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ELLIPTIK TIPDAGI TENGLAMALAR UCHUN ASOSIY CHEGARAVIY MASALALAR

Homidov Farhod Faxriddinovich

Osiyo Xalqaro Universiteti "Umumtexnik fanlar" kafedrasi o'qituvchisi

Annotatsiya: *Elliptik tipdagi tenglamalar sistemasi uchun Koshi masalasi korrekt bo'lmagan masalaga kiradi.Lekin uning integral formulasida chegaraning bir qismida qiymati ma'lum bolganligi sababli chegaraning qolgan qismida cheksiz kichik qilib aniqlash masalasi Karleman matrisasini tuzish bilan teng kuchlidir.Karleman matrisasini tuzish esa masalani yechishning dolzarbligini ifodalaydi.*

Kalit so'zlar: *Elliptik tipli tenglamalar uchun asosiy chegaraviy masalalar keltirilgan. Bunda elliptik tipli tenglamalar uchun Laplas va Puasson tenlamalari haqida so'z boradi.*

Elliptik tipdagi tenglamalar uchun asosiy chegaraviy masalalar

Asosan stasionar bo'lgan, ya'ni vaqtga bog'liq bo'lmagan fizik prosesslarini, ya'ni issiqlikning tarqalishi to'lqinning harakati, maydon potensialining tortilish kuchi kabilarni tekshirishda asosan elliptik tipdagi tenglamalarga keltiriladi. Ya'ni yuqoridagi qaralgan barcha tenglamalarda qatnashayotgan noma'lum funksiya vaqt t ga bog'liq bo'lmaydi.

Bu xildagi tenglamalarga Laplas $\Delta u = 0$ va Puasson $\Delta u = f$ tenglamalari misol bo'ladi. Agar Laplas tenglamasida qatnashayotgan noma'lum funksiyaning ko'rinishi

$$u = u(x_1, x_2, \dots, x_n) \qquad \Delta u = \frac{\partial^2 u}{\partial x_1^2} + \frac{\partial^2 u}{\partial x_2^2} + \dots + \frac{\partial^2 u}{\partial x_n^2}$$

Laplas tenglamasining qanoatlantiradigan funksiyaga umuman olganda garmonik funksiya deb yuritiladi.

Quyidagi belgilashlar kiritamiz.

T – soha, n – tashqi birlik normal.

Ta'rif: S sirt bilan chegaralangan T sohada $u = u(x, y, z)$ funksiya o'zining barcha argumentlari bo'yicha 2 tartibgacha differensiallanuvchi funksiyadan iborat bo'lib, bu funksiya shu sohaning barcha nuqtalarida Laplas tenglamasini qanoatlantirsa, u funksiyaga garmonik funksiya deyiladi. Bu funksiya $u = u(x, y, z)$ funksiya chegaralanmagan T sohada garmonik deb yuritiladi, agarda shu chegaralanmagan sohaning barcha nuqtalarida ikkinchi tartibgacha differensiallanuvchi bo'lib, shu chegaralanmagan sohadagi M nuqtaning cheksizcha intilganda funksiyaning shu nuqtadagi qiymati nolga tekis intilsa, ya'ni $\forall E > 0 \quad \exists A > 0$ bo'lsaki, buning natijasida koordinata boshida shu M nuqtagacha bo'lgan masofa $\tau \geq A$ sondan katta bo'lganda funksiyaning shu nuqtadagi qiymati $|u(M)| \leq E$ bo'lsa, endi garmonik funksiyalarga tegishli quyidagi sodda lemmalarni qaraymiz.

1-Lemma:

$$u = u(x,y,z) = \frac{1}{(x-x_0)^2 + (y-y_0)^2 + (z-z_0)^2} = \frac{1}{r}$$

$$r = (x-x_0)^2 + (y-y_0)^2 + (z-z_0)^2$$

Funksiya uch o'lchovli fazodagi M_0 va M nuqtalar orasida masofani bildiradi. Funksiya uch o'lchovli fazodagi $M_0(x_0, y_0, z_0)$ nuqtalardan tashqari barcha nuqtalarda garmonik funksiyadan iboratdir. Ya'ni

$$\Delta(1/r) = \partial^2(1/r)/\partial x^2 + \partial^2\,(1/r)/\partial y^2 + \partial^2(1/r)\partial z^2 = 0$$

Shu sababli $u(x,y,z) = 1/r$ funksiyaga Laplas tenglamasining fundamental yechimi deyiladi.

Isbot: Haqiqatan $M_0 \neq M$ bo'lganligi sababli

$$r = (x-x_0)^2 + (y-y_0)^2 + (z-z_0)^2$$

dan tenglik xossalarini hisoblasak quyidagilarga kelamiz.

$$\partial r/\partial x = (x-x_0)/r\,, \qquad \partial r/\partial y = (y-y_0)/r, \quad \partial r/\partial z = (z-z_0)/r,$$

Endi $u = 1/r$ funksiyadan tegishli xossalarni hisoblaymiz.

$$\frac{\partial\left(\frac{1}{r}\right)}{\partial x} = \frac{\partial\left(\frac{1}{r}\right)}{\partial r}\frac{\partial r}{\partial x} = -\frac{1}{r^2}\frac{x-x_0}{r} = \frac{x-x_0}{r^2};$$

$$\frac{\partial\left(\frac{1}{r}\right)}{\partial x} = -\frac{x-x_0}{r^3}; \qquad \frac{\partial\left(\frac{1}{r}\right)}{\partial y} = -\frac{y-y_0}{r^3}; \qquad \frac{\partial\left(\frac{1}{r}\right)}{\partial z} = -\frac{z-z_0}{r^3};$$

$$\frac{\partial^2\left(\frac{1}{r}\right)}{\partial x^2} = \frac{\partial}{\partial x}\left[-\frac{\partial\left(\frac{1}{r}\right)}{\partial x}\right] = -\frac{\partial}{\partial x}\left[\frac{x-x_0}{r}\right] =$$

$$= \frac{-r^3 - (x-x_0)3r^2\frac{\partial r}{\partial x}}{r^6} = \frac{-r^3 - 3(x-x_0)r^2\left(\frac{x-x_0}{r}\right)}{r^6} =$$

$$= -\frac{1}{r^3} + \frac{3(x-x_0)^2}{r^5};$$

Xuddi shuningdek, quyidagilarga kelamiz.

$$\frac{\partial^2\left(\frac{1}{r}\right)}{\partial y} = -\frac{1}{r^2} + \frac{3(y-y_0)^2}{r^2};$$

$$\frac{\partial^2\left(\frac{1}{r}\right)}{\partial z^2} = -\frac{1}{r^3} + \frac{3(z-z_0)^2}{r^5}$$

Demak,

$$\Delta\left(\frac{1}{r}\right) = \frac{\partial^2\left(\frac{1}{r}\right)}{\partial^2 x} + \frac{\partial^2\left(\frac{1}{r}\right)}{\partial y^2} + \frac{\partial^2\left(\frac{1}{r}\right)}{\partial z^2} =$$

$$= \frac{3}{r^3} + 3\left[\frac{(x-x_0)^2 + (y-y_0)^2 + (z-z_0)^2}{r^5}\right] = \frac{3}{r^3} - \frac{3}{r^3} = 0$$

Haqiqatan ham $u = \frac{1}{r}$ qaralayotgan sohadagi M_0 nuqtadan tashqari barcha nuqtalarga garmonik funksiyadan iborat ekan.

2-Lemma.

$$u(x,y) = ln\frac{1}{r} = ln\frac{1}{\sqrt{(x-x_0)^2+(y-y_0)^2}}$$

Funksiya tekislikdagi $U_0(x_0, y_0)$ nuqtadan tashqari barcha nuqtalarda garmonik funksiyadan iborat.

Ya'ni

$$\Delta\left(ln\frac{1}{r}\right) = \frac{\partial^2\left(ln\frac{1}{r}\right)}{\partial x^2} + \frac{\partial^2\left(ln\frac{1}{r}\right)}{\partial y^2} = 0$$

Isbot: Haqiqatan ham $M_0 \neq M$ bo'lganligi sababli

$$r = \sqrt{(x-x_0)^2+(y-y_0)^2}$$

$$\frac{\partial r}{\partial x} = \frac{x-x_0}{r}; \quad \frac{\partial r}{\partial y} = \frac{y-y_0}{r}$$

ga kelamiz.

Endi $u = ln\frac{1}{r}$ funksiyaning tegishli xossalarini hisoblaymiz. Ya'ni

$$\frac{\partial\left(ln\frac{1}{r}\right)}{\partial x} = \frac{\partial\left(ln\frac{1}{r}\right)}{\partial r}\frac{\partial r}{\partial x} = \frac{1}{\frac{1}{r}}\left(-\frac{1}{r^2}\right)\frac{x-x_0}{r} = -\frac{x-x_0}{r^2}$$

$$\frac{\partial\left(ln\frac{1}{r}\right)}{\partial x} = \frac{x-x_0}{r^2}; \qquad \frac{\partial\left(ln\frac{1}{r}\right)}{\partial y} = -\frac{y-y_0}{r^2}$$

$$\frac{\partial^2\left(ln\frac{1}{r}\right)}{\partial x^2} = \frac{\partial}{\partial x}\left[\frac{\partial\left(ln\frac{1}{r}\right)}{\partial x}\right] = \frac{\partial}{\partial x}\left[\frac{x-x_0}{r^2}\right] = \frac{-r^2-(x-x_0)/r\cdot\frac{\partial}{\partial x}}{r^4} =$$

$$= \frac{-r^2-2(x-x_0)^2}{r^4} = \frac{1}{r^2} + \frac{2(x-x_0)^2}{r^4}$$

$$\frac{\partial^2\left(ln\frac{1}{r}\right)}{\partial x^2} = -\frac{1}{r^2} + \frac{2(x-x_0)^2}{r^4}$$

oxirgi tengliklarni qo'shamiz:

$$\Delta\left(ln\frac{1}{r}\right) = \frac{\partial^2\left(ln\frac{1}{r}\right)}{\partial x^2} + \frac{\partial^2\left(ln\frac{1}{r}\right)}{\partial y^2} =$$

$$= -\frac{2}{r^2} + \frac{2[(x-x_0)^2+(y-y_0)^2]}{r^4} = -\frac{2}{r^2} + \frac{2}{r^2} = 0$$

3 – Lemma: $u(x,y) = \ln r$ funksiya $M_0(x_0, y_0)$ nuqtadan tashqari barcha nuqtalarda garmonik funksiyadan iborat. Ya'ni

$$\Delta lnr = \frac{\partial^2(lnr)}{\partial x^2} + \frac{\partial^2(lnr)}{\partial y^2} = 0$$

Isbot: $M_0 \neq M$ bo'lganligidan $\frac{\partial r}{\partial x} = \frac{x-x_0}{r}$; $\frac{\partial r}{\partial y} = \frac{y-y_0}{r}$ ga kelamiz.

Endi $\ln r$ funksiyaning tegishli xosilalarini hisoblaymiz.

$$\frac{\partial(lnr)}{\partial x} = \frac{\partial(ln\, r)}{\partial \curlyvee}; \quad \frac{\partial r}{\partial x} = \frac{1}{r}\cdot\frac{x-x_0}{r} = \frac{x-x_0}{r^2}$$

$$\frac{\partial(lnr)}{\partial r} = \frac{y-y_0}{r^2}$$

$$\frac{\partial^2(lnr)}{\partial x^2} = \frac{\partial}{\partial x}\left[\frac{\partial(lnr)}{\partial x}\right] = \frac{\partial}{\partial x}\left[\frac{x-x_0}{r^2}\right] = \frac{r^2-(x-x_0)/r\frac{\partial r}{\partial x}}{r^4} =$$

$$\frac{r^2-2(x-x_0)^2}{r^4} = -\frac{1}{r^2} - \frac{2(x-x_0)^2}{r^4}$$

Demak,

$$\frac{\partial^2(lnr)}{\partial x^2} = -\frac{1}{r^2} - \frac{2(x-x_0)^2}{r^4}$$

$$\frac{\partial^2(lnr)}{\partial x^2} = -\frac{1}{r^2} - \frac{2(y-y_0)^2}{r^4}$$

Demak bularni qo'shamiz

$$\Delta(lnr) = \frac{\partial^2(lnr)}{\partial x^2} + \frac{\partial^2(lnr)}{\partial y^2} = 0$$

Yuqorida ko'rdikki, vaqtga bog'liq bo'lmagan stasionar chegaraviy masalalarni tekshirishda Laplas va Puasson tenglamalarini

$\Delta u = 0$ (1.2.1)

$\Delta u = -f(u)$ (1.2.2)

ko'rgan edik.

Qaralayotgan masala stasionar chegaraviy masalalardan iborat bo'lganligi uchun bu masalalarda boshlang'ich shartlar ishtirok etmaydi. Xuddi yuqoridagilar kabi chegaraviy masalalarning ko'rinishlarini qarab chiqamiz.

Ma'lumki,

$\Delta u = 0$ (1.2.3)

$\Delta u = -f(u)$ (1.2.4)

(1.2.1) va (1.2.2) ko'rinishdagi tenglamalar vaqtga bog'liq bo'lmagan prosesslarning to'liq tarqalishi qonuniyatlarni aniqlashga yetarli emas. Shu sababli bu qonuniyatlarning to'la aniqlash uchun topilishi kerak bo'lgan funksiyaning qaralayotgan sohaning sirtidagi qiymati ma'lum bo'lishi kerak.

1) S sirt bilan chegaralangan T sohada shunday bir funksiyani $u = u(x,y,z)$ topish kerakki, bu natijada (1.2.1) yoki (1.2.2) shu sohaning sirtida $u/s = f_1\ (x,y,z)$ berilgan funksiyaga aylansin. Ya'ni quyidagi masalalarga kelamiz.

$$\left.\begin{array}{l}\Delta u = 0\\ u/s = f_1\ (x,y,z)\end{array}\right\} \quad (1.2.5)$$

$$\left.\begin{array}{l}\Delta\, u = -f\\ u/s = f_1\ (x,y,z)\end{array}\right\} \quad (1.2.6.)$$

Bu keltirgan masalalarga elliptik tipdagi tenglamalar uchun qo'yilgan birinchi chegaraviy masala deb yoki Dirixle masalasi deyiladi.

2) S sirt bilan chegaralangan T sohada shunday bir $u = u(x,y,z)$ funksiyani topish kerakki, natijada bu funksiya (1.2.1) yoki (1.2.2) ni qanoatlantirib quyidagi chegaraviy shartni qanoatlantirsin.

$$\frac{\partial u}{\partial n}/S = f_2 \ (x,y,z)$$

Bundagi

$$\frac{\partial u}{\partial n}/S = \left[\frac{\partial \varphi}{\partial x}cos\alpha + \frac{\partial u}{\partial y}cos\beta + \frac{\partial \varphi}{\partial z}cos\gamma\right]/S$$

Tashqi normal bo'yicha olingan hosilaning S sirtdagi qiymati, ya'ni quyidagi masalaga kelamiz.

$$\left.\begin{array}{l}\Delta u = 0 \\ \frac{\partial \varphi}{\partial \bar{n}}/s = f_2 \ (x,y,z)\end{array}\right\} \qquad (1.2.7)$$

$$\left.\begin{array}{l}\Delta\, u = -f \\ \frac{\partial u}{\partial \bar{n}}/s = f_2 \ (x,y,z)\end{array}\right\} \qquad (1.2.8)$$

Bu masalalarga elliptik tipli tenglama uchun qo'yilgan ikkinchi chegaraviy masala yoki Neyman masalasi deyiladi.

3) S sirt bilan chegaralangan T sohada shunday bir funksiyani, ya'ni $u = u(x,y,z)$ ni topish kerakki, natijada bu funksiya shu qaralayotgan sohada (1.2.1) yoki (1.2.2) tenglamani qanoatlantirib, quyidagi chegaraviy shart bajarilsin.

$$\left[\frac{\partial \varphi}{\partial \bar{n}} + ku\right]/S = f_3 \ (x,y,z)$$

ya'ni quyidagi masalaga kelamiz.

$$\left.\begin{array}{l}\Delta u = 0 \\ \left[\frac{\partial \varphi}{\partial \bar{n}} + Hu\right]/s = f_3 \ (x,y,z)\end{array}\right\} \qquad (1.2.9)$$

Bu keltirgan masalalargga elliptik tipdagi tenglamalar uchun qo'yilgan uchinchi chegaraviy masala deb yuritiladi. Bunda ham uchinchi chegaraviy masala umumlashgan chegaraviy masaladan iboratdir. Bu masalalarning yechish jarayonida agar yechimi qaralayotgan T sohaning S sirtga nisbatan sohaning ichkarisida yoki tashqarisida topishni talab etiliishi mumkin. Shu sababli bu xildagi masalalarga ichki yoki tashqi masalalar deyiladi. Bu keltirgan masalalardagi f_1, f_2, f_3 lar sohaning sirtida berilgan funksiyalardan bo'lib hisoblanadilar.

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