Ref No. Ex/PG/MEC/PE/T/124I/2025

M.E. MECHANICAL ENGINEERING FIRST YEAR SECOND SEMESTER EXAM 2025

Thermal Design and Optimization

Full Marks: 100 **Time : 3 hours**

Use separate answerscript for each part

Part I

Answer Q: 1 and any TWO questions from the rest

Q:1 Answer any TWO parts 5+5=10

(a) Explain the algorithm of uniform dichotomous search method for finding the maximum of a univariate unimodal function.

(b) Consider the following optimization problem:

$$\begin{aligned} &\text{minimize } f(x_1, x_2, \dots, x_n) \\ &\text{subject to } g(x_1, x_2, \dots, x_n) = 0 \\ &\qquad\qquad h(x_1, x_2, \dots, x_n) \le 0 \end{aligned}$$

Formulate the problem for solution using Lagrange multiplier method. Set up the equations

(c) Consider the problem of power generation from a steam power cycle. Considering boiler pressure, turbine inlet temperature and condenser pressure as inputs and thermal efficiency of the cycle as output, develop an ANN model with input layer, output layer, a single hidden layer and no activation function. Show the model schematically and write down the equations to be solved.

Q:2 The objective function U, which represents the cost of a fan and duct system is given in terms of the design variables, fan capacity (x) and the duct length (y) as 20

$$U = \frac{x^2}{6} + \frac{4}{xy} + 3y$$

Taking initial guess as $x = 0.5, y = 0.5$, use method of steepest descent for finding the minimum cost. Take $\Delta x = 0.5$ and carry out three iterations.

Q:3 Consider the cylindrical solar water heater storage problem (Minimize surface area A for a given volume V = 4000 litres). Perform 5 function evaluations with the uniform exhaustive search method for one variable. Initial interval of uncertainty is $0.5 \le r \le 3.5$ m. What is the reduction ratio obtained? 20

Q:4 In an electronic circuitry, the power source may be considered as a thin square with side dimension L in meters. It is desired to minimize the heat transfer from the surface of the power supply to the local surroundings. The heat transfer coefficient h (in W/m^2K) is given by 20

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$$h = \left(2 + L^{1/2}\right)(\Delta T)^{1/4} L^{-1}$$

where ΔT is the temperature difference in K from the local ambient. A constraint arises due to the strength of the bond that attaches the power supply to the electronic circuit board as $L(\Delta T) = 5.6$. Calculate the side dimension L of the square that would minimize the total heat loss using Lagrange multiplier method

Part II

Answer Q: 1 and any TWO questions from the rest

Q:1 Answer any TWO parts 5+5=10

(a) Explain the step by step design procedure by a flowchart.

(b) What do you mean by fixed quantity, design variables and constraints?

(c) A system for the storage of thermal energy is to be designed using an underground tank of water. The tank is buried at a depth of 3 m and is a cube of 1 m on each side. The water in the tank is heated by circulating it through a solar energy collection system. A given heat input to the water may be assumed due to the solar energy flux. Characterize the design problem in terms of the fixed quantities and design variables.

Q:2 The temperature T of a small copper sphere cooling in air is measured as a function of time to yield the following data: 20

τ (s)	0.2	0.6	1.0	1.8	2.0	3.0	5.0	6.0	8.0
T (°C)	146.0	129.5	114.8	90.3	85.1	63.0	34.6	25.6	14.1

An exponential decrease in temperature is expected from lumped mass modeling. Obtain a best fit to represent these data

Q:3 In a manufacturing process, a spherical piece of metal is subjected to radiative and convective heat transfer, resulting in the energy balance equation $0.6 \times 5.67 \times 10^{-8}\,[850^4 - T^4] = 40 \times (T - 350)$. Here, the surface emissivity of the metal is 0.6, the temperature of the radiating source is 850 K, 5.67×10^{-8} W/($m^2 \cdot K^4$) is the Stefan-Boltzman constant, 350 K is the ambient fluid temperature, and 40 W/($m^2 \cdot K$) is the convective heat transfer coefficient. Find the temperature T using any suitable numerical method. 20

Q:4 For a straight fin with known base temperature and heat transfer co-efficient find the optimal geometry (profile length) for a maximum heat transfer. Consider adiabatic tip. Use fixed volume constraint in the design problem. 20

Q:5 In a thermal system, the volume flow rate R of a fluid through a duct due to a fan is given in terms of the pressure difference P, which drives the flow as $R = 15 - 75 \times 10^{-6} \times P^2$ with $P = 80 + 10.5R^{5/3}$ where R is in m^3/s and P is in N/m^2. The first equation represents the characteristics of the fan and the other that of the duct. Simulate this system by the successive substitution and Newton-Raphson methods to obtain the flow rate and pressure difference. 20