UNIT 3 PARTIAL DIFFERENTIAL EQUATIONS

Linear partial differential equations of second order with constant coefficients of homogeneous types

Linear PDE of 2nd order with constant coefficients

Homogeneous Linear PDE's:

A Linear PDE with constant coefficients in which all the partial derivatives are of the same order is called homogenous, otherwise it is called non-homogenous

Example:

Homogenous Equation:-

$$\frac{\partial^2 z}{\partial x^2} + 5\frac{\partial^2 z}{\partial x \partial y} + 6\frac{\partial^2 z}{\partial y^2} = \sin x.$$

Non Homogeneous Equation:

$$\frac{\partial^2 z}{\partial x^2} - 5\frac{\partial z}{\partial x} + 7\frac{\partial z}{\partial y} + \frac{\partial^2 z}{\partial y^2} = e^{x+y}$$

Notation: $D = \frac{\partial}{\partial x}$, $D' = \frac{\partial}{\partial y}$

Method of finding complementary function (CF):

Let the given equation be of the form

$$f(D, D')z = f(x,y)$$

Put $D = m$, $D' = 1$

$$f(m,1) = 0 \Rightarrow a_0 m^n + a_1 m^{n-1} + \dots + a_n = 0$$

Let the roots of the eqn be $m_1, m_2, \dots m_n$

Roots	Complementary function
1. The Roots are different $m_1, m_2, \dots m_n$	$CF = f_1(y+m_1x) + f_2(y+m_2x) + \dots + f_n(y+m_nx)$
2. The roots are equal $m_1 = m_2 = \dots = m_n = m$	$CF = f_1(y+mx) + x f_2(y+mx) + \dots + x^{n-1} f_n(y+mx)$

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General solution is $y = CF + PI$

RHS=0 $(z = CF)$

1. Solve $(D^2 - 6DD' + 9D'^2)z = 0$

Put $D = m$, $D' = 1$

The auxillary equation is,

$$m^2 - 6m + 9 = 0$$
$$(m-3)(m-3) = 0$$
$$m = 3, 3 \text{ (equal)}$$

The solution is $z = CF$
$$= f_1(y+3x) + x f_2(y+3x)$$

Type-I

1. Solve $(D^2 - 5DD' + 6D'^2)z = e^{x+y}$

The auxillary equation is,

$$m^2 - 5m + 6 = 0$$
$$(m-3)(m-2) = 0$$
$$m = 2, 3$$

$$CF = f_1(y+2x) + f_2(y+3x)$$

$$PI = \frac{1}{D^2 - 5DD' + 6D'^2} e^{x+y}$$

Replace
$D \to a = 1$
$D' \to b = 1$

$$= \frac{1}{1-5+6} e^{x+y}$$
$$= \frac{1}{2} e^{x+y}$$

The solution is $z = CF + PI$
$$= f_1(y+2x) + f_2(y+3x) + \frac{e^{x+y}}{2}$$

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3. Type-I Solve : $(D^2-4DD'+4D'^2)z = e^{2x+y}$

The auxillary equation is

$$m^2-4m+4=0$$

$$(m-2)(m-2)=0.$$

$$m=2,2 \quad (\text{equal})$$

$$CF = f_1(y+2x)+x f_2(y+2x)$$

$$PI = \frac{1}{D^2-4DD'+4D'^2} e^{2x+y}$$

Replace $D \to a=2$, $D' \to b=1$

$$= \frac{1}{2^2-4(2)(1)+4(1)^2} e^{2x+y}$$

$$= \frac{1}{4-8+4} e^{2x+y}$$

$$= x\frac{1}{2D-4D'} e^{2x+y} = x\frac{1}{2(2)-4(1)} e^{2x+y}$$

$$= x^2 \frac{e^{2x+y}}{2} = \frac{x^2}{2} e^{2x+y}$$

The solution is $z = CF+PI$

$$= f_1(y+2x)+x f_2(y+2x)+\frac{x^2}{2}e^{2x+y}$$

4. Solve : $2\frac{\partial^2 z}{\partial x^2}+5\frac{\partial^2 z}{\partial x \partial y}+2\frac{\partial^2 z}{\partial y^2}=0.$

Given: $(2D^2+5DD'+2D'^2)z=0.$

A.E is $2m^2+5m+2=0$

$$2m^2+4m+m+2=0$$

$$2m(m+2)+1(m+2)=0$$

$$(2m+1)(m+2)=0 \quad m_1=\frac{-1}{2},\ m_2=-2$$

$\Rightarrow$ roots are different

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CF ⇒ $z = f_1(y - \frac{1}{2}x) + f_2(y - 2x)$

PI ⇒ PI = 0.

∴ solution is $z = CF + PI$

$= f_1(y - \frac{1}{2}x) + f_2(y - 2x)$

To find Particular Integral (PI)

Type I: RHS = $f(x,y) = e^{ax+by}$

$$PI = \frac{1}{\phi(D,D')} e^{ax+by}$$

Replace $D \to a$, $D' \to b$

then $PI = \frac{1}{\phi(a,b)} e^{ax+by}$, provided $\phi(a,b) \neq 0$

If $\phi(a,b) = 0$ then differentiate the Denominator wrt 'D' and multiply by x in Numerator.

2. Solve: $(2D^2 - 2DD' + D'^2)z = 2e^{3y} + e^{x+y}$.

AE is $2m^2 - 2m + 1 = 0$

$$m = \frac{-(-2) \pm \sqrt{(2)^2 - 4(2)(1)}}{2(2)} = \frac{2 \pm \sqrt{4-8}}{4} = \frac{2 \pm 2i}{4} = \frac{1 \pm i}{2}$$

$m = \frac{1}{2} \pm \frac{1}{2}i$

∴ The roots are imaginary

CF is $z = f_1(y + x(\frac{1}{2} + \frac{1}{2}i)) + f_2(y + (\frac{1}{2} - \frac{1}{2}i)x)$

PI ⇒ $PI_1 = \frac{1}{2D^2 - 2DD' + D'^2} 2e^{3y}$ → $D = 0$ & $D' = 3$

$$= \frac{1}{2(0) - 2(0)(3) + (3)^2} 2e^{3y} = \frac{2}{9} e^{3y}.$$

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$$PI_2 = \frac{1}{2D^2-2DD'+D'^2} e^{x+y} \qquad D=1, D'=1$$

$$= \frac{1}{2(1)^2-2(1)(1)+(1)^2} e^{x+y}$$

$$= e^{x+y}$$

$\therefore$ The solution is $z = CF + PI$

$$z = f_1(y+(\tfrac{1}{2}+\tfrac{1}{2}i)x)+f_2(y+(\tfrac{1}{2}-\tfrac{1}{2}i)x)+\frac{2}{9}e^{3y}+e^{x+y}$$

4. Solve : $(D^2-3DD'+2D'^2)z = e^{3x+2y}$

AE is $m^2-3m+2=0$

$$(m-2)(m-1)=0.$$

$$m_1=1, m_2=2$$

CF is $z = f_1(y+x)+f_2(y+2x)$

$$PI = \frac{1}{D^2-3DD'+2D'^2} e^{3x+2y} \qquad D=3, D'=2$$

$$= \frac{1}{(3)^2-3(3)(2)+2(2)^2} e^{3x+2y}$$

$$= \frac{1}{9-18+8} e^{3x+2y} = -e^{3x+2y}$$

$\therefore$ The solution is $z = CF + PI$

$$= f_1(y+x)+f_2(y+2x)-e^{3x+2y}.$$

5. Solve: $(D^2-DD'-20D'^2)z = e^{5x+y}$

AE is $m^2-m-20=0$

$$(m-5)(m+4)=0 \quad m_1=-4, m_2=5$$

$\therefore$ CF is $z = f_1(y-4x)+f_2(y+5x)$

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5. $PI = \frac{1}{D^2 - DD' - 20D'^2} e^{5x+y}$ $\quad D = 5, D' = 1$

$= \frac{1}{(5)^2 - (5)(1) - 20(1)} e^{5x+y} = \frac{1}{25 - 5 - 20} e^{5x+y}$

$= \frac{x}{2D - D'} e^{5x+y} = \frac{x}{2(5) - 1} e^{5x+y}$

$= \frac{x}{9} e^{5x+y}$

$\therefore$ The solution is $z = CF + PI$

$= f_1(y-4x) + f_2(y+5x) + \frac{xe^{5x+y}}{9}$

6. Solve: $(D^2 + 2DD' + D'^2)z = e^{x-y}$

AE is $m^2 + 2m + 1 = 0 \Rightarrow (m+1)(m+1) = 0$.

$m = -1, -1$ Roots are equal

$\therefore$ CF is $z = f_1(y-x) + xf_2(y-x)$

$PI = \frac{1}{D^2 + 2DD' + D'^2} e^{x-y}$ $\quad D = 1, D' = -1$

$= \frac{1}{(1)^2 + 2(1)(-1) + (-1)^2} e^{x-y} = \frac{e^{x-y}}{1 - 2 + 1}$

$= \frac{x}{2D + 2D'} e^{x-y} = \frac{x}{2(1) + 2(-1)} e^{x-y}$

$= \frac{x^2}{2} e^{x-y}$

The solution is $z = CF + PI$

$= f_1(y-x) + xf_2(y-x) + \frac{x^2}{2} e^{x-y}$.