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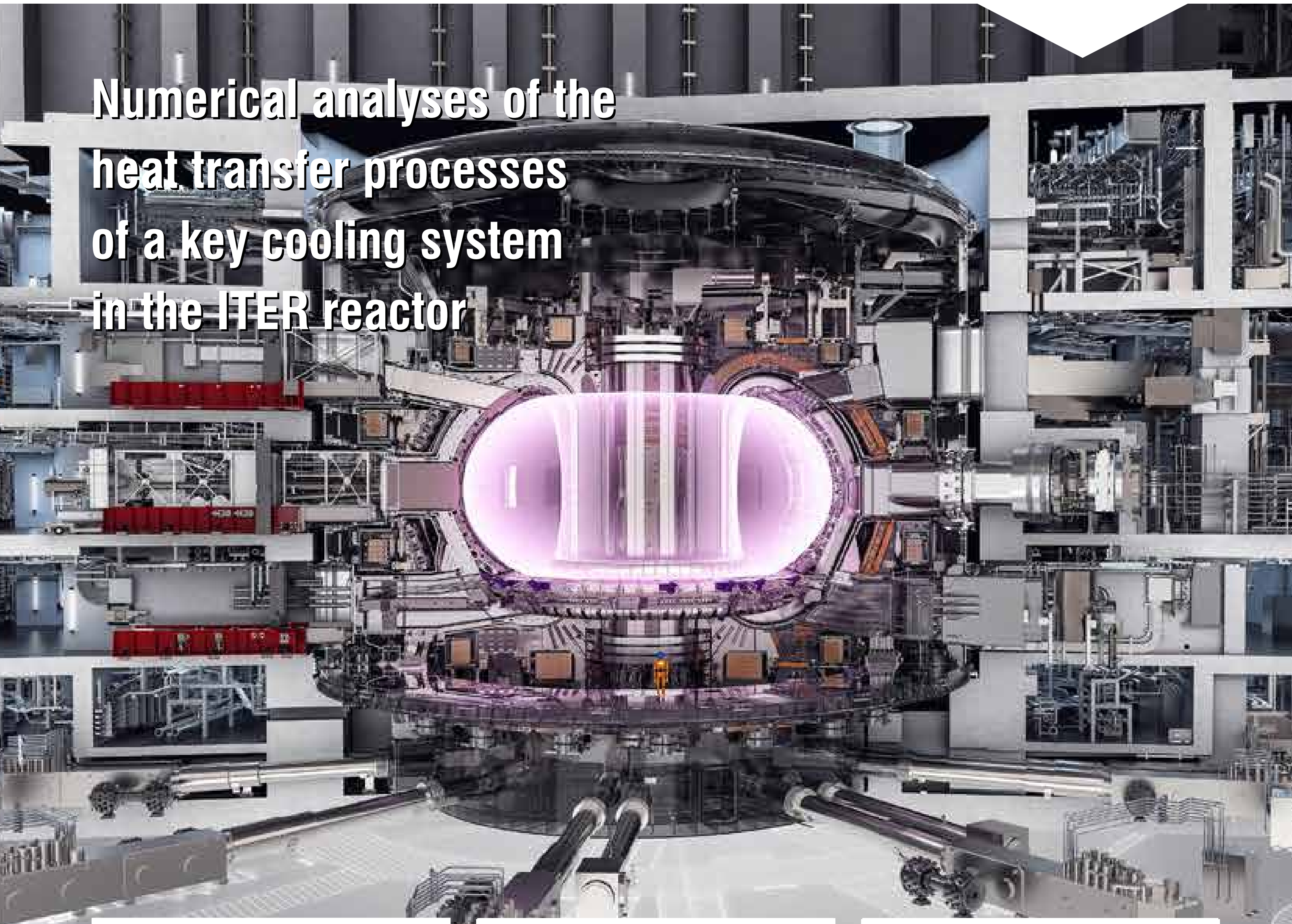


Numerical analyses of the heat transfer processes of a key cooling system in the ITER reactor

Development and optimization of crash brackets for ECE R29 regulation compliance

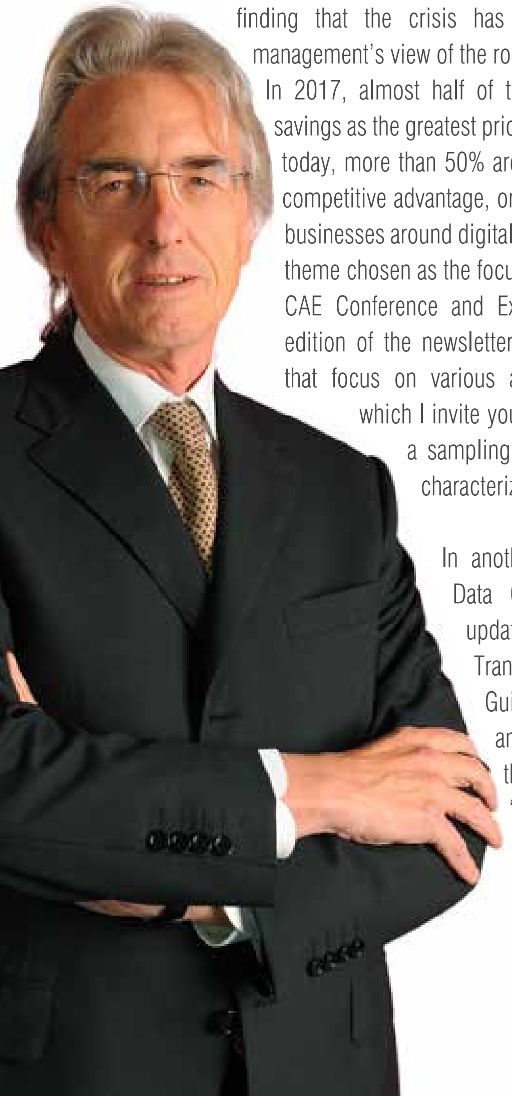
Optimizing the cable routing for a hyper-redundant inspection robot for harsh, hazardous environments

Life-safety assessment of a hotel using fire and evacuation simulations

Flash

The end of 2020 is upon us and I am sure that most of us cannot wait to close it out, although all indications are that the effects of the Covid-19 pandemic will still be felt for much of the next year – and probably even the one after – in spite of the fragile hopes being vested in the various vaccines, all of which have been developed and are being brought to market faster than ever before in vaccine history!

This speed was also noticeable and experienced in other areas. Nine hundred C-suite executives polled by McKinsey & Company (https://mck.co/3r73jr6) in July said that COVID-19 accelerated their digital plans by as much as a decade in a matter of months, with the average acceleration of digitalization plans around the world being seven years. This digitalization concerned products, services, back office, production, and R&D. According to McKinsey, the survey respondents expect most of these changes to become permanent. Not all sectors have reported the same rates, obviously. For instance, manufacturing has been slower to implement digitalization due to the time frames involved in implementing these changes. These increases were far greater in the services related industries, and in pharma and healthcare.



Possibly of even greater significance in the long term was McKinsey's finding that the crisis has led to a sea change in management's view of the role of technology in business. In 2017, almost half of the respondents cited cost-savings as the greatest priority for digital strategy, while today, more than 50% are looking to digital to create competitive advantage, or even refocusing their entire businesses around digital technologies. Never was the theme chosen as the focus for this year's International CAE Conference and Exhibition more timely! This edition of the newsletter has a selection of articles that focus on various aspects of the conference, which I invite you to read, since they provide a sampling of the type of content that characterizes the event.

In another study, the International Data Corporation (IDC) recently updated its Worldwide Digital Transformation (DX) Spending Guide (https://bit.ly/3p42qxl) and found that investments in this area will remain solid, "growing to a forecast 10.4% in 2020 to $1.3 trillion. The specific areas of focus for these investments are autonomic operations ($51 billion), robotics manufacturing ($47 billion), and root cause ($35 billion), all driven by the manufacturing sector." Almost one-third of this spend will be in the United States, with China coming third after Western Europe.

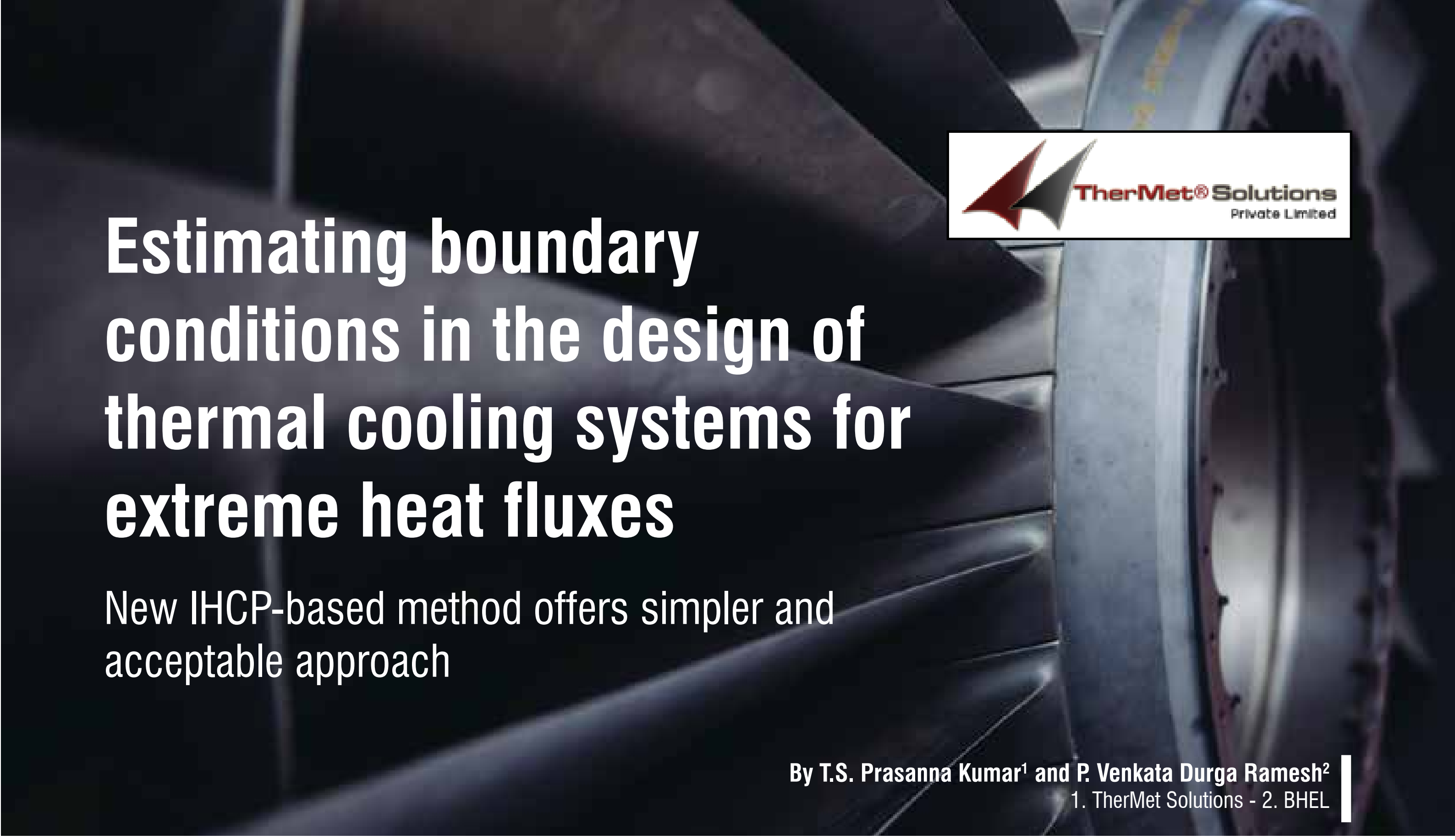
Another aspect of industry that was dramatically impacted by the initial shutdowns in March was the supply chain and this has resulted in a serious re-think around addressing this vulnerability with regard to raw materials for production. A Gartner Inc survey (https://gtnr.it/3p2xBJu) found that more than half of supply chain management professionals will be increasing their focus on circular economy strategies to secure their access to and availability of raw materials during global disruptions.

The arguably biggest change we all experienced in our work lives this year was the pivot to remote working and the use of video-based meeting platforms and cloud meeting services. Many of these conversations are being recorded as a digital record and AI will increasingly be used in organizations to monitor their internal regulatory and legal compliance and to identify future performance and behavior among staff, according to Gartner research (https://gtnr.it/3mvft9o), which estimates that by 2025, three-quarters of work conversations will be recorded and analyzed to identify value or risk to the business, which will dramatically increase the need for policies and regulations to manage and direct the related ethical and privacy issues!

With all of its myriad challenges, many of which are still being grappled with – and have yet to be confronted – at all levels of politics, research, business, industry, and society, and in spite of the inevitable sadness that must accompany the loss of so much life and the hardship being experienced by so many, the pandemic has generated and continues to stimulate substantial innovation and collaborative activities to celebrate. While this is truer in certain sectors that in others, and many will justifiably protest that the news in their sector is worse than ever and shows no signs of improving, I believe we should look to the positive developments and remember that always in human evolution, adversity has been the incubator for great invention. As engineers, particularly, we should keep this in mind and turn our focus to how and where we can innovate in our specific business or specialization.

This edition of the Newsletter includes a series of articles that covers a selection of engineering innovation examples, which I invite you to read with as much interest as I did. All that remains is for me to wish you and those you hold dear, a peaceful and safe festive season, however you decide to celebrate it, and I look forward to working with you on innovation in 2021.

Stefano Odorizzi,
Editor in chief



Estimating boundary conditions in the design of thermal cooling systems for extreme heat fluxes

New IHCP-based method offers simpler and acceptable approach

By T.S. Prasanna Kumar[1] and P. Venkata Durga Ramesh[2]
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Designing cooling systems for high heat environments is highly complex. The heat flux needs to be carefully calculated in order to select the correct materials and cooling fluid and to design the components. This article presents a method based on the Inverse Heat Conduction Problem for calculating the heat flux within any type of fluid-structure interaction, irrespective of the way the heat is generated.

Introduction

There are many challenges revolving around material selection and component design when designing cooling systems to dissipate high heat. Some examples include the design of heat shields for re-entry space vehicles, and cooling systems for the plasma facing components in the tokamak. In the “first wall” structure of the tokamak, particularly, the heat flux may reach 20 MW/m^2[1]. Among the many critical requirements for the design of such systems, correctly estimating the heat flux is essential because it dictates the choice of materials, the cooling fluid, and the component design.

This article presents a method based on the Inverse Heat Conduction Problem (IHCP) to estimate heat flux within any conceivable structure-fluid interaction - without needing to go into the myriad complications on the fluid side. Such heat could be generated by a burning gas, high intensity radiation, or a plasma, and the heat dissipation may be the result of the forced convection of a fluid. While computing heat flux on either side of the cooling system using computational fluid dynamics (CFD) principles is an onerous task, the IHCP-based method offers a far simpler and acceptable approach to estimating the heat fluxes on both the heating and the cooling sides.

The Gas Tungsten Arc (GTA) used in welding applications was chosen as the heat source to demonstrate IHCP’s ability to estimate high heat fluxes. GTA can generate highly concentrated heat fluxes up to 40 MW/m2. Experiments were conducted to measure the transient thermal response in blocks of synthetic graphite, aluminum and stainless steel when their surfaces were exposed to a stationary GTA. Current, voltage and arc time were varied to deliver heat fluxes up to 28 MW/m^2. The heat flux was estimated by analyzing the time-temperature records in the solids using the commercially available software InverseSOLVER[2]. The measured and the estimated temperatures at the locations of the thermocouples were shown to be in close agreement[3].

What is the Inverse Heat Conduction Problem and how is it solved?

The numerical solution to a heat conduction problem with specified boundary conditions and known material properties is known as Direct Heat Transfer Problem. However, if we want to obtain the solution to the heat flux (the cause) at a boundary with a known temperature history (the effect) at a point inside the solid, we have to use the Inverse Heat Conduction Problem (IHCP). IHCP requires data based on measurements from a real situation, which can be taken either from a working prototype or from a laboratory setup. Once the actual plant measurements have been taken, IHCP can be used as a diagnostic tool. If a system needs to be designed where the heat fluxes are unknown, test rigs can be set up for data collection, which is then used for scaling up.

Since the IHCP falls under the category of ill-conditioned problems, many regularization and stabilization schemes have been developed, ranging from classical algorithms for solving the IHCP[4], to purely serendipitous solutions for estimating heat fluxes that vary in time and space[5]. The serial solution has been shown to provide acceptable solutions for industrial problems like heat transfer from boiling during the quenching of steels, and heat transfer at the metal-mold interface during die casting etc.[6-8].

Experimental procedure

Three materials with varying thermal properties were chosen for data generation, viz synthetic graphite (ATJ-S), aluminum (99% purity) and stainless steel (304L). The properties of these materials as a function of temperature are provided in Appendix 1.

Fig. 1 - Experimental setup: (a) Data acquisition unit (b) GTAW torch (c) Specimen (d) Test rig (e) Thermocouples (f) Power source (g) Shielding gas

Discs of 10mm-20mm thickness and 60mm diameter were used as specimens. This paper reports the results of three trials that were conducted using the stainless-steel specimens. The GT arc was focused locally over a circular area approximately 12mm in diameter on the specimen surface where it yielded heat fluxes up to 16MW/m2. The arc was maintained on the position for a maximum of 2.3s which was the upper limit to avoid any melting of the specimen.

Mineral insulated stainless steel-sheathed ‘K’-type thermocouples were used to measure the temperature 2-3mm below the surface, as shown in Fig. 2.

Mathematical Model

Heat transfer in the steel disc specimen from the stationary welding arc was assumed to be axi-symmetric and was modelled as shown below (Fig. 2). The relevant heat transfer equations with appropriate boundary conditions are provided in equations (1), (2) and (3).

$$\frac{k}{r}\frac{\partial}{\partial r}\left(r\frac{\partial T(r,z,t)}{\partial r}\right)+k\frac{\partial}{\partial z}\left(\frac{\partial T(r,z,t)}{\partial z}\right)=\rho c\frac{\partial T(r,z,t)}{\partial t}$$

with the initial condition

$$T(r,z)=T_a \quad at \quad t=0$$

and the boundary conditions:

$$-k\frac{\partial T}{\partial z}=q(t)\ on\ S_1$$

$$-k\frac{\partial T}{\partial r}n_r-k\frac{\partial T}{\partial z}n_z=h(T-T_\infty)\ \ on\ S'$$

where n_r, n_z are the direction cosines of the outward normal vector at the domain boundary, *h* is the convective heat transfer coefficient at the boundary, *q(t)* is the unknown heat flux boundary The temperatures recorded for 10-12 seconds were then used as inputs to solve the heat conduction equation inversely.

The Finite-Element-based software, InverseSOLVER [2], was used to solve the problem. The model domain was discretized into 40x120 and 80x120 for the 10mm and 20mm thickness samples respectively, with a uniform grid using four node toroidal elements.

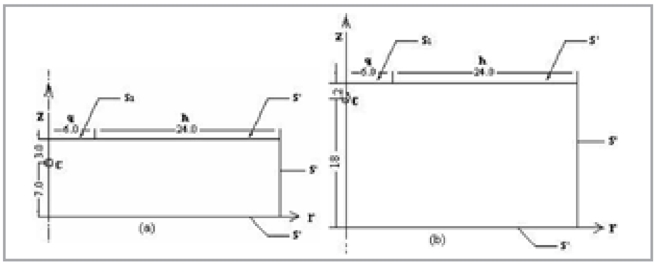

Fig. 2 - The model domain (a) for Case 1 and (b) for Cases 2 and 3

Starting from a nominal value of the heat flux at zero time, the equations were solved every 0.1s. The heat flux incremented based on a sensitivity analysis, and the calculations were repeated within the time step until the heat flux value converged to an acceptable value. The convergence limit was set to 10e-4 for the flux values and 10e-6 for the temperatures.

The method is computationally costly and the present problem took about 40 minutes to solve on an Intel Pentium 4 Processor. The solution algorithm has been detailed in other publications[7-9], hence it has not been repeated here.

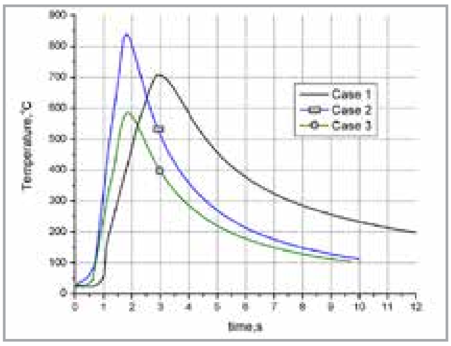

Fig. 3 - Measured time-temperature curves for the three cases

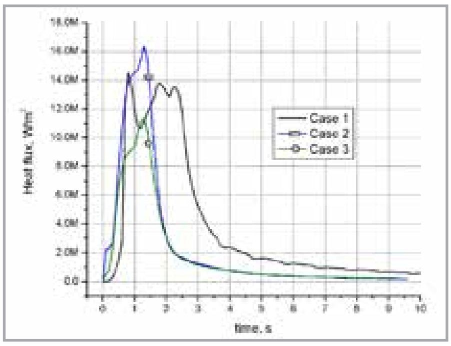

Fig. 4 - Heat flux variation over time

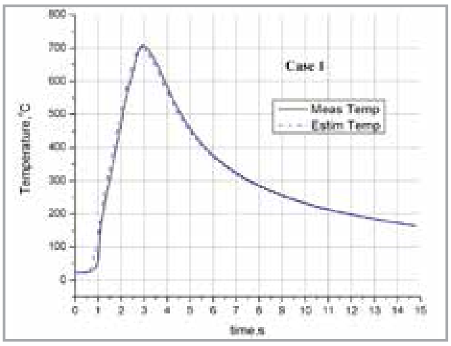

Fig. 5 - Comparison of measured and estimated temperatures for Case 1.

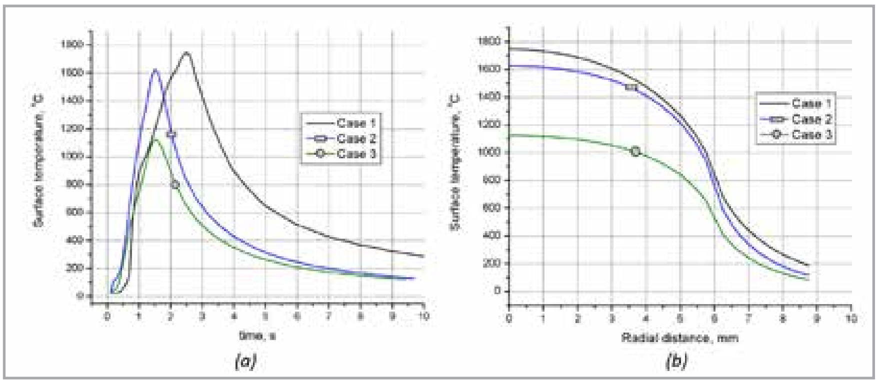

Fig. 6 - Estimation of surface temperature by thermocouple measurement (a) over time (b) with radial distance at the time of maximum heat flux

Results

The temperatures recorded during the experiments are shown in Fig. 3 for all three cases. The heat flux history obtained by solving the equation (1) inversely in all three cases is shown in Fig. 4. Fig. 5 shows a comparison of the measured and estimated temperatures in a typical case, which show excellent convergence.

Heat flux

In case 1, the heat flux reached a maximum of 13MW/m^2 within 1.7s and stayed at that level until the arc was cut-off at 2.3s. (Fig. 4). Since the mass of the solid block was half of that in cases 2 and 3, the heat dissipation took more time, as shown by the cooling curve. In cases 2 and 3, a maximum of 16.43 and 11.32MW/m^2 was reached within 1-1.2 seconds, although the electrical inputs to the arc were more or less the same. This shows the highly non-linear nature of the arc's properties.

Surface temperature

The solution to the IHCP can also be used to estimate the surface temperature along with the heat flux, which is not possible by direct measurement. This is a distinct advantage of the IHCP since surface melting can be hazardous, particularly in nuclear fusion reactors. The estimated surface temperature at the center of the arc's contact area as a function of time is shown in Fig. 6(a) for all three cases. The temperature distribution over the arc's contact area at the instant of maximum heat flux is given in Fig. 6(b) for all three cases.

Conclusions

A reliable method to estimate highly transient heat flux from a plasma such as a gas tungsten arc has been developed. The method is based on measuring temperatures inside a solid body by inserting thermocouples near the surface that is exposed to the heat flux. The measured time-temperature data is then used to solve the heat conduction equation inversely to obtain both the heat flux and the surface temperatures. This method can be extended to systems where the heat fluxes over time and space are unknown. By developing test rigs that replicate the real-world conditions on a smaller scale and generating thermal data, the estimated heat flux results can be used to design prototypes of highly complex thermal systems. The advantage of this procedure is that it eliminates the need for assumptions in the solution since only measured thermal data is used.

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Material	Temp K	Density (kg/m^3)	Specific heat (J/kgK)	Thermal conductivity (W/mK)
Pure aluminium (99%)	200	2702	798	237
	300		903	237
	400		949	240
	500		996	236
	600		1033	231
	800		1146	218
Synthetic graphite (ATJ-S)	300	1810	1300	98
	1000		1926	55
	2000		2139	38
	3000		2180	33
Stainless steel (304 L)	200	8000	402	13
	300		477	15
	400		515	17
	500		539	18
	600		557	20
	800		582	23
	1000		611	25
	1200		640	25
	1500		682	25

Appendix 1: Thermophysical properties of materials

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