Abstract

A huge amount of unwanted heat is generated in many equipment, like heat exchangers and electronic devices. Such excess heat is required to be dissipated in order to maintain the performance as well as the longevity of an equipment. The dissipation of generated heat from a heat exchanger having a cylindrical primary surface can be increased by attaching annular fins to the cylindrical surface. The attachment of fins increases the rate of heat transfer by enhancing the heat transfer surface area. However, the attachment of fins raises production costs by requiring additional design, material, and fabrication. Hence, effort has been put in recent years for optimizing fin design. Both size and shape of fins as well as the fin inter-spacing in a fin array can be optimized by targeting effective utilization of fin material. Designers are required to identify a fin configuration that would maximize the heat dissipation rate and minimize the fin volume or weight. Apart from the heat transfer rate and fin volume, another big concern in the fin design is the development of thermal stresses due to the change in temperature gradient along a fin. The developed thermal stresses may shorten the life of a fin by causing various types of mechanical failures, such as creep, crack propagation, and fatigue. Hence, for better life expectancy and performance, the design of a fin demands to minimize the induced thermal stress also.

Rectangular cross-section is the simplest shape of an annular fin. However, in such a uniform thickness fin, the fin material is not utilized effectively in conducting heat near the tip of the fin, which encourages the use of fins having step change in thickness and continuously varying thickness. Accordingly, designers strive to

optimize the shape of a fin either to maximize the heat transfer rate from a given fin volume, or to achieve a specified heat duty by minimizing the fin volume. Since the applicability of fins with complicated profiles is limited because of the involved complex fabrication processes, the optimization of a predefined fin size is also attempted in many cases. Further, a single fin is rarely used in practice for heat dissipation, but an array of fins arranged in a row. Hence, optimization of the fin profile in combination with the fin inter-spacing in an array of fins becomes essential from the practical point of view. However, most of the reported works on annular fins were concerned with the optimization of a single fin isolated from the surrounding. Only a limited number of works optimizing an array of annular fins could be found in specialized literature. On the other hand, the complex non-linear nature of thermal stress has reduced its analysis in the case of annular fins.

Motivated by such practical requirements and research gap, the present thesis work is focused on investigating different optimum scenarios of six types of annular fin arrangements. Both isolated fins and fin arrays are studied with three types of fin profiles, which are rectangular fins with step change in thickness, fins with linearly varying thickness, and fins with non-linearly varying thickness. Considering constant base temperature and variable thermal conductivity, the fin arrangements are studied under steady-state one-dimensional heat transfer in the radial direction of the fins. In the isolated fin arrangements, heat dissipation is considered by both convection and radiation, while only convection is considered in the case of fin arrays. All the six fin arrangements are formulated as multi-objective optimization problems for optimizing simultaneously different combinations of six objective functions, which are maximization of heat transfer rate, minimization of fin volume, minimization of induced thermal stress, maximization of fin efficiency (surface efficiency in fin arrays), maximization of fin effectiveness (augmentation factor in fin arrays), and minimization of heat transfer surface area. The objective functions are evaluated through some established numerical methods as well as the hybrid spline difference method (HSDM), while they are optimized employing the nondominated sorting genetic algorithm II (NSGA-II). In each case, the final result is an approximation of the Pareto-optimal front containing a set of trade-off solutions in terms of the considered objective functions. In some cases, the sensitivity of an optimized design with design variables is also analyzed. Further, the performances of stepped and non-linearly varying thickness fins (both isolated fins and fin arrays) are compared with those of the conventional uniform thickness fins.

In the first instance, two-stepped rectangular annular fin is studied. Taking cross-sectional half thicknesses and outer radii of the two fin steps as design variables, the variation in the efficient fin geometries is analyzed primarily by optimizing the heat transfer rate and fin volume. Additionally, the fin surface area, fin efficiency and fin effectiveness are considered for exploring the trade-off nature among different objective functions. The sensitiveness of the heat transfer rate with the design variables is also analyzed.

Secondly, annular fin with linearly varying thickness is studied considering the half thickness at the base, half thickness at the tip and outer radius of the fin as the design variables. In this case, the variation in the efficient fin geometries is analyzed in terms of the heat transfer rate and thermal stress. Additionally, the effects of the fin volume, fin efficiency and fin effectiveness are also studied. Further, the sensitiveness of the heat transfer rate and thermal stress with the design variables are also analyzed.

In the third case, a non-linear fin profile defined by a B-spline curve is investigated with the control points of the curve as the design variables. In this case also, the variation in the efficient fin geometries is analyzed in terms of the heat transfer rate and thermal stress. The effects of the same set of additional objective functions, as in the case of the fin with linearly varying thickness, are also analyzed.

The fourth, fifth and sixth fin arrangements are, respectively, the direct extension of the first, second and third fin arrangements, where the single isolated fin is replaced by an array of fins. In these cases, the number of fins (alternatively, fin inter-spacing) in a fin array is taken as an additional design variable in order to take into account the existence of the fin array.

The main contributions of the thesis are summarized below:

- ▷ Owing the practical requirement and research gap, detailed procedures are presented for optimizing both isolated fins and fin arrays with different fin profiles.
- ▷ All the cases are investigated as multi-objective optimization problems by simultaneously optimizing various fin performance measuring functions (including primarily the maximization of the heat transfer rate, minimization of the total fin volume, and minimization of the induced thermal stress), which would serve as guidelines to designers in selecting compromise designs for practical implementation.
- ▷ The sensitiveness of the primary objective functions with the design variables is also analyzed, so that a designer can be careful with the sensitive parameters while designing fins.
- ▷ Further, the performances of some fin arrangements are compared with those of the conventional uniform thickness fins, which would help designers in selecting a fin profile based upon the availability of facilities.