ENERGY STORAGE MODULE SHALL NOT RESULT IN A HIGHER THAN ALLOWABLE OUTPUT VOLTAGE

Figure 5

POWER TRANSFER ACROSS ROTATING INTERFACES

- DC ROTATING POWER TRANSFER TECHNOLOGY APPEARS TO BE WELL IN HAND

Figure 6

ANALYTICAL MODELING AND SIMULATION

- AS PART OF THE INERTIAL ENERGY STORAGE DEVELOPMENT PROGRAM THE STATIC AND DYNAMIC BEHAVIOR OF THE MOTOR/GENERATOR AND ITS ELECTRONICS, THE MAGNETIC SUSPENSION, AND THE ELECTRICAL POWER SYSTEM (CONSISTING OF THE SOLAR ARRAY, ENERGY STORAGE, POWER DISTRIBUTION AND CONDITIONING) SHALL BE MODELED AND ANALYZED

- DEFINE PROPER SCALING FACTORS FOR THE EXTRAPOLATION AND CORRELATION OF SCALED-DOWN DEVELOPMENT MODEL TEST RESULTS WITH LARGE-SCALE COMPONENTS AND SYSTEM PERFORMANCE

- DEVELOP ENERGY STORAGE SYSTEM MANAGEMENT STRATEGIES FOR NORMAL AND ABNORMAL OPERATION (WHERE THE ENERGY STORAGE SYSTEM WILL CONSIST OF PARALLELED ENERGY STORAGE MODULES CONFIGURED IN MULTIPLE REDUNDANT POWER DISTRIBUTION BUSES)

Figure 7

MAJOR STEPS TOWARD TECHNOLOGY DEVELOPMENT

(FOR 1987 TECHNOLOGY READINESS)

- DEFINE REQUIREMENTS
- DEFINE CANDIDATE CONFIGURATION
- DEMONSTRATE HIGH EFFICIENCY M-G AND ELECTRONICS
- DEMONSTRATE POWER QUALITY (VOLTAGE REGULATION AND RIPPLE) AND DYNAMIC PERFORMANCE
- DEMONSTRATE INTEGRATED M-G AND MAGNETIC SUSPENSION SYSTEM PERFORMANCE OF PARALLELED ENERGY STORAGE MODULES
- DEMONSTRATE ENERGY STORAGE SYSTEM ENERGY BALANCE, REDUNDANCY, AND FAILURE RECOVERY MANAGEMENT
- LIFE TESTING
- COMPILE DATA BASE FOR TECHNOLOGY READINESS DEMONSTRATION

Figure 8