Automatic Detection of Subsurface anomalies using Non-Linear chirped Thermography

B. Suresh, Sai kiran Jammula, G V Subbarao

***Abstract*: Detection of subsurface anomalies facilitates easy assessment with assuring the industrial quality of materials. Infrared imaging has found to be promising non-intrusive approach to cater to it. But the expertise required for the thermographic analysis is time consuming and for the laborious detection task over the post-processed history leads to limitation of its applications. Any automatic defect detection procedures along with post-processing facilitates practitioner to get comprehensive information without manual intervention. This manuscript introduces a level set based image segmentation to locate anomalies in post-processed Frequency Modulated Thermal Wave Image (FMTWI).To ratify the applicability of the method proposed, the trail is done on the Teflon patches specimen.**

***Index Terms*: Infrared Non-Destructive Testing, QFMTWI, Pulse compression (PC), Level-set.**

I. INTRODUCTION

From the past few years the usage of composite materials in various fields has been increasing due to their unique properties like high strength and less prone to corrosion. However due to the delamination's and cracks which are developed during the manufacture process the structural stability and strength of the materials are reduced which effects the durability of the material. So, this leads to the development of non-contact and non-destructive evaluation of the materials for sake of subsurface anomaly identification.Among the various NDT(Non-Destructive Techniques)[1] methods thermography holds an edge due to its advantages like non-contact, non-invasive and wide range investigation of the materials, out of the two methods of thermography the passive thermography doesn't need an additional coded excitation for creating contrast in thermal response over the surface of the object. On other hand the active thermography requires an additional excitation for creating contrast in thermal response and can effectively trace the subsurface anomalies.

In the active thermography the additional coded excitation is given to the material with the help of the halogen lamps, among the various stimulation methods Pulse Thermography (PT)[2, 3], Lock-in Thermography(LT)[4, 5] and Pulse Phased Thermography(PPT)[6, 7]are popular in thermal applications. A high peak power stimulus for a short duration of time is given to the sample in PT which leads to the non-uniform emissivity and non-uniform heating of the material due to this effect it has limited applications.

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In LT and Frequency Modulated Thermal Wave Imaging(FMTWI)[8, 9]methods low peak power source for a long duration is given to the material, but the mono-frequency excitation by the LT method requires repetitive experimentation for identification of various subsurface anomalies.

The Frequency Modulated Thermal Wave Imaging (FMTWI)[8] method have more deposition of energy, better depth resolution,dynamic range and side lobe reduction compared to all its counter parts and making it a novel stimulation method.
An Infrared camera is used for capturing the thermal response of the specimen and various processing methods are applied on the captured data to extract the minute temporal temperature evolution details which reveal the subsurface details of the material. The polynomial fittingis used to remove the mean from the captured thermal data there by getting the dynamic response and conventional methods like Pulse Compression(PC)[10] and FFT based phase analysis[9]are applied on this mean removal temporal data in order to get the subsurface details.

As thermograms which are obtained from the processing methods such as PC and FFT can't trace the boundaries of the subsurface anomalies, the level set based image segmentation [11, 12]which is more robust to the initialization is applied on the PC and FFT thermograms with the intent of tracing the boundaries of subsurface anomalies. The segmented thermal frames of PC and FFT are compared in this manuscript.

The present article discusses the FFT and pulse compression-based methodologies for post processing of captured thermal response in segment II. Materials and experimentation are discussed in segment III, segment IV has the results with discussion followed by segment V which has conclusion.

II. METHODOLOGY AND EXPERIMENTATION

1. FFT based phase analysis

In this frequency domain analysis method, the FFT will be applied on each pixel thermal profile and phase values corresponding to every frequency component are extracted [9].Then from the phase values obtained at a chosen frequency component of each pixel in the view the phasegrams are constructed[13-19]. Thecontrast in the phase obtained from these phasegrams will beused for the anomaly identificationasthephasegramfrequency obtained by FFT based estimations is equal to the sample frequency, given by

$$F = \frac{F_S n}{N} \quad (1)$$

Where
F_s = Frequency of the sample or rate of capturing
n = Phasegram number
N=number of samples in the thermal profile

2. Pulse Compression (PC)

Pulse Compression belongs to time domain analysis. In this method, the cross correlation is carried overthe profile chosen as reference and the mean removed thermal profiles of all the pixels [10]. The normalized correlation data sequence is computed for all the pixels from the cross correlation and in order to keep the normalized correlation coefficients at delayed instant in to their respective spatial locations the profiles are rearranged. The coefficient contrast in the correlated images gives the information about subsurface anomalies [13-19].

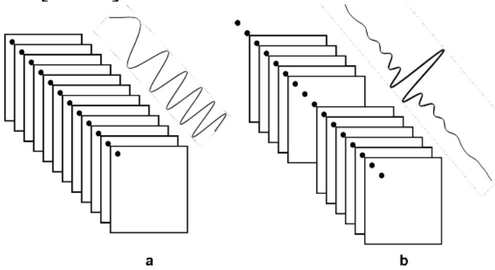

Fig. 1 Pulse Compression (PC) method

3. Level set method for image segmentation

Level set method is one of the significant methods for the contour evolution. In order to study the level set function, let us assume a function $\phi(x,y,z)$ where (x,y) are the coordinates of the image at an instant 'z'. At any given time, the level set function simultaneously defines an edge contour and segmentation of the image. The edge contour is referred as the zero-level set i.e.$\{\Omega(x,y)\ s.t\ \phi(x,y,\ z)=0\}$and the segmentation is splitted in to two regions such as $\{\phi \geq 0$and$\phi<0$. The level set function which is evolved using a partial differential equation reaches to a steady state$lim_{t\rightarrow\infty}\phi$ which results in to the image segmentation [11,12].

To elucidate a level set function which can segment the image in a significant way is the most crucial and difficult step.The simple technique which is useful to do so is to term the level set function to be the value which is obtained by subtracting some threshold from the pixel value P(x, y) in a gray level image i.e. $\phi(x,y) = p(x,y) - z$. If the gray level for the regions in the image is higher than the threshold then level set function will be positive, it will be negative if the gray level is less than the threshold [11,12].

The level set method is more effective because it can easily sustain thehierarchicalchanges that occurs in the edge contour which is difficult for a model in which the contour evolves directly. For the higher dimensional surface, the contour is indirectly taken as zero thereby eliminating the computational complexity when the contour splitting takes place [11,12].

Experimentation

In order to ratify the method proposed a Teflon patches specimen material with twelve layers and different thickness is taken, as shown in the fig. 2.

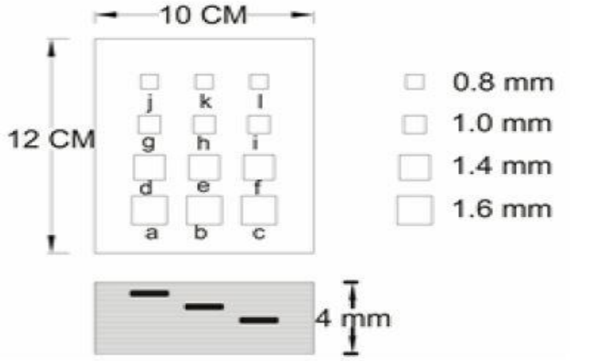

Fig. 2 Teflon patches layout

During the experimentation, the frequency modulated optical stimulus generated by a set of halogen lamps of power 1kw each is used to energize the Teflon patches specimen as shown in fig.3. The stimulus has a frequency sweep from 0.01 to 0.1 Hz in duration of 100 s.FLIR infrared imager SC6200 embedded with InGaAs detector having spectral range of 0.9-1.7 micro seconds and with an IR resolution 320 x 256 is placed opposite to Teflon patches specimenat 1 m distance. The thermal response is captured by imager at frame rate of 25 Hz.

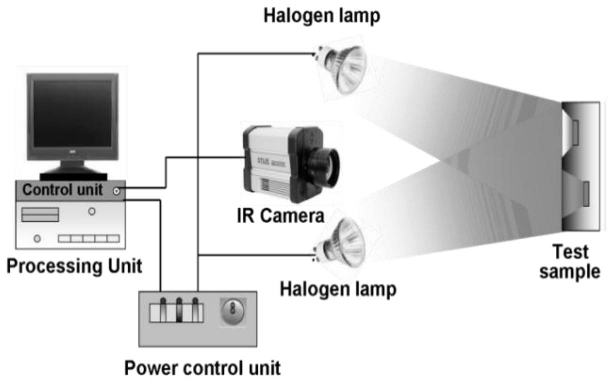

Fig. 3 Experimental setup of Active thermography

On the captured thermal response, the post processing methods such as conventional FFT and Pulse Compression (PC) are applied and the resultant frames from the PC and FFT are taken and level set based image segmentation is performed.

III. RESULTS AND DISCUSSIONS

The FFT and Pulse compression processed images are taken and the Signal to noise ratio (SNR) of all the defects in both the methods are calculated and tabulated Table.1. Then level set based image segmentation is performed on the both the frames and the segmented images of FFT and PC are obtained and visualized in figure 4. From the segmentation results and SNR values we can state that Pulse Compression (PC) have better defect detection compared to the FFT based phase analysis in FMTWI modality.

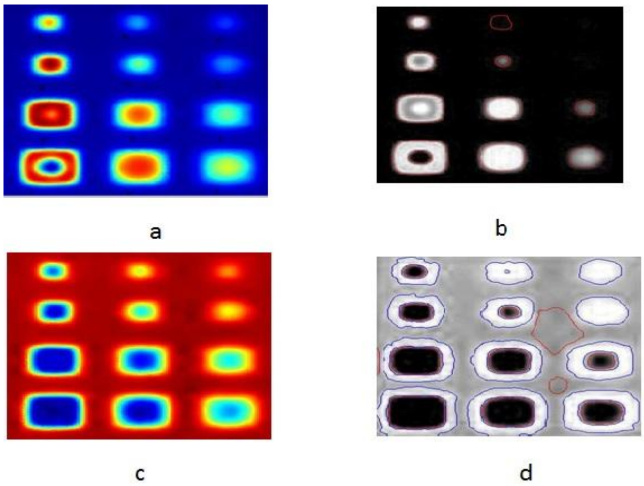

Fig. 4 a. FFT Processed image b. FFT Segmented image c. PC Processed image d. PC Segmented image

Table 1 SNR of Teflon patches specimen

Processing method / SNR of defects(in dB)	Conventional FFT	Pulse Compression(PC)
a	76	79
b	71	75
c	59	69
d	60	70
e	59	72
f	55	64
g	51	56
h	49	56
i	21	55
j	28	54
k	22	52
l	21	51

IV. CONCLUSION

The level set based image segmentation for locating the subsurface anomalies in thermal wave image is performed on the Teflon patches specimen with embedded flat bottom holes of different sizes at different depths. The proposed method performs the better defect detection compared to all the conventional and existing methods.

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