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3D Finite Element Analysis of Crack in Aluminium Plate Using Tone Burst Eddy Current Thermography

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ABSTRACT

Tone Burst Eddy Current Thermography (TBET) technique is mainly used for the evaluation of crack and corrosion damage in Aluminium plate or pipe like structures especially in aircraft industries. The life of structural members can be evaluated by determining the size and orientation of cracks. Our work describes about how the various crack parameters affects distribution of temp produced by TBET heating.3D simulation results have been achieved by using COMSOL multi-physics with AC/DC module and general heat transfer. Parameters considered in this study are i) optimum frequency ii) excitation time and iii) crack depth . At crack edges, induced current is seen concentrated thus indicating a localized high heating in those areas relative to other regions. It was determined that TBET technique has some advantages for the inspection aircraft structural components compared to other modalities, particularly in cracked regions. A comparison of results obtained by varying the above mention parameters is to be done.

INRODUCTION

TBET is an evolving non-contact, non-destructive evaluation method with applications especially in aircraft industries for surface and subsurface crack detection under paints[1]. TBET technique combines both Thermographic non-destructive evaluation (TNDT) techniques and Eddy Current Testing (ECT) to provide efficient method for defect detection and characterization over a relatively wide area in very short time. Due to electromagnetic induction Eddy currents are developed on them conducting material and generation of heat by Joule heating. Defect detection is based on the changes of induced eddy current flow and IR camera is used for detecting and characterizing surface and sub-surfaces defects[2].Heat diffusion into the material, when perturbed by the presence of a subsurface defect, causes a local temperature contrast between the defective and the non-defective regions on the measuring surface. This temperature contrast is detected by the thermal imaging equipment. Recorded images over several time frames are processed for extracting the internal flaw information [1].

The main difference between TBET and eddy current thermography is the type of signal that is applied to the coil. In TBET a burst of signal having high frequency is applied to the coil for short period of time which for a few seconds for semiconductors and few microseconds for conductors. The time for which the signal is applied to the coil is called excitation time and the time between two successive signals is called observation time. The IR image of the thermal wave distribution produced by tone burst eddy current heating is taken for both observation time and excitation time.

SIMULATION MODEL

The simulations were performed on am aluminium plate of 220mm×150mm×2mm. A circular coil made of copper with 2mm diameter is used for induction. The lift-off of the coil from the plate was kept at 2mm. It is placed parallel to the specimen (X-direction). A peak current of nearly 1000A was passed through the coil and the temperature history of the surface was monitored. The simulation was done with various excitation frequencies ranging from 250 to 1500Hz.

The Simulation of TBET technique requires a multi-physics electro-thermal approach involving,

a) An electromagnetic model for the eddy-current generation,

b) An electro-thermal model for the conversion of eddy-currents into heat, and

c) The heat transfer model for the heat conduction from the heating surface into the material[2].

A 3D Finite Element Modelling (FEM) approach has been selected so that the model can be later extended to more complex and arbitrary configurations. All models were developed using the Multiphysics COMSOL package version 3.4.

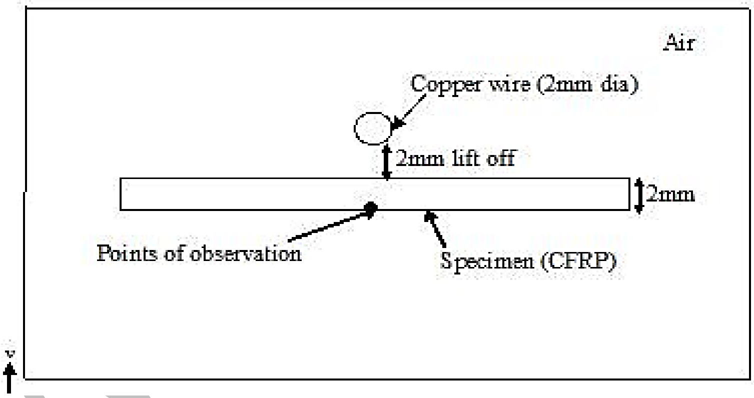

Fig 1: 2 D view of the model

Table 1; Material properties used for the simulation.

Material Property	*Air*	*Aluminium*	*Copper*
Relative permeability, µr	1	1	1
Electrical Conductivity, s(S/m)	0	3.774×10^{-7}	5.998×10^{-7}
Thermal Conductivity, k (W/m. K)	0.026	160	400
Density, r(Kg/m^3)	1.23	2700	8700
Specific Heat, C_p(J/kg. K)	1005	900	385

Table 2; Constants used for the simulation

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Constants	*Air*	*Aluminium*	*Copper*
Convective Coefficient, h (W/m^2. K)	-	5	-
Emissivity, e	-	0.3	-
Ambient Temperature(K)	-	300	-

FINITE ELEMENT BASED TBECT MODEL

A 3-D model of TBECT system is made on COMSOL multiphysics software. The model consists of an aluminum plate having 210mm×150mm×2mm size and a copper coil having 2mm diameter is placed at a lift-off distance of 2mm above the plate. This whole set up is enclosed in air having 270mm×180mm×50mm size. Figure 2 shows the model of the test environment made.

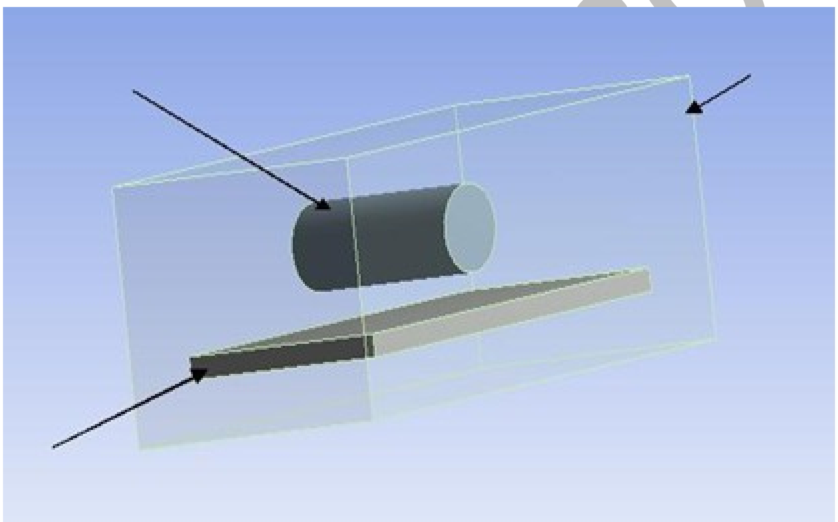

Fig 2;3-D model of TBET system

The Boundary conditions used for the electromagnetic induction were

1) Axial symmetry at r=0
2) Magnetic insulation at the air boundaries (Aj=0)
3) Continuity of magnetic fields at the interior boundaries

And for the heat transfer,

1) Axial symmetry at r=0
2) Temperature boundary condition at the air boundaries
(T=Ta =300 K)
3) Heat flux at the other boundaries.

The loads applied where

1) Excitation frequency

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2) External current density
3) Excitation time and observation time

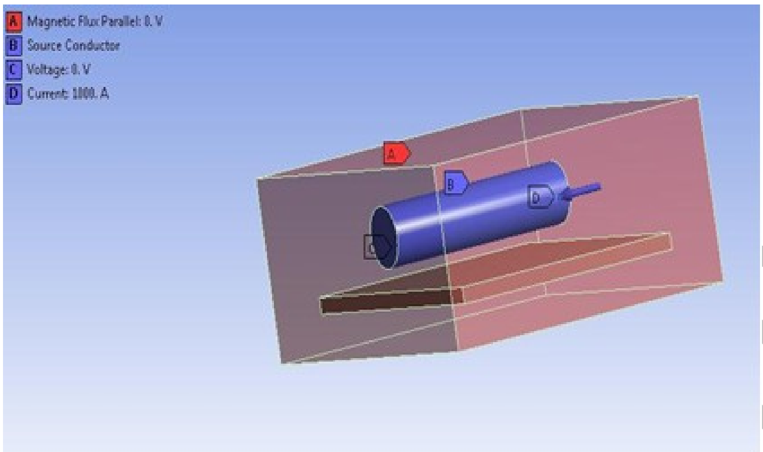

Fig 3: Model after applying loads

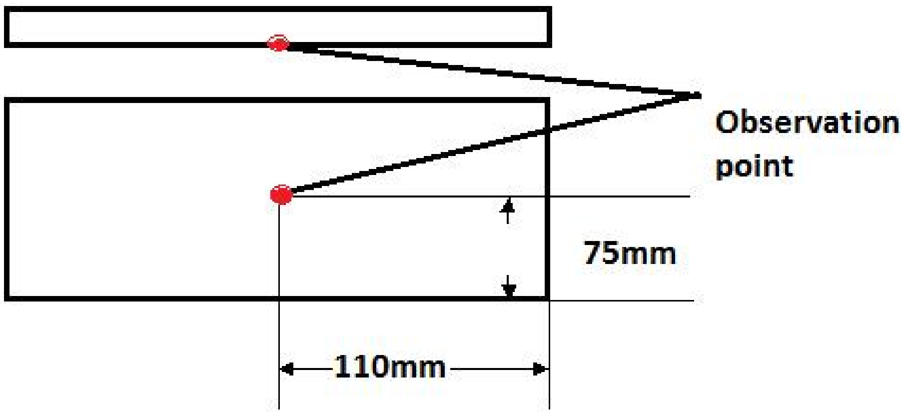

Fig 4: Observation point

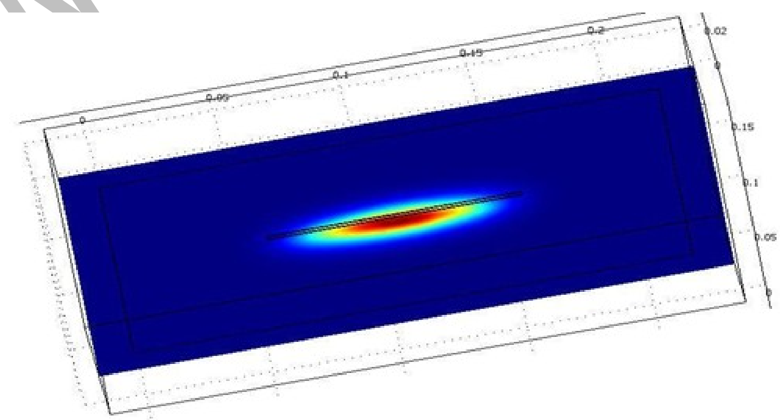

Fig 5: Slice image plotted in COMSOL

The first thing to do while designing a TBET system is to find the optimum frequency and the excitation time

FINDING THE OPTIMUM FREQUENCY

Analysis was conducted to find out the optimum frequency of the setup modeled because the optimum frequency changes with change in material and lift off distance. So for finding the optimum frequency an aluminium plate with a coil placed at a lift off distance of 2mm is modeled, then a excitation current of 1000A is applied to the coil and various excitation frequency ranging from 250Hz to 1500Hz are given to find out the optimum frequency.

Temperature rise on a alluminium plate without crack at various frequency

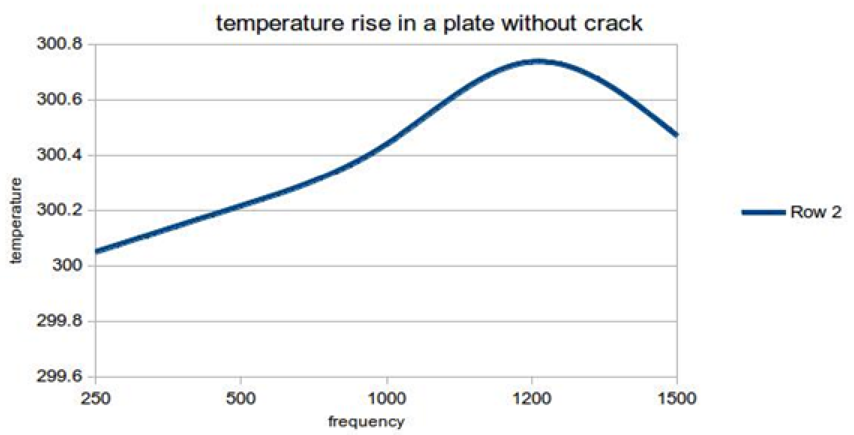

Fig 6: Temperature vs frequency

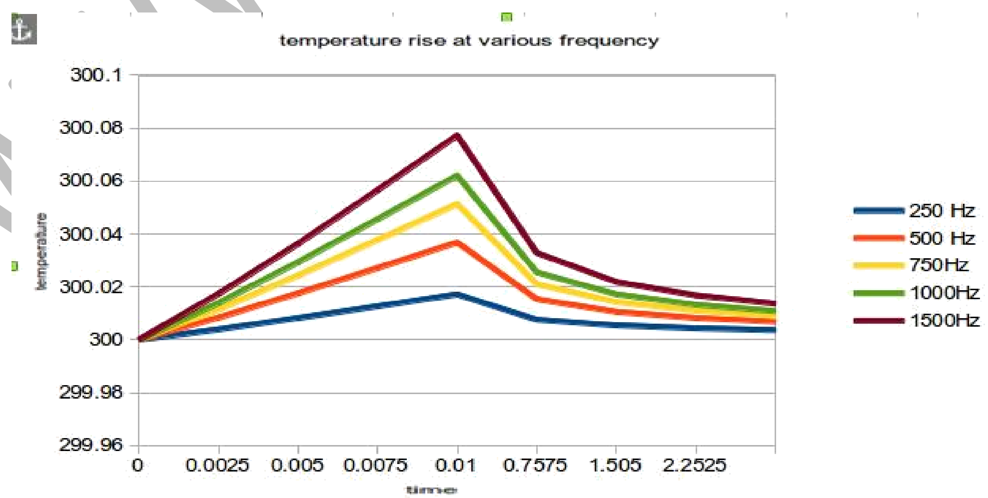

Fig 7: Temperature rise at various frequency

Table 3: Temperature rise for various excitation times

Excitation frequency (Hz)	Temperature rise for 10 ms heating
250	300.04993
500	300.2159
1000	300.43868
1200	300.73578
1500	300.46985

While changing the excitation frequency from 250-1200 Hz, it was found that the temperature rise produced increased with increase in frequency, but after 1200 Hz the temperature begins to fail.

OPTIMISING THE EXCITATION TIME

Stimulation is done at various excitation time to find the appropriate time of excitation in which the clearly visible in their image obtained by the camera. For that the thermal profile on the surface of the plate with a crack having 2mmx5mmx1mm is plotted at various excitation times. It is found that the crack is visible at lower excitation time and as the time increases the thermal image become difficult to interpret.

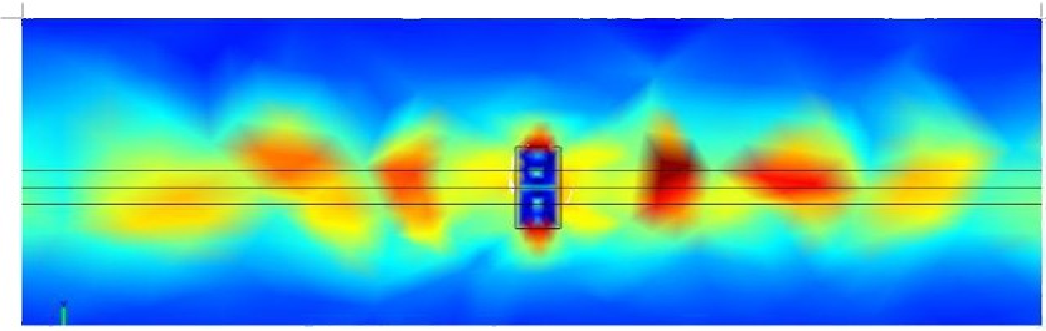

Fig 8: Temperature distribution at an excitation time of 1ms

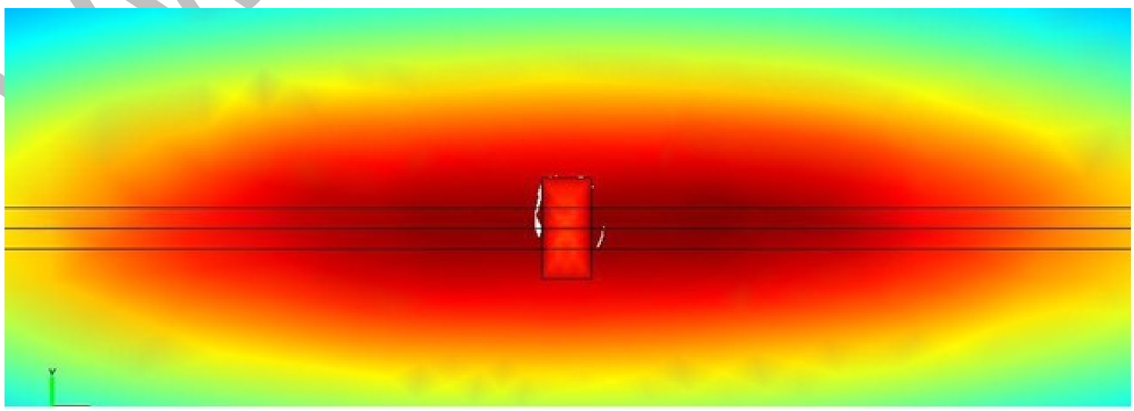

Fig 9: Temperature distribution at an excitation time of 1.5s

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Table 4: Temperature rise for various excitation time

Excitation time	Temperature rise
10ms	300.08453
50ms	300.30798
100ms	301.501
500ms	302.0715
1s	303.16922
1.5s	304.35956

Excitation time is an important parameter that affects the temperature rise produced by TBET method .Here we can see that excitation time of signal increases from 10ms to 1.5s the temperature also increases.

EFFECT OF CRACK DEPTH

In my work I conducted an analysis to find the effect of crack depth on temperature rise. For this analysis a surface crack having 2mmx5mm is modeled with depth 0.25mm,0.5mm,1mm and 1.5mm. For this study an excitation current of 1000A having a frequency of 1200Hz is applied for 10ms. The temperature rise at observation point for each crack depth is plotted. From the result it is found that the max temperature attained increases the increase in crack depth

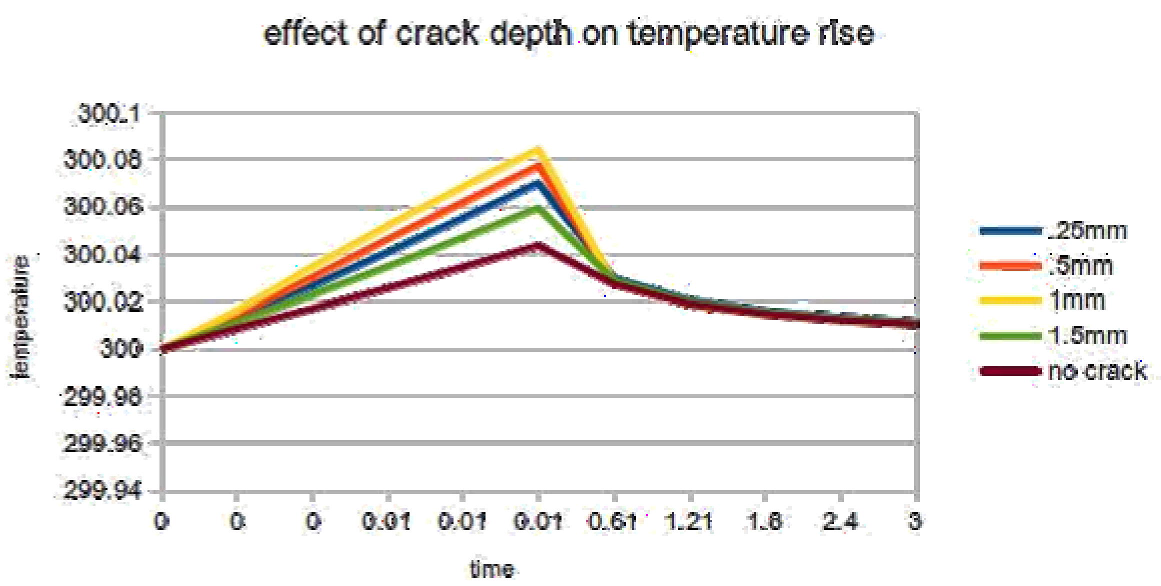

Fig 10: Effect of crack depth on temperature rise

Table 5: Temperature rise for various crack depth

Crack depth	Temperature rise
0.25mm	300.05957
0.5mm	300.0701
1mm	300.08453
No crack	300.0437

CONCLUSION

Tone burst eddy current thermography, a relatively new NDT technique which combines the advantages of eddy current testing and thermography, is being demonstrated well numerically. NDT techniques are mainly used for defect detection. But in the present work, the new NDT technique has been successfully demonstrated in estimation of both surface and sub-surface crack in an aluminium plate.

A 3D finite element model was developed for simulation in the electro-thermal environment of COMSOL MULTIPHYSICS 3.5 software with aluminium plate as the test specimen and surface and subsurface cracks where modeled.

From the study of the optimized data that was obtained during analysis it was found that a clear picture of the crack is obtained at lower excitation time. So for a TBET system a high sensitivity IR camera with high frame rate is preferred because such camera can pick up small change in temperature at a very high frame rate less than 5ms. In my analysis I came to a conclusion that images obtained with excitation time less that 5ms gives a clear picture about the crack. It was also found out that there will be a optimum frequency at which maximum temperature rise occurs for every model which depend on the lift off distance and the properties of the test specimen [1]. So while designing a TBECT system finding out the optimum frequency is very important.Also the result obtained by the analysis of crack depth is clear that the crack depth affect the maximum temperature rise produced by TBET method..

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