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FIBEROPTICS TECHNOLOGY AND ITS APPLICATION TO PROPULSION CONTROL SYSTEMS

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Abstract

Electro-optical systems have many advantages over conventional electrical systems. Among these are optics' insensitivity to electromagnetic interference, good electrical isolation, and the ability to make measurements in highly explosive areas without risk. These advantages promise to help improve the reliability of electronic digital engine control systems in future aircraft. To improve the reliability of these systems, especially against lightning strikes, passive optical sensors and fiberoptic transmission lines are being considered for use in future engine systems. Also under consideration are actuators which receive their command signals over fiber optic cables. This paper reviews concepts used for optical instrumentation and actuation systems and discusses work being done by NASA Lewis Research Center in this area.

Introduction

The number of concepts for measuring physical parameters using optics has increased dramatically in the past few years. This is due in large part to the great strides made by the communications industry in component improvements, especially in the area of fiber optics and integrated optical circuits. Optics has desirable advantages over electrical systems such as immunity to electromagnetic interference, good electrical isolation, and no fire risk. Optical measurements use phase, amplitude, wavelength, or polarization modulation to measure physical parameters such as pressure, temperature, position, magnetic field, and electrical current. Many optical sensor schemes have been demonstrated in the laboratory and some prototypes have been built and tested. Before widespread use of optical sensors occurs, more work must be done on fiber coatings, sources, detectors, and packaging.

Optical sensors for measuring acoustic pressure and magnetic fields using phase modulation are well documented as are amplitude modulating sensors for measuring temperature and rotation. Various instrumentation schemes are compared for sensitivity and performance.[1,2]

Optical sensors with fiber optic transmission lines promise improved reliability for propulsion control systems. Future engine control systems are expected to be all electronic, without hydromechanical backup. Special precautions have to be taken to guard the electronic control against lighting strikes. Electrical wire systems must be heavily shielded and special circuitry is needed to protect the electronic control against damage from lightning. Fiber optics promises a viable alternative to the conventional wire systems since fiber optic cables are not electrical conductors and are resistant to electromagnetic interference. In addition to sensing, optics can be used to control actuators either as switching signals to control locally generated electrical power or as a source of power to supply electrical power to drive the actuators.

A conceptual fiber optic controlled engine (FOCE) is shown in Fig. 1. The electronic computer, optical sources, and detectors are located in a controlled environment. Fiber optic cables connect the computer to optical sensors and to optical-electrical converters at the actuators. The sensors measure such engine parameters as pressure, temperature, speed, actuator position, and may, in some cases, measure turbine tip clearance. The computer accepts these measured signals, computes and outputs electrical signals to the light sources which generate optical signals that are used to drive the actuators.

The environment in the nacelle is severe with temperatures ranging from -55° to 260° C. The fiber optic cables and connectors must operate reliably under these conditions. This paper discusses work being done by NASA Lewis Research Center on optical sensors and optically controlled actuators for use in airbreathing engine control systems. The status of fiber optics technology for use in this engine environment is reviewed.

Sensors

The first passive optical sensors to be built and tested at NASA Lewis were a tachometer and rotary position encoder built by Spectronics, Inc. Fig. 2 shows these instruments. The optical tachometer is a 9-pulse/revolution sensor and the rotary encoder is a 9-bit word Gray code sensor which measures 360° of rotation. Both sensors were installed on an F100 engine with a 3.65-m cable connecting the sensors to the electronics box that contained the sources and detectors. The sensors operated without failure for over 100 cumulative hours of engine testing.

When airfoil tip clearances in compressors and turbines are excessive, component performance and efficiency are adversely affected. To decrease this loss closed-loop tip clearance control can be used. Optical sensing of tip clearances is attractive for the reasons previously cited. An optical tip clearance sensor, shown in Fig. 3, was built and tested in the laboratory by General Electric under contract to NASA Lewis. Fiber optic bundles direct light to the sensor and carry the modulated signal to the detectors. Light from the input bundle is directed across the gap between the engine case and blade tips and is imaged onto a coherent output bundle which transmits the signal to the detector array. As the blade intercepts part of the light beam directed between the source and detector fibers, light that normally would fall on the detector bundle is blocked. Blade clearance is determined by the position of the boundary between light and dark areas on the detector array. The laboratory tests on the tip clearance sensor were conducted with a compressor rotor stage driven by an electric motor.[3]

Two concepts for measuring engine gas temperatures using optical techniques are the Fabry Perot interferometer[4] and the intensity modulated rare-earth sensor.[5] In the Fabry Perot sensor shown in Fig. 4, a spectral amplitude modulation is produced by multiple interference of a broad band input spectrum. The modulation is related to the resonator thickness which is a function of temperature. A metallic cylinder controls the spacing between two parallel mirrored surfaces whose faces are partially transmitting and partially reflecting. The Fabry-Perot principle provides for multiple reflections between mirrored surfaces. The maximum transmitted intensities occur at wavelengths for which the resonator gap $d = N\lambda/2$ where N is the order of interference.

The modulated spectrum produced by Fabry Perot is passed through a prism which separates the spectral components according to their wavelength. The dispersed spectrum is focused on the face of a 128-element linear CCD array. The output from the CCD array is converted to 128 8-bit digital words and fed into a microprocessor. Algorithms are then used to determine the maximum intensity wavelengths, which are then correlated to resonator gap thickness and hence temperature. This sensor is being built by OPCOA Inc. (Anaheim, CA) under contract to NASA Lewis. This sensor is being designed to measure temperatures to 1000° C. A prototype model, Fig. 5, was built and tested to temperatures of 575° C.

Another sensor measures temperature by measuring the change in light intensity as it passes through a rare-earth material. This sensor is being developed by United Technologies Research Center under contract to NASA Lewis. Rare-earth materials were chosen for the sensor because they have numerous absorption lines in the visible and near IR spectrum. Absorption lines result from optical transitions originating in the electronic ground state of the ion and from low lying excited states. The population distribution of ions is a function of temperature. The strength of the absorption is proportional to the populations of ions in the state from which the absorbing transition originates.

Figure 6 shows some of the energy levels of europium. Absorption peaks arise from the transition from the low lying states to the $^5D_0$ and $^5D_1$ states. The expected distribution of ions in the lower states as a function of temperature is shown in Fig. 7.[4] The population of the ground state N_0 decreases with temperature. The $^7F_2$ state (N_2) shows a population that increases with temperature. Absorption lines that originate in this state would increase in strength as temperature increases.

The physical configuration of this rare earth sensor is shown in Fig. 8. This configuration uses a YAG host doped with neodymium rather than europium-doped glass because this sensor is designed for much higher temperatures (>1000° C) than glass can stand. A sensor using this configuration is currently being designed for testing in a turboshaft engine (Fig. 9) in between the gas generator turbine and the power turbine. To measure temperature by measuring the change in intensity of a light signal a separate wavelength, at which there is no temperature dependent an absorption, is used to factor out the losses in the cable and connectors.

Actuators

United Technologies under contract to NASA Lewis has fabricated a high-temperature photoswitch and tested it over the temperature range -55° to 260° C. The photoswitch is used to turn on an electrical current in response to an optical signal. The electronic components are made of gallium arsenide and are designed to switch up to 100 mA of current with an off-state voltage of +20 V. The configuration is shown in Fig. 10. A power supply is connected to a torque motor through a JFET power transistor. The gate of the JFET is connected to the circuit containing the phototransistor. When an optical signal is applied to the photo transistor the

JFET turns on allowing current to flow through the torque motor. The torque motor drives a hydraulic servovalve which in turn supplies power to an actuator. Figure 11 shows the test phototransistor, diode, and JFET power switch. These components have been tested over temperatures from -55° to 260° C with satisfactory results.

An evolution of the system in the previous figure is shown in Fig. 12. In this scheme no local power supply is required at the torque motor. Optical power is transmitted to the actuator and converted to electrical energy by a photovoltaic type device. Studies are now under way to evaluate the optical power transmission and conversion scheme. A detailed evaluation of light sources and detector-converters will define more precisely the practical aspects of this approach.

Cables and Connectors

The development of rugged, reliable optical cables and connectors is still needed before fiber optics can be seriously considered as a replacement for electric cables. An optical cable made of glass core and glass cladding usually has a buffer material applied to the cladding to give the optical fiber protection. Most available cables come with buffer material that breaks down at temperatures above 125° C. There is in-house work going on at NASA Lewis to develop connectors and cables capable of operating reliably over the temperature range of -55° to 260° C. Two types of connectors are being used (see Fig. 13). The ITT connectors and Hewlett Packard connectors shown are made of metal and are both butt type couplers. The ITT connector has a jeweled ferrule into which the fiber fits. Both have alinement sleeves that maintain the proper position between the two connectors. The material used to hold the cable in the connectors is EPO-TEC 353ND which has a low viscosity for easy flowing and high operating temperature capability. The cables that are being tested are 100- and 200-μm core cables. Current research on buffer materials indicates that polyimides or silcone rubber with teflon jackets have the most potential for success. The high-temperature testing of cables and materials is being done in-house at NASA Lewis.

Discussion

The advantages of optics over conventional wire systems used for sensing and actuator control have potential for improving the reliability of digital electronic control systems. The immunity of fiber optics to EMI and its good electrical isolation are especially important because the electronic control system must be protected from damage by lightning. In conventional wire systems heavy shielding and special pulse-arresting circuitry must be used. With fiber optics and optical sensors this could be eliminated.

The fiber optic cables to be used in jet engine applications require special high-temperature buffers. Fiber coatings currently available are generally for low-temperature applications. Components for use on the air-breathing engine must operate reliably over temperatures from -55° to 260° C. Significant progress has been made in developing the various components needed for the fiber optic engine control system. More engine test experience and system integration effort is needed before fiber optics can be considered a practical alternative to electric sensing, actuation, and cabling technology.

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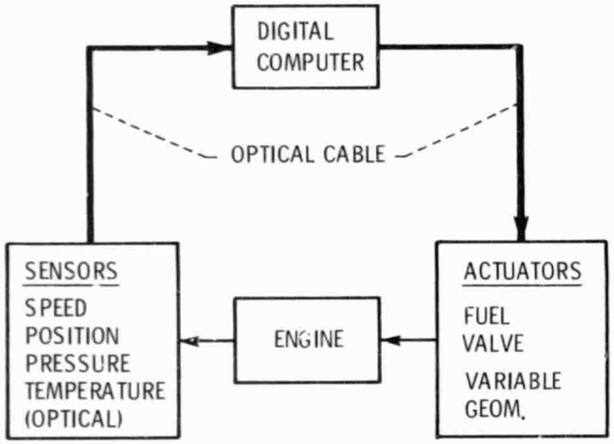

Figure 1. - Fiberoptic controlled engine (FOCE).

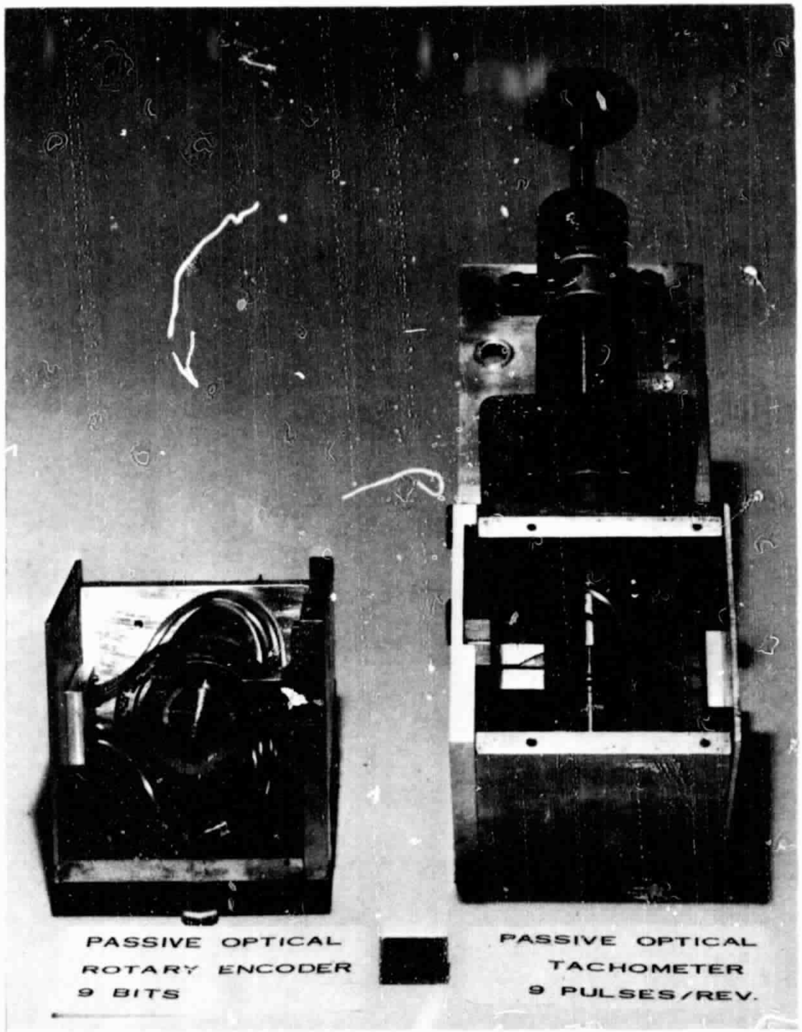

Figure 2. - Optical rotary encoder and optical tachometer.

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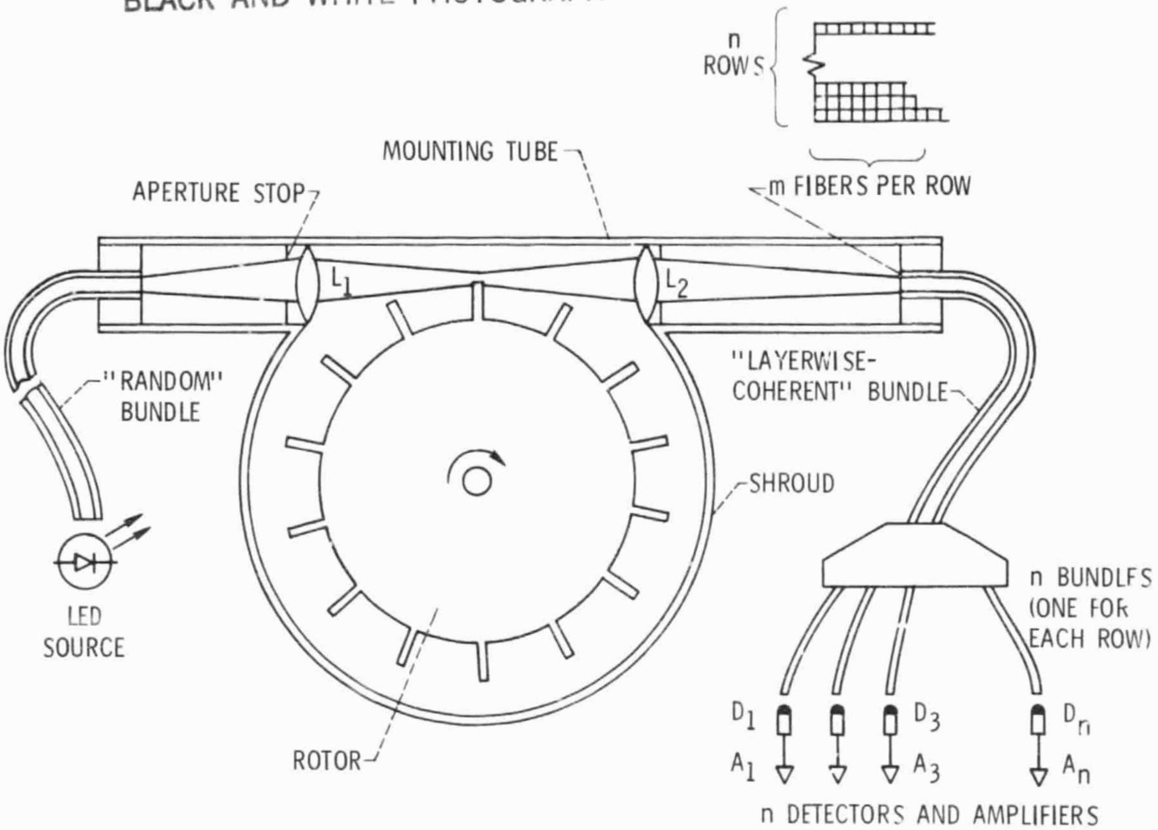

Figure 3. - Optical tip clearance sensor.

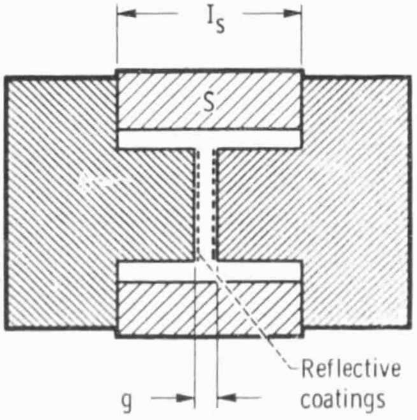

Figure 4. - Temperature sensitive gap for use in Fabry-Perot temperature sensor.

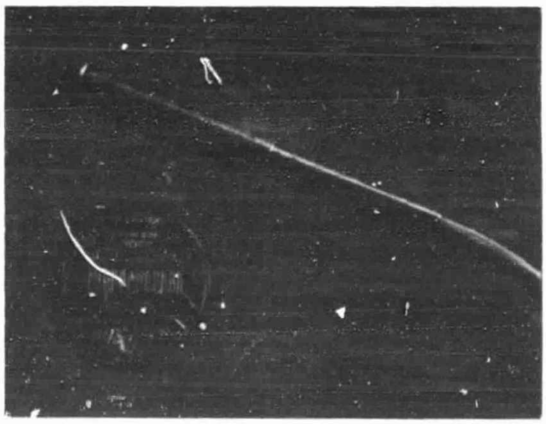

Figure 5. - Fabry-Perot temperature sensor.

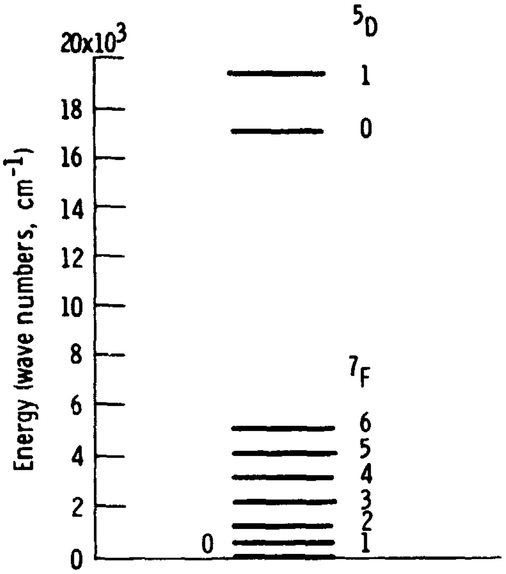

Figure 6. - Energy level diagram for europium in glass.

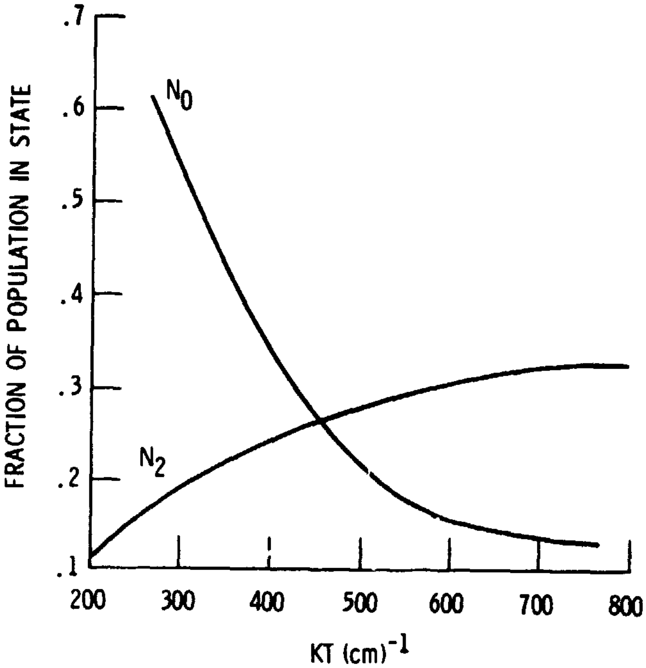

Figure 7. - Population of ground states of EU^{3+}.

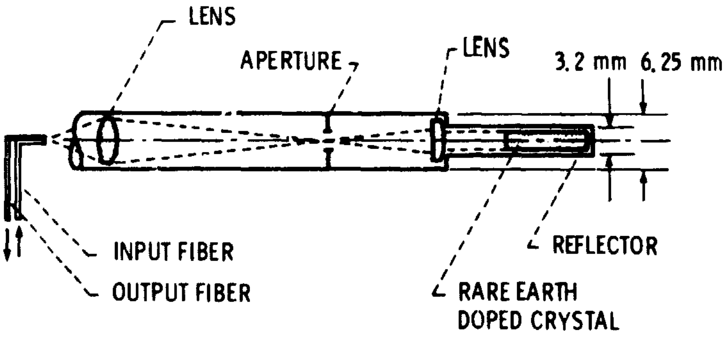

Figure 8. - Schematic of (yag doped with neodymium) temperature sensor.

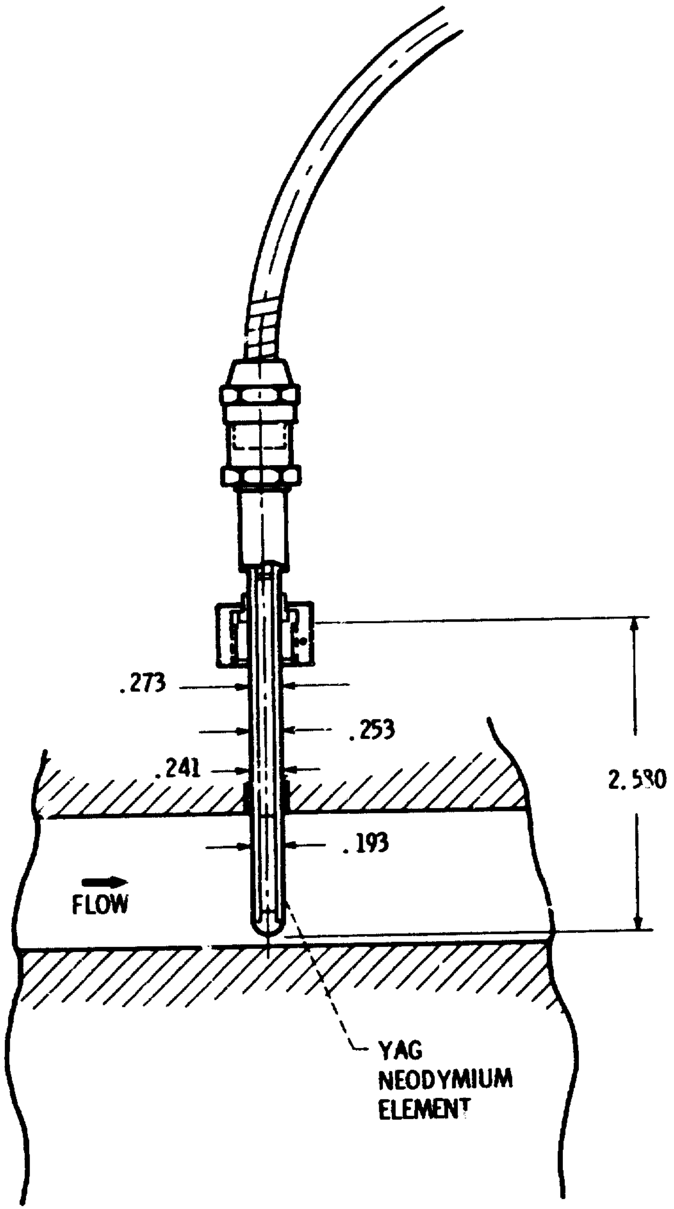

Figure 9. - Rare-earth temperature probe.

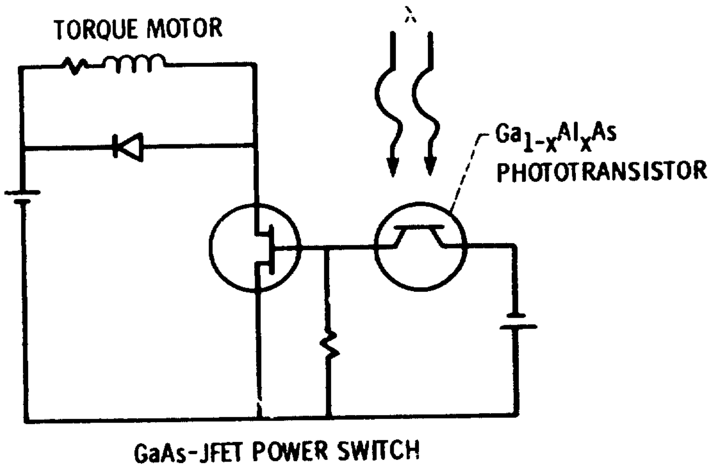

Figure 10. - Light on, power switch off.

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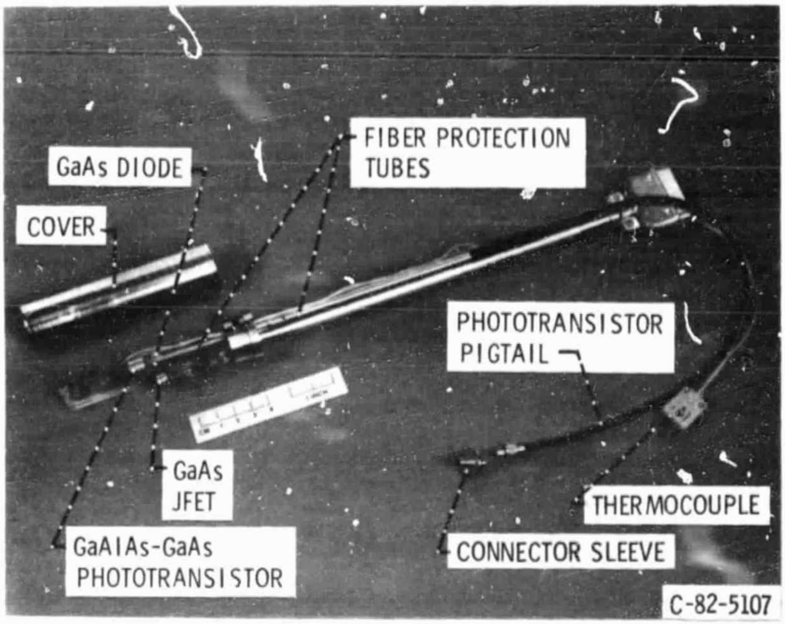

Figure 11. - High temperature photo-switch hardware.

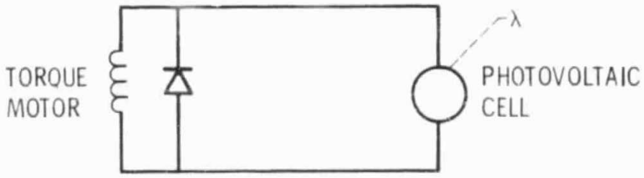

Figure 12. - Direct optical power conversion through photovoltaic cell.

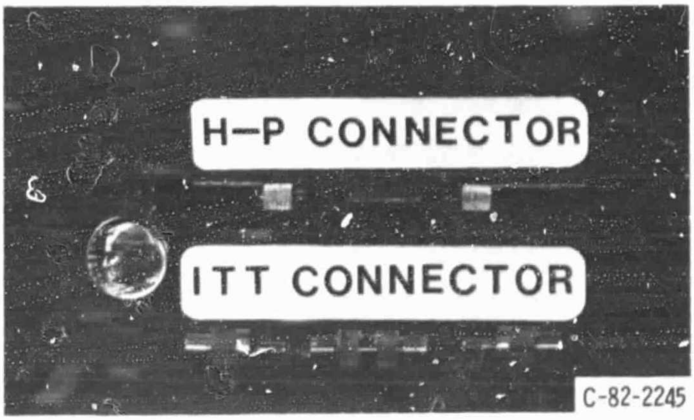

Figure 13. - 100 µm Fiber-optic connectors.