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STATUS OF FIBEROPTICS TECHNOLOGY FOR PROPULSION CONTROL SYSTEMS

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Summary

Lightning and other sources of electromagnetic noise can be detrimental to digital control systems. Heavy shielding of transmission lines from sensors to computer is required to prevent electromagnetic pulses from making their way into the computer via the metallic transmission lines.

Fiberoptic transmission lines are inherently immune to EMI noise and offer a potential alternative to heavy shielded metallic cables. Optics can also be used to measure engine parameters such as temperature, pressure, speed and actuator positions. The resulting optical signals can be transmitted over fiberoptic cables to electronic computers located in a controlled environment.

Optical signals can also be used to control actuator motion, either as switching signals, which control power from local sources, or as a source of power to drive the actuator directly.

This paper discusses work being done by NASA Lewis Research Center in the area of optical sensors and optically controlled actuators for use in airbreathing engine control systems. The environmental conditions, in which the aircraft will operate, require the fiberoptic cables and optical connectors to perform reliably at temperatures over the -55° to 260° C range. The status of fiberoptics technology for operation in this environment is reviewed.

Introduction

The use of optical sensors and fiberoptic data transmission promises to improve the reliability of propulsion control systems because of optics' inherent immunity to electromagnetic interference. Lightning and other sources of electromagnetic noise can be detrimental to digital electronic control systems. Since future engine control systems are expected to be entirely electronic, without hydromechanical backup, all metallic transmission lines between sensors, actuators, and the control computer will have to be heavily shielded to prevent transmission of lightning induced pulses to the computer.

In an effort to improve control system isolation from electromagnetic disturbances passive optical sensors together with fiberoptic data transmission are being considered for use on future digitally controlled propulsion systems. These sensors would measure engine parameters such as speed, actuator positions, temperature and pressure.

A fiberoptic controlled engine (FOCE) is shown conceptually in figure 1. The electronic computer communicates with engine sensors and actuators via optical signals transmitted along fiberoptic cables. Passive optical sensors measure engine parameters and transmit these signals to the computer. Optically controlled actuators respond to signals from the computer. The actuator power can either be generated locally and controlled via optical signals or the power can be supplied directly by the optical signal itself.

The environment in the nacelle will be severe with temperatures ranging from -55° to 260° C. Optical fibers and connectors must operate reliably in this environment. This paper discusses work being done by NASA Lewis Research Center in the area of optical sensors and optically controlled actuators for use in airbreathing engine control systems. The status of fiberoptics technology for use in the engine environment is reviewed.

Sensors

In current electronically-controlled engine configurations all engine parameter measurements, with the exception of pressure, are transmitted electrically from engine mounted sensors to the computer. Pressure sensors are usually located in the same box as the computer. Pneumatic signals from the engine are directed to the pressure sensor via tubes which could be nonmetallic to prevent a conductive path for lightning to the computer box. Temperature measurement in the turbine region is currently accomplished with thermocouples. Likewise position and speed are measured electrically. These signals are directed to the computer via metallic conductors. These conductors must be heavily shielded to prevent damage to the electronic control from lightning. The use of fiberoptics along with optical sensors promises to improve the reliability of the control system by improving isolation from electromagnetic disturbances.

The technology of optical encoders and tachometers is relatively mature compared to other types of optical sensors, although significant development effort is still needed to integrate these components into an engine control system. Two passive optical sensors for measuring rotary position and speed have been built and tested on an engine in an altitude facility. The rotary encoder is 9 bit 360° encoder. The tachometer is a 9 pulse per revolution encoder. More detailed information on these sensors is presented in reference 1.

A review of work to develop optical pressure, temperature, and liquid level sensors for aerospace applications is presented in reference 2. One class of sensors currently being worked on by NASA LeRC are optical sensors to measure turbine gas temperatures. One concept discussed in reference 2 is beyond the proof of concept stage. This sensor uses rare-earth elements whose optical transmission characteristics are a unique function of temperature. This sensor is being developed for NASA by the United Technologies Research Center (UTRC). In this scheme glass is doped with a rare-earth, europium, and drawn into a fiber. Changes in transmission through the doped fiber are measured. Rare-earth materials like europium have energy levels located relatively close to the ground state. These states are optically connected to higher excited states with energy differences corresponding to wave lengths in the visible region. The absorption peaks correspond to

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energy transitions between the ground states and the higher excited states. The amount of absorption is proportional to the population of ions at the level where the absorbing transition originates. The population distribution of ions is a unique function of temperature. An experimental section of europium doped glass was fabricated for a proof of concept demonstration (fig. 2). Two wavelengths of light are transmitted via the optical cable to the sensors. One wavelength passes through the rare-earth. It's transmission characteristic is a function of temperature. The other wavelength is not affected by the rare-earth material and thus represents a reference wavelength to factor out the cable and connector losses. Laboratory tests of this sensor included operation up to 400° C. Accuracy and resolution of this laboratory model were better than 1%.

A rare-earth temperature sensor is being developed by UTRC for testing in a turboshaft helicopter engine. The engine, figure 3, is a GE-T700 turboshaft engine with a 5 stage axial and a single stage centrifugal compressor. The compressors are driven by a two stage air cooled gas generator turbine. A tandem two stage, uncooled power turbine drives the helicopter rotor. The optical temperature probe will be installed in an existing thermocouple hole at a location in between the two turbines as shown in figure 4. The maximum temperature in this region is expected to be about 850° C.

The sensor being developed for engine testing is designed to measure temperatures up to 850° C. The configuration chosen for this sensor is shown in figure 5. The sensing element is neodymium embedded in a YAG (Yttrium Aluminum Garnet) host material, instead of glass, because YAG has a higher melting point. Sapphire lenses are used to focus the light into the sensing element and back into the receiving cable. The probe designed to hold the rare-earth sensor is shown in figure 6. The fiberoptic cables carry the signal to the sensor and return the modulated signal to the detector. The fibers are quartz and have 200 μm cores.

Reference 3 discusses in more detail the rare-earth temperature sensor developed by United Technologies Research Center (UTRC).

Actuators

The illustration shown in figure 1 implies the FOCE uses optically activated actuators. The actuators considered here are two stage electro hydraulic servovalves that drive hydraulic pistons. Minimum power levels required to operate servovalve torque motors is 60 μW. This power requirement can be higher depending on the valve size. However, even the minimum power requirement is considerable for optical transmission and conversion. Two configurations for optically controlled actuators are shown in figure 7. One configuration, (7a) requires a local source of electric power. The optical signal is used to operate a photoswitch which controls the flow of electrical energy to the torque motor. The second configuration (7b) implies that sufficient optical power can be transferred to and efficiently converted by an opto-electric converter to drive the torque motor of the servo valve. This latter configuration does not require a local power supply.

UTRC has built a model of a high temperature photoswitch which controls power to a servovalve. This system, similar to the configuration shown in figure 7(a), consists of components shown schematically in figure 8.

This system consists of a diode to protect the electronics from the inductive load, a JFET power switch and phototransistor. All these components are made of gallium arsenide because specifications for this system require operation at high temperature (260° C) for extended periods of time. A photograph of the high temperature photoswitch is shown in figure 9. This photoswitch has the capability to switch up to 100ma of current with off state voltage of 20 V.

The second configuration (optical power transmission) is more difficult to realize because the level of technology is not sufficient to efficiently couple high power light sources into optical fibers and to efficiently convert the transmitted optical power into electrical power. Further research in these component areas is required. Higher output light sources, low loss couplers and more efficient optical to electrical converters are required before this type of system becomes practical.

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° C to 260° C. Two types of connectors are being used. These are shown in figure 10. The ITT connectors and Hewlett Packard connectors shown are made of metal. Both are butt type couplers. The ITT connector has a jeweled ferrule into which the fiber fits. Both have alignment 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 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

Optical sensors, optically controlled actuators, and fiberoptic transmission lines offer advantages over electrical systems because of optics' inherent immunity to EMI and lightning induced currents. This is important when digital control systems without hydromechanical backup are used. Work sponsored by NASA in optical temperature sensors and optically controlled actuators has been presented. Further work areas are identified in order to realize power transmission and conversion without the need for local power supplies.

The fiberoptic 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 air-breathing engines must operate reliably over temperatures from -50° to 260° C. Significant progress has been made in developing the various components needed for fiberoptic 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.

REFERENCES

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2. Baumbick, R. J., Alexander, J., Katz, R., and Terry, J.; "Optical Sensors for Aeronautics and Space," NASA TM 81407, National Aeronautics and Space Administration (Cleveland, Ohio), January 1980.

3. Morey , W.W., Glenn, W. H., Decker, R. O., McClurg, W. C.; "Design Fabrication and Testing of an Optical Temperature Sensor," NASA CR 165125, United Technologies Research Center, East Hartford, CT (1980).

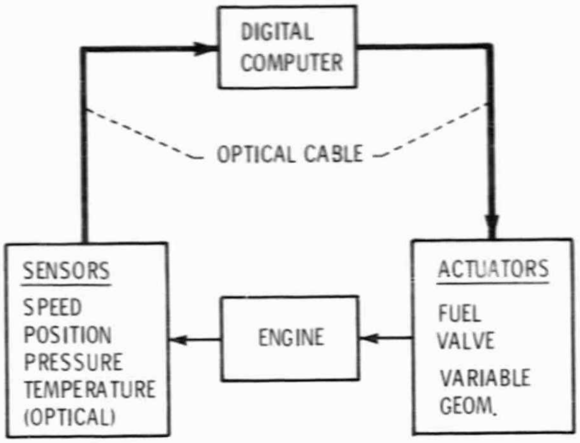


Figure 1. - Fiberoptic configured engine (FOCE).

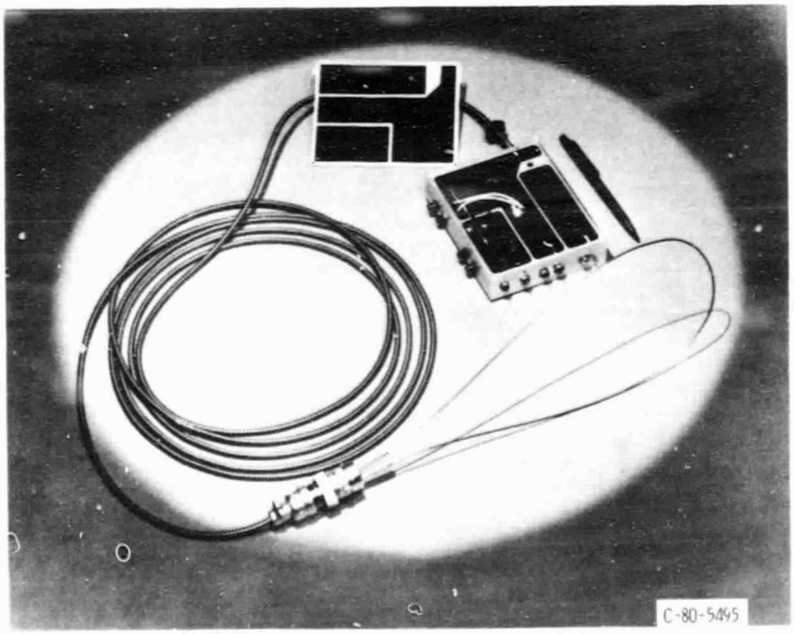


Figure 2. - Optical temperature sensor using europium-doped fiber.

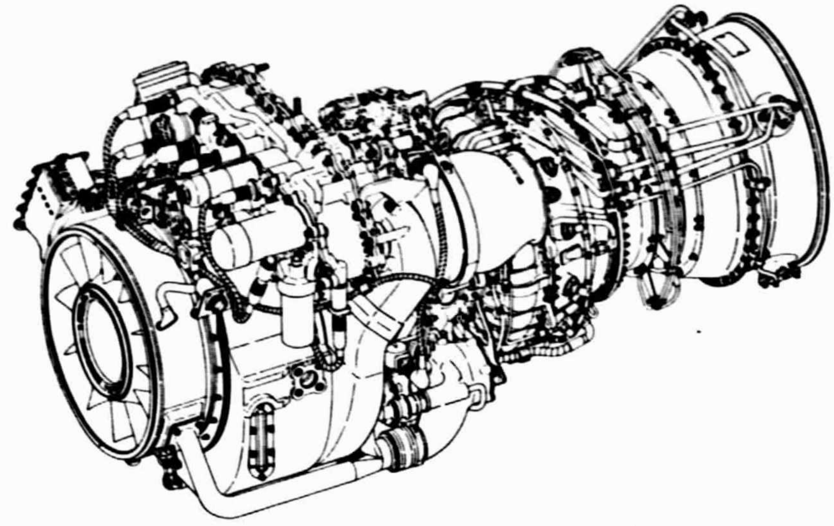


Figure 3. - T700-GE-700 turboshaft engine.

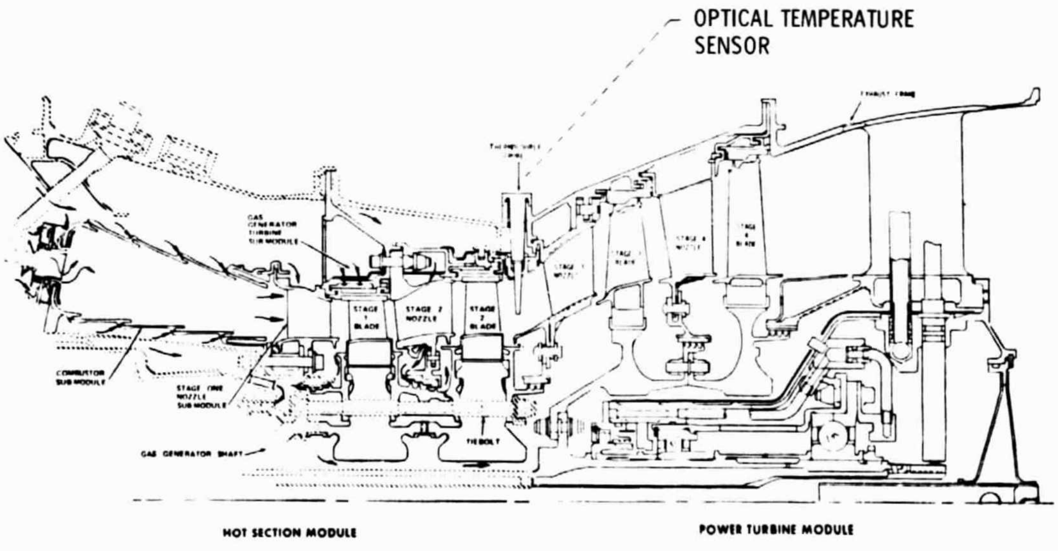


Figure 4. - View showing inter turbine location of optical sensor.

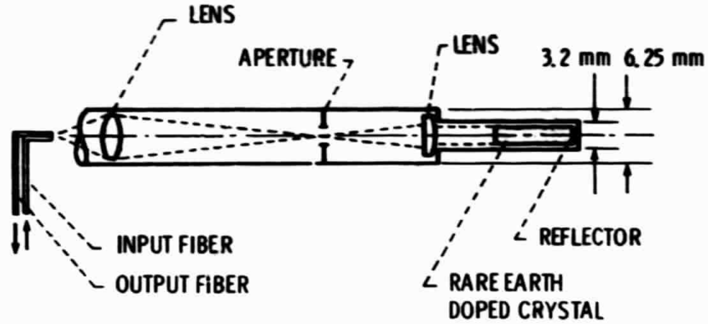


Figure 5. - Schematic of (yag doped with neodymium) temperature sensor.

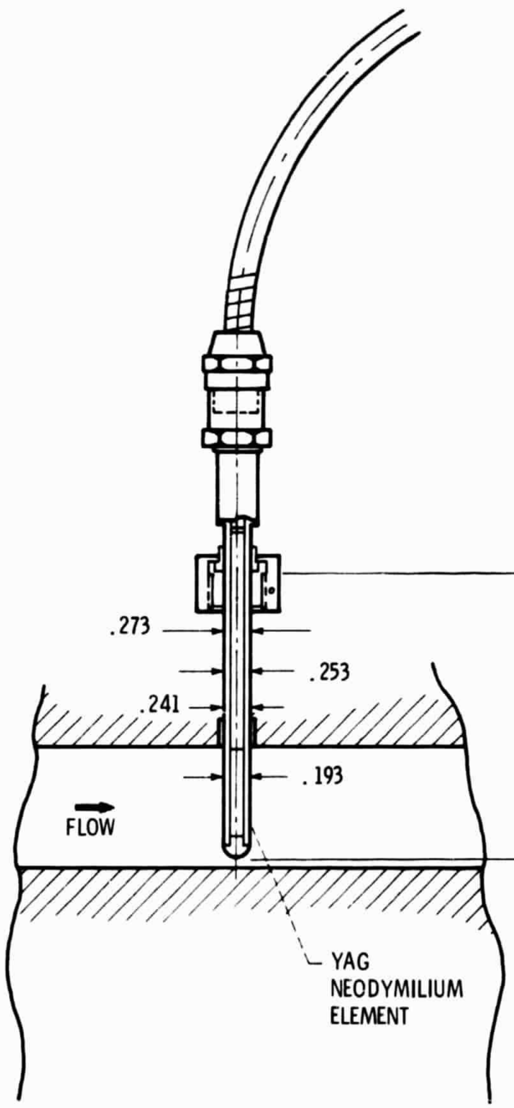
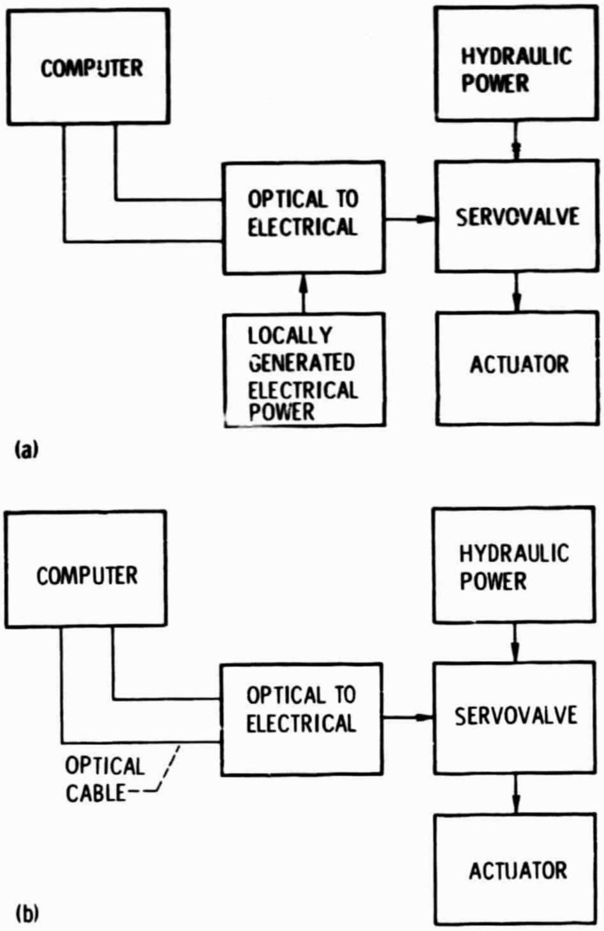


Figure 6. - Rare-earth temperature probe.



(a) Optically controlled switch with locally generated power for driving actuator.

(b) Optical power transmission and conversion at actuator.

Figure 7. - Configurations for driving actuators with optical signals.

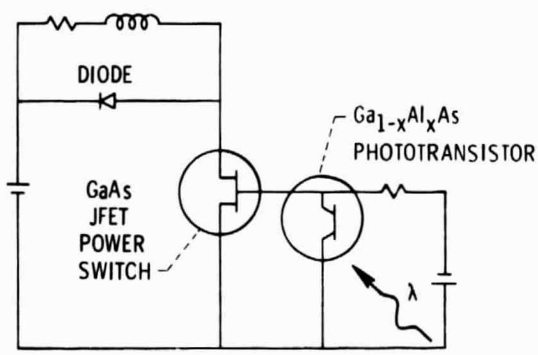


Figure 8. - Configurations for optical switching of actuators.

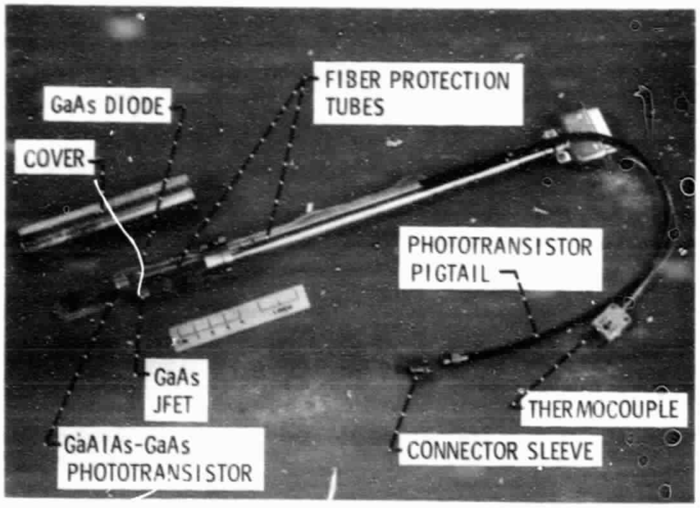


Figure 9. - High temperature photo-switch hardware.

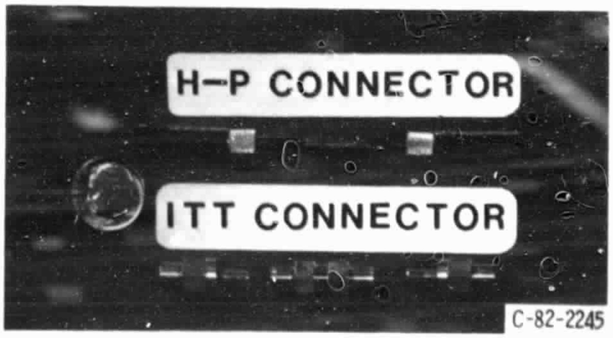


Figure 10. - 100 μm Fiber-optic connectors.