Thermal Transient Measurements of Optical Periscope Lamp Assembly for Different Flow Rates using Thermal Imaging

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Abstract

Optical Periscope is an instrument used for visual inspection if any obstacles are present in the direct line of sight of the observer. In a nuclear reactor where the visual inspection is limited by many factors, instruments like periscope are very vital for in-service inspections. In Prototype Fast Breeder Reactor (PFBR) the Periscope is used for the inspection of reactor internals at cover gas region above the liquid Sodium level. It is of 400mm diameter and 10m length housing image channel and two Xenon lamps for illuminating the region of inspection. The lamps operate at high voltage, 24kV and switches to 14V during regular operation. Due to the high voltage, excess heat generation was observed which was causing frequent failures of the lamp. Remote Handling & Irradiation Experiments Division (RHIED) of IGCAR carried out design modification for optimizing the proper coolant flow and other geometrical parameters. For validation of design modifications and ensuring better heat transfer efficiency Infrared Thermography was carried out on the lamp assembly of the periscope. The main objectives of present study is to evaluate thermal profiles of the system at different flow rates of coolant (800 lpm, 1000 lpm & 1200 lpm) and investigate thermal distribution across the fin. This paper discusses temperature measurement on the lamp and fin region of periscope assembly. The effect of flow rate to facilitate cooling of the lamp on the temperature distribution of the lamp assembly was investigated.

Keywords: *Optical Periscope, Prototype Fast Breeder Reactor, Non-Destructive Evaluation, Infrared Thermography*

1. Introduction:

An optical periscope is a device that enables visual inspection of objects which are not in the direct line of sight. The periscope can be an essential in-service inspection tool for routine maintenance and other activities in a nuclear reactor. It is a mandatory requirement to carry out visual inspection of reactor vessel internals during periodic in-service, under shut down conditions and in pre-commissioning of used for visual examination of the Prototype Fast Breeder Reactor (PFBR) in Kalpakkam [1]. PFBR is a 500 MWe, sodium cooled, pool type, mixed oxide (MOX) fuelled reactor with two secondary loops. any nuclear reactor. In this connection, an indigenously designed Optical Periscope has been The primary objective of PFBR is to demonstrate techno-economic viability of fast breeder reactors on an industrial scale [3]. During operation, the periscope will be inserted into the reactor from the top of roof slab vertically for inspecting objects present in the space above the liquid sodium level filled with argon cover gas. Illuminating system is housed just beside the viewing canal at the periscope end for illuminating the objects under inspection. Two xenon arc lamps of 300 W powers consisting of an integral reflector are used. The xenon lamps used in the illuminator has heat-sinks mounted on copper electrodes operating with 25 kV striking pulse. The lamps are originally designed for operation in air with forced cooling. Since the periscope is a sealed device and has argon as operating environment, an additional arrangement with ceramic enclosure on the lamp for electrically isolating the electrodes, while facilitating cooling with argon flow has been designed.

The periscope's xenon lamp had frequent failures even at room temperature operations and hence Remote Handling and Irradiation Experiments Division have taken up to study the system and to carry out the design modifications to make the lamp holder assembly and to ensure successful working of the lamp. The pulse voltage for the starting of the lamp has changed from 24kV to 15kV, and then switches back to 14V during regular operation. A technology modification has been done by placing an RTD temperature sensor close to the lamp terminal [4]. The validation of the design modification was carried out through comprehensive temperature profiling of the system using thermal imaging.

2. Material and Methods

The PFBR periscope optical instrument is of 400mm diameter and about 10 meter length, housing image canal and two lamps for illuminating the area of interest. The image canal (optical tube), contains prisms and zoom lens, relay lens, focusing lens and eye piece. The illuminator has two lamps, light directing prisms and argon cooling system for the lamps. The periscope will be fixed in the IVTP port of PFBR for the visual inspection [3]. The lamp used in the illuminator of the Periscope is a Xenon arc lamp, with a luminous flux of 5000 lumens and 300W power [2].

The anode and cathode side cooling of the fins are separated with proper insulation to avoid any discharge through the cooling gas. The lamp holder assembly has separate cooling loops from a common cooling gas header. The xenon strike voltage during the start of the lamp is 15kV DC and the lamp holder assembly is fabricated in Teflon material. The upper and lower heat sinks have been machined through a wire cut EDM machine to the required precision. Fig.1 shows the lamp assembly with cooling arrangement. The designed maximum temperature for this system is 150°C. An RTD is placed in the cathode side for temperature measurement and it is designed to cut off the lamp if the temperature goes above the preferred level.

The coolant inlet of 3/8 inch is modified to 3 numbers of inlets of diameter ¼ inch in the header.

For our experiment, Passive thermal mapping was carried out using T400 Infrared Camera (Fig. 2) which has an uncooled micro-bolometer detector. The spectral range of the system is 7-13 µm in wavelength. The system was mounted on a tripod stand having a distance of 50 cm from the sample. Factors like emissivity, relative humidity and ambient temperature influencing temperature measurement are taken into consideration while obtaining images [5]. The thermograms were obtained at regular interval of times, which was later analyzed using FLIR Tools software.

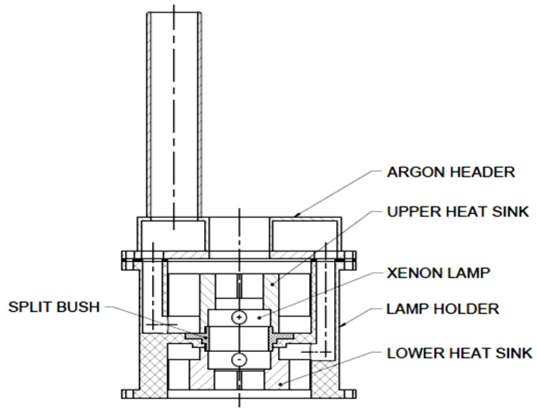

Figure 1: Lamp assembly with cooling arrangement

A total of three experiments were carried out for the non-contact temperature mapping of the surface of xenon flash lamp and the Fin Region (Fig: 3), at three different flow rates- 800lpm, 1000lpm and 1200lpm.

Figure 2: FLIR T400 Infrared camera.

3. Results and Discussion

The acquired images were analysed after appropriate radiometric corrections. The measurement tools such as area profiling- circle or rectangle, line profiling were chosen for the analysis. The spot and area measurement tool provides the spot temperature and mean, maximum and minimum temperature over an area respectively. Line profile provides the temperature at the particular pixels lying in the given line. Using the data obtained from the images, graphs were plotted and analysed.

The figure 4 shows the 3D surface plot of the lamp assembly with fin region. It can be observed from the image that the maximum temperature recorded is on the lamp compared to fin region.

Figure3: shows the Periscope Lamp Assembly during the operation with Lamp and Fin Region.

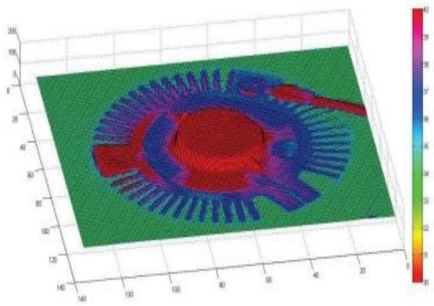

Figure 4: 3D surface plot of the thermal image taken during the operation of the lamp.

Typical thermal Images (fig 5) acquired during operation of the lamp have been given below. This clearly shows that the maximum temperature recorded was always on the lamp surface.

The closure look of thermal image indicates that Fin Region exhibits uniform temperature (fig.6) and no significant hot spot was observed in the thermal image during operation of the lamp.

Temperature Profiles on Lamp

The maximum temperatures mapped on the outer glass surface of the lamp during the operation and during the cooling phase at each flow rate is plotted (fig. 7) against time. It was observed from the plot, the increase in temperature was high for the initial few minutes (heating region). After the initial rise in temperature, saturation region has been observed in which there was no significant temperature rise. During the cooling phase (cooling region), temperature fall has been observed to have steep slope.

The overall temperature profile of the lamp with respect to time is same for all three flow rates- 800lpm, 1000lpm and 1200lpm. The effect of flow rate was observed in the maximum temperature recorded on the lamp and in the thermal decay rates.

Temperature Profiles on Fin Region

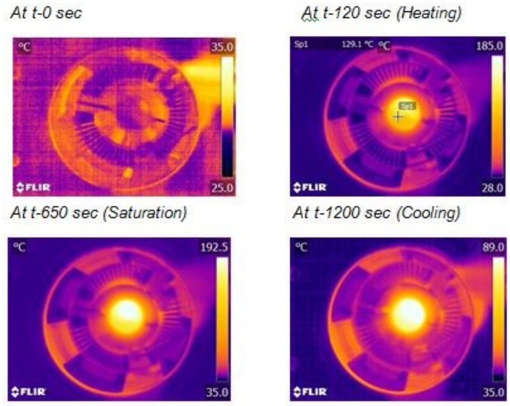

Figure 5: Typical thermal images of the lamp assembly at different time during operation of the lamp for 1000lpm flow rate

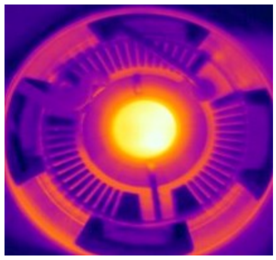

Figure 6: Close up view of the Fin Region of a typical IR Thermal image.

The maximum temperature of the surface of Fin Region during the operation and in the cooling phase is plotted. Similar to the lamp temperature profile plot, the temperature of the fin region also showed three distinct regions (heating, saturation and cooling region). The fluctuations in the temperature (rise and fall of temperature) at the saturation region can be attributed to the air flow.

Temperature profile of the fin region for different flow rates revealed that the maximum temperature attained was above 80°C for 800lpm, whereas the temperature rise was 70°C and less than 70 °C for 1000lpm and 1200 lpm respectively.

The temperature difference on the cooling phase for a time laps of 50s for 1000lpm and 1200lpm is given below in the table and this data clearly indicates that the cooling is more efficient with a higher flow rate.

	Drop in temperature during cooling phase for the time of 50 s
1000 lpm	21.7 C
1200 lpm	2.8 C

A separate graph (Fig: 9) is plotted for the cooling phase to get a clear picture of thermal decay of the Fin Region at different flow rates. The comparison between the three decay curves for 800lpm, 1000lpm and 1200lpm indicates that the thermal decay happens faster for 1200lpm and then 1000lpm and comparatively slower for 800lpm.

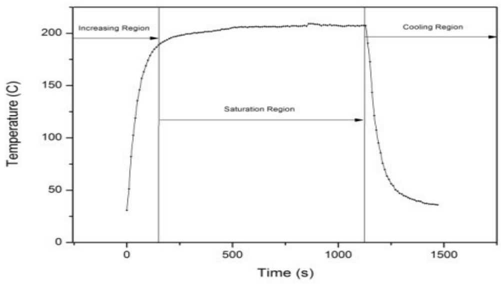

Figure 7: Plot of maximum temperature at the Lamp surface during the operation of the lamp and switch off state with respect to time at a flow rate of 1000lpm.

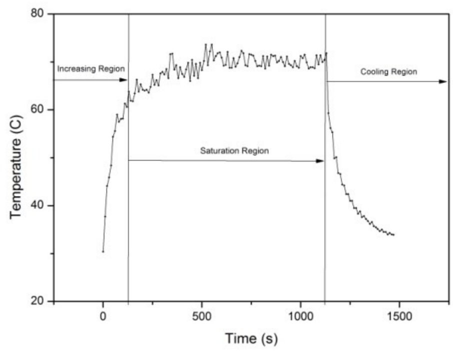

Figure 8: Plot of maximum temperature at the Fin Region during operation of the lamp and switch off state with respect to time at 1000lpm

4. Conclusion:

Infrared Thermography was carried out on the lamp assembly of the periscope for the validation of design modifications and ensuring better heat transfer efficiency. Mapping of temperature profiles of periscope lamp and Fin Region through the non-contact temperature measurement was done successfully. The temperature measurement revealed that the maximum temperature recorded was on the lamp region and uniform distribution of temperature was exhibited in the Fin Region with no significant hot spot. The effect of flow rate in the heat dissipation of the Fin Region by forced convection was also clearly indicated by the comparison of surface temperature mapping of the Fin Region in all three flow rates- 800lpm, 1000lpm and 1200lpm.

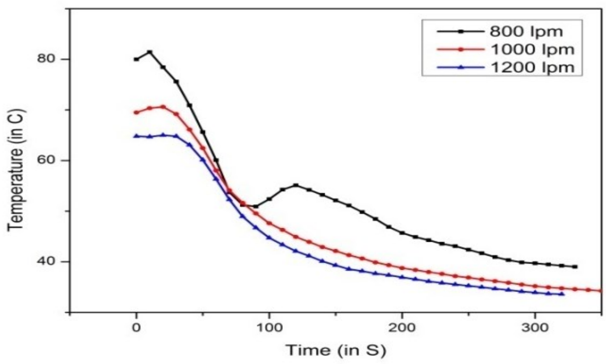

Figure 9: Plot of Thermal decay of Fin Region for different flow rates- 800lpm, 1000lpm and 1200lpm.

Cooling is more efficient for 1200lpm and 1000lpm and comparatively less for 800lpm. Trend in temperature profile recorded during the operation and lamp assembly and cooling phase has been clearly brought by the study.

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