1. **Maxwell's Equations and Constitutive Equations**:
   * Maxwell's equations are a set of four fundamental equations that describe how electric and magnetic fields interact. They are:
     1. Gauss's law for electricity
     2. Gauss's law for magnetism
     3. Faraday's law of electromagnetic induction
     4. Ampère's law with Maxwell's addition
   * Constitutive equations describe the relationship between the electric field, the magnetic field, and the electric displacement field (D) and magnetic flux density (B) in a medium. They vary depending on the material properties of the medium.
2. **Electrostatic Field**:
   * Electrostatics deals with stationary electric charges and their interactions.
   * Basic laws include Coulomb's law, which describes the force between two charged particles, and Gauss's law for electricity, which relates the electric flux through a closed surface to the charge enclosed by the surface.
3. **Magnetostatic Field**:
   * Magnetostatics deals with stationary magnetic fields and their interactions.
   * Basic laws include Ampère's law, which relates the magnetic field around a closed loop to the electric current passing through the loop, and Gauss's law for magnetism, which states that there are no magnetic monopoles.
4. **Dirichlet's and Neumann's Boundary Conditions**:
   * Dirichlet boundary conditions specify the values of the field (e.g., electric potential or magnetic field) on the boundary of the region.
   * Neumann boundary conditions specify the derivative of the field normal to the boundary.
5. **Classical Residual Method (Galerkin's Method)**:
   * Galerkin's method is a numerical technique used for solving partial differential equations (PDEs) by transforming them into a finite-dimensional problem.
   * It involves approximating the solution using a finite number of basis functions and then minimizing the residual, which is the difference between the actual PDE and its approximate solution.
6. **Classical Variational Method (Rayleigh–Ritz's Method)**:
   * Rayleigh–Ritz's method is a variational technique used for finding approximate solutions to eigenvalue problems and PDEs.
   * It involves minimizing the functional associated with the problem by varying a set of trial functions (often called basis functions or trial functions) that satisfy the boundary conditions.
   * The method seeks to find the best approximation to the solution within a finite-dimensional subspace of the function space.

**Basics of the finite element’s method – the four stages of finite element analysis**

**answer**

1. **Discretization**:
   * In this stage, the continuous domain is divided into a finite number of smaller subdomains called elements.
   * Nodes are defined at the corners of these elements, and the behavior of the field variable (e.g., displacement, temperature, electric potential) is approximated within each element using interpolation functions.
   * The choice of element type (e.g., linear, quadratic, triangular, quadrilateral) depends on the geometry and the nature of the problem.
2. **Formulation of Element Equations**:
   * After discretization, the behavior of the field variable within each element is described by a set of element equations.
   * These equations are derived by applying the principle of minimum potential energy, virtual work principle, or other variational principles to each individual element.
   * The element equations typically involve unknown nodal values of the field variable and are expressed in terms of matrices and vectors.
3. **Assembly of Global Equations**:
   * Once the element equations are formulated, they are assembled to form the global equations that describe the behavior of the entire system.
   * This involves combining the contributions of individual elements while considering the continuity of the field variable at the shared nodes.
   * The resulting global equations form a large sparse system of algebraic equations.
4. **Solution and Post-Processing**:
   * The global equations obtained from the assembly stage are solved to determine the nodal values of the field variable throughout the domain.
   * Various solution techniques such as direct solvers, iterative methods, or numerical optimization algorithms can be employed.
   * After obtaining the solution, post-processing is performed to extract desired quantities of interest (e.g., stresses, strains, fluxes) and visualize the results.
   * Post-processing may involve interpolation to obtain field values at arbitrary points within the domain and generating graphical representations of the solution.
5. **Application of FEM to 2D fields • Formulation of the field problem • Linear interpolation of the potential function • Application of the variational method – definition of the functional referred to a single finite element and to the whole domain**

**answer**

1. **Formulation of the Field Problem**:
   * In 2D FEM, the field problem typically involves solving a partial differential equation (PDE) governing the behavior of a field variable (e.g., electric potential, temperature) over a two-dimensional domain.
   * The domain is discretized into triangular or quadrilateral elements, each with its own set of nodes and associated degrees of freedom.
   * The governing PDE is usually expressed in terms of the field variable, its derivatives, and any source terms or boundary conditions.
2. **Linear Interpolation of the Potential Function**:
   * Within each finite element, the potential function (or any other field variable) is approximated using linear interpolation.
   * Linear interpolation means that the field variable is assumed to vary linearly between the nodal values within each element.
   * Mathematically, the potential function within an element can be expressed as a linear combination of nodal values and shape functions:

*ϕ*(*x*,*y*) =∑*i*=1*n*​*Ni*​(*x*,*y*)*ϕi*​

*ϕ*(*x*,*y*)=∑*i*=1*n*​*Ni*​(*x*,*y*)*ϕi*​

* + Here, *ϕ*(*x*,*y*) represents the potential function at any point within the element, *Ni*​(*x*,*y*) are the linear shape functions associated with each node, and *ϕi*​ are the nodal values of the potential.

1. **Application of the Variational Method**:
   * The variational method, such as the principle of minimum potential energy or the principle of virtual work, is applied to derive the element equations and the global equations.
   * For a single finite element, the functional to be minimized can be expressed as the total potential energy within the element, which is the integral of the strain energy density over the element volume.
   * Mathematically, this can be written as: F*e*​=∫Ω*e*​​U*e*​*d*Ω
   * Here, F*e*​ is the functional associated with a single element, U*e*​ is the strain energy density within the element, and Ω*e*​ denotes the volume of the element.
2. **Definition of the Functional for the Whole Domain**:
   * To obtain the functional for the entire domain, the contributions from all individual elements are summed up.
   * The global functional represents the total potential energy of the entire system and is defined as the sum of the functionals associated with each element.
   * Mathematically, this can be written as: F=∑*e*=1*N*​F*e*​
   * Here, F is the global functional for the entire domain, and *N* is the total number of elements.

**Application of FEM to stationary current fields and magnetostatic fields**

**answer**

1. **Formulation of the Field Problem**:
   * For stationary current fields and magnetostatic fields, the governing equations are typically Maxwell's equations in their static form.
   * In magnetostatics, Maxwell's equations simplify to:

∇⋅B=0 ∇×H=**J**​

* + Where **B** is the magnetic flux density, **H** is the magnetic field intensity, and **J** is the current density.

1. **Discretization**:
   * The domain containing the current-carrying conductors is discretized into finite elements.
   * Nodes are defined at the vertices of the elements, and the magnetic field is approximated within each element using basis functions.
2. **Linear Interpolation of Magnetic Field**:
   * Similar to other FEM applications, the magnetic field within each element is linearly interpolated using shape functions.
   * This interpolation assumes a linear variation of the magnetic field between nodal points within the element.
3. **Application of the Variational Method**:
   * The variational method, such as the principle of minimum total magnetic energy or the principle of virtual work, is applied to derive the element equations.
   * The functional to be minimized typically represents the total magnetic energy within the system, which includes contributions from magnetic field energy and possibly additional energy terms due to material properties or boundary conditions.
4. **Solution and Post-Processing**:
   * Once the element equations are derived and assembled into the global system, they are solved to obtain the magnetic field distribution throughout the domain.
   * Post-processing involves analyzing the results, extracting quantities of interest (such as magnetic flux density, magnetic field intensity, and magnetic forces), and visualizing the solution.
5. **Finite element analysis of induction machines • Reduction of the 3D field problem to the 2D problem • Dirichlet’s and periodic boundary conditions in the electric machines • Magnetic part of the field-circuit model • Electric circuit equations of the stator windings • Computation of torque**

**answer**

1. **Reduction of the 3D Field Problem to the 2D Problem**:
   * Induction machines are often axially symmetric, allowing the 3D problem to be simplified to a 2D problem using techniques such as axisymmetric modeling or 2D slice modeling.
   * This simplification reduces computational complexity while still capturing essential features of the machine's behavior.
2. **Dirichlet's and Periodic Boundary Conditions in Electric Machines**:
   * Dirichlet boundary conditions specify the potential or field values at specific boundaries of the machine, such as the stator or rotor surfaces.
   * Periodic boundary conditions are applied in machines with periodic structures, such as induction machines with repeated stator or rotor slots.
   * These boundary conditions ensure continuity and allow accurate representation of the machine's behavior while minimizing computational resources.
3. **Magnetic Part of the Field-Circuit Model**:
   * The magnetic part of the field-circuit model describes the magnetic behavior of the machine, including flux distribution, magnetic field intensity, and magnetic forces.
   * In FEA, the magnetic part is typically modeled using Maxwell's equations in magnetostatic or quasi-static form.
   * Material properties, such as magnetic permeability, are incorporated into the model to account for the magnetic characteristics of the machine's components.
4. **Electric Circuit Equations of the Stator Windings**:
   * In addition to the magnetic part, the electric circuit equations of the stator windings are included to capture the electromagnetic interaction between the magnetic field and the electric currents in the machine.
   * These equations describe the electrical behavior of the windings, including voltage and current distribution, resistance, and inductance.
   * Kirchhoff's voltage and current laws are commonly used to formulate these circuit equations.
5. **Computation of Torque**:
   * Torque in induction machines arises from the interaction between the magnetic field and the currents induced in the rotor.
   * It can be computed using methods such as the Lorentz force law or the electromagnetic torque equation, which relates the torque to the electromagnetic quantities, such as the magnetic field and the rotor current.

**7. Incorporating motion in FEM**

**answer**

1. **Time-Dependent Analysis**:
   * For transient or dynamic problems, time-dependent analysis is performed where the solution evolves over time.
   * The equations of motion, which include inertia, damping, and external forces, are discretized in time using methods such as the implicit or explicit time-stepping schemes.
   * At each time step, the finite element equations are solved to update the system response.
2. **Geometric Nonlinearity**:
   * In systems undergoing large deformations or significant motion, geometric nonlinearity must be considered.
   * The geometry of the system changes with time, and the finite element mesh needs to adapt accordingly.
   * Updated Lagrangian or Total Lagrangian formulations are often used to handle geometric nonlinearity in FEA.
3. **Modal Analysis**:
   * Modal analysis is used to study the natural frequencies and mode shapes of vibrating structures.
   * The system is represented as a set of interconnected mass, damping, and stiffness elements.
   * Eigenvalue analysis is performed to determine the modes of vibration and their corresponding frequencies.
4. **Coupled Analysis**:
   * Systems with strong coupling between different physical domains, such as fluid-structure interaction or electromagnetic-structural interaction, require coupled analysis.
   * In coupled analysis, equations governing each domain are solved simultaneously, and the interaction between domains is accounted for iteratively.
5. **Boundary Conditions and Loading**:
   * Boundary conditions and loading must be appropriately defined to account for motion.
   * Time-varying loads, such as forces, torques, or prescribed displacements, are applied to simulate external influences on the system.
   * Constraints are applied to restrict the motion of certain degrees of freedom or to model connections between different components.
6. **Integration with Multi-body Dynamics (MBD)**:
   * For systems with complex motion involving rigid bodies, joints, and contact interactions, FEA can be integrated with multi-body dynamics (MBD) simulations.
   * MBD software packages simulate the dynamic behavior of interconnected rigid bodies, while FEA provides detailed analysis of individual components or structural integrity.

**8. Iron losses and computation of efficiency**

**The actual questions will be less broad. Here are some examples:**

* **Describe briefly, in your own words, the classical method of field problem solution,**
* **Compare the sliding surface and moving band approaches of accounting for motion,**
* **How are the conductors modelled in a field model of electric machine? Briefly describe and compare the two types of conductors, provide examples of their applications.**
* **Three types of core losses (describe them briefly). How can we apply the field solution to estimate them.**
* **What is an interpolation function, in context of the finite element method? What interpolation functions are used in modelling of electrical machines? Describe briefly its application**

**Answer**

1. **Classical Method of Field Problem Solution**:
   * The classical method of field problem solution involves mathematically formulating the problem using fundamental laws (such as Maxwell's equations), applying appropriate boundary conditions, and solving the resulting equations analytically or numerically to obtain the desired field distribution.
2. **Comparison of Sliding Surface and Moving Band Approaches**:
   * The sliding surface approach assumes that the motion occurs along a designated surface within the finite element mesh, while the moving band approach involves updating the mesh as the motion progresses.
   * Sliding surface approach is computationally more efficient for certain types of motion, while the moving band approach offers more accurate representation of complex motion but requires more computational resources.
3. **Modelling Conductors in Field Models of Electric Machines**:
   * Conductors in field models of electric machines are typically represented as line or surface elements.
   * Line conductors are used to model wire windings, while surface conductors are used for solid conductive parts such as busbars or rotor bars.
   * Examples include winding conductors in transformers (line conductors) and rotor bars in induction motors (surface conductors).
4. **Three Types of Core Losses**:
   * Core losses in electric machines include hysteresis, eddy current, and excess losses.
   * Hysteresis losses occur due to the reversal of magnetization within the magnetic material.
   * Eddy current losses arise from currents induced in the conductive core material.
   * Excess losses encompass other losses such as mechanical and stray losses.
   * Field solution methods can be used to estimate core losses by simulating the magnetic field distribution and calculating the associated losses using appropriate loss models.
5. **Interpolation Function in Finite Element Method**:
   * An interpolation function is used to approximate the behavior of a field variable within an element based on nodal values.
   * In modeling electrical machines with FEM, interpolation functions such as linear or quadratic shape functions are commonly used.
   * These functions enable the representation of field variables (e.g., magnetic flux, electric potential) within each element and facilitate the solution of the finite element equations to obtain the overall field distribution.