# THERMAL STRESS MEASUREMENT ON PISTON RINGS BY REAL TIME HOLOGRAPHIC INTERFEROMETRY

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**Abstract**
The real time holographic interferometry (RTHI) technique was used to study the thermal stress on the motor cycle piston rings. The object holograms of piston rings were recorded and after processing the holographic plate, it was placed back on the holder. It was at this time, the processed holographic plate was illuminated by reference and object beams as the piston ring used to record the hologram was subjected to thermal stress. The generated interferograms before and after the piston ring was stressed were captured by a CCD camera for analysis. The results demonstrated interferograms abnormalities as a result of thermal stress. This was exhibited by interferograms bending and compressions. Using Atmosfringe version 3.3 software and origin version 8.0 software, the analysis of the interferograms were performed. The peak to valley (P-V) aberrations ranged from 0.0128λ to 1.2989λ for the whole range of measurements. Using the Fast Fourier Transform analysis of the interference fringes, phase changes were determined for each of the piston rings. From this result, it was evident that the three piston rings on the piston have different structural characteristics. This depends on the position of the ring on the piston due to their function. The ring near the head of the piston (compression ring), whose purpose is to seal the combustion chamber for maintenance of compression had less phase change and P-V aberrations due to thermal stress in comparison with the other two rings near its skirt.

## 1.0 Introduction

One of the major applications of holography in non-destructive testing is holographic interferometry (Puśkar, *et al.,* 2010). The technique was developed in the late 1960s by Stetson and Powell (Leith and Upatnieks, 1962; 1964). Since the inception of holographic Interferometry (HI), the technique has been widely used in detecting deformities on opaque surfaces or refractive index variation in a transparent media (Matsumoto *et al.,* 1974; Balalov *et al*., 1990). Unlike other non-destructive testing methods HI is able to make a full field inspection as opposed to point inspection. Using the technique, it is possible to resolve optical path change up to one hundredth of the light source wavelength due to its high degree of sensitivity. This implies that the technique yields extremely accurate measurement of minute surface deformation (Hildebrand and Haines, 1966) in comparison with other techniques.

Among the engine components exposed to thermal stress, a piston is one of the most severely stressed since it absorbs the energy released after the ignition of air/fuel mixture. To accomplish their function, piston is sealed so that it can compress the air/fuel mixture and hinder gas leakage out of the combustion chamber. This is accomplished by use of the piston rings. The piston rings which are inserted on the piston ring groove also helps in conducting heat on the piston head away among any other functions (Senzer, 2007). The ability of the piston ring to transfer heat energy away is dependent on the thermal conductivity of the material employed as well as the geometry of the ring (Stecher, 1979). In order to understand the thermal mechanical behaviour of the piston rings, an accurate measurement method is essential. In this paper, a non-destructive testing method based on real time holographic Interferometry is presented. The technique was used to investigate thermal stress subjected on the piston rings surface. This was carried out by analyzing the generated interferograms at different temperatures.

## 2.0 Materials and Methods

### 2.1 Piston Rings Thermal Stress Measurement

To measure the effect of thermal stress on the piston rings, three new motor cycle piston rings of the same piston were used. The set-up used to measure the thermal stress on the piston rings is as shown in Figure 1. The process was carried out in two major steps. First the piston ring hologram was recorded on

PFG-01 holographic plates of dimensions 102mm x 127 mm and later underwent wet chemical processing. The recording of the piston ring holograms was carried out when all the light sources were blocked, the movements within the room minimized and temperature equilibrium attained. To record the piston ring hologram, light from a 35mW linearly polarised Helium Neon Laser of wavelength 632.8 nm was used. The light from the Laser was spatially filtered using the microscope objective lens of x10 magnification and a 30µm diameter pinhole located at the microscope objective focal point. Using a 50:50 beam splitter the Laser beam was split to give two arms (object beam and reference beam). The object beam was the beam transmitted through the Beam Splitter and incident on the piston ring whose hologram was to be recorded. This beam was reflected to the holographic plate by the piston ring. The beam reflected by the beam splitter (the reference beam) was incident on the holographic plate. The set- up was allowed to stabilize for about two minutes before exposing the holographic plate. To ensure attainment of Laser beam stability a spectrum analyzer was used. The two beams were superimposed on the holographic plate for 20 seconds. After the holographic plates were exposed, they were processed and dried by placing them in an upright position.

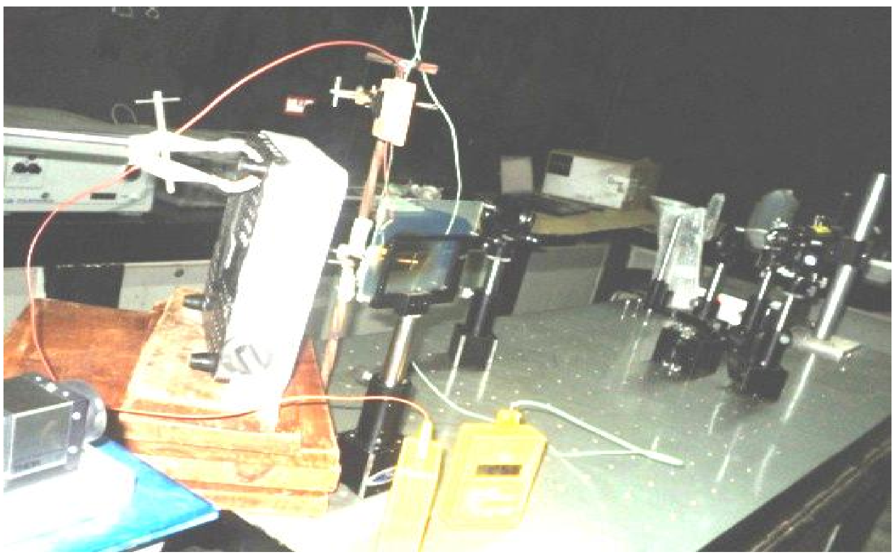
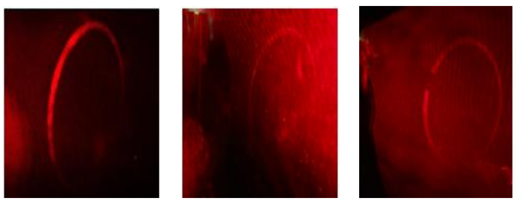


*Figure 1: Real time holographic interferometric set-up. The developed plate was replaced on the holder and the object subjected to heating. Using the CCD camera the generated interferograms were captured for analysis*

The dry chemically processed holographic plate was inserted on the holographic plate holder and illuminated with the reference beam only as the object beam was blocked with a shutter. The holographic image observed was captured by use of a digital camera. Later the processed holographic plate and the piston ring were illuminated by reference beam and object beam respectively. This process led to generation of interferograms which were captured by a CCD camera of pixel resolution 1024x768 and used as the reference interferogram. To measure the temperature changes, two thermo couples were used placed equidistant from each other to ensure uniform temperature distribution. On heating the piston ring as the developed holographic plate was illuminated by reference and the ring illuminated by object beams in the same orientation as during hologram recording, interferograms were generated. These interferograms were as a result of the interference between the reconstructed object beam and the new object beam carrying information of thermal stress on the ring. The generated interferograms were captured for analysis at temperature intervals of 50C until a temperature of 1000C was attained. To determine the effect of thermal stress on the piston rings both qualitative and quantitative analysis was carried out. The quantitative analysis of the interferograms was done using Atmosfringe version 3.3 software and origin version 8 software.

### 3.0 Results and Discussion

To access the information encoded on the holographic plate on exposure, the development of the exposed plate was carried out. After processing of the exposed plate, it was inserted on the holographic plate holder and replayed. This was done by illuminating the processed holographic plate using reference beam. The reconstruction process affirmed the presence of successfully recorded hologram of the piston ring under test. To capture the holographic images of the piston ring a 16.2 Megapixels Kodak digital camera was used. The photographs of the hologram images are as shown in Figure 2(a), (b) and (c).

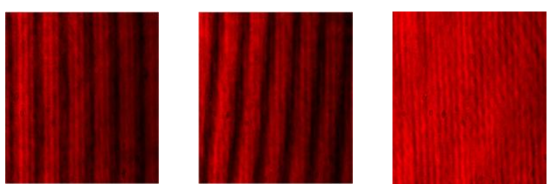


(a) (b) (c)

*Figure 2: Photographic images of: (a) A hologram of piston ring 1. (b) A hologram of piston ring 2. (c) A hologram of piston ring 3*

The three piston rings used in the work differed as they were subjected to thermal stress. This was exhibited by the captured interferograms as thermal stress was varied. In comparison with piston ring 1 and 3, piston ring 2 interferograms were stable at low temperatures though at higher temperatures they were adversely affected.

As piston ring 2 was subjected to thermal stress, a unique behavior of interferograms was observed. It was noticed that at low thermal stress (temperatures) the interference fringes were linear but from temperature increased the interferograms were characterized by geometrical variation in reference to interferograms recorded before the piston ring was subjected to thermal stress. This variation were more visible to the sense of sight at temperatures of 25°C, 35°C and 100°C as shown in figure 3(a), (b) and (c).



(a) (b) (c)

*Figure 3: Sample interferograms captured by CCD for piston ring 2. The interferograms were characterized by geometrical variation as temperature increased. (a) The interference fringes are linear at 25$^{o}$C (b) The interference fringes are curved at 35$^{o}$C (c) The interference fringes appear compressed at 100$^{o}$C*

These were characterized by bending and compression of the interferograms. The compression of the interference fringes was depicted by an increase in optical fringe densities where more fringes occupy a unit length than before. This also affected visibility of the interferograms without the aid of a CCD camera due to resolution limitation of the human eyes.

All the experimentally recorded interferograms were analyzed using Atmosfringe version 3.3 from Astro-physics and origin version 8.0. To analyze the interferograms captured using the CCD, they were loaded into the Atmosfringe software. Three points whose co-ordinates were given as follows: point 1: (231, 11), point 2: (13,251) and point 3: (502, 277) on each interferogram aperture were selected for analysis. The extracted interferogram data was used in determination of the wavefronts aberration as different interferograms were loaded into the software. The peak to valley (P-V) aberrations on the interferograms was obtained. The analysis revealed a variation of aberrations with change in temperature for each of the piston ring under test. 2D graphical analysis of the inteferograms obtained for sampled temperature of 25$^{o}$C, 40$^{o}$C and 60$^{o}$C on the piston rings are displayed in the figures 4(i), (ii) and (iii).

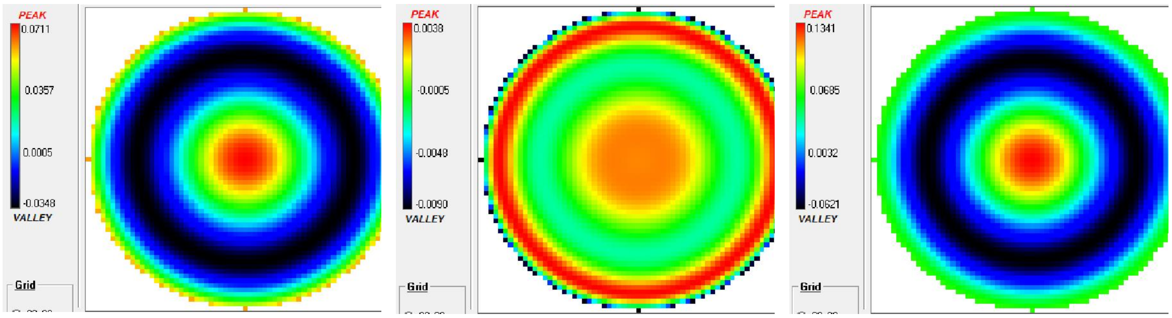



*Figure 4 (i): Graphical analysis of wavefront surface of piston rings at 25ºC. The profiles illustrate the P-V aberration of the piston rings as they were subjected to thermal stress. The P-V aberration for (a) ring 1 is 67.0 nm (b) ring 2 is 8.1 nm and (c) ring 3 is 124.2 nm*

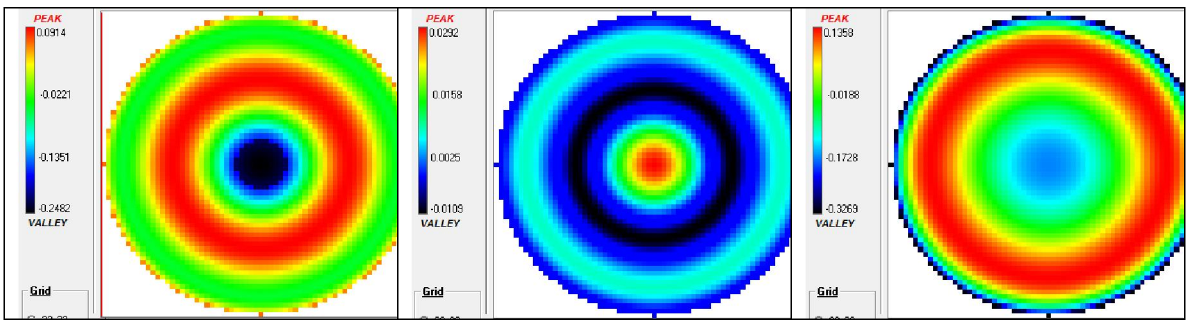



*Figure 4 (ii): Graphical analysis of wavefront surface of piston rings at 40ºC. The profiles illustrate the P-V aberration of the piston rings as they were subjected to thermal stress. The P-V aberration for (a) ring 1 is 214.9 nm (b) ring 2 is 825.4 nm and (c) ring 3 is 292.8 nm*

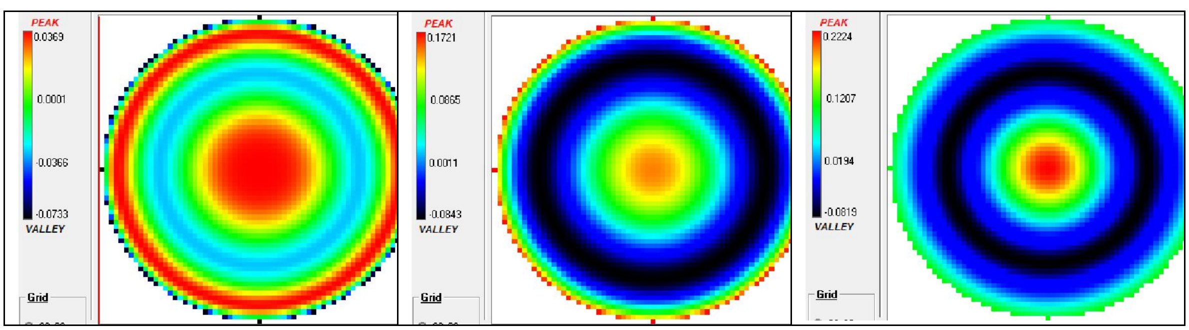



*Figure 4 (iii): Graphical analysis of wavefront surface of piston rings at 60ºC. The profiles illustrate the P-V aberration of the piston rings as they were subjected to thermal stress. The P-V aberration for (a) ring 1 is 69.7 nm (b) ring 2 is 162.2 nm and (c) ring 3 is 192.5 nm*

The analysis clearly displays in Figures 4. of variation in peaks and valleys of the interferogram as temperature varied. The variations were characterised by shifts in peak and valleys of the interferograms for the same piston ring as thermal stress was increased for example at temperature of 25$^{o}$C, 40$^{o}$C and 60$^{o}$C piston ring 1 had P-V aberrations of 67.0nm, 214.9nm and 69.7nm respectively.The same trend was observed from the other two rings that were under investigation. Similarly at the same temperature the piston rings interferograms had different P-V aberrations. For example at 40$^{o}$C, ring 1, 2 and 3 had P-V aberrations of 214.9nm, 25.4nm and 292.8nm respectively. The variations in aberration between piston rings at the same temperature demonstrated their structural differences.

The phase change as a result of thermal stress was also measured from the generated interferograms. This analysis of the interferogram was done using origin version 8 software. The process of extracting the phase variation across the interferogram was undertaken using the Fast Fourier Transform (FFT) function of the software. Like any other fringe analysing technique, Fourier Fringe Analysis (FFA) extracts phase information from intensity distribution of the source fringe pattern. To retrieve the phase information from the interferogram, low pass FFT filtering was done. This was followed by shifting to eliminate the carrier frequency from the extracted phase. Since FFA uses arctangent function, it led to extraction of wrapped phase which provided discontinuous phase information. To provide the continuous phase information, unwrapping process was performed. The phase unwrapping process solves the ambiguity problem caused by the fact that the absolute phase is wrapped into interval recovering the continuous phase information. One of the limitations associated with FFA is the frequency leakage. The frequency leakage is related to discontinuities at the end of the measurement time. Therefore reduction of the frequency leakage was necessary when working with this fringe pattern analysing technique. To minimize the frequency leakage associated with FFA, the fringe patterns were multiplied by hamming window for smoothening. The window reduced the discontinuities at the end of the signal measurement. This was attained by reducing the signal to zero at the end point.

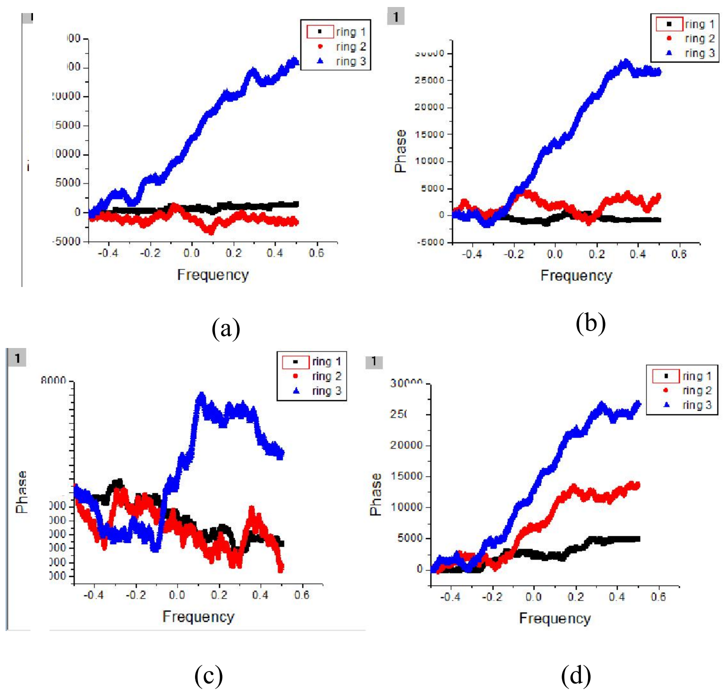



*Figure 5: Piston rings interferograms phase representation with respect frequency. The graphs are arranged in order of increasing thermal stress on the rings 1, 2 and 3. (a) 25$^{o}$C. (b) 40$^{o}$C (c) 60$^{o}$C and (d) 100$^{o}$C*

From the plots, the phase change for the three piston rings is illustrated. The change in phase for the three piston rings was observed to be nonlinear as temperature varied. At certain temperatures the change in phase of the piston rings had almost the same trend. This phenomenon was observed with piston ring 1 and 2 at temperatures of 300C and 600C. Though the trend was almost the same on considering certain frequency value there were variation of phase values. Similarly at certain temperatures, the phase changes between the rings were diverse. This diversity in phase change is clearly noted at temperatures of 800C and 1000C. This implies that the rings were affected differently by the same thermal load. This unique piston rings behavior clearly demonstrated how the piston rings are fabricated differently to perform their task. These include; sealing of combustion chamber, regulating oil consumption, stabilize the piston and heat transfer. These tasks leads to subjecting the piston rings to stress hence they are designed to maintain their function as the environment changes.

## 4.0 Conclusion

Measurement of thermal stress on the piston ring was achieved. This was achieved by designing and configuring of highly sensitive surface analyzing set-up. Using the set-up, monitoring of the effect of thermal stress on the piston rings was done in real time. The high sensitivity of the technique was demonstrated by its ability to measure small surface changes as a result of the piston ring subjection to thermal stress. The major advantage of technique was the continuous investigation of the piston rings as heating was done. The non-invasive property of the technique made it possible to analyze the surface of an object before using.

To study the effect of thermal stress on piston rings qualitative and quantitative analysis was performed. In qualitative analysis, change in fringe pattern was easily visualized. This analysis relies on visual inspection on the fringe patterns. In quantitative analysis Atmosfringe version 3.3 was used. The analysis provided information on the magnitude of deformation as a result of thermal stress subjected on the piston rings. The deformations were expressed in terms of phase change and 2D wavefront surfaces. To verify the high sensitivity of the technique, small changes on the piston ring were determined. This resulted to obtaining P-V aberration values as low as 0.0128λ. Further analysis using FFT revealed change in phase as the ring was subjected to thermal stress. The technique also demonstrated the difference in structural design of different piston rings on a piston.

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