RATSIONAL KASRLAR VA ULARNI INTEGRALLASHGA DOIR BA'ZI MASALALAR.

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ANNOTATSIYA: Har qanday aniqmas integral elementar funksiyalar orqali ifodalanishi shart emas. Shu sababli elementar funksiyalarda ifodalanadigan integrallar sinfini topish masalasi paydo bo'ladi. Bu masalaning xususiy bir javobi sifatida ratsional funksiyalardan olingan integrallarni ko'rsatish mumkin. Bunda dastlab I-IV turdagi eng sodda ratsional funksiyalarni integrallash usuli ko'rsatiladi. So'ngra, ixtiyoriy ratsional funksiyani ularning algebraik yig'indisi kabi yozish mumkinligidan foydalanib, umumiy holda ratsional funksiyadan olingan integrallarni hisoblash amalga oshiriladi. Bu integrallar logarifmik, arctg($ax+b$) ko'rinishdagi teskari trigonometrik funksiyalar hamda ratsional kasrlar, ya'ni elementar funksiyalar orqali ifodalanadi.
Kalit so'zlar: Ko'phad * Ratsional kasr (funksiya) * Noto'g'ri ratsional kasr * To'g'ri ratsional kasr * I tur eng sodda ratsional kasr * II tur eng sodda ratsional kasr

1.Ratsional funksiyalar. Ma'lumki ,

$$P_n(x)=a_nx^n + a_{n-1}x^{n-1} + a_{n-2}x^{n-2} +\dots a_1x + a_0 \quad (a_n\neq 0) \qquad (1)$$

ko'rinishdagi funksiya ***ko'phad*** deyiladi. Bunda $a_n, a_{n-1}, a_{n-2}, \dots, a_1, a_0$ o'zgarmas sonlar bo'lib, ular ko'phadning ***koeffitsiyentlari*** , n esa ko'phadning ***darajasi*** deb ataladi.

Masalan, $P_3(x)=5x^3 -x^2 +2x+4$ – III darajali, $P_2(x)=3x^2 -5x+2$ – II darajali, $P_1(x)=8x+3$ – I darajali ko'phadlardir.

Izoh: Har qanday o'zgarmas funksiyani $P_0(x)=a_0$ – 0-darajali ko'phad deb qarash mumkin.

1-TA'RIF: Ikkita ko'phad nisbatidan iborat funksiya ***ratsional kasr yoki ratsional funksiya*** deyiladi.

Odatda ratsional kasr $R(x)$ kabi belgilanadi va, ta'rifga asosan,

$$R(x)=\frac{Q_m(x)}{P_n(x)}=\frac{b_mx^m+b_{m-1}x^{m-1}+\dots+b_1x+b_0}{a_nx^n+a_{n-1}x^{n-1}+\dots+a_1x+a_0} \qquad (2)$$

ko'rinishda bo'ladi.

Masalan,

$$\frac{3x-5}{x^2-2x+7},\quad \frac{4x^2+x-3}{5x^2-3x+1},\quad \frac{6x^3+5x^2+9x-3}{5x^2-3x+1}$$

ratsional kasrlardir.

Izoh: Har qanday $Q_m(x)$ ko'phadni maxraji $P_0(x)=1$ bo'lgan ratsional kasr kabi qarash mumkin va shu nuqtai nazardan ko'phadlar ba'zan butun funksiyalar deb ataladi.

Ma'lumki, m/n oddiy (sonli) kasrda maxraj suratdan katta, ya'ni $n>m$ bo'lsa, bu kasr to'g'ri, $n\leq m$ holda esa noto'g'ri kasr deyiladi. Bu tushuncha ratsional kasrlar uchun quyidagicha kiritiladi.

2-TA'RIF: Agar (2) ratsional kasrda maxrajning darajasi $n>m$ bo'lsa, u ***to'g'ri***, $n\leq m$ holda esa ***noto'g'ri ratsional kasr*** deb aytiladi.

Masalan,

$$R(x)=\frac{3x^4-x^3+2x^2-5x+1}{x^6+2x^4+3x^2+7}$$

to'g'ri,

$$R_1(x)=\frac{2x^3-3x^2+4x-5}{x^3+x^2-6x+1}, \quad R_2(x)=\frac{2x^5-3x^3+x+5}{x^3+2x^2-4x+1}$$

noto'g'ri ratsional kasrlar bo'ladi.

Har qanday noto'g'ri m/n ($m>n$) oddiy kasrni

$$\frac{m}{n}=k+\frac{r}{n}, \quad k \quad Z, \quad r<n$$

ko'rinishda, ya'ni butun son va to'g'ri kasr yig'indisi kabi ifodalash mumkin. Xuddi shunday tasdiq noto'g'ri ratsional kasrlar uchun ham o'rinli bo'ladi, ya'ni ular uchun ushbu tenglikni hosil qilish mumkin:

$$R(x)=\frac{Q_m(x)}{P_n(x)}=L_{m-n}(x)+\frac{G_r(x)}{P_n(x)}, \quad r<n. \qquad (3)$$

Bunda $L_{m-n}(x)$ va $G_r(x)$ ko'rsatilgan tartibli ko'phadlar bo'ladi.

Demak, har doim noto'g'ri ratsional kasrni ko'phad (butun funksiya) va to'g'ri ratsional kasr yig'indisi kabi ifodalash mumkin.

Masalan,

$$R(x)=\frac{2x^4-3x^3+1}{x^2+x-2}$$

noto'g'ri ratsional kasr suratini maxrajiga ustun usulida bo'lib, uni

$$R(x)=\frac{2x^4-3x^3+1}{x^2+x-2}=2x^2-5x+9+\frac{-19x+19}{x^2+x-2}$$

ko'rinishga keltira olamiz.

Har qanday ko'phad darajali funksiyalarning algebraik yig'indisi sifatida oson integrallamadi va uning integrali yana ko'phaddan iborat, ya'ni elementar funksiya bo'ladi. Demak, (3) tenglikka asosan, har qanday ratsional kasrni integrallash masalasi to‘g‘ri ratsional kasrni integrallash masalasiga olib keladi. Shu sababli kelgusida faqat to‘g‘ri ratsional kasrlarni integrallash bilan shug‘ullanamiz.

2. Eng sodda ratsional funksiyalar va ularni integrallash. Quyidagi ko‘rinishdagi to‘g‘ri ratsional kasrlarni qaraymiz:

I. $R_I(x) = \dfrac{A}{x-a}$, II. $R_{II}(x) = \dfrac{A}{(x-a)^k}$,

III. $R_{III}(x) = \dfrac{Ax+B}{x^2+px+q}$, IV. $R_{IV}(x) = \dfrac{Ax+B}{(x^2+px+q)^k}$.

Bunda A, B, a, p, q–haqiqiy sonlar, k=2,3,4, ... , va x^2+px+q kvadrat uchhad haqiqiy ildizlarga ega emas, ya’ni uning diskriminanti $D=p^2-4q<0$ deb olinadi.

3-TA’RIF: Yuqorida kiritilgan $R_{I}(x)$ – $R_{IV}(x)$ mos ravishda I–IV tur ***eng sodda ratsional kasrlar*** deb ataladi.

Eng sodda ratsional kasrlarni integrallash masalasini qaraymiz.

I va II turdagi oddiy kasrlarni integrallash jadval integrallariga oson keltiriladi:

$$R_I(x)dx = \frac{Adx}{x-a} = A\frac{d(x-a)}{x-a} = A\ln|x-a| + C;$$

$$R_{II}(x)dx = \frac{Adx}{(x-a)^{\kappa}} = A\ (x-a)^{-\kappa}d(x-a) =$$

$$= A\frac{(x-a)^{-\kappa+1}}{-\kappa+1} + C = \frac{A}{(1-\kappa)(x-a)^{\kappa-1}} + C, \quad k = 2,3,4,\cdots .$$

III turdagi eng sodda $R_{III}(x)$ ratsional kasrning integralini hisoblash usuli oldingi paragrafda (I_3 integral) ko‘rilgan edi. Shunday bo‘lsada, bayonimizni to‘liq bo‘lishi va hisoblashlarni so‘ngi nuqtasigacha yetkazish maqsadida , bu usulni biz qarayotgan

$$p^2 - 4q < 0 \qquad q - \frac{p^2}{4} = \sigma^2 > 0$$

hol uchun yana bir marta eslatamiz:

$$R_{III}(x)dx = \frac{Ax+B}{x^2+px+q}dx = \frac{\frac{A}{2}(2x+p) - \frac{Ap}{2} + B}{x^2+px+q}dx =$$

$$= \frac{A}{2}\ \frac{(2x+p)dx}{x^2+px+q} + (B - \frac{Ap}{2})\ \frac{dx}{x^2+px+q} =$$

$$= \begin{matrix} x^2+px+q=t \\ (2x+p)dx=dt \end{matrix} = \frac{A}{2}\ \frac{dt}{t}+(B-\frac{Ap}{2})\ \frac{dx}{x^2+px+q}=$$

$$=\frac{A}{2}\ln\left|x^2+px+q\right|+(B-\frac{Ap}{2})\ \frac{d(x+\frac{p}{2})}{(x+\frac{p}{2})^2+\sigma^2}=$$

$$=\frac{A}{2}\ln\left|x^2+px+q\right|-(B-\frac{Ap}{2})\ \frac{1}{\sigma}\mathrm{arctg}\frac{x+\frac{p}{2}}{\sigma}+C\ .$$

Endi IV turdagi eng sodda $R_{IV}(x)$ kasrning integralini hisoblaymiz:

$$R_{IV}(x)dx=\frac{Ax+B}{(x^2+px+q)^k}dx=\frac{\frac{A}{2}(2x+p)+B-\frac{Ap}{2}}{(x^2+px+q)^k}dx=$$

$$=\frac{A}{2}\ \frac{(2x+p)dx}{(x^2+px+q)^k}+(B-\frac{Ap}{2})\ \frac{d(x+\frac{p}{2})}{[(x+\frac{p}{2})^2+\sigma^2]^k}=\frac{A}{2}I_k+(B-\frac{Ap}{2})J_k\ .$$

Bu yerdagi

$$I_k=\ \frac{(2x+p)dx}{(x^2+px+q)^k},\ k=2,3,4,\cdots \qquad ,$$

$$J_k=\ \frac{d(x+\frac{p}{2})}{[(x+\frac{p}{2})^2+\sigma^2]^k},\ \ \sigma=\sqrt{q-\frac{p^2}{4}},\ k=2,3,4,\cdots$$

integrallarni hisoblaymiz:

$$I_k=\ \frac{(2x+p)dx}{(x^2+px+q)^k}=\begin{matrix} x^2+px+q=t \\ (2x+p)dx=dt \end{matrix}=\ \frac{dt}{t^k}=$$

$$=\frac{1}{(1-k)t^{k-1}}+C=\frac{1}{(1-k)(x^2+px+q)^{k-1}}+C;$$

$$J_k = \frac{d(x+\frac{p}{2})}{[(x+\frac{p}{2})^2+\sigma^2)^k} = \begin{matrix} t = x+\frac{p}{2}, \\ dt = dx \end{matrix} = \frac{dt}{(t^2+\sigma^2)^k} =$$

$$= \frac{1}{\sigma^2} \frac{t^2+\sigma^2-t^2}{(t^2+\sigma^2)^n} dt = \frac{1}{\sigma^2} \frac{dt}{(t^2+\sigma^2)^{k-1}} - \frac{1}{\sigma^2} \frac{t^2 dt}{(t^2+\sigma^2)^k} .$$

Bu tenglikdagi oxirgi integralga bo‘laklab integrallash formulasini qo‘llaymiz. Buning uchun integral ostidagi ifodani

$$u = t , \quad dv = \frac{tdt}{(t^2+\sigma^2)^k}$$

ko‘rinishda bo‘laklaymiz. Bu holda *du=dt* va

$$v = dv = \frac{tdt}{(t^2+\sigma^2)^k} = \frac{1}{2} \frac{d(t^2+\sigma^2)}{(t^2+\sigma^2)^k} = \frac{1}{2(1-k)(t^2+\sigma^2)^{k-1}}$$

bo‘lgani uchun , bo‘laklab integrallash formulasiga asosan, ushbu tenglikni hosil qilamiz:

$$\frac{t^2 dt}{(t^2+\sigma^2)^k} = \frac{t}{2(1-k)(t^2+\sigma^2)^{k-1}} - \frac{1}{2(1-k)} \frac{dt}{(t^2+\sigma^2)^{k-1}} .$$

Natijada J_k integralni hisoblash uchun

$$J_k = \frac{1}{\sigma^2} \frac{dt}{(t^2+\sigma^2)^{k-1}} - \frac{1}{\sigma^2} \frac{t^2 dt}{(t^2+\sigma^2)^k} =$$

$$= \frac{1}{\sigma^2} \frac{dt}{(t^2+\sigma^2)^{k-1}} + \frac{t}{2(k-1)\sigma^2(t^2+\sigma^2)^{k-1}} - \frac{1}{2(k-1)\sigma^2} \frac{dt}{(t^2+\sigma^2)^{k-1}} =$$

$$= \frac{1}{2(k-1)\sigma^2} \frac{t}{(t^2+\sigma^2)^{k-1}} + (2k-3) \frac{dt}{(t^2+\sigma^2)^{k-1}}$$

formulani hosil etamiz. Bu yerdan J_k integralni hisoblash uchun ushbu

$$J_k = \frac{dt}{(t^2+\sigma^2)^k} = \frac{1}{2(k-1)\sigma^2} [\frac{t}{(t^2+\sigma^2)^{k-1}} + (2k-3)J_{k-1}] \quad (4)$$

rekkurent formula o‘rinli ekanligini ko‘ramiz. Bu rekkurent formula bo‘yicha J_k integralni hisoblash xuddi shu ko‘rinishdagi, ammo k parametrining qiymati bittaga kichik bo‘lgan J_{k-1}

integralni hisoblashga olib keladi. O‘z navbatida J_{k-1} integralni hisoblash J_{k-2} integralga keltiriladi va bu jarayon quyidagi J_1 jadval integrali hosil bo‘lguncha davom ettiriladi:

$$J_1 = \frac{dt}{t^2+\sigma^2} = \frac{1}{\sigma}\operatorname{arctg}\frac{t}{\sigma} + C.$$

J_k integral uchun hosil qilingan ifodaga t va σ o‘rniga ularning

$$t = x + \frac{p}{2}, \quad \sigma = \sqrt{q - \frac{p^2}{4}}$$

qiymatlarini qo‘yib, bu integral javobini topamiz.

Misol sifatida IV turdagi ratsional kasrning ushbu integralini hisoblaymiz:

$$I = \frac{(x-1)dx}{(x^2+2x+3)^2} = \frac{\frac{1}{2}(2x+2)-2}{(x^2+2x+3)^2}dx =$$

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

$$= -\frac{1}{2}\frac{1}{(x^2+2x+3)} - 2\frac{dx}{(x^2+2x+3)^2} = -\frac{1}{2}\frac{1}{(x^2+2x+3)} - 2J_2 . \quad (5)$$

Bunda J_2 quyidagi integralni ifodalaydi:

$$J_2 = \frac{dx}{(x^2+2x+3)^2} = \frac{dx}{[(x+1)^2+2]^2} = \begin{matrix} t = x+1, \\ dt = dx \end{matrix} =$$

$$= \frac{dt}{(t^2+2)^2} = \frac{1}{2}\frac{t^2+2-t^2}{(t^2+2)^2}dt = \frac{1}{2}\frac{dt}{t^2+(\sqrt{2})^2} - \frac{1}{2}\frac{t^2dt}{(t^2+2)^2} =$$

$$= \frac{1}{2\sqrt{2}}\operatorname{arctg}\frac{t}{\sqrt{2}} - \frac{1}{2}\frac{t^2dt}{(t^2+2)^2} .$$

Oxirgi integralni yuqorida ko‘rsatilgan usulda bo‘laklab integrallaymiz:

$$\frac{t^2dt}{(t^2+2)^2} = \begin{matrix} u = t, \ dv = \frac{tdt}{(t^2+2)^2} \\ du = dt, v = -\frac{1}{2(t^2+2)} \end{matrix} = -\frac{t}{2(t^2+2)} + \frac{1}{2}\frac{dt}{t^2+2} =$$

$$= -\frac{t}{2(t^2+2)} + \frac{1}{2\sqrt{2}}\text{arctg}\frac{t}{2} + C = -\frac{x+1}{2(x^2+2x+3)} + \frac{1}{\sqrt{2}}\text{arctg}\frac{x+1}{\sqrt{2}} + C.$$

Demak ,

$$J_2 = \frac{1}{4\sqrt{2}}\text{arctg}\frac{x+1}{\sqrt{2}} + \frac{x+1}{4(x^2+2x+3)} + C.$$

J_2 integralning bu qiymatini I uchun hosil qilingan (5) tenglikka qo'yib, berilgan I integral javobini topamiz :

$$I = \frac{(x-1)dx}{(x^2+2x+3)^2} = -\frac{x+2}{2(x^2+2x+3)} - \frac{\sqrt{2}}{4}\text{arctg}\frac{x+1}{\sqrt{2}} + C.$$

Foydalanilgan adabiyotlar ro'yhati.

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