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Application of Non-Contact Infrared Thermography Technique for Gas Turbine Blades

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ABSTRACT
Hydrobased power generation plants, rotating componentsused are critical for overall performance of plant. The materials used are subjected to bear heavy erosiondue to mud containing water to rotate the blade. The manufacturer has an option of using high wear resistant material which are costlier or using cheaper materials with ceramic coatings over it. The coatings exposed to harsh conditions will withstand mechanical wear and hence coating needs to be adhered properly on the material. Coatings of 300-500-micron thickness serve the purpose and the techniques available for spray are High Velocity Oxy Fuel (HVOF), Plasma, Twin wire arc, etc. The evaluation of coatings w.r.t quality is required to be done to enhance the life of components. Comparing to the traditional Non-Destructive Tests such as Acoustic Emission, Ultrasonic, and Eddy Current, Magnetic Particle and Radiography Tests where experimental equipment is non-portable, tedious and time consuming, profile dependant and difficulties during interpretation of results. A new approach Infrared Thermography Testing (IRT) has been introduced for qualitative evaluation of coatings. In this technique, high energy optical source along with Pulse phase thermography system has been used for detection of surface and sub-surface coating defects in wear resistant coatings. Pulse phase thermography is helpful in finding defects in high reflecting and thermal conductive materials like steel. The IRT methodology and IR results are discussed in this paper.

Keywords: *Pulse Phase Thermography, Coatings, Wear Resistant Coatings, Components.*

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I. INTRODUCTION

Hydel power stations power is generated by the using water head as source to move large turbines. Many designs are used like Kaplan, Pelton etc. for turbine manufacturing depending on water pressure heads. These turbines blade are of high alloy steels which faces water force containing contaminants like mud, wood scales etc. which causes wear of the turbine blades and need repairs. To enhance the life of blades a superficialthin wear resistance coating comprise of WC are applied over turbines. To measure the continuity of wear resistant coatings and defect assessment various methods which are inconclusive. Hence an alternate thermography method is attempted to find the defects in wear resistant coating. The pulsed phase thermography (PPT) is a well-known method in non-destructive testing in assessing engineering materialdefects near to the surface because of its simplicity and fast inspection results. It combines features of pulse thermography (PT) and lock-in thermography (LT) [1]. The experimental set-up and data acquisition are identical for both, PT and PPT, whereas data analysis procedures are different. In PT, material is exited for short interval of by flashing using high heat source and raw data obtained is analysed for particular frequency contrary to PPT where each pixel's time history of a series of consecutive thermograms is merged to describe obtain transient cooling down behaviour of the inspected specimen surface after a heating pulse, The infrared raw data is analysed by application of discrete Fourier transformation (DFT) [2] in terms of phase shift of waves at each frequency. The computed phase grams are excellent for defect visualization in a wide range of materials [3]. This is partly due to their low sensitivity to uneven heating. However, DFT are often saturated within a time domain of thermal data, when acquired using low cost infrared scanned detector cameras. This is due to the fact of limited camera capability slow data acquisition rate and low spatial resolution. In this paper we have presented a relativity efficient approach towards pre-processing of raw data, time dependent experimental thermal data sets obtained by this type of infrared imagers, before their 1D DFT treatment and also the approach to their post processing after frequency analysis of waves obtained.

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II. EXPERIMENTAL PROCEDURE

The experimental data set of wear resistant coating on steel plate thicknesses,1000-1500micron for study by flashing 6 KJ of energywith flash lamp for 2ms.To study the thermal decay plotting temperature vs frame CEDIP camera short wave band (3-5 µm)of 5500-M used to capture sequence.To study the thermal behavior on coating thermography system used consists of- IRX Box,an excitation source, and a panel with Hansen high power lamp and IR-NDT softwarepower electronics module. Phase and amplitude image sequence is recorded and analyzed. The thermal wave signal generated on the surface of the sample were processed using one-dimensional and extracted the shape of an oscillation with a damping factor and a proportion, describing the phase shift as per equation given below (1) [2,3].

$$T(z,t) = T_0 e^{-\sqrt{\frac{\omega\rho c}{2\lambda}}z} \cos\square(\omega t + \sqrt{\frac{\omega\rho c}{2\lambda}}z) \qquad (1)$$

λ = Thermal Conductivity
ω = Angular Frequency, 2π*n (Excitation Frequency)
ρ = Density
c = Specific Heat Capacity
z = Coordinate

Experimentation on samples reveals, the decrease of the amplitude of the thermal wave with increasing material depth depends and on the thermos physical properties and the stimulation frequency. Within a depth of the amplitude drops to 37% (1/e) of the surface value.

$$\square = \sqrt{\frac{2\lambda}{\omega\rho c}} = \sqrt{\frac{2\alpha}{\omega}} \qquad (2)$$

EXPERIMENTAL RESULTS ON C30 CARBON STEEL SPECIMEN
Where Thermal Conductivity of Carbon Steel, λ= 68 W/0k
Excited Frequency through lamps n=0.25 Hz
Density, ρ=7840 kg/m3
Specific Heat Capacity, Cp=0.49 KJ/Kg. K

Depth of Penetration of Thermal Wave, $\mu = \frac{(2\lambda)}{(\omega \times \rho \times C_{p})}$

$$= \frac{2\times 68}{2\pi \times 0.25 \times 7840 \times 0.49}$$

= 0.022 mm

The actual known thickness of C30 Carbon Steel Sample is 6 mm, where PPT thermography technique can reveal the defects upto 0.22 mm depth.

FAST FOURIER TRANSFORMATION (FFT) SIGNAL PROCESSING:

Discrete fourier transformations of the image formed by serval pixels acts a single point for large sample. DFT is the best possible computing method for processingsignal and image processing application.

A discrete Fourier transform (DFT) is a method which converts a signal n time domain into its counterpart in frequency domain. Let {x1} be a sequence of length N, then its DFT is the sequence {Fn}given by

$$F_n = \sum_{i=0}^{N-1} X_i \times e^{-j2\pi\frac{n}{N}i}$$

While using FFT algorithms, a contrast is made between the image sequence of the test performed and the output of the computed DFT is referred as transform length. The execution time of an FFT algorithm depends on the transform length and is highest when the transform length is a power of two, with less prime factors variables and more processing when prime factor variables are more. FFT allows to read the frequency data and the complex transformed result and it can provide conclusive magnitude, amplitude, phase, power density and other computation results. [4,5,6]

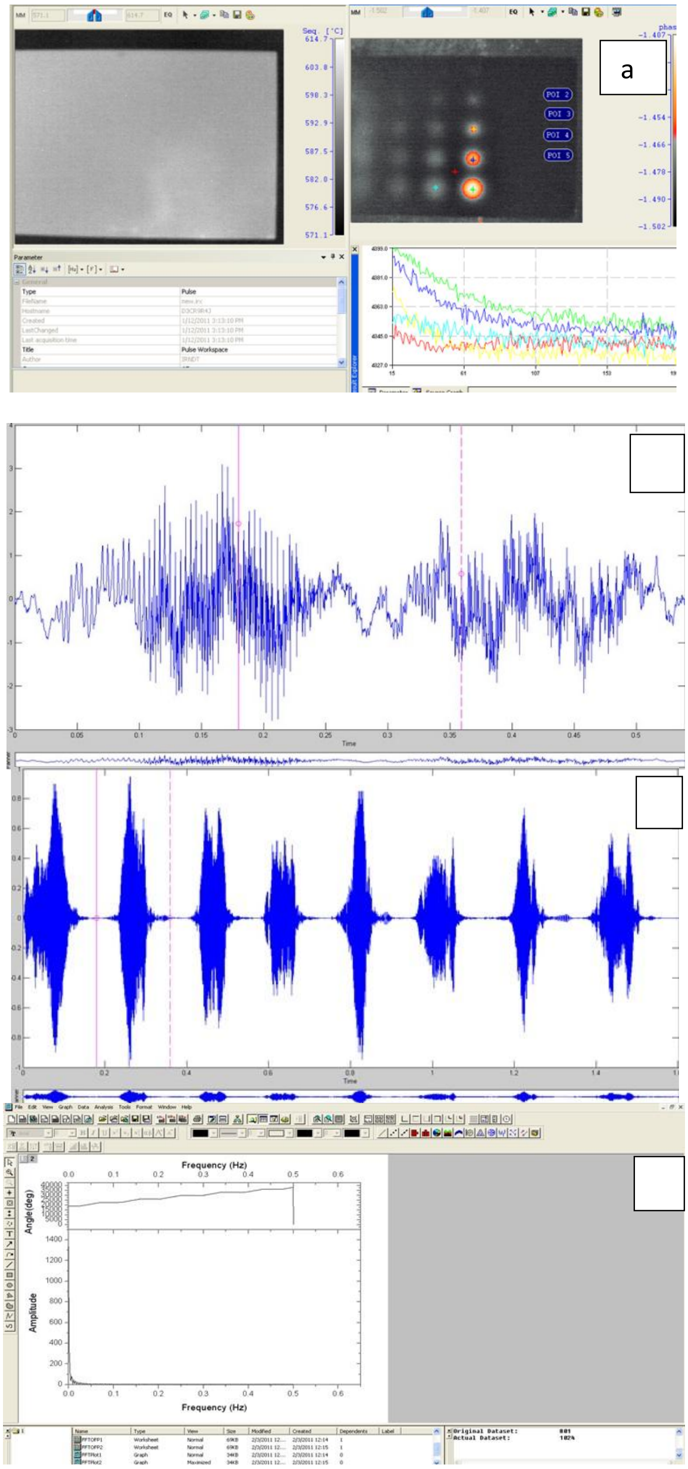

Figure 1 (a), (b), (c) & (d) True Signal and processed signal output with frequencies values

The acquired consecutive thermograms were converted into a scaled intensity thermal images series with an arbitrary selectedinterval of the sampled time history of each discretionary selected rectangular region of pixels of any its thermal image. The full time series of complete converted thermograms was chosen as a region of interest in the described thermographic measurement. Having these samples of the original time dependent thermal signal, the DFT can be applied to estimate the potential capabilities of analysis in the frequency domain [7-8].The experimental results show that the pulse phase thermography software helps in distinguishing surface and subsurface defects. Further, the amplitude and phase angle images were processed in image processing using MATLAB (student version) software and evaluated.

III. RESULTS AND DISCUSSION

Corresponding to the physical fundamentals of the Lock-In procedure the evaluated phase and amplitude images have some interesting characteristics compared to normal infrared images:

The amplitude and the phase image are not influenced by the proportion of the environment radiation reflected by the object surface. All additive temperature components have to influence on the analysis.

The phase image is not influenced by the locally differing emissivity of the object surface. All multiplicative temperature components have no influence on the analysis. In the first approximation, this applies also to locally uneven heating of the object surface by the heat source.

However, thereby the local dissolution of the procedure is limited e.g. for material defects. While the thermal wave moves inside the test object, it is strongly damped. Therefore, the wave can advance only up to a certain material depth. This range depends strongly on the excitation frequency.

The lower the frequency, the greater is the penetration depth. By changing the modulation frequency, you are able to analyze the material structure in different layers. In relation to the amplitude information, the phase information possesses a double depth range.

Apart from the excitation frequency, the penetration depth of the thermal wave is influenced strongly by the thermo-physical properties of the material (thermal conductivity, heat capacity, and density). Therefore, the depth range is clearly larger in metals than in plastics or wood.

Approximate values with a frequency of 1 Hz are 1-5 mm for metals and 0.1-1 mm for other materials. With a frequency of 0.1 Hz, one achieves a depth of approximately 5-20 mm with metals and 0.5-2 mm with other materials.

Experimental Trials were made on Gas turbine blades provided with cooling holes with conventional thermography technique to reveal cooling design present inside the blades which could not reveal effective data. Blade was stimulated with high power flash lamps and thermography signatures obtained were then recorded. Thermography signatures were then post processed with Pulse Phase Thermography analyzing software available in IRNDT software to reveal internal condition of blades. Defects and blockages present in the blades could be identified easily by manipulating the frequency and phasegrams available in the software.

The results of the described power spectral analysis for frequencies of 0.1, 0.4and 5.9Hz are presented in Fig.1(a). Hidden defects fall in these frequencies where maximum energy is stored in the pixels and helped in the locating the various sizes present in different surface depths. The darkest point in Fig. 1arepresents a relatively shallow subsurface flaw or a little inclusion situated fairly deeply because at higher frequencies, with the absence of the external thermal stimulus energy for a deeper penetration into the tested material, it fades from the power spectral pictures. On the other hand, both defects visible in Fig. 1b and Fig. 1c are much larger because of their strong visibility in the wider frequency band at Fig.1(d). At the same time, these defects of various sizes must be also situated deeply below the surface considering their detectability already at very low frequency as shown in Fig.2(a) & Fig.2(b). The right one is larger and deeper as it provides a higher contrast on the low frequency picture.

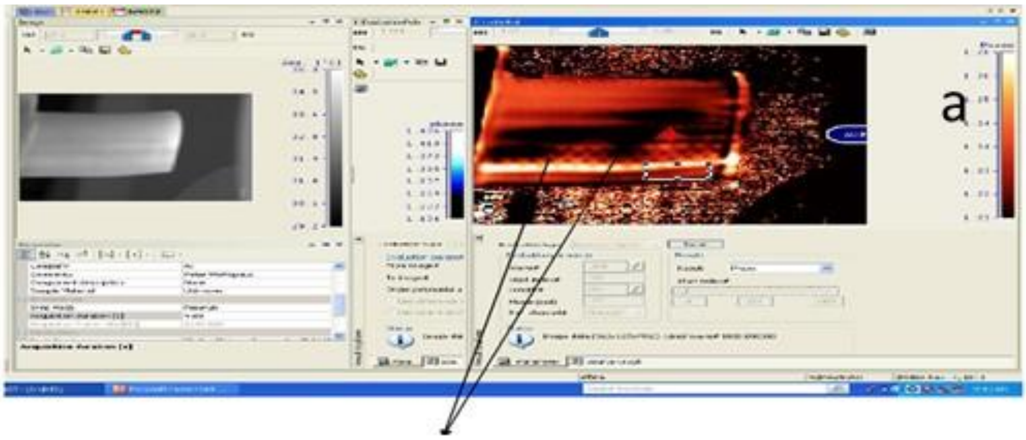

Fig.2(a) Blockage inside Honey comb structure revealed at 0.1Hz

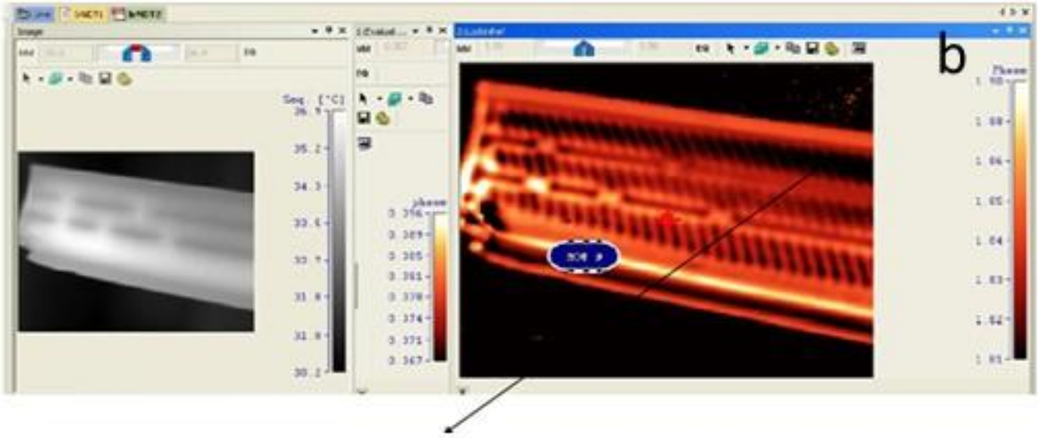

Fig.2(b) Presence of oxide scale inside turbine blade revealed at 0.2Hz

IV. CONCLUSIONS

The approach followed above of sequencing raw data and converting in to thermal image enhances the defect visibility with the wavelet-based extensions and its resampling individually into one dimension from multichannel parts makes possible effective power spectrum analysis of the total frequency as sub surface defects are sensitive to frequency domain. The experimental data is relatively simple for finding defects in coatings and techniques can be utilised for fast and accurate measurement.

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