LITERATURE REVIEW ON INNOVATIVE TECHNOLOGIES FOR TEMPERATURE MEASUREMENT OF AERO ENGINE COMPONENT

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Abstract - *This review over the existing technology used for temperature measurement of aero engine component. Advanced sensing and analytics are being used increasingly in power systems, to improve diagnostic and prognostic capabilities for expensive power generation equipment, increase performance and operability, estimate remaining useful life, and manage risk. To improved engine operating efficiency gas turbine is design to operate at higher temperature which is just few degree below the melting point of material so accurate temperature measurement inside turbine engines required to provide better prediction of component life. Measurement of temperature under harsh rotating condition is challenging the temperature sensor solve the problem of measuring the temperature profile of hot end components. There are several contact and non-contact type of sensor used for temperature measurement such as thermocouple, thermal paints and pyrometer. The main objectives of this review are to identify devices for measuring temperature by choosing the proper sensors according to their characteristics, to quantify the measurement errors and the problems associated with these devices and Innovation in Aerospace Engineering and Technology.*

Key Words: **Thermocouple, RTD$_s$, Thin Film Thermocouple, Thermal Paints, Radiation Pyrometer, Thermography Phosphorous.**

1. INTRODUCTION

There is a continuing demand to increase the efficiency of gas turbines and reduce their pollution emission. Performance has improved with higher combustor temperatures and staged combustion but these improvements require greater control of the combustion process. Instrumentation is needed to directly determine gas properties in the turbine region, yet historically conventional temperature sensors have not had the durability to survive in the hotter regions. Gas turbine temperature sensors measure the temperature at different points in a turbine, from the exhaust temperature to the bearing temperature. Temperature in gas turbine engine is very high especially in first stage of turbine section, to handle such demanding variations, exhaust gas temperature sensors must be of high quality, extremely robust and reliable. Surface temperature measurements in operating engines are only possible using a few techniques. Commonly used examples are phosphor thermometry, thermocouples, thermal paints or pyrometer. Relatively new is the application of phosphorescent materials to remotely detect temperatures on turbine components and even on rotating blades, combustor walls or on reacting solid propellants. The main objectives of this review are to identify devices for measuring temperature by choosing the proper sensors according to their characteristics, to quantify the measurement errors and the problems associated with these devices and Innovation in Aerospace Engineering and Technology.

2. Need for Sensors in the Hot Section of Turbine Engines

Problem:-

1. Disgrace and damage that develops over time in hot section components can lead to disastrous failure.

2. Poor characterization of degradation process in harsh environments can affect the development of durable components.

Demonstrated Need:-

1. Difficult to model turbine blade temperature, strain, and heat flux due to severe temperature gradients across surface of the blade.

2. Thus, there is a great need for sensors for direct measurement on the surfaces of the blade.

3. Sensors must be able to survive with very low drift rates for extended periods of time.

In the following section the different temperature measurement techniques are introduce, such as contact and non-contact types of temperature sensors.

Types of Sensors:-

2.1 Contact types

1. Thermocouples:-

Particularly the most common contact technique for temperature measurement involves the use of thermocouples, which consist of two different metallic wires connected together. They rely on the See beck Effect where a voltage is created due to the diffusion of electrons along a temperature gradient. Thermocouples are intrusive sensors - the sensor head is placed directly in the flow path of the gas whose temperature it is measuring. Thermocouples for practical measurement of temperature are junctions of specific alloys which have a predictable and repeatable relationship between temperature and voltage. Different alloys are used for different temperature ranges. Most common types of thermocouples used in engine environment are highlighted below in Table 1.

TYPE		Chemical Composition Wire 1 (+)	Chemical Composition Wire 2 (-)	Typical Range (^0C)	Comments
Base Metals	E	Nickel-chromium alloy	copper-nickel alloy	–270 to 1000	Suited for low temperature
	K	Nickel-chromium alloy	Nickel aluminium Alloy	–270 to 1372	Cheap high temperature Thermocouple. However suffers from high hysteresis
	N	Nickel-chromium silicon	nickel-silicon magnesium	–270 to 1300	Most suitable base metal thermocouple for high Temperatures. Low hysteresis.
Nobel Metals	R	platinum-13% rhodium	Platinum	–50 to 1768	R types are better suited for temperatures below 1300oC
	S	platinum-10% rhodium	Platinum	–50 to 1768	S types are better suited for temperatures below 1350oC
	B	platinum-30% rhodium	platinum-6% rhodium	0to 1820	B is better suited for temperatures above 1300oC

Table No 1:- Most common thermocouple types used in aero engines

Type B thermocouples have the highest maximum temperature; however they also have the smallest voltage range -0.001 to 8.018, making them the least sensitive out of these thermocouple types. R type is better suited for temperatures below 1300oC and also has the voltage range -0.063 to 14.926. The temperature range of Type R, S and B thermocouples is adequate for surviving and sensing temperature of a turbine engine. There are some issues with using thermocouples to measure temperature according to the temperature limitations and need of sensors. One issue is related with the fact that the thermocouple is immersed in the flow path. Gas flow passages in turbine is to be very small, which means that the cross sectional area available to the flow is limited. Thus thermocouple placed directly in gas flow path may occur relatively a large flow disturbance in the form of blockage. As a result, the thermocouple may be affecting the actual temperature measure. Another issue related with thermocouples is their poor response time. The ability for the thermocouple to sense temperature is based on the actual sensing element itself reaching the temperature of the gas. Thermocouple joint and sheathing (housing) slows down the actual response time of thermocouples, which can be too slow to meet the requirements for temperature sensing. Thermocouple has certain advantages such as Offer real-time temperature monitoring, relatively cheap in cost, large temperature range. Also having issue such as they are intrusive contact sensors and have to withstand the harsh gas turbine environment, Difficult to use on rotating components, Limited number of installations, Bonding to ceramic surfaces, Electromagnetic interference, Lack detail since it provides discrete diagnosis, Rotating components will require telemetry or slip rings.

Fig 1:- Thermocouple

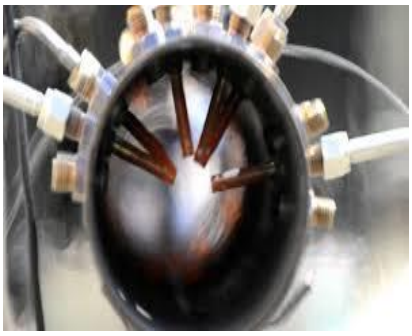

Fig 2:-Thermocouple Installed In Aero-engine Component

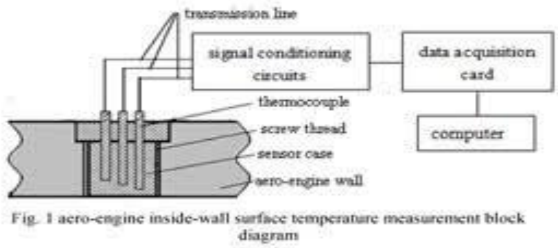

Fig 3: aero engine inside-wall surface temperature measurement block diagram

2. Thin Film Thermocouple (TFTCs):-

Over the past several decades, thin film sensor techniques have been the subject of increased interest and research. The driving force behind the research into thin film sensors is their considerable advantages over conventional methods. The main application of this technology has been for the study of compressor blade strain, turbine blade temperature measurements and study of boundary layer states. Thin film sensors do not require special machining of the components on which they are mounted, and, with thicknesses less than 10 microns (μm), they are considerably thinner than wire or foils. Thin film sensors have a minimal impact on the physical characteristics of the supporting components. An example of thin film thermocouples deposited on engine components is shown in Figure 4.

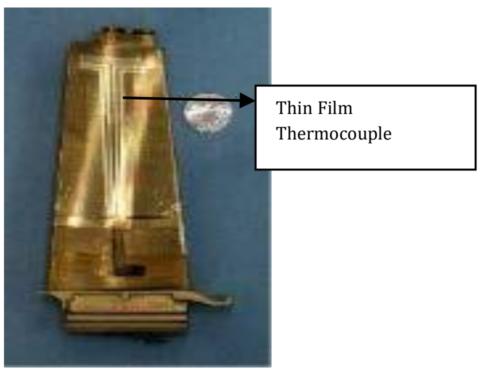

Fig 4:-Nickel alloy turbine blade

In an engine environment, wires thermocouples are fitted on surface create a disorder of the gas flow over the surface by altering the environmental conditions at that surface. Wire thermocouples set into machined grooves in the surface prevent disorder of the gas flow; however, this method concerns the structural integrity of the component. As a result, the surface thermal mapping profiles delivered by wire thermocouples do not precisely reflect the true working conditions. Thin film thermocouples are spit deposited directly onto the surface and have thicknesses on the order of a few micrometers. Therefore, TFTCs create minimum disorder of the gas flow over the surface and do not require that the surface be physically transformed. Subsequently, TFTCs add negligible mass to the surface and have minimum impact on the temperature distribution. They are appropriate to a variability of materials including ceramics, minimum structural disruption (minimal machining), familiar sensor to substrate touching base & correct placement, High resilience compared to unguarded wire sensors ,Skillful for setup to very high temperatures (>1000°C).

3. RTDs (Resistance Temperature Detectors):-

Resistance temperature detectors (RTDs) count on the change in resistance of a material with temperature; thus measurement of resistance is converted to a temperature measurement. There are two basic types of RTDs: metal based devices and semiconductor devices (also known as thermistors). While quite accurate temperature measurements can be obtained with RTDs. they are usually limited to "low slung temperature" operation. For example, platinum resistance thermometers can operate only up to ~1000°C, while thermistors are generally limited to a few hundred degrees Celsius. Resistance temperature devices (RTDs) use the inherent characteristic of most metals – as the temperature raises their resistance increases. This broadly linear characteristic is ideal for applications with a wide temperature range. The high accuracy and predictability of these devices make them ideal for consistent temperature measurement. Traditionally RTDs were made from platinum wire, but printed film technology is now used, so reducing costs, long-term stability and improving repeatability. The disadvantage of RTDs is their low resistance output and temperature variation coefficient (typically around 0.38% per °C). A lead resistance of just 0.33R can introduce an equivalent temperature error of 1°C, but this can be compensated for by using an additional amplifier. Although RTDs can theoretically measure temperatures to about 1000^{0}C, it becomes increasingly difficult to prevent contamination from impurities and therefore a practical upper temperature limit is reached at around 700^{0}C. RTD has certain advantages such as more stable, accurate, linear than thermocouple, relatively cheap in cost. Issues related to RTDs are larger in size, Slower response times, expensive, Compared to standard base metal thermocouples, Self-heating.

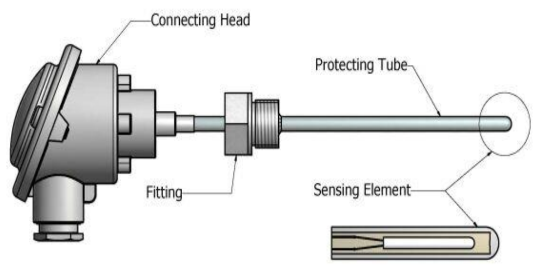

Fig 5:- Resistance temperature detectors

4. Thermal Paints:-

Temperature indicating paints is a kind of superior efficient coating which computes the temperature dispersal by judging the color variation of the paint film applied on the surface. It is widely applied in aero-engine testing to solve the problem of measuring the temperature profile of hot end components. Thermal paints are comparatively preferred alternative temperature sensors due to their capability of generating a complete thermal gradient on the component surface. Also providing a visual record of the temperature distribution is an additional advantage. Thermal paints exhibit a range of color profiles when heated at different temperature with each color representing the temperature at which it is formed. Also there are no mounting issues even on the most complex area compared to the thermocouples and RTD_S where mounting is quite difficult and permanently disturbed the components geometry. Alternatively the thermal paints can be coated easily as good as regular paints and re-moved using common paint recovers without any damage to the component material and geometry. The tested components can be reused for further operation making it a cost effective solution. A variety of multi-change paints are available covering a temperature range from 150-1350^0C.

Fig 6:- calibration scale

Calibration Scale: -

The thermal paint is calibrated by applying it on the test coupons and heating every coupon at an interval of 15^0C. The color profiles of all the coupons are recorded and stored in a calibration database file assigning every coupon color with its respective temperature value. On selection of an image pixel point on the thermal paint contour image for temperature identification, the pixel value is compared with the pixel values of the calibration database and its closest match is been found .The temperature value of this calibration database pixel is assigned to the image pixel point. Automation in thermal paint interpretation using Digital Image Processing generates a more accurate and reliable thermal mapping.

2.2 Optical Types:-

1. Radiation Pyrometry:-

A radiation pyrometer is used to eliminate many problems associated with contact sensor. The pyrometer consists of an optical system, which collects radiation from a defined area of the surface being measured and relays it to a suitable detector. The temperature measurement system views the rotating turbine blades and by measuring the emitted, electromagnetic radiation produces a signal directly proportional to the temperature of the blades. The system is shown schematically in Figure 7.

Fig 7:-Radiation Pyrometry

The sensor head containing the optical system is attached to the outer case of the turbine with a clear optical path from the objective aperture to the turbine blades. The area on the blade from which radiation is accepted is called the target area. Energy is radiated from a solid target as a function of its temperature and the emittance of its surface. The sensor head holds the optics in position and provides a stream of purge air to maintain the optical window free from soot, dirt or other contaminants that would block transmission. The optical system generally consists of a lens or light pipe and aperture to gather the radiation from the blades and define the target area and a fiber optic bundle to transmit the radiation to the detector. Solid state detectors produce an electrical current proportional to the radiant power incident upon their surface within a spectral band characteristic of the detector. Silicon detectors have been shown to be effective for turbine applications when operated in the photovoltaic mode. Silicon detectors are responsive to radiation between approximately 0.4 and 1. 1 micron. The radiation intensity over this spectral band is exponentially proportional to temperature, thus causing the detector to produce a current that charges logarithmically with the target temperature. The logarithmic chart provided to the signal processor varies as a function of time as the blades pass through the optical path of the sensor. The signal processor operates on this signal to extract temperature information of interest, linearizes the signal as a function of temperature and provides linear digital and analog output signals for control, data acquisition, over temperature protection and direct readout. An advantage related to pyrometer is Non-intrusive, No upper temperature limit because radiation energy increases with temperature, Fast response as there is no inherent thermal inertia of thermocouples, Reduced routing problems for rotating components, Immunity to electromagnetic interferences from the surrounding environment. A limitation of pyrometer such as Optical access is required, Emissivity variation with temperature and surface condition, Translucency of ceramic coatings, Reflected radiation, Optical contamination, Combustion Gas stream and flame interference.

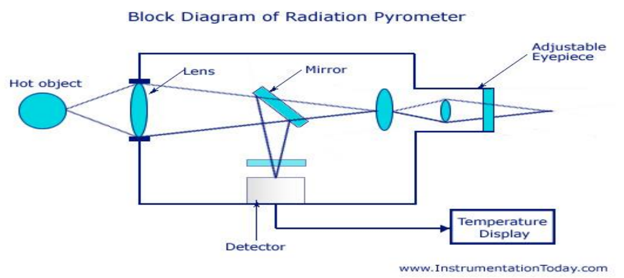

Fig 8:-Block Diagram of Radiation pyrometry

2. Thermographic Phosphors:-

Thermographic Phosphors which have temperature dependent emission are mostly inorganic and made of some ceramic material. The thermographic phosphor is composed by a carrier material which is doped with some activator material. The activator is often a rare earth metal. The fixing concentration is typically about one percent, which is a slight enough concentration for the activator atoms to be insulated from each other by the host matrix. The host material is mostly transparent to radiation, i.e. it is mostly the activators that absorb and emit radiation. Most phosphors used for thermometry are excited by laser radiation. The energy is absorbed by the rare earth metal in an electron excitation. The electron is then non radioactively relaxed to a meta-stable energy level, i.e. a level from where no transitions are allowed.

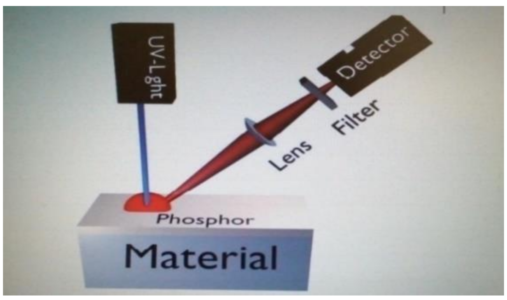

Fig 9: material temperature detect with help of phosphor thermometry

The phosphor components used in thermometry are usually inorganic materials having the form of white-brown fine particles some 1 - 10 µm in diameter. Such a phosphor consists of a host material and a fixing agent from which the light is emanated. A large number of different phosphors are produced today. These cover a wide range of temperatures, from 500 C to 1700 C or higher, making they appropriate for many different solicitations. Each phosphor that is carefully chosen is highly sensitive within a definite range of temperatures, displaying accuracy in the order of 1 to 5 C. Once placed on the surface of attention and excited by a proper wavelength, mainly UV light, the phosphor elements discharge an strong luminescent light. This radiation is called phosphorescence or fluorescence, terms often used interchangeably, although fluorescence usually talk about to releases having a duration of 10-10-10-7 s and phosphorescence to their having a duration in the order of 10-7-1 s. After excitation of the thermographic phosphor, the successive release is imaged onto a receiver. The temperature can then be deduced from the spectral or temporal properties of the recorded signal. This technique provides a high substantial yield, two dimensional measurements and remote thermometry, as well as a high degree of accuracy. Thermographic phosphors have generally been used for hard material that does not burn if exposed to fire such as steel or concrete. For those surfaces the phosphor can be applied to the surface and only a very thin layer is required ensuring that the phosphor layer does not influence the flow and heat transfer from and to the surface. It has certain advantages such as Non- intrusive, Fast response and does not have inherent thermal inertia of thermocouples, Immunity to Electromagnetic interferences from the surrounding environment, Reduced routing problems for rotating components, 2D Surface map possible with scanning, Immune to effects caused by emissivity, flame interference and reflections from components, Range 20 ^{0}C – 1700 ^{0}C Achievable through various phosphors. Drawbacks of its are decreasing signals with increasing temperature, Bonding of the phosphors, Thick phosphor coatings might be intrusive, Cooled fiber optic, if necessary, Optical access required.

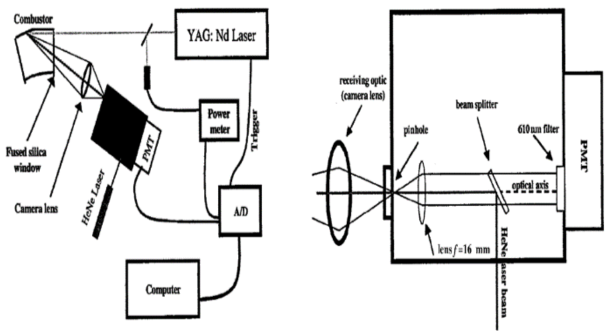

Fig 10: experimental setup for phosphor thermometry

3. Future work:-

With the advancement of combustor and turbine technologies there needs to be a parallel advancement in the ability to sense and control these areas. Exhaust gas temperature measurement, in particular, is an area of concern for future engines as turbine temperatures continue to rise. The true benefit of advanced, adaptive engines will come from accurately sensing the salient parameters and optimizing the adaptive features in response. The techniques used to measure or estimate Exhaust gas temperature ought to be continually reevaluated based on new data and technological advancements. Although the barrier to entry on turbine engines is high for new sensors, eventually we will reach a point where certain techniques of measurement can be accepted as sufficiently consistent and accurate. With the operation temperature of the hot components continues to increase, the temperature indicating sensor is required to have wider temperature range and higher measurement accuracy, thus future work need to be concentrated on develop sensor of higher accuracy and wider measurement range.

4. CONCLUSIONS

We have reviewed many different techniques and sensor systems that have been used for the turbine temperature sensing application including thermal paints, thermocouples, thin film thermocouple, $RTD_{s,}$ Radiation pyrometry and thermographic phosphors. Conventional thermometry fails to generate a complete thermal map of the components with critical geometries and rotating at heavy speeds in aggressive environments. Contact type thermal sensors like thermocouples and thermistors on the components generating stresses within them and also are intrusive in nature. The cable network is quite complex and source of errors at the read out units.

Non-contact type of sensors like optical pyrometry is a quite challenging option for temperatures measurements due to limitations in generating a proper database of exact radiation emission characteristics of different materials for a range of temperatures. Also providing a visual record of the temperature distribution is an additional advantage. Thermal paints exhibit a range of color profiles when heated at different temperature with each color representing the temperature at which it is formed. Also there are no mounting issues even on the most complex geometries compared to the thermocouples and temperature plugs where mounting is quite difficult and permanently distorts the components geometry. Alternatively the thermal paints can be coated easily as good as regular paints and re-moved using common paint recovers without any damage to the component material and geometry.

The literature survey study made reveals that the thermal paints have the benefits of both the contact and non-contact sensors and can be capable as a better alternate for thermal mapping of gas turbine engines. Thermal paints are recognized as operative thermal sensors for thermal mapping of complex gas turbine hot section components compared to conventional thermometry techniques. Thermal paints change their color permanently when exposed to elevated temperatures generating a color pattern with distinguished color profiles with each color representing its formation temperature.

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