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Ansys Mechanical Automation using Python for the Steady State Thermal Analysis of Fins

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Abstract – A numerical investigation of the heat transfer enhancement through fins using the Ansys Mechanical solver is presented. Results are given for a uniform fin with elliptical cross-sections and uniform heat flux applied on its base while heat is dissipated to its surroundings by convection from both its lateral surface and tip. The peak temperature at the base of the fin is used to evaluate the thermal performance. Ansys Mechanical solver is automated using Python scripting to run 792 simulations for various materials, fin lengths, and ratios between the minor and major axes of the elliptical cross-sectional shape for both cases of natural and forced convection. The use of the original automated numerical procedure significantly decreases the computational time and the user intervention. It was found that the thermal performance is improved by increasing the length of the fin, using a material with higher thermal conductivity, or having a ratio between the minor and major axes of the ellipse that is farther from unity. Forced convection gives better thermal performance compared to natural convection.

***Keywords*:** Steady State Thermal Analysis, Fins, Ansys Mechanical Automation, Python Scripting

1. Introduction

Extended surfaces or fins [1] are used to improve heat transfer performances in many engineering applications such as air-conditioning, car radiators, heat exchangers, electronic components cooling, refrigerators, etc. They are useful to dissipate the generated heat in a system while operating, to its surroundings, and to prevent overheating. The improvement of heat transfer of the extended surfaces or fins will maintain the functionality of the system at its recommended working temperature as well as its effectiveness and safety. Nagarani et *al*. [2] present a review of the utilization of the extended surfaces in heat transfer problems. The methods that are used to enhance heat transfer performances are usually classified into passive ones which do not require external power to maintain their effects such as fins, and active methods which require external power such as the use of fans or vibrating the solid surface.

Many investigations have studied the efficiency of extended surfaces or fins with various geometries and different configurations. Sharqawy and Zubair [3] have studied analytically the efficiency of straight non-uniform fins with different configurations including rectangular, triangular, concave parabolic, and convex parabolic profiles. Turkyilmazoglu [4] has studied the heat transfer through exponential fins in movement and exposed to heat generation. The results in the case of different straight fin profiles including rectangular, exponentially decaying, and exponentially growing were compared. Hajmohammadi et *al*. [5] have carried out a geometric optimization to attain maximum cooling performance of an annular fin with a highly conductive insert intruded. The objective of their optimization study was to obtain the minimum peak temperature of the fin where uniform heat flux is applied at its base. Risal et *al*. [6] and Varghese et *al*. [7] have studied numerically the design optimization of annular fins by using the steady state thermal analysis solver in the multi-physics engineering simulation software Ansys and by implementing a genetic algorithm through the programming language Python.

The objective of this paper is a numerical investigation of the heat transfer enhancement through uniform fins with elliptical cross-sections using the Ansys Mechanical solver. Python scripting is used to automate and run the simulation for various configurations, including both natural and forced convection, with different materials having different values of the thermal conductivity as well as for various lengths of the uniform fin and in a range of values between 0.04 (ellipse) and 1 (circle) for the ratio between the minor and major axes of the elliptical cross-section.

2. Methodology

Ansys Mechanical is a Finite Element Analysis (FEA) solver for various physical phenomena such as thermal, structural, vibration, and acoustic problems. It can model static or dynamic, linear or non-linear, and steady or transient situations. It is widely used in various industrial fields and different physical phenomena can be coupled to study the influence of one on another.

2.1. Problem Configuration

Figs. 1(a)-(b) show respectively the side-view and the cross-sectional shape of the uniform elliptical fin. (x, y, z) are the cartesian coordinates. The semimajor and semiminor axes of the ellipse are respectively a and b, and L is the length of the fin. The temperature of the surrounding fluid is T_∞ and the convective heat transfer coefficient is h. Uniform heat flux q'' is applied at the base of the uniform fin. The heat is transferred to the surrounding fluid from the lateral surface and the tip of the fin.

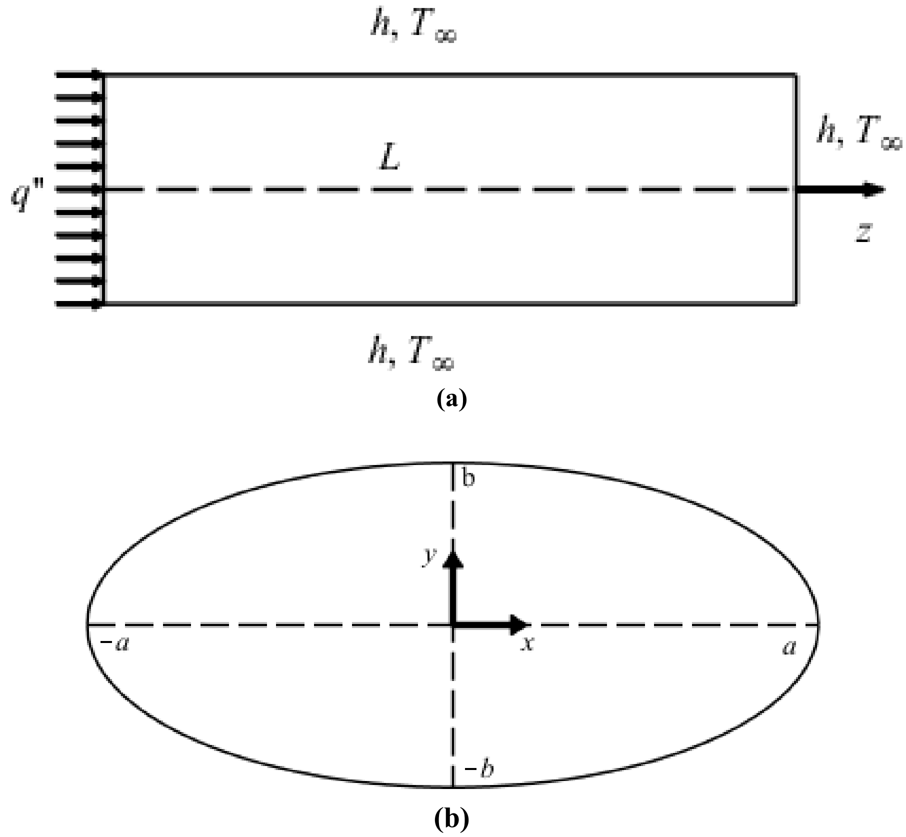

Fig. 1: The geometrical configuration of the uniform fin: (a) Side-view, (b) Elliptical cross-sectional shape.

The inlet power is considered constant which means that the area of the base A is constant in the case of uniform heat flux q'' applied on that base and thus the volume of the uniform fin is constant for a fixed value of the length L. The elliptical cross-section is given by the following equation:

$$\left(\frac{x}{a}\right)^2 + \left(\frac{y}{b}\right)^2 = 1 \quad (1)$$

By using Eq. (1), the functions of the upper and lower curves can be obtained as functions of the coordinate x as the following:

$$y = \pm b\sqrt{1-\left(\frac{x}{a}\right)^2} \tag{2}$$

The area of the base A is supposed constant and equal to the area of a circle of radius R given by $A_c = \pi R^2$. Thus, the semiminor and semimajor axes of the ellipse satisfy $ab = R^2$.

2.2. Mathematical Formulation

The steady state thermal analysis of fins composed of a homogenous isotropic material that has a constant thermal conductivity k, with negligible radiation effects, and at constant ambient temperature T_∞ and constant convective heat transfer coefficient h is governed by the energy equation which is written as:

$$\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}+\frac{\partial^2 T}{\partial z^2} = 0 \tag{3}$$

where $T(x, y, z)$ is the temperature of the fin at the position (x, y, z).

The boundary conditions are given as follows:

- At the base of the fin (applied uniform heat flux):

$$q'' = -k\left.\frac{\partial T}{\partial z}\right|_{z=0} = constant \tag{4}$$

where, $\left.\frac{\partial T}{\partial z}\right|_{z=0}$ is the temperature gradient at the base of the fin.

- At the lateral surface (Newton's law of cooling):

$$-k\left.\frac{\partial T}{\partial n}\right|_{w} = h(T_w - T_\infty) \tag{5}$$

where $\left.\frac{\partial T}{\partial n}\right|_{w}$ and T_w are respectively the temperature gradient and the temperature at the lateral surface, and n is the outward normal to the lateral surface.

- At the tip of the fin (Newton's law of cooling):

$$-k\left.\frac{\partial T}{\partial z}\right|_{z=L} = h(T(x, y, z = L) - T_\infty) \tag{6}$$

where, $\left.\frac{\partial T}{\partial z}\right|_{z=L}$ and $T(x, y, z = L)$ are respectively the temperature gradient and the temperature at the tip of the fin.

2.3. Numerical Procedure

The geometry is created by using Ansys Space Claim and Python scripting to automate the creation of the uniform fin for repeated simulation with different ratios between the minor and major axes of the elliptical cross-sectional shape. The creation of the named selections using Python scripting allows their use to be automated in the creation of the mesh and the setting of the boundary conditions which are uniform heat flux at the base and the convection for the lateral and the tip surfaces of the fin. The semiminor axis of the ellipse b, the length of the fin $L$and the thermal conductivity k are used as input parameters of the study while the maximum temperature T_{max} is the output parameter. The convective heat transfer coefficient h is assumed to be known, and typical values will be used in this study to represent both natural and forced convection processes.

3. Results and Discussions

The extended surfaces or fins are used to increase the heat transfer surface with the surrounding fluid to prevent the base from achieving high values of the temperature which may cause the failure of the system. For constant inlet power, which means constant heat flux applied on the base of the constant area, the thermal performances are sought to be improved by decreasing the maximum temperature at the base which is the peak temperature.

For the cases studied, the length of the fin L is going to take various values, $25, 50, 75,$ and $100mm$, to be simulated. The temperature of the surrounding fluid is $T_\infty = 20°C$ and the convective heat transfer coefficient h respectively for the natural and forced convection of a gas is given by the typical values, $10\, W/m^2 \cdot °C$ and $50\, W/m^2 \cdot °C$. The uniform heat flux is given by $q'' = 10000\, W/m^2$ which is applied on the base of the uniform fin. Table 1 shows the materials of the fin studied with their different values of thermal conductivity k.

Table 1: Thermal conductivity of the materials studied.

Case	**Material**	$\boldsymbol{k\ (W/m \cdot °C)}$
1	Steel	50.2
2	Aluminum	205
3	Copper	385

The radius of the reference circular base R is equal to $10mm$ and therefore the constant area of the base A is equal to $100\pi mm^2$. The semiminor axis b will be varied in the range between $2mm$ and $10mm$ with a step equal to $0.25mm$ and the semimajor axis will be calculated by $a = \frac{R^2}{b}$ which means that 33 different geometrical configurations will be simulated for each case studied including the three different materials with different values of the thermal conductivity, four various lengths of the uniform fin, and for both natural and forced convection. The total number of the simulations is 792 which are done using Python code that automated Ansys Mechanical without any intervention of the user.

Figs. 2 and 3 show the maximum temperature T_{max} as a function of the ratio between the minor and major axes of the elliptical cross-section $\frac{2b}{2a}$ for the three materials, Steel, Aluminum, and Copper as well as for various values of the length of the fin respectively in the case of the natural and forced convection. For the two cases, the maximum temperature decreases with the increase of the length of the fin or the use of materials with high values of thermal conductivity. However as can be seen for the Aluminum and Copper from Figs. 2 and 3, it does not always provide a high drop in the maximum temperature. So, it is preferable to choose Aluminum that is less costly and lighter than Copper and still has approximately the same thermal performance. The same thing is applicable for the length of the fin for very small ratios between the minor and major axes which by increasing the length further does not provide high drops of the maximum temperature. The decrease in the ratio decreases the maximum temperature considerably due to the increase of the lateral surface which is in contact with the surrounding fluid and thus the thermal performances are better. The maximum temperature in the case of forced convection is so much lower than that in the case of natural convection due to the movement of the fluid which leads to higher heat transfer however an external power source is required such as a fan.

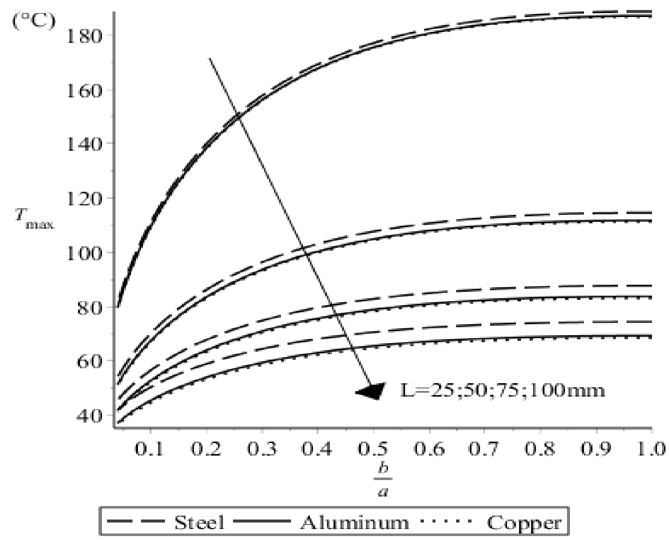

Fig. 2: The maximum temperature as a function of the ratio between the semiminor and semimajor axes of the ellipse for the three materials and different lengths in the case of natural convection.

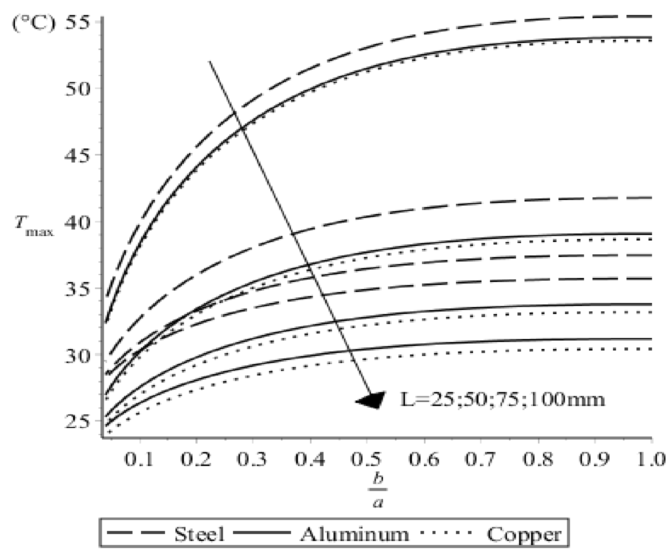

Fig. 3: The maximum temperature as a function of the ratio between the semiminor and semimajor axes of the ellipse for the three materials and different lengths in the case of forced convection.

4. Conclusion

In this paper, Ansys Mechanical automation using Python for the steady state thermal analysis of uniform fins is presented. The automation procedure presented for Ansys Mechanical can be used for other Ansys products that can model a large spectrum of physical phenomena for various applications in science and engineering. Running a large number of simulations, in this study 792, becomes easier using the proposed automation procedure where the computational time, human errors, and user interventions are reduced significantly. The data of these simulations can be analyzed directly using a programming language such as Python. The IronPython version of Python is used by Ansys.

The following main conclusions can be established:

− Forced convection provides better thermal performances than natural convection.

- The thermal performances increase with the increase of the length of the fin.
- Materials with high thermal conductivity have better thermal performances.
- The thermal performances increase with the decrease of the ratio between the minor and major axes of the elliptical cross-section.

Acknowledgements

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