22. OPTICAL MODULE FOR THE INTEGRATED REAL-TIME CONTAMINATION MONITOR*

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SUMMARY

This paper describes the concept of a real-time contamination monitor and traces the evolution of the optical module component from laboratory model through the engineering evaluation model. Mechanisms employed and problems experienced are described. Current efforts are directed toward a major simplification of design in a unit intended for flight.

INTRODUCTION

With the current and projected use of optics in space, consideration must be given to the possible degradation of optical components by contaminants evolving from the spacecraft. The potentially severe consequences of such degradation have led NASA to the philosophy that "contamination is an engineering environment just like shock or vibration and, as such, must be measured." Beginning in 1966, NASA has maintained a continuing program to develop contamination monitoring equipment and, in 1971, undertook development of an Integrated Real-Time Contamination Monitor (IRTCM).

The integrated module (Figure 1) consists of four independent instruments and an experimental active cleaner. The independent instruments include a quartz crystal microbalance (QCM) for measuring mass accumulation, a residual gas analyzer to identify the contaminant, a particle size analyzer, and an optical module for measuring the degradation of optical properties. This paper describes the evolution of the optical module design.

LABORATORY FEASIBILITY VERSION

In 1970, Convair Aerospace Division of General Dynamics undertook to design and develop a laboratory feasibility version of an optical module for measuring reflectance, transmission, and scattering of optical surfaces in a contaminating environment. The feasibility model (Ref. 1) uses a pair of monochromatic ultraviolet sources to illuminate the sample. To eliminate effects of source and detector gain change, a single photomultiplier sequentially measures incident and specularly reflected beams. Scattered radiation from the sample is collected by a hemiellipsoidal reflector and reimaged onto the same photomultiplier. Figure 2 shows the optical elements and photomultiplier positions for the various measurements.

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Since the ultraviolet radiation employed (1,236A and 1,849A) is absorbed in air, the instrument must be operated in a vacuum. The mechanical design problem thus becomes one of physical manipulation within a vacuum chamber. For manual operation of the feasibility model, magnetic motion feedthroughs were employed. Rotary motions, which included sample and light source selection, used Varian magnetic rotary feedthroughs and conventional CRES ball bearings lubricated with molybdenum disulfide. Both rotary and translational motions were required to move the phototube between the transmission, reflectance, and scattering measurement positions. A push-pull-rotary magnetic feedthrough from Huntington Mechanical Laboratories was used. A soft iron slug on the output shaft of this feedthrough is supported on a rotary bearing which, in turn, is mounted to a wheeled carriage riding on the inside of the sealing tube. An external magnet slides on the exterior of the tube and is free to rotate or translate. Both feedthroughs worked well, although the push-pull operation is mushy when operating with appreciable loads.

In the feasibility model shown in Figure 3, the rotary and push-pull feedthrough can be seen to the right of the vacuum chamber flange; the light source housing, photomultiplier mount, hemiellipsoid, and sample mount wheel are at left.

ENGINEERING EVALUATION MODEL

In 1971, Convair Aerospace began development of an engineering model version of the optical module. It was specified that this instrument employ the same optical system, including the sources and photomultiplier, but that the instrument be fully automated and capable of unattended operation and data printout under computer control. The instrument was to incorporate provisions to electrically heat and monitor the temperature of the samples. Further, since the instrument was intended for use in ATM testing, a rigid material selection criteron was established (Ref. 2).

Since the optical design and sequence of operations were fixed, the task became one of automating the manual manipulations to occur in a specified sequence. The requirement manipulations are:

Open or close doors to expose samples to contaminants, either on command or as part of the measurement sequence. On command, move sample wheel to bring any one of three sample groups to a contaminant exposure position. Rotate sample wheel four positions to bring contaminated group to the measurement station, advance wheel one position for each of four measurements, and return wheel eight divisions after measurement.

Move photomultiplier in both translation and rotation, dwelling for measurement at the transmission, scattered, and reflectance positions. Return to initial position.

Change light source from krypton to mercury source and back after each measurement cycle.

All of these motions can be produced by a clockwise and counterclockwise rotation or by a forward or aft translation, which can itself be produced by a rotating screw. Initially, it was proposed to use the module shown in Figure 4, which consists of the geneva mechanism and segmented gear reverser described in Ref. 3. A breadboard of this device encountered a number of difficulties. Note that the teeth that drive in the forward direction must be completely disengaged before the reverse drive teeth can engage. When the geneva reaches the dwell point, the load is completely decoupled from the drive. If the load shifts even a fraction of a tooth, re-engagement may occur with the teeth meeting tip-to-tip rather than tip-to-valley. Further, even when properly phased the first tooth takes the full load only at the tip and at an angle considerably displaced from the line of centers. Since smooth operation could not be achieved, this approach was abandoned.

An alternative drive module for producing intermittent and reversing motion consists of a pair of geneva mechanisms coupled through a differential (Figure 5). This combination, which operated smoothly and efficiently when breadboarded, was adopted for the engineering model. After assembly of the complete unit, a basic deficiency was discovered: prohibitively high torques were required to move the load. Since ball bearings were used for the shafts and the drive stud, we initially suspected improper gear centers and went so far as to dress the genevas to increase clearance. Still, the effect persisted. The input turned freely until an output load was introduced; then it bound up. The source of the binding is now understood. In Figure 5, note that when Geneva A is being driven through the low-friction ball bearing stud, the torque is transmitted not only to the load, but back through the differential to the locked Geneva B. The binding is produced by friction between the drive wheel and the stationary geneva, which is under load. Note that this effect will occur whenever a geneva is used to support a load and will occur during the dwell interval rather than when the load is being moved. We eliminated this binding by fabricating new geneva drivers having a double row of miniature ball bearing rollers around the periphery of the locking cam (Figure 6). The technique worked very well with the loads involved, though it should be noted that each roller must be capable of withstanding the full torque load and that the roller rather than the drive stud bearing may become the critical component.

A mechanical schematic of the full gear train is shown in Figure 7. With the demise of the mechanical calculator and the poor repute of the cuckoo clock, this may well be the last of the gear train sequencers. The doors for sample exposure and the initial position of the sample wheel, which are under operator command control, employ separate motors with electrical limits. The remainder of the mechanism employs a single motor and automatically sequences the position of the photomultiplier, selection of the light source, and incremental advancement of the sample wheel. The train employs eleven geneva motions and five differentials.

The sequence consists of 32 unique steps which are then repeated. Four sequences are performed to measure each sample group. Completion of the fourth group electrically initiates repositioning of the sample wheel to the contaminant exposure station and opens the contaminant doors. Figure 8 shows the gear train, while Figure 9 shows the complete instrument and Figure 10, the control console with manual controls and the computer for automatic operation and data printout.

OPERATIONAL EXPERIENCE

One major failure was encountered with the instrument and the history of events leading to the failure is instructive. One requirement for the instrument was incorporation of QCMs and sample heaters into the sample wheel. Electrical connections to the wheel used a ribbon wire wrapped into a jellyroll configuration (Figure 11). The ribbon worked properly for the 1-1/3 revolution reversible movement required. End of travel was electrically sensed.

A second requirement of the program was to demonstrate cleanliness of the vacuum rated system by measuring the vacuum obtainable at elevated temperature While we had rigidly adhered to the material selection criteria of Ref. 2 and had specified and used nylon wire ties, a few ties were inadvertently made with waxed tie cord.

The unit was placed in a vacuum chamber, pumped down to approximately 10^{-6} torr, and the exterior of the chamber heated to 250° F with electrical heater tape. The unit was energized to use the temperature sensors incorporated into the instrument.

Since heat transfer was primarily by radiation from the walls, the temperature rise of the instrument was only a few degrees per hour and the bakeout cycle extended over 72 hours of continuous operation. As luck would have it, it reached the melting point of the waxed cord at

3 o'clock in the morning. The pressure, which had been gradually decreasing, suddenly surged up, causing the ion pump to arc. We valved off the ion pump, restarted the roughing pump, and attempted to cycle the instrument. The arcing had destroyed electronic components used to sense the sample wheel position and the end-of-travel sensor failed. The wire ribbon jellyroll continued to wind up, eventually failing the ribbon. Unfortunately, we did not have a spare ribbon and were faced with a delivery deadline tied to the schedule for testing the Apollo telescope mount at Chamber A in Houston. In desperation, we fabricated a substitute wheel harness by bundling wires into a heat-shrinkable sleeve and winding into a helix (Figure 9). The improvised fix worked during the remainder of the tests in San Diego: however, after installation and pumpdown in Chamber A, the instrument failed to operate. Post-test inspection revealed that an upper coil of the helix had expanded when the wheel was unwinding and had dropped over a lower coil. Upon reversal, the helix attempted to tighten but the overlapped loop cinched up on the inner loop, resulting in binding. The conscious application of motor overvoltage in an attempt to break loose the bind eventually burned out one motor and apparently caused insulation damage in the second.

Fortunately, we were not the only ones to experience difficulties during the test. Water cooling lines in the chamber ruptured, producing a rare Texas blizzard and the test was terminated. We were able to return the unit to San Diego and, by then, had obtained additional ribbon wire. We rebuilt the wheel harness to the original configuration and replaced the shorted motor. During the second test at Chamber A the instrument operated for approximately 40 hours under computer control, producing hundreds of print outs. About eight hours before conclusion of the test, the instrument failed while operating unattended. Post-test inspection revealed a failure of the second original motor, presumably due to abuse when subjected to overvoltage during the aborted test. Thus, all failures encountered resulted not from the proverbial horseshoe nail but from a piece of string or – more exactly – from the wax on a piece of string.

FLIGHT ARTICLE SIMPLIFICATION

We are currently performing a study to achieve a major reduction in complexity for a flight article. This simplification is based upon our experience with the previous configuration. Originally, it was feared that the intensity of the ultraviolet sources might be marginal when measuring scattered radiation and that the number of optical surfaces in the light path should be minimized. In practice, we have found it necessary to use a perforated screen with a transmission of only 7% to prevent saturation of the photomultiplier when viewing the impinging beam. By taking advantage of the available intensity, we can introduce an optical crank and eliminate the necessity of moving the photomultiplier. The conceptual design of the optical train for measuring the impinging and specular beam is shown in Figure 12. The sole moving part is the optical rotor, which advances stepwise to each of four positions. No reversal of rotation is required since no electrical leads are needed on the rotor.

Scattered radiation is collected and reimaged on a second stationary photomultiplier. A double-paraboloid collection system (Figure 13) is currently under study as a replacement for the hemiellipsoid. The paraboloids permit positioning of the photomultiplier above the plane of the sample. This allows the samples to be mounted on a drum where electrical connection can be made with the hardwire rotating coupling described in Ref. 4. The coupling permits unidirectional continuous rotation of the sample drum and eliminates the possibility of the overtravel failure encountered on the current model.

An inexpensive demonstration breadboard of the optical train has been fabricated employing filament sources and photoresistors. Figure 14 shows the optical module alone and as assembled into a housing with analog outputs displayed on meters. The conceptual design of the flight unit is shown in Figure 15.

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1. "A Module for Measuring Optical Degradation," AIAA Paper 71-461, AIAA 6th Thermophysics Confernence, Tullahoma, Tenn., April 1971.
2. "ATM Material Control for Contamination Due to Outgassing," 50M02442
3. "Ingenious Mechanisms for Designers and Inventors," Volume III, Industrial Press, 1951, pp 143-145.
4. E.H. Wrench and L. Veillette, "A Hardwire Rotating Coupling," 4th Aerospace Mechanisms Symposium, May 1969.

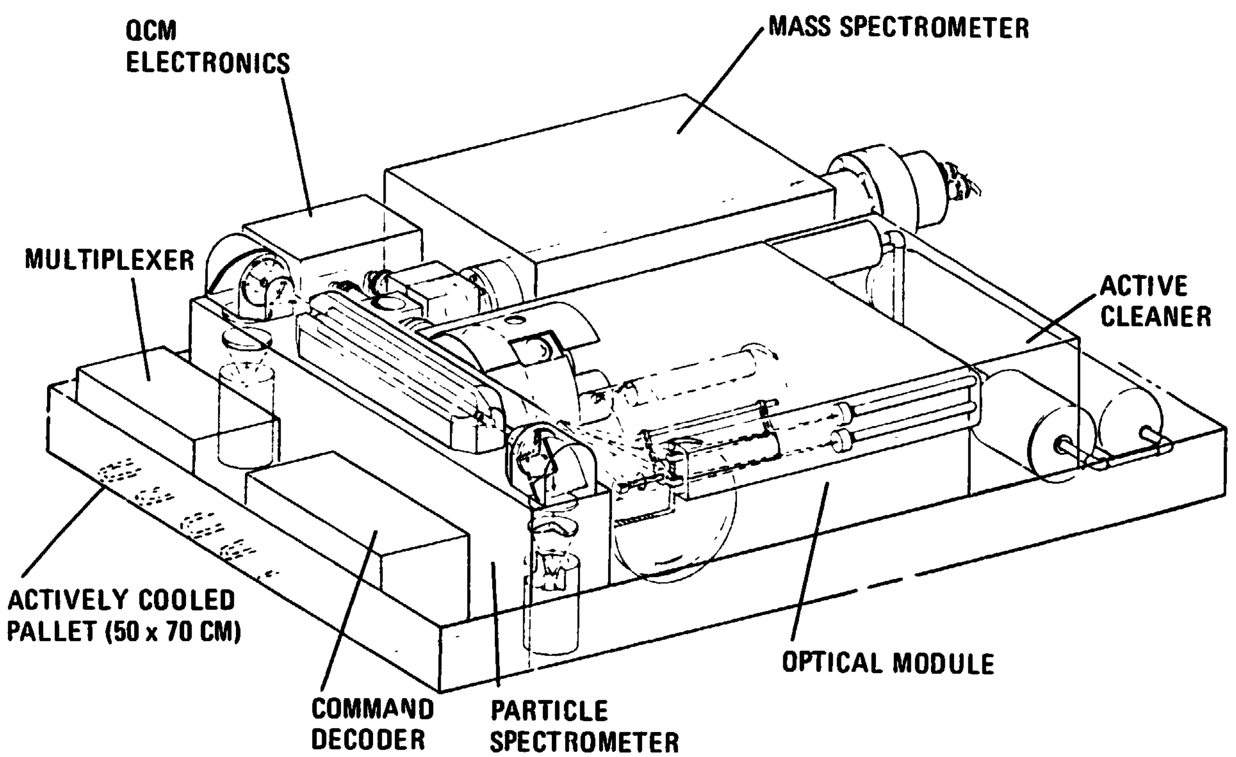
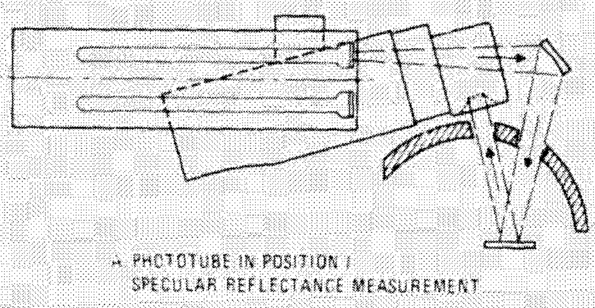
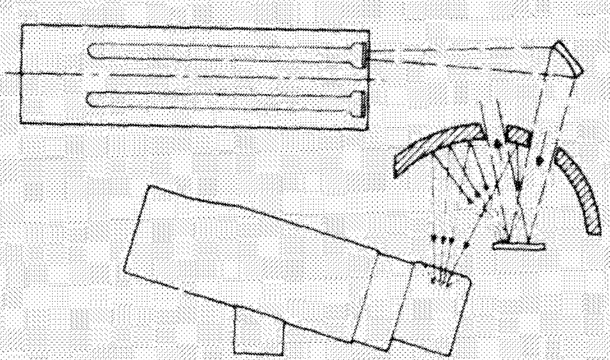


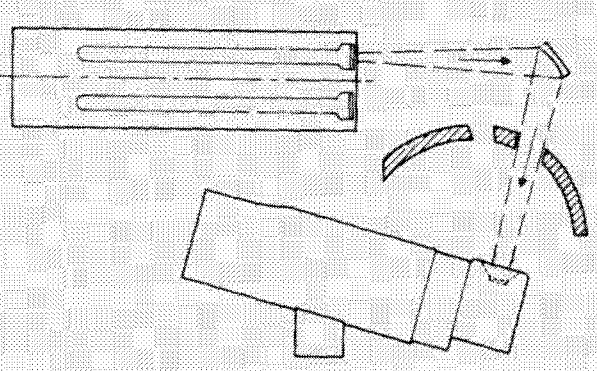
Figure 1.- Integrated real-time contamination monitor.



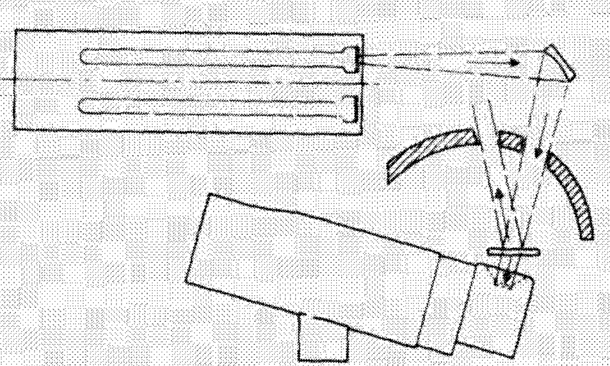
(a) Phototube in position 1 specular reflectance measurement.



(b) Phototube in position 2 scattering measurement.



(c) Phototube in position 3 sample "out," I_o (100%) measurement.



(d) Phototube in position 3 sample "in," transmission measurement.

Figure 2.- Optical design.

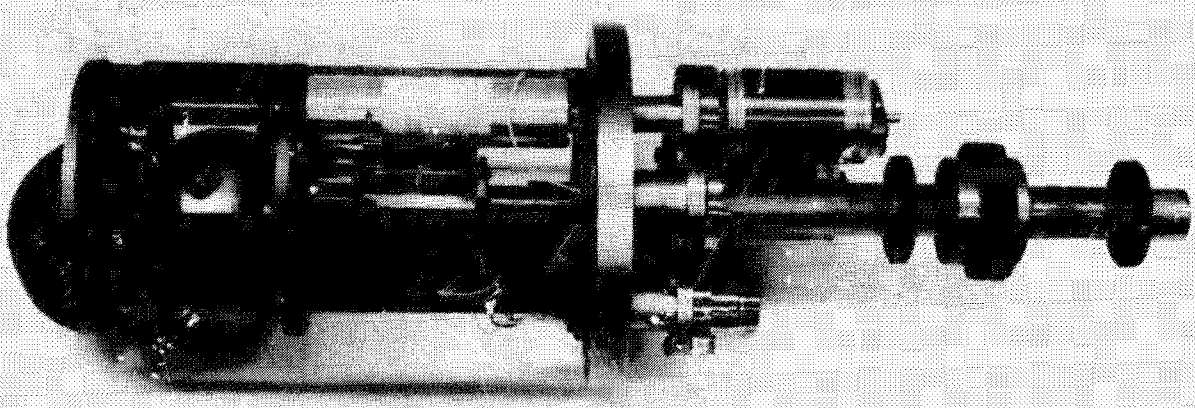


Figure 3.- Feasibility model.

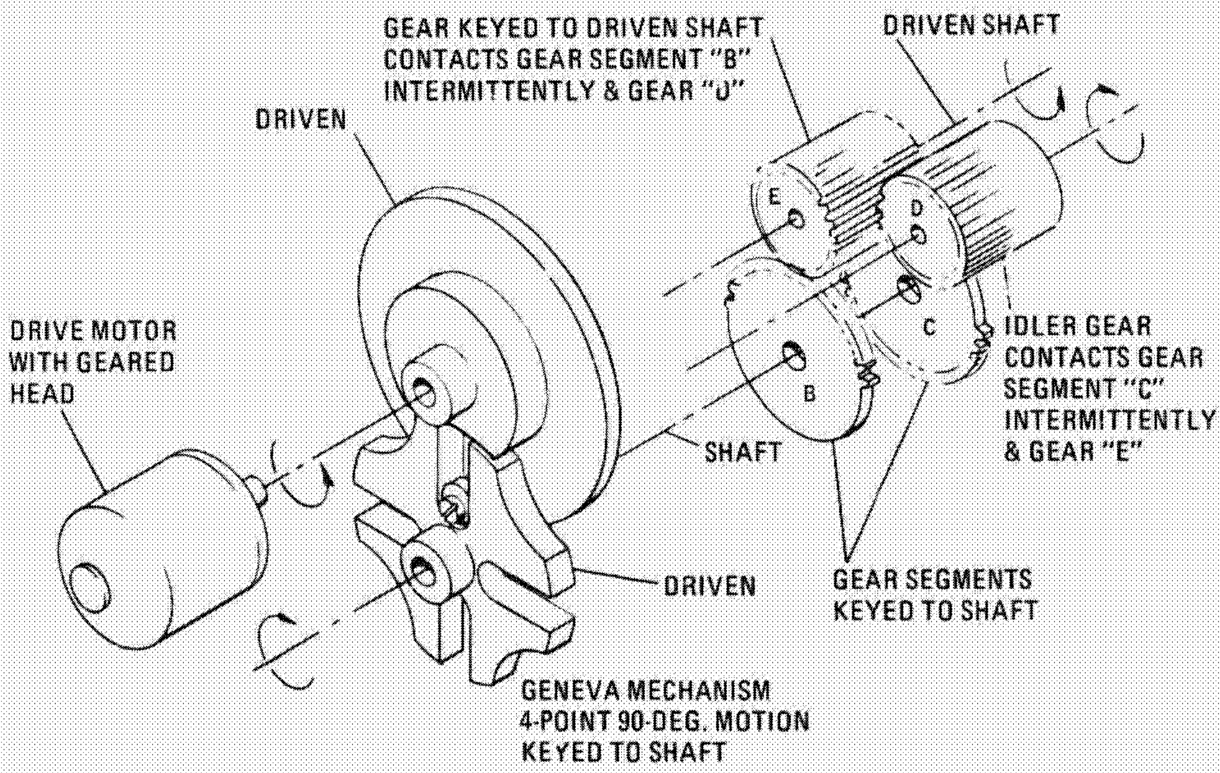


Figure 4.- Module with geneva mechanism and segmented gear reverser.

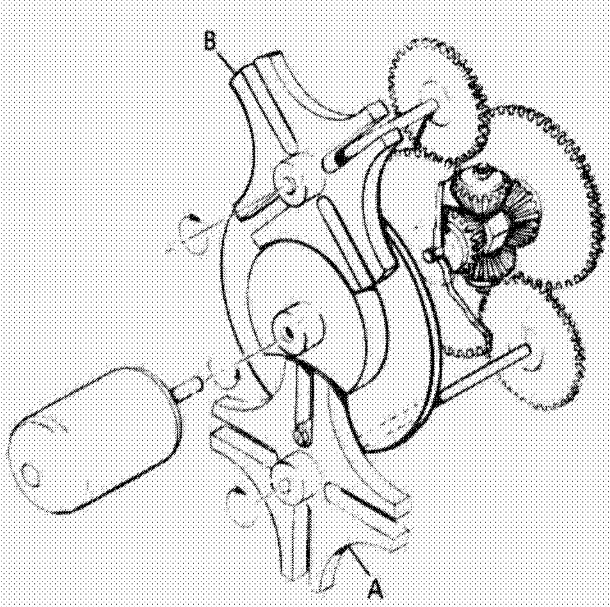


Figure 5.- Genevas with differential.

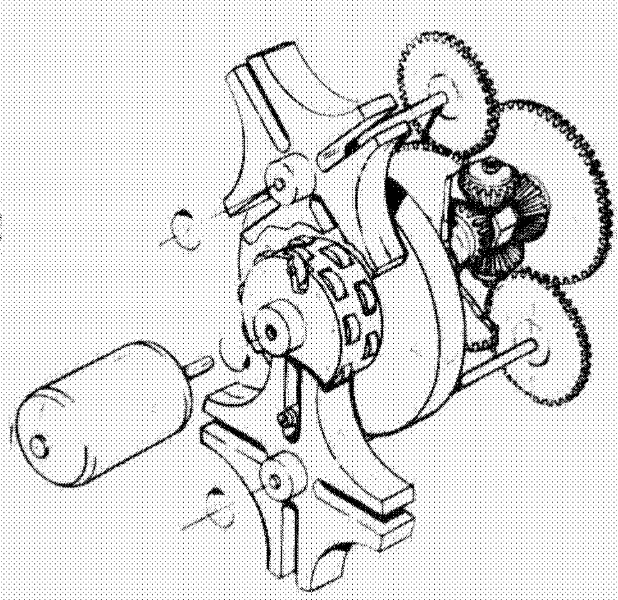


Figure 6.- Ball bearing geneva cam.

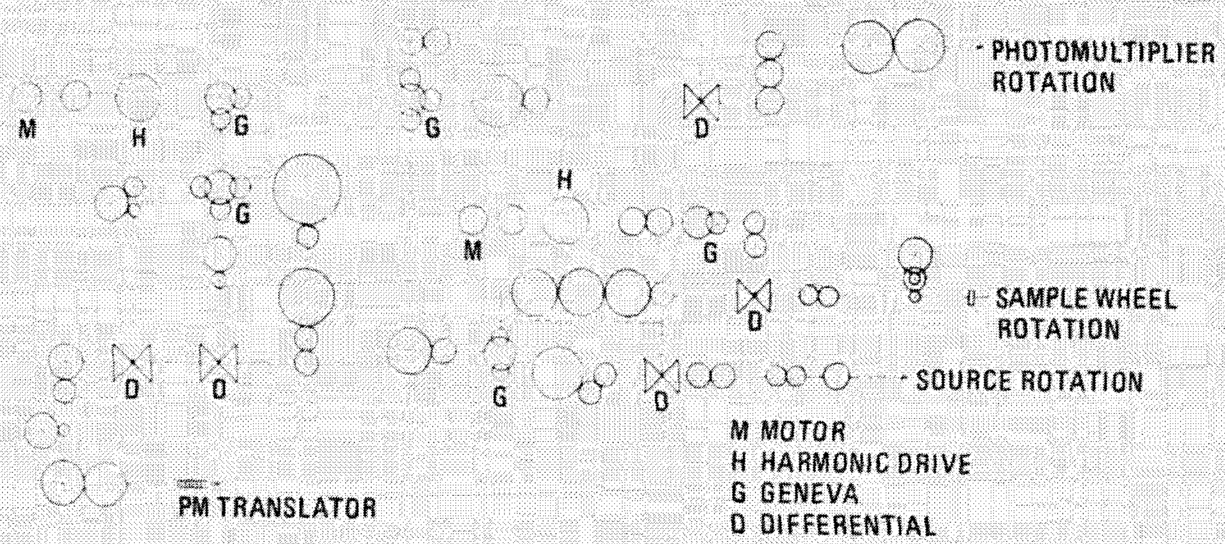


Figure 7.- Mechanical schematic.

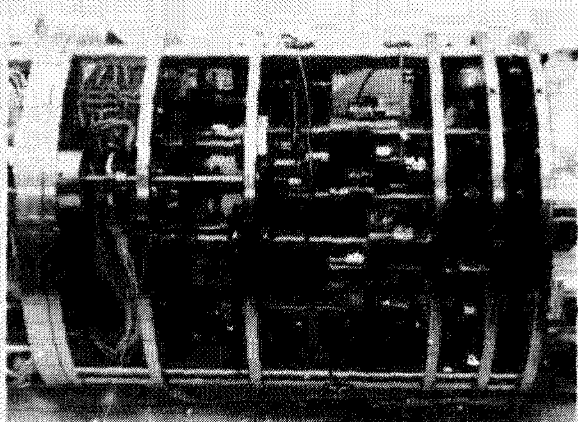


Figure 8.- Gear train.

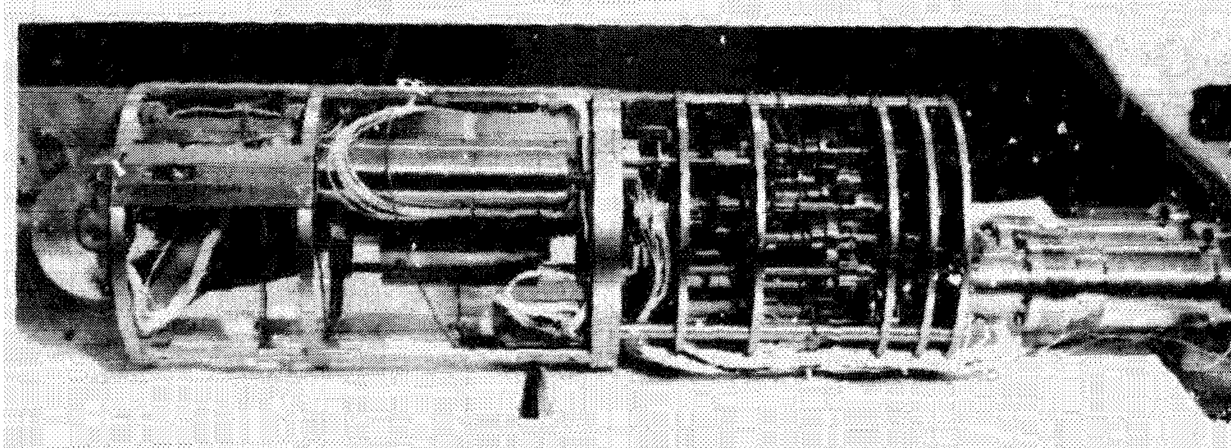


Figure 9.- Engineering model.

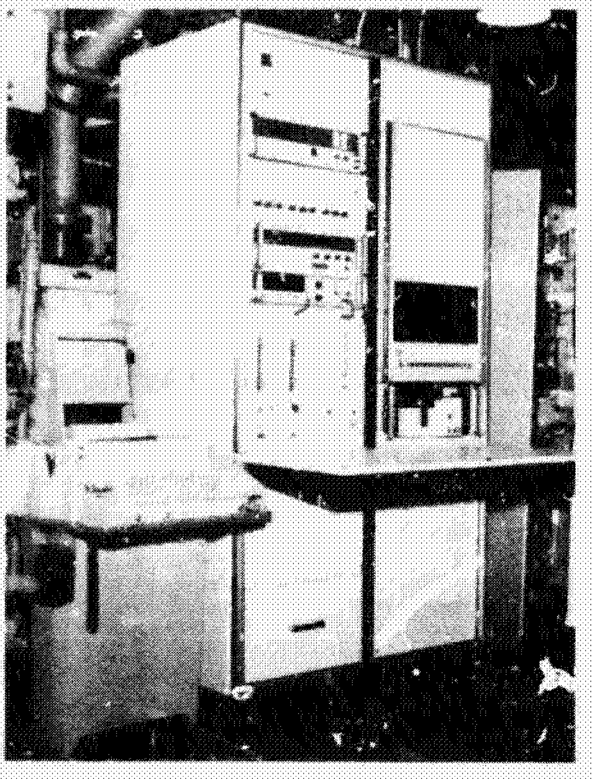


Figure 10.- Control console.

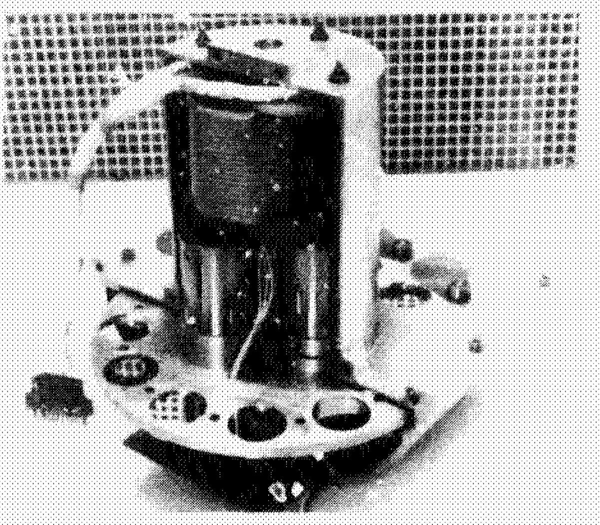


Figure 11.- Sample wheel.

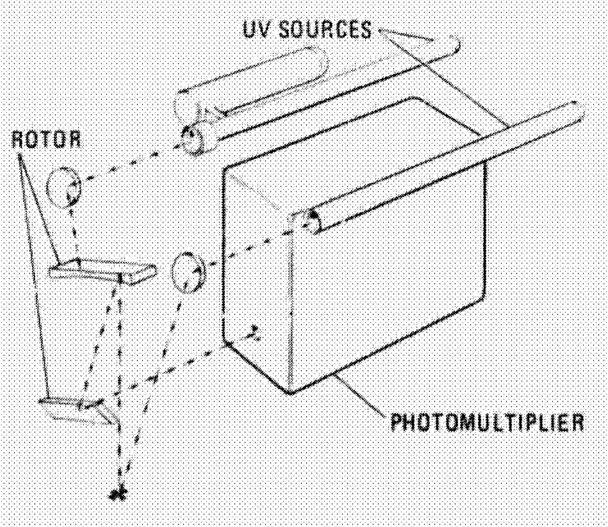


Figure 12.- Specular reflectance measurement.

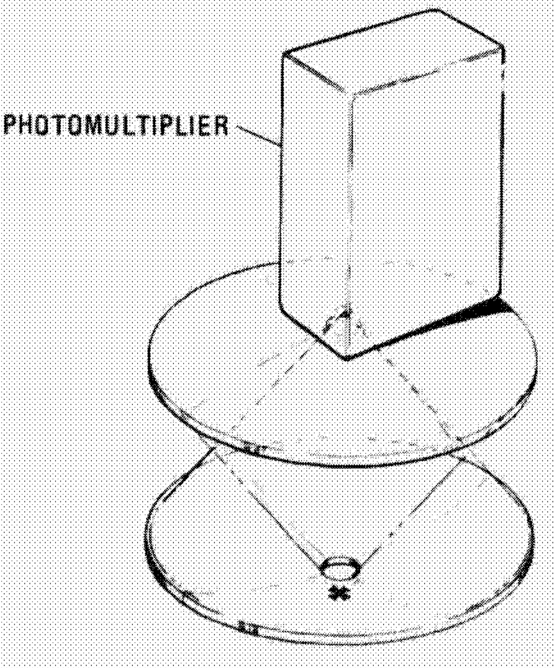


Figure 13.- Scattering measurement.

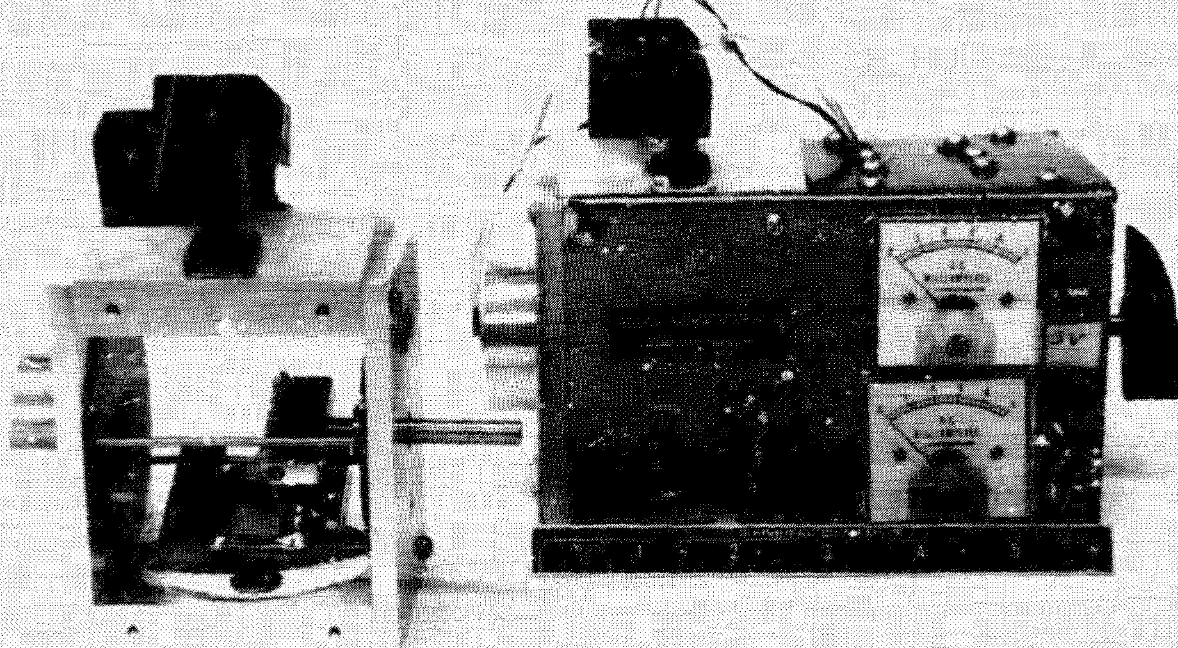
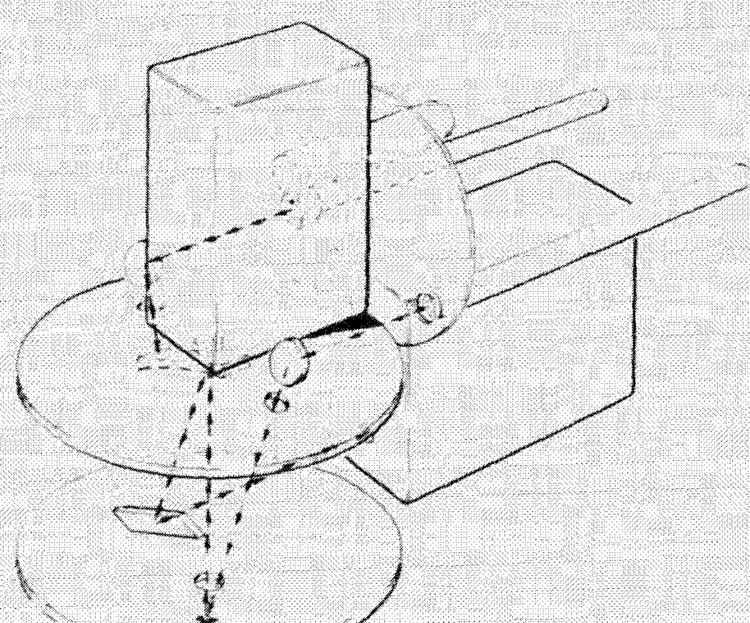


Figure 14.- Breadboard of conceptual design.



'igure 15.- Flight article preliminary design.