ALTERNATIVE SEAL CONDITION MONITORING TECHNOLOGIES

George Madzar
NASA Lewis Research Center
Cleveland, Ohio

SUMMARY

Alternative instrumentation and methods to the traditional temperature/pressure based seal condition monitoring techniques used in rotating type propulsion systems are presented. These methods include determination of seal condition by direct measurement of gas leakage, shaft speed/torque/power/resonance, and seal erosion. These techniques are extremely powerful since they not only provide information on seal condition, but also a host of other engine related health issues, thus minimizing the required instrumentation while maximizing the available information regarding seal/engine condition.

A prime consideration fore seals is leakage. Utilizing a "global" leak detection scheme enables measurement of leakage from seals as well as other engine components. Such a system could identify and locate leaking specie, and eliminate sensor redundancy. Numerous techniques are schematically described; including semiconductor chemical sensors and optical measurement techniques. Selection of the appropriate technique is dependent on the particular application and/or installation.

The determination of speed, torque, power and resonance of a rotating shaft enables condition, control, and performance monitoring. A non contact fiber optic sensor that can be utilized for these measurements is described. Torque measurement can provides an assessment of seal of seal and bearing condition; resonance measurements may enable isolation of the specific component. Speed measurement enables control, and the overall performance/efficiency may be inferred from these measurements.

The measurement if seal erosion can be accomplished by spectroscopic analysis the engines' exhaust plume. This technique, originally pioneered for detection of rocket engine degradation, operates by determining the identities of the (eroded) specie that pass through and engine and out the exhaust. It is a real time system that enables early warning of impending failure, diagnosis of component degradation, inspection/maintenance planning, and failure analysis. Its capabilities include direct detection of wear/erosion, and identification of eroded species/alloy/component. It is independent of engine cycle/propellants, is a non intrusive/non contact measurement, and is flight compatible.

The techniques and technologies described in this presentation were not originally developed for seal condition monitoring. However if the view that seal condition monitoring is a subset of engine health monitoring is adopted, the attractiveness of using these more complicated schemes can readily be seen.

Outline

Leak Detection - Optical techniques and semiconductor sensors for determination of leakage rate and location

Rotating Components - Measurement of shaft speed, torque, power, and resonance for determination of rotating component health

Erosion - Methodology for determination of component erosion using spectroscopic techniques

Leak Detection for Seal/Engine Condition

- A “global” leak detection system can detect leaks from seals and other engine components
  - Identification of (leaking) species
  - Specie concentration/leakage rate
  - Leakage location
- Reduces redundancy

Technologies for Leak Detection

- Solid State
  - Semiconductor chemical sensors
- Optical
  - Interferometric
  - Schlieren
  - Laser Induced Fluorescence
  - Raman
  - Differential Absorption
  - Opacity

Speed, Torque, Power and Resonance Measurements for Control, Condition and Performance Monitoring

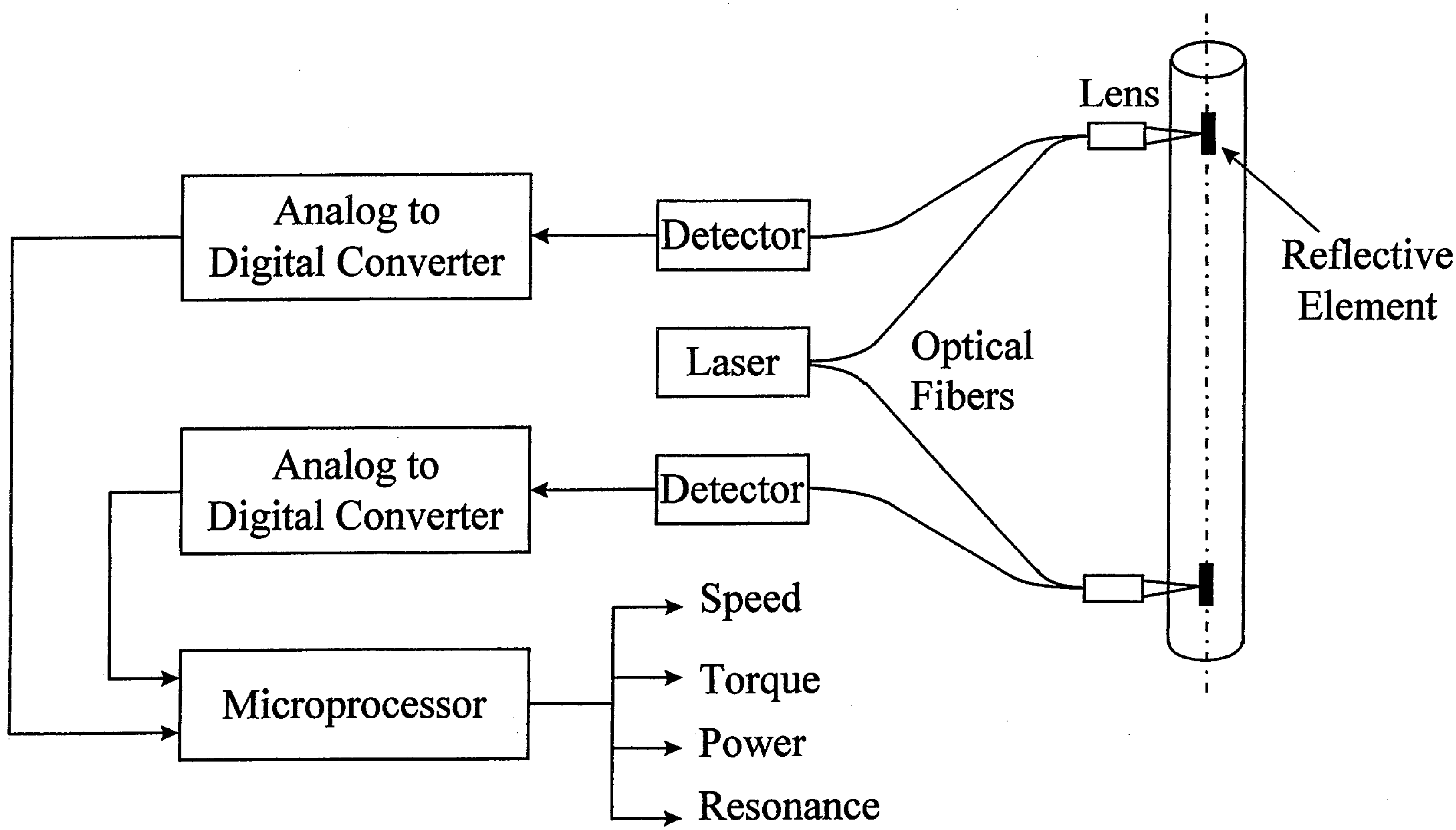
Control - Speed is controllable parameter

Condition - Torque measurement provides assessment of seal and bearing condition; power measurement provides assessment of rotor/stator condition; resonance measurement may enable isolation of specific component.

Performance - Performance/efficiency can be determined from speed, torque, and power measurements.

SHAFT SPEED, TORQUE, POWER, AND RESONANCE MAY BE DERIVED FROM A SINGLE SENSOR.

Fiber Optic Sensor for Speed, Torque, Power and Resonance Measurements



Fiber Optic Sensor for Speed, Torque, Power and Resonance Measurements

Shaft Rotational Speed - Determined from time of passage of one reflective element.

Shaft Twist - Determined from time delay between reflective elements on spinning shaft. Note: This version of sensor does not operate for static (non spinning) shafts.

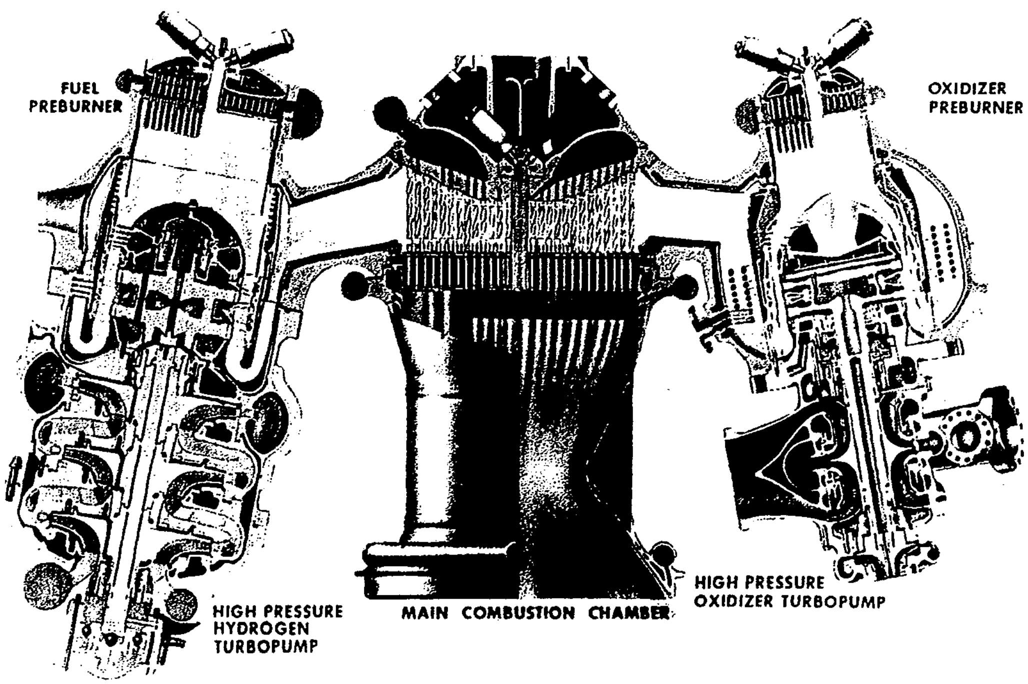
Torque - Determined from a calibrated to shaft twist.

Power - Determined from speed and torque.

Resonance - Determined from Fourrier analysis of speed, torque, or power.

Plume Spectroscopy: Spectral Analysis of Rocket Engine Exhaust

SSME POWERHEAD COMPONENT ARRANGEMENT



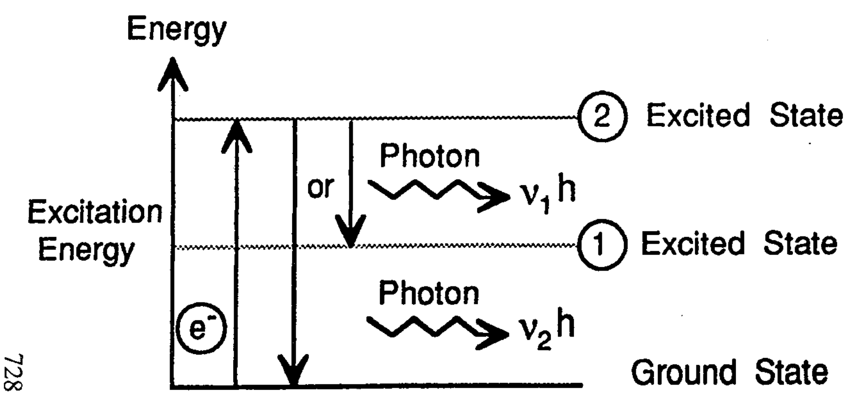
- Critical components in contact with propellants
- Eroded materials entrained in flowfield
- Metal species heated to 3600 K during combustion
- Strong, narrow line atomic emissions produced
- Spectrally bright emissions observed prior to engine degradation / failures

Plume Spectroscopy for Condition Monitoring

UTILIZATION:	- Early warning of impending failure
	- Diagnosis of component degradation
	- Real time analysis
	- Inspection and maintenance planning
	- Failure analysis
CAPABILITIES:	- Direct detection of wear/erosion
	- ID eroded species/alloys/components
IMPLEMENTATION:	- Independent of engine cycle/propellants
	- Non-intrusive, non-contact measurement
	- Flight/test stand compatible

TECHNOLOGY

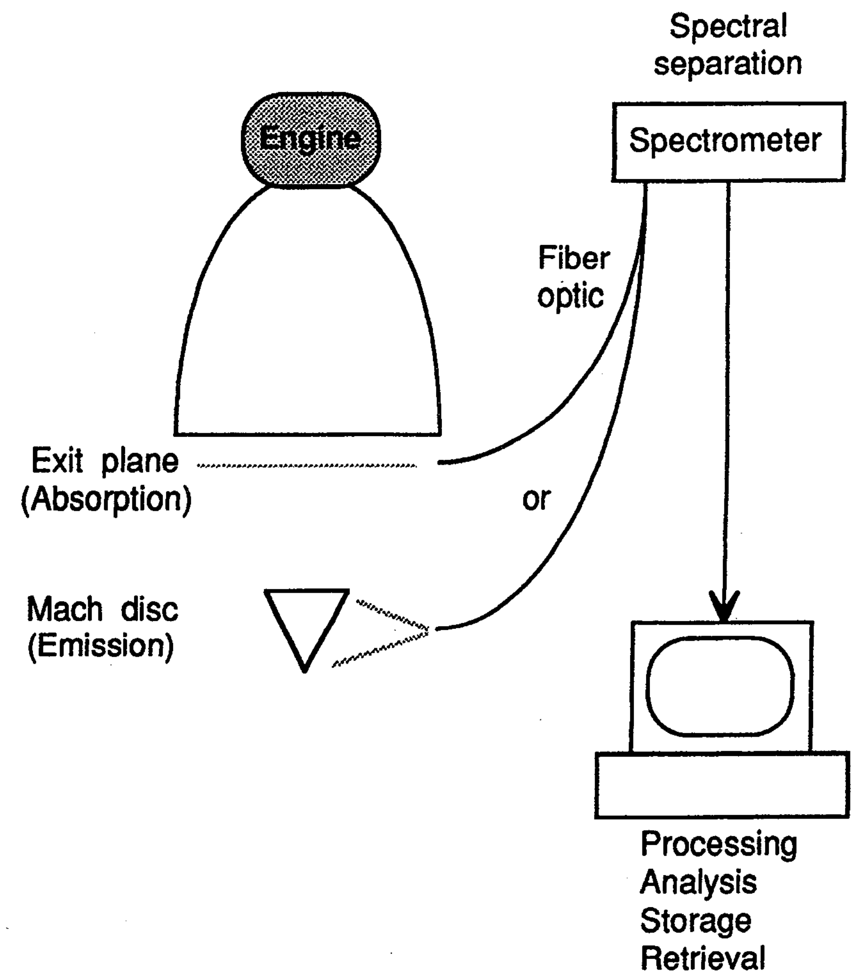
Theory



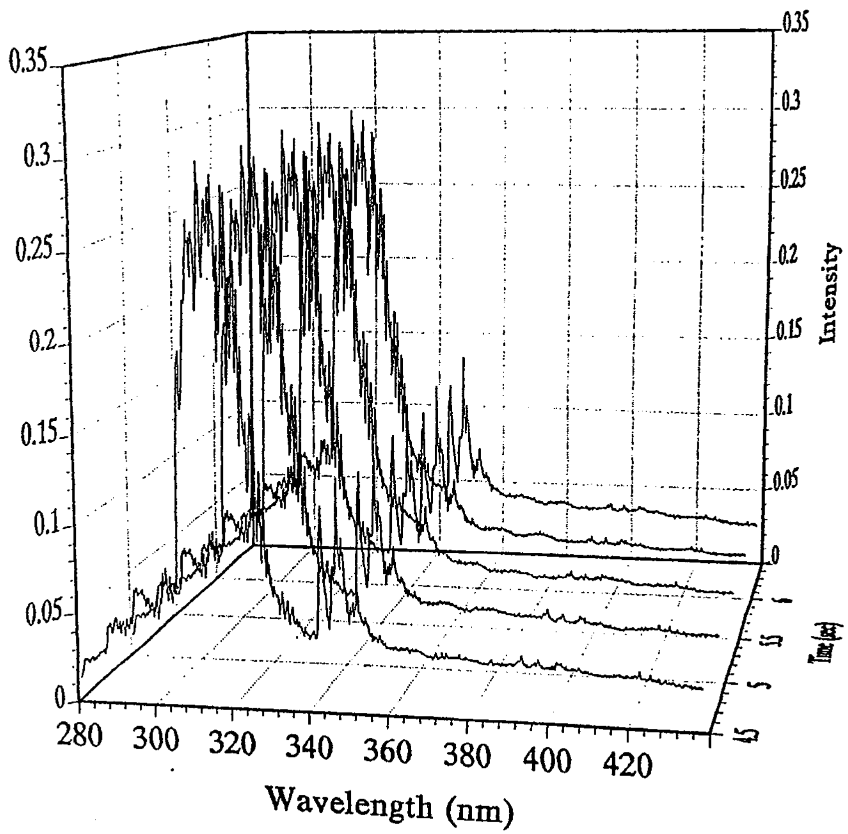
$$I = \frac{A_{ij} N h(\nu) g_i e^{(-E_i/kT)}}{F(T)}$$

- I = Emission intensity
- A_{ij} = Transition probability
- N = Specie population
- $h(v)$ = Photon energy
- g_i = Statistical weight
- E_i = Energy level
- k = Boltzmann constant
- T = Absolute temperature
- $F(T)$ = Partition function

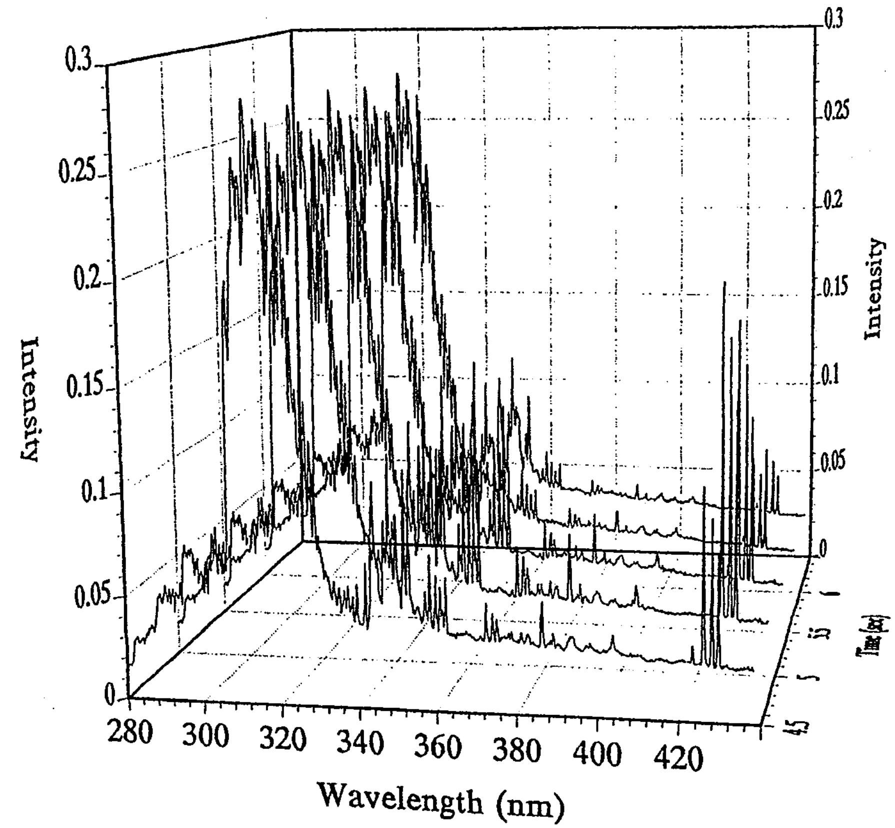
Methodology



Spectral History of TTBE Firings 017 & 024



Note consistency of the spectrum over time during firing 017.



Note consistency of OH emissions with varying emissions from metals

Summary/Conclusions

Alternative seal condition monitoring technologies are conceivable

Capability exists to monitor condition of seals as well as other engine components without increasing sensor count

Much developmental work remains