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# Source Position Identification by Inverse Method Time Step Effect on Identification Accuracy

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***Abstract*— This research work is a practical study which conducted a spatiotemporal identification of a thermal source inside a domain using inverse method. Temperatures are simulated by means of resolving direct problem with Finite Differences Method. We suggested heat source identification in diffusive medium. The studied problem has two distinctive aspects:**

- ***Source location research.***
- ***Identifying source amplitude in terms of time.***

***Direct simulation: We achieved a leveled scale on the studied source over the total duration of the study time interval. Step responses, at measuring points, are saved (for matrix building). After that, we computed source value at every step time. In order to characterize inverse quality, we have introduced mean square deviations corresponding to inverse process. Finally, we examined step time effect on source identification accuracy.***

*Key words* - **Heat source, Finite Differences Method, convolution integral, step time, direct method.**

## I. INTRODUCTION

Data processing means enable us to reach a significant development in thermal systems numerical modeling. Determining temperature and flux fields is made through two types of factors:

- Parameters which are intrinsic to the studied system as, for instance, thermal properties.
- Parameters which are external to the system, and belong to thermal stresses as, for instance, boundary conditions, internal sources or heat sinks, and heat flux.

This research work is put in the framework of inverse methods consisting of determining thermal stresses by means of temperature measures (or measures simulation).

In many industrial applications, a direct measure of heat flux or surface temperature (inner wall of an engine combustion chamber or steam generators piping, interfaces between brakes pads and discs, external surface of a spacecraft penetrating the atmosphere, etc.) is complicated and sometimes impossible. Determining these surface factors, out of transitory temperature measures inside and on solid faces, is an inverse problem of heat conduction. Although they have a practical interest, methods that are able of resolving inverse problems of heat transfer are very few in specialized literature.[1] [2]

## II. SYSTEM MODELING

The studied geometry consists of a rectangular flat plate of 0.2m length and 0.1m wide illustrated in the Figure1. In this research work, results are of a building material, plaster, which has the following thermo-physical characteristics **[Schmidt Jurgen]**: [3]

- Thermal conductivity $\lambda = 1.5\ W.m^{-1}.K^{-1}$
- Mass density $\rho = 2300\ kg.m^{-3}$
- Mass thermal capacity $C = 800\ J.kg^{-1}.K^{-1}$

On the rectangle four sides, domain boundary conditions are of Fourier type $h = 20\ W.m^{2}.k^{-1}$ regarding a reference temperature that equals $0^{o}C$. At the starting time, all the system equals $0^{o}C$.

Heat source is situated at the point C: $x_c = 0.05$ m, $y_c = 0.06$ m.

In order to have a modeling of this system by finite deference, we have chosen the following meshing: $\Delta X = 0.01$ m and $\Delta Y = 0.005$ m.[2]

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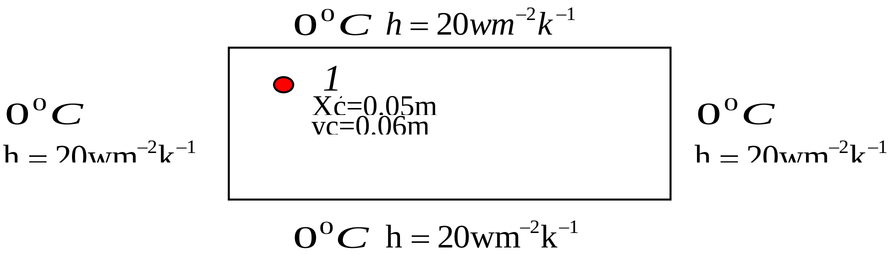


**Fig 1: Boundary Conditions, point source at C.**

Given $P_{i,j}(t)$ the transmitted power by the aforementioned source in terms of time, we have for this power, over the time interval [0,6800s], the following variation law (in $W.m^{-1}$).

- $P_{i,j}(t) = 200$ for $0< t \leq 6000s$

This evolution is represented in the Figure 2.

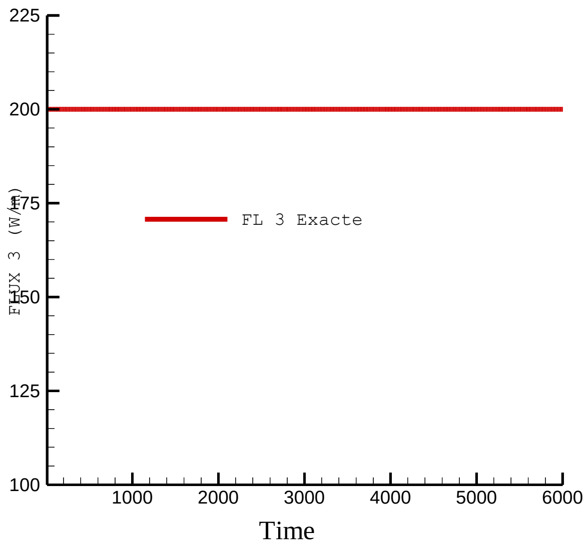


**Fig. 2. Evolution of the heat source**

In order to locate and quantify this source, we carried out direct simulation that enabled us to save measures made inside and on the plate faces. For example, some chosen temperatures evolved as represented in the following Figures (3):

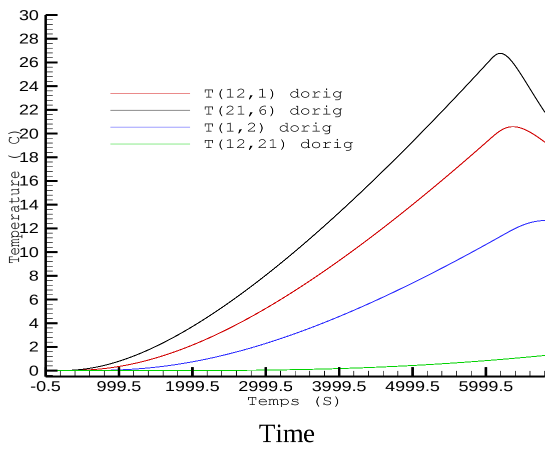


**Fig 3: Evolution of surface temperatures on the faces.**

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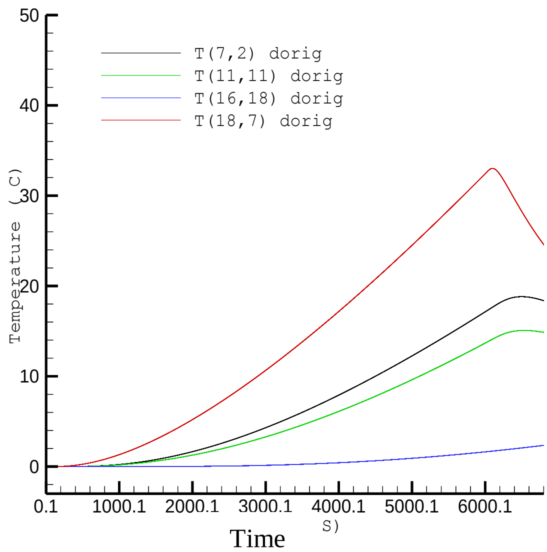


**Fig 4: Evolution of internal temperatures.**

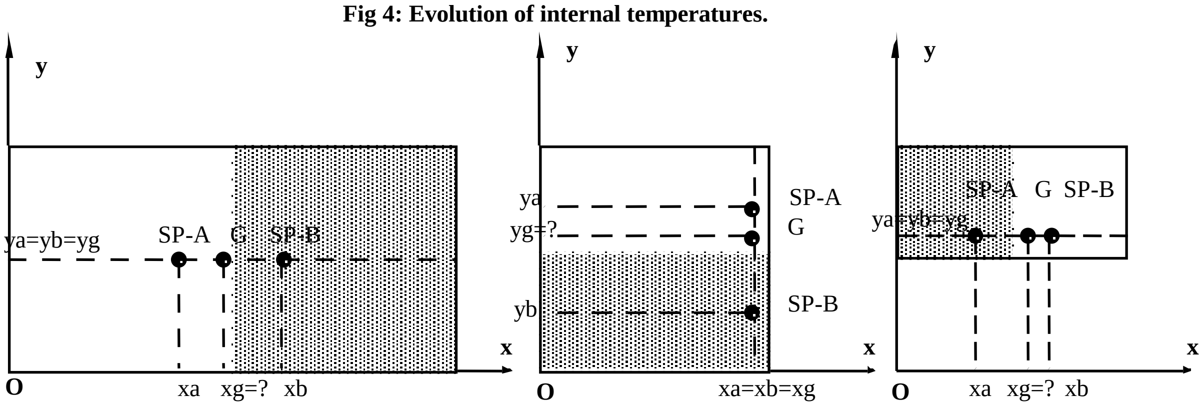


**Fig 5: Localization Principle-Domain**

We show in Figure6 how phenomenon convergence is reached: we notice how successive calculations of $x_g$ and $y_g$ tend to searched values $x_c$ and $y_c$.

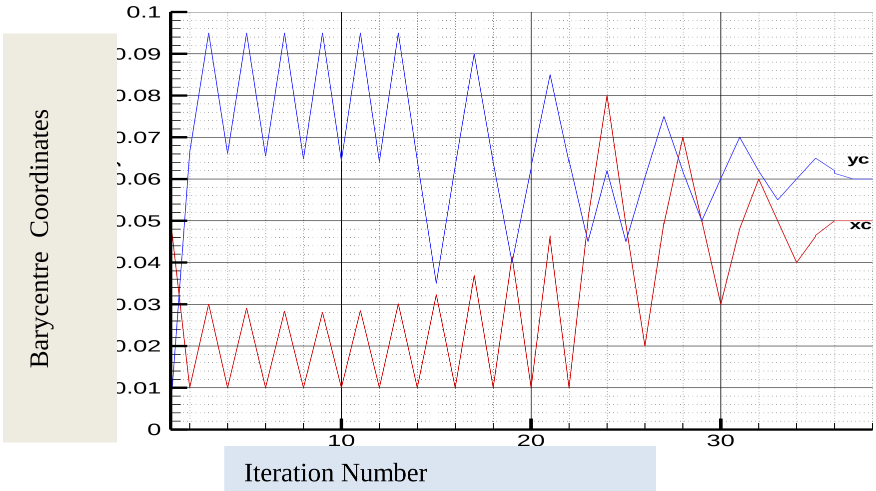


**Fig 6: Localization Convergence**

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## III. TEMPORAL IDENTIFICATION

Once the source is localized on the first time step, we carry out a direct simulation: we make a scale on the source over the total duration of the studied time interval. Step responses at measure points are saved (to build **M** matrix), then we calculate source value at every time step. In order to wholly identify inversion quality, we have introduced mean square deviations related to:

- Source amplitude: [4]

$$e_{sp} = \left( \frac{\sum_{t=1}^{F} (Sp_{ident}(t) - Sp_{orig}(t))^2}{F} \right)^{1/2} \quad (1)$$

Where:

- F: Final time.
- $Sp_{orig}$ (t): Source original value at time t.
- $Sp_{ident}$ (t): The identified source value at time t.
- $e_{sp}$: Mean square deviation (in W/m).

- Temperatures:

$$e_T = \left( \frac{\sum_{t=1}^{F} \sum_{i=1}^{N} (T_i(t) - \hat{T}_i(t))^2}{N.F} \right)^{1/2} \quad (2)$$

Where:

- i: Node number index,
- N: Total nodes number.
- $T_i(t)$: temperature at node I at time t.
- $\hat{T}_i(t)$ : Simulated temperature corresponding to identified source value
- $e_T$ :Mean square deviation (in °C).

Concerning these identification results, we introduce the following:

- Assessed source value compared to theoretical curve used for direct modeling, and its corresponding deviation $e_{sp}$.
- Temperatures evolution built upon the identification with their corresponding deviation $e_T$.

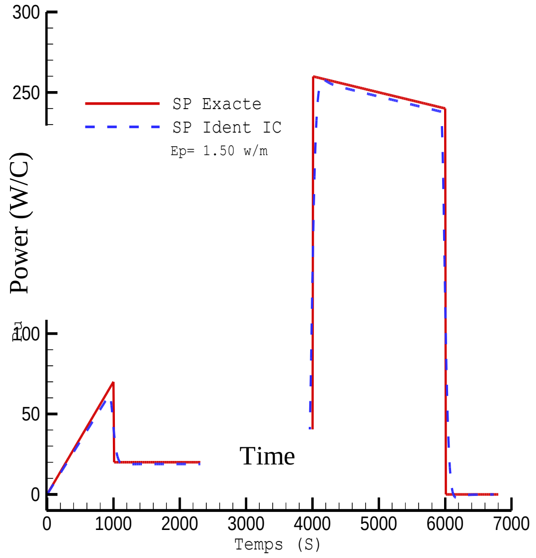


**Fig 7. Comparison between original and identified point sources.**

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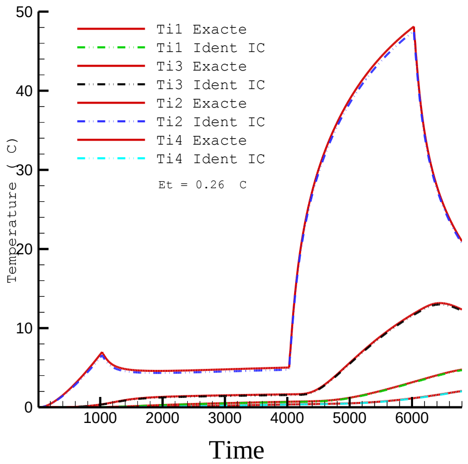


**Fig 8. Evolution of internal nodes temperatures**

## IV. RESULTS

- The obtained results (figure 7 and 8) show a good matching concerning the identified source and reconstructed temperatures.
- Concerning the source, the first level is rightly identified, the second one corresponding to t = 1000s, is a little less, because of the fact that temperatures are still in a rising process at the time of introducing the second level.
- Concerning temperatures, especially nodes that are close to the source, we have the following:
  - Over the time interval [0,2000s], all the curves are rightly identified.
  - Over the time interval [2000,6000s], matching is a little less right than the first time interval.
  - All the curves which are reconstructed from nodes that are far from the source have good matching.

In order to assess the global quality of the identification process, we have computed mean square deviation both for the source and temperatures ($e_T$= 0.26°C for internal nodes, $e_T$= 0.21°C for surface nodes and $e_{sp}$= 1.50W/m for the source). We have noticed that temperatures deviation is relatively less than the source's deviation. This additional fact confirms our results, since in thermal problems the sole criterion upon which a research is assessed is temperatures deviation.

## V. SENSORS NUMBER EFFECT ON HEAT SOURCE IDENTIFICATION

We studied different sensors numbers. Three cases have been chosen: 05 sensors, 50 sensors and 100 sensors. Sensors are situated inside the domain and at its frontiers. For this research work, time step remains unchanged and so is the case of time discretization of the heat source to be identified. [6]

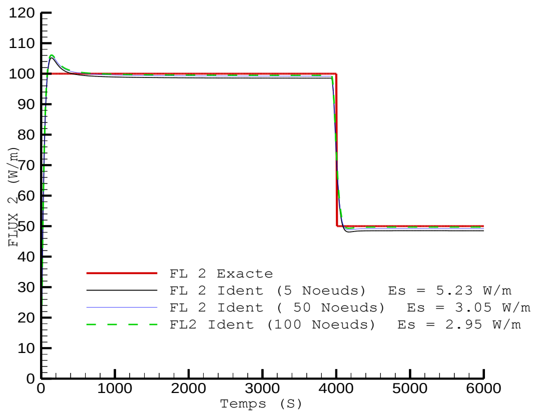


**Fig 9: Flux Identified for Different Locations and Sensors Number**

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## VI. RESULTS DISCUSSION

The identified heat source is very close to the exact value till 2000s, except for final times and five nodes. Square deviations evolving shows that we generally have a good accuracy between computed values and exact ones when sensors number is high (Figure 9), but actually if we have to seek an experimental confirmation, we have to extremely minimize internal sensors number.

### *A. TIME STEP EFFECT ON HEAT SOURCE IDENTIFICATION*

Time step used in resolving previous inverse problems was $\Delta t = 0{,}01s$ . Hence, we planned to resolve the studied inverse problem with a higher time step: $\Delta t = 0{,}05s$ . Sensors number is the same one used previously.[7] We have obtained the following results:

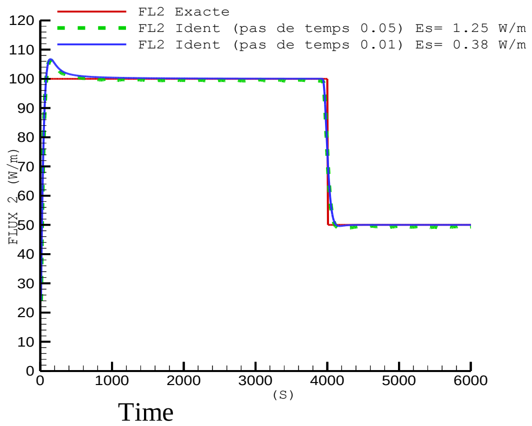


**Fig 10: Identified Flux for Two Different Time Steps in Resolving the Studied Inverse Problem**

The identified heat source is well assessed when time step is small. For a time step that equals 0.05s, heat source is rightly assessed until time t$\leq$3000s. It is also rightly assessed for time step that equals 0.01 until time t$\leq$6000s. Results show clearly that when the identification is achieved with a higher time step, accuracy of computed values will be affected badly regarding exact values, and this prevents us from relevant heat source identifications. Knowing the good time step is a necessary task to have calculation times for a rational resolving of studied inverse problems.

## VII. CONCLUSION

In this research work, we introduced an inverse method for thermal conduction problems, to identify heat source in 2D diffusive medium. The studied inverse problem consists of four stages:

- First Stage: Source Position Localization
- Second Stage: Source Amplitude Identification in terms of time
- Sensors number effect on heat source identification
- Time step effect on heat source identification

To solve the studied problem, we used:

***For direct modeling:***

We used Finite Differences Method to solve our direct problem. Then we retrieved simulated temperatures (inside and on the studied domain's faces).

***For source localization:***

We made barycenter calculations from two fictive sources which are placed inside the studied domain.

***For the source amplitude:***

We used inverse method based on convolution integral. Concerning numerical simulation exploitation, we can distinguish the following aspects: Identifying heat source position and amplitude is satisfactory, as well as reconstructed temperatures which have good matching with simulated ones. Concerning sensors number effect on the identification process, square deviations evolving shows that we have generally obtained a good accuracy between computed values and exact ones when sensors number is high.

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Concerning step time effect on identification, results showed clearly that identification achieved with higher step time affects badly computed value accuracy regarding exact values, something which prevents relevant heat source identification. This research work constitutes a first approach of spatiotemporal identification of a thermal source. In the future, we will address a 3D problem, with a special concern to the geometrical form of the volume thermal source which still remains a problem to be solved.

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