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# A Novel Treatment of Moving Heat Sources with Applications to Additive Manufacturing and Welding

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## Abstract

Moving heat sources are central concepts in many mechanical and manufacturing systems, especially in additive manufacturing and welding. The amount of literature on moving heat sources and their applications is very large, and almost all of it falls into three categories: experimental, analytical solutions, and numerical and semi-analytical solutions. These three approaches share a common limitation: they provide a temperature field in space and time as a function of process parameters. Although a problem is also considered "solved" when this temperature field is known, this result is of limited use for practitioners, who typically know characteristic temperatures of interest such as melting temperature or phase transformation temperatures, but desire to know the location or rate of change of the known temperature. An example for both welding and additive manufacturing include the width of the deposited bead, which is given by the maximum width of the isotherm of melting temperature. Another common example is the cooling rate at the melting temperature, which determines solidification microstructure in welding and additive manufacturing. The size of heat affected zone and cooling rate during transformations is also of much relevance especially for steels in welding and WAAM (wire arc additive manufacturing). Although all these magnitudes could be estimated using any of the three methodologies mentioned above, they are time consuming and are often avoided by practitioners, typically resorting to trial and error approaches, which can become expensive and time consuming. Also although trial and error approaches often solve the immediate problem, that knowledge is seldom extrapolable to different parameters or alloys.

The novel approach proposed is based on dimensional analysis, asymptotic analysis, and blending techniques, these last first introduced to moving heat sources by Muzychka and Yovanovich. The results are closed-form expressions based only on process parameters such as travel speed or heat source power known before any experiment and does not involve empirical fitting from similar experiments. The closed-form expressions are amenable to implementation in spreadsheets, to be summarized in practical graphs, for implementation in codes and standards, and for teaching. Moving heat sources, despite their technological relevance, are absent from most syllabi and textbooks in heat transfer courses. Examples of the approach will include solidification structure of AM of Grade 91 steel, teaching materials, and size of HAZ in a welding procedure.