Table 1 Outgassing parameters for aluminum

Material	c_0, cm^{-3}	D_H(20°C), cm^2·s^{-1}	ν_d, Torr l·cm^{-2}·s^{-1}
As-received Al	6.3×10^{17}	3.2×10^{-10} [a]	8.0×10^{-11}
Vacuum-melted Al	2.1×10^{12}	3.2×10^{-10}	2.7×10^{-16}
Vacuum-degassed Al	5.8×10^{10}	3.2×10^{-10}	7.4×10^{-18}

[a] Diffusion coefficient assumed for porous Al.
[b] Units for outgassing presented here are those most often employed.

Table 2 Molecular shield gas density parameters for vacuum-processed aluminum

Material	ν_d, Torr ℓ·cm^{-2}·s^{-1}	n_d, cm^{-3}	n_d/n_H [a]
As-received Al	8.0×10^{-11}	6.0×10^{4}	3.0×10^{2}
Vacuum-melted Al	2.7×10^{-16}	0.2	1.0×10^{-3}
Vacuum-degassed Al	7.4×10^{-18}	5.5×10^{-3}	2.8×10^{-5}

[a] n_H = molecular shield gas density due to the atomic hydrogen flux at orbital altitude of 500 km = 200 cm^{-3}.

nine at 660°C. Unfortunately, the latter process does not remove the porosity. Other researchers have also indicated that low outgassing rates of aluminum and aluminum alloys can be achieved. Young[9] measured 4×10^{-13} Torr ℓ/s· cm^2 after only a 15 h, 250°C bake. Halama and Herrera[10] determined the outgassing rate for 6061 aluminum to be less than 1×10^{-14} Torr ℓ/s· cm^2 after 24 h at 200°C. In these experiments, however, the time and temperature of the vacuum processing may not have been sufficient to desorb all of the bulk hydrogen which would accordingly prevent achieving the lowest outgassing rate. Austenitic stainless steels vacuum processed at high temperature (~1000°C) also yield low outgassing rates and have recently been compared with the aluminum discussed in this work.[7]

Molecular Shield Gas Density

The density distribution within a hemispherical molecular shield is given by[2]

$$n_d(r,\mu) = 2\nu_d(\sqrt{\pi}\nu_m')^{-1}\int_0^{\pi/2} h(r,\mu,\zeta)d\zeta \tag{2}$$

where v_m' is the most probable speed of the desorption gas, μ, ζ are azimuthal angles, $h(r,\mu,\zeta)=f[E(k),K(k)]$, $E(k)$ and $K(k)$ are complete elliptic integrals of the first and second kind with modulus k, and r is the normalized radius. The density at the origin of the shield due to outgassing ν_d reduces to

$$n_d(0,0) = (2\sqrt{\pi}/\nu_m')\nu_d \tag{3}$$

The calculated shield densities $n_d(0,0)$, due to outgassing [molecular hydrogen desorbing at 20°C and $v_m' = (2kT/m)^{1/2} = 1.56\times10^5$ cm/s] for the vacuum-processed aluminum are given in Table 2. The lowest value obtained is for the vacuum-degassed aluminum. A shield constructed of this material would result in a density due to outgassing 3.6×10^4 times lower than n_H, the shield density due to the atomic hydrogen flux. This material would still contain the porosity, however, and may result in unwanted pinholes. The most desirable processing for the aluminum would be to go through vacuum melting, thus eliminating the porosity, and then follow with vacuum degassing in the solid state to insure the lowest ultimate outgassing rate and therefore the lowest shield density. Since aluminum is also very light in weight, possesses a stable surface oxide, is difficult to recharge with hydrogen, and can be vacuum processed at relatively low temperatures (<700°C), it appears to be a suitable candidate construction material for an orbiting molecular shield.

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Computer Controlled Operation of Ultraviolet Spectrometer and Polarimeter on Solar Maximum Mission Satellite

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Hardware Organization

Overview

THE Ultraviolet Spectrometer and Polarimeter (UVSP)[1] is one of the instruments on NASA's Solar Maximum Mission (SMM) satellite. This instrument has four optical path mechanisms which control and select solar light reaching

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a set of sensitive photodetectors. The light is controlled in wavelength, polarization, spatial source, and spatial area. All of the optical path mechanisms are electronically interfaced to a computer (CPU) which is part of the UVSP instrument. The motions and settings of the mechanisms are defined as experiments which are controlled by the CPU. The CPU software executes experiments according to directions stored in the memory, which are supplied from scientists on the ground. During experiment execution, the CPU software annotates the science data with header and block messages.

The electronics system consists of several assemblies which are remote from the instrument structure. The interface function is the largest part of the system. It is a collection of electronics which interfaces the computer to the spacecraft as well as to the optical path devices. The spacecraft serves as a source of commands and handles telemetry data. The instrument structure contains the electronics for motor drivers, servo controls, and photomultiplier tubes. The computer and its software are what determine the operating modes for this instrument.

Computer

The computer (CPU) used on this instrument is a small general purpose unit. It was one of two designed and built for the predecessor to the UVSP, the University of Colorado UV Spectrometer,[2] which is aboard the OSO-8 satellite. The CPU contains 4096 words of 16-bit nonvolatile memory, and uses a 31 command instruction set. The CPU internal register complement consists of two 16-bit registers, the accumulator and the input/output (I/O) register, one 10-bit index register, and a segment address register of 2 bits. Memory reference instructions contain 10 bits of address and can access two segments (1024 words each) of the memory.

Command and Data

Information flows in and out of the CPU over a direct memory access (DMA) interface. The DMA is a powerful interface to the computer. This interface supports memory loading and verification. The default mode of DMA continuously dumps a 64-word memory block called the software status buffer. One DMA command function sets a special memory word to a 12-bit value. The CPU polls this word and uses its contents as command information. From this input the software initiates all experiment sequences and controls several other functions as well.

Computer Software

The computer operating system is a single task, interrupt supported, real-time control design. A significant degree of modularity was maintained in the software implementation. A memory size limitation required that reusability have a high priority in producing the code. An example of this is that commonly used instruction sequences as short as two words were implemented as subroutines if they were used frequently enough.

Data Structure

Part of the computer memory is reserved for information loaded by commands from the ground. The first 48 words of this area are a table of pointers called a vector table. This table is split into thirds. One word following the vector table identifies the part in use for the current day of operation. The pointers in the vector table reference the remaining 880 words, which are referred to as the observing sequence area.

The UVSP instrument is directed to perform experiments in groups which are known as observing sequences. Like the vector table, the observing sequence area of the memory is divided into three parts. These are termed observing lists. Each list is an independent set of 16 observing sequences. Two of these lists are alternately loaded and executed on a daily cycle basis. The third list remains loaded with a contingency set of observing sequences which are resident for longer periods of time. The active observing list of the day is selected by a command sent from the SMM spacecraft computer. Any of the 16 observing sequences from the active list can be initiated by a spacecraft information SÇI command.

Instructions and Parameters

Each observing sequence is composed of command mode instructions and parameter blocks. The command mode instruction set has 12 functions. These include experiment initiation, limited integer variable manipulation, conditional and unconditional transfer of control, and initiating other observing sequences. Instructions performing variable manipulation can use input data from two sources. Immediate values are one source and are found following the instruction. Indexed values are from a 32-word user memory area. Each instruction has two 5-bit fields which serve as the source and destination indices. The destination for data manipulation instructions is always the user memory area.

Many of the words in the user area are defined to contain useful experiment results such as the location of the brightest point in the field of view. These variables are updated during experiment execution. The computer monitors the data to obtain the range of wavelength variations due to line-of-sight mass velocity and the range of light intensity found. The associated device positions are also stored for possible use by command mode instructions.

Experiment Parameters

The parameter block for an experiment specifies the ordering of the device control loops. All control loops are not normally active in a given experiment. Parameter block information for each device allows deactivation of that loop. The device handler logic checks for this condition and responds to it as if the cycle is complete.

Each parameter block is a 9-word section of memory and specifies 20 parameters. This information is the computer's input for operating a two axis rastering mirror, a rotating ¼ waveplate mechanism, a diffraction grating wavelength drive, and a selection of the photomultipliers. Parameters are assigned to fixed locations in the block. In general, each device has a step size entry and a step quantity. In addition, starting wavelength drive position information is supplied.

Control Nesting

To examine a software controlled measurement cycle, consider a nested loop structure with several levels. The inner loop is executed most frequently and contains one fixed operation and one variable operation. The fixed item in the inside loop is a subroutine call to measure the light intensity reaching photomultipliers. The variable operation contained in the inside loop is a device handler call. This subroutine may be the device handler for any of the four optical devices. The handler first determines if the loop has completed a specified cycle. If not, a device step is made and control passes back to start a new measurement cycle. If the loop had completed a cycle, first the device handler would reset that device to the beginning point of the desired cycle. Control would then pass to the next outer device handler subroutine. That subroutine completes the same logical sequence as the inner loop. When the loop cycle at any nesting level is incomplete and after device operation, control transfers to the measurement subroutine once again. As many as four of these nested device control loops may be active, plus two special functions. The outside loop is always a repetition control which allows the experiment to repeat.

Two selectable features are available in the software to provide functions of scientific use. A calibration loop applies a periodic offset to the spectrometer wavelength position. The offset is used for an entire cycle of the loops nested inside this loop. This function provides calibration information about the velocity sensitivity by Doppler shift of an atomic emission line. The parameter block indicates the nesting level for the calibration loop and what interval and wavelength offset to use. The other special control function is a software servo to track an ultraviolet emission line over long periods of time. This is useful to compensate for temperature drifts of the instrument structure. The design of the instrument optics allows certain detector pairs to measure different portions of the same emission line. The servo software detects and compensates for the thermal drift by maintaining constant proportions of light measured by a detector pair. The fixed position of this function is immediately before the outer loop, which controls experiment repetition.

Parallel Operation

The power consumption of the entire UVSP instrument was an important concern. Since the variable power consumption is a function of motor stepping rates, control of these rates was required. The step rate of the entire set of electromechanical functions is software limited by an end-off shift of an assigned memory word. The shift period of this word is set by a 16-ms clock interrupt. Each software device handler tests this word before commanding any device steps. If the value of the word is zero, the handler proceeds; otherwise it must wait for the timed shifts to clear the word. The word is set by each device handler to a value proportional to the device's load. While the interrupt routine continues to shift the power delay words, other software activities can proceed in parallel with this delay function.

Another form of parallel functioning was applied to processing data from dual detector experiments. Velocity information can be calculated from these measurements, but it consumes a relatively large amount of time. A speedup of the measurement processing cycle was found necessary after launch. Since no computation is required during a light measurement interval, a portion of the computer's time was unused. This unused time was used by storing the data from a measurement until the next measurement interval when the calculations are performed.

Interrupt Support

The interrupt structure has three priority levels. The highest priority level is caused by a power fail detection circuit. It may not be locked out under any condition. The second level interrupt is associated with DMA operations. The software supports this level with a minimum of overhead. Interrupt level 3 is connected to a general purpose party line. The interrupt service software polls device addresses to identify the source. Possible sources are programmable timers, fixed period clocks, wavelength drive limit switches, day-night transition logic, and others.

The software requires timing information to carry out the experiment control task. Two clock interrupts are used to supply most of the timing and synchronization information. The periods of these clocks are 16 and 64 ms. The longer period is used by the software mainly for data output synchronization. The 16-ms period matches the science data output rate for this instrument. The software uses this to control output data flow. The 16-ms event is also used to test for new SCI commands from the spacecraft. The ELU contains two programmable timers which are used for precision interval timing. These support the photomultiplier measurements and wavelength drive stepper motor motion.

Wavelength Drive Control

The wavelength drive is operated by a combination of software and hardware functions. The wavelength drive steps are triggered by a computer controlled programmable timer. The wavelength drive software controls a ramp which starts at 100 Hz and peaks at 500 Hz. This is required because the stepper motor turns a reduction gear train with significant inertia. The ramp function is defined by data from a table in memory. In addition, the software tracks a motor feedback signal to detect stepping errors. This signal is produced by optically sensing a slit on a disk fastened to the motor shaft. If the slit is not found within a preset range, the software terminates the ramp and attempts to resynchronize the motor position with the software position count.

The software directing this unit is the most time-critical function performed. During wavelength drive motion a short polling list is substituted for the level 3 interrupts to detect the minimum set of external events needed. This polling is done for a variable period of time proportional to and shorter than the motor stepping period. Between each motor step the software calculates the number of polling cycles, allowing for the maximum time required to manage the ramp and rotation tracking. When either all the polling cycles are completed or a clock event signal is detected and serviced, control proceeds to poll for a timer-triggered wavelength motor step. DMA operations function normally during wavelength motion, but software does not recognize experiment control functions from the spacecraft.

Conclusion

This discussion has covered only a portion of the features and complexity of this software. While the operational objectives did contribute to the quantity of programming, the mechanical and electronic constraints caused much of the difficulty in attaining the objectives. The greatest need was for good computer access to timing, synchronization, and device position information.

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Helmholtz Resonator Burners: Analysis for Response Function Measurements

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Nomenclature

A_{nm} = integration constant
a = velocity of sound

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