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ANIQMAS INTEGRALNI HISOBLASH USULLARI. KVADRAT UCHHADLI AYRIM INTEGRALLARNI HISOBLASH.

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Annotatsiya: *Differensiallanuvchi har qanday elementar funksiyaning hosilasini hosilalar jadvali va differensiallash qoidalari yordamida topish mumkin ekanligini ko'rib o'tgan edik. Bunda elementar funksiyaning hosilasi yana elementar funksiyadan iborat bo'ladi. Endi berilgan funksiyani integrallash masalasiga kelsak, vaziyat ancha murakkab bo'ladi. Bunda berilgan elementar funksiya uchun boshlang'ich funksiya (aniqmas integral) mavjudligini aniqlash bir masala bo'lib integral mavjudligi ma'lum taqdirda uni hisoblash ancha qiyin muammo bo'ladi.*

Kalit so'zlar. * *Yoyish usuli* * *Differensial ostiga kiritish usuli* * *O'zgaruvchilarni almashtirish usuli* * *Bo'laklab integrallash usuli* * *Kvadrat uchhadli integrallar.*

Shunday qilib, aniqmas integralni hisoblashning umumiy usuli mavjud bo'lmasdan, har bir integral o'ziga xos bir usulda topilishi mumkin. Ammo ma'lum bir hollar uchun integralni hisoblash usullari ishlab chiqilgan va ular bilan tanishishga o'tamiz.

1. Yoyish usuli. Bu usulda dastlab berilgan integral ostidagi murakkabroq $f(x)$ funksiya soddaroq (masalan, integrallari bevosita jadval orqali topiladigan) $f_k(x)$ ($k=1,2,\ldots,n$) funksiyalarning chiziqli kombinatsiyasiga yoyiladi. So'ngra bu chiziqli yoyilma integrali oldingi paragrafda ko'rilgan integralning chiziqlilik xossalaridan foydalanilib hisoblanadi. Bu usulni matematik ko'rinishda quyidagicha ifodalash mumkin:

$$\int f(x)dx = \int [A_1 f_1(x) + A_2 f_2(x) + \cdots + A_n f_n(x)]dx =$$
$$= A_1 \int f_1(x)dx + A_2 \int f_2(x)dx + \cdots + A_n \int f_n(x)dx \qquad (1)$$

Misol sifatida bu usulda quyidagi integrallarni hisoblaymiz:

❖ $$\int \frac{7x - 5x^2 + 1}{x^2}dx = \int (\frac{7}{x} - 5 + \frac{1}{x^2})dx = 7\int \frac{dx}{x} - 5\int dx + \int \frac{dx}{x^2} =$$
$$= 7\ln|x| - 5x - \frac{1}{x} + C$$;

❖ $$\int \mathrm{tg}^2 x dx = \int \frac{\sin^2 x}{\cos^2 x}dx = \int \frac{1 - \cos^2 x}{\cos^2 x}dx = \int (\frac{1}{\cos^2 x} - 1)dx =$$

$$= \int \frac{1}{\cos^2 x} dx - \int dx = \mathrm{tg} x - x + C$$;

❖ $$\int \frac{dx}{x^2 - a^2} = \int \frac{1}{2a}[\frac{1}{x-a} - \frac{1}{x+a}]dx = \frac{1}{2a}[\int \frac{dx}{x-a} - \int \frac{dx}{x+a}] =$$

$$= \frac{1}{2a}[\ln|x-a| - \ln|x+a|] + C = \frac{1}{2a}\ln\left|\frac{x-a}{x+a}\right| + C$$.

2. **Differensial belgisi ostiga kiritish usuli.** Bu usul aniqmas integralning ushbu ***invariantlik xossasi*** orqali amalga oshiriladi:

$$\int f(x)dx = F(x) + C \Rightarrow \int f(u)du = F(u) + C. \quad (2)$$

Bu tenglik differensialning invariantlik xossasidan kelib chiqadi va unda $u=u(x)$ ixtiyoriy differentsiallanuvchi funksiyani ifodalaydi. Shunday qilib, integrallash o‘zgaruvchisi x biror differentsiallanuvchi $u=u(x)$ funksiya bilan almashtirilsa, integral javobida ham x o‘rniga $u=u(x)$ funksiya qo‘yiladi.

Ko‘p hollarda bu usulni qo‘llash uchun dastlab integral ostidagi funksiyaning bir qismi differensial ostiga kiritiladi va integral kerakli ko‘rinishga keltiriladi. Misol sifatida quyidagi integrallarni hisoblaymiz.

➢ $$\int \ln x d\ln x = (u = \ln x) = \int u du = \frac{u^2}{2} + C = \frac{\ln^2 x}{2} + C$$.

➢ $$\int (x+4)^{99} dx = \int (x+4)^{99} d(x+4) = (u = x+4) =$$

$$= \int u^{99} du = \frac{u^{100}}{100} + C = \frac{(x+4)^{100}}{100} + C$$.

Bu yerda $dx=d(x+4)$ ekanligidan foydalandik.

➢ $$\int \mathrm{tg} x dx = \int \frac{\sin x dx}{\cos x} = \int \frac{-d\cos x}{\cos x} = (u = \cos x) =$$

$$= -\int \frac{du}{u} = -\ln|u| + C = -\ln|\cos x| + C$$.

Bu asosiy integrallar jadvalidagi 13-integral javobining isbotini ifodalaydi.

Bu usul yordamida quyidagi ko‘rinishdagi integrallarni ham hisoblash mumkin:

$$\int \frac{f'(x)dx}{f(x)} = \int \frac{df(x)}{f(x)} = \ln|f(x)| + C, \quad \int \frac{f'(x)dx}{\sqrt{f(x)}} = \int \frac{df(x)}{\sqrt{f(x)}} = 2\sqrt{f(x)} + C.$$

3. **O‘zgaruvchilarni almashtirish usuli.** Bu usulda berilgan $\int f(x)dx$ integraldagi “eski” x o‘zgaruvchidan “yangi” t o‘zgaruvchiga biror $x=j(t)$ funksiya orqali o‘tamiz. Bunda $j(t)$ funksiya ***almashtirma*** deb ataladi va u differensiallanuvchi, hosilasi uzluksiz hamda teskari funksiyasi $t=j^{-1}(x)$ mavjud deb olinadi. Bu holda

$$\int f(x)dx = \int f[\varphi(t)]d\varphi(t) = \int f[\varphi(t)]\varphi'(t)dt \quad (3)$$

tenglik (oʻzgarmas son aniqligida) oʻrinli boʻladi. Bunda tenglikning oʻng tomonidagi integral hisoblangandan keyin, t oʻzgaruvchi oʻrniga $t=\varphi^{-1}(x)$ qoʻyilib, berilgan integral javobi olinadi.

Yuqoridagi (3) tenglikni oʻrinli ekanligini isbotlash uchun uning har ikki tomonining hosilalari oʻzaro teng ekanligi koʻrsatish kifoya. Bunda, oldingi paragrafda koʻrsatilgan aniqmas integralning I xossasiga asosan, chap tomondagi integral hosilasi integral ostidagi $f(x)$ funksiyaga teng boʻladi. Oʻng tomondagi integralda $t=\varphi^{-1}(x)$ boʻlgani uchun u x oʻzgaruvchining murakkab funksiyasi boʻladi. Shu sababli murakkab funksiyani differensiallash qoidasi va teskari funksiya hosilasi formulasiga asosan

$$(\int f[\varphi(t)]\cdot\varphi'(t)dt)'_x=(\int f[\varphi(t)]\cdot\varphi'(t)dt)'_t\cdot\frac{dt}{dx}=$$

$$=f[\varphi(t)]\cdot\varphi'(t)\cdot[\varphi^{-1}(x)]'=f[\varphi(t)]\cdot\varphi'(t)\cdot\frac{1}{\varphi'(t)}=f[\varphi(t)]=f(x)$$

natijani olamiz. Demak, haqiqatan (3) tenglikning ikkala tomoni bir xil $f(x)$ hosilaga ega va shu sababli u oʻrinlidir.

Berilgan integralni (3) tenglik yordamida hisoblash ***oʻzgaruvchilarni almashtirish usuli*** deb ataladi. Agar (3) tenglikda $f[\varphi(t)]\cdot\varphi'(t)=g(t)$ deb belgilasak, unda oʻzgaruvchilarni almashtirish usulida $f(x)$ funksiyani integrallash masalasi $g(t)$ funksiyani integrallash masalasiga keladi. Ayrim hollarda $x=\varphi(t)$ yoki $t=\varphi^{-1}(x)$ almashtirmani shunday tanlash mumkinki, $g(t)$ funksiya oson integrallamadi. Bu almashtirmani tanlash berilgan integral koʻrinishiga qarab amalga oshiriladi va integral hisoblovchini mahorati va tajribasiga bogʻliq boʻladi.

Oʻzgaruvchilarni almashtirish usuliga misol sifatida ushbu integrallarni hisoblaymiz.

- $$\int\frac{dx}{x\sqrt{x+4}}=\begin{bmatrix}\sqrt{x+4}=t,\ x+4=t^2\\ x=t^2-4,\ dx=2tdt\end{bmatrix}=\int\frac{2tdt}{(t^2-4)\cdot t}=$$

$$=2\int\frac{dt}{t^2-2^2}=2\cdot\frac{1}{2\cdot2}\ln\left|\frac{t-2}{t+2}\right|+C=\frac{1}{2}\ln\left|\frac{\sqrt{x+4}-2}{\sqrt{x+4}+2}\right|+C$$

- $$\int\frac{dx}{x^2+a^2}=(a\neq0)=\begin{bmatrix}x=at\,,\quad t=x/a,\\ dx=d(at)=adt\end{bmatrix}=\int\frac{adt}{a^2t^2+a^2}=$$

$$=\frac{1}{a}\int\frac{dt}{t^2+1}=\frac{1}{a}\operatorname{arctg}t+C=\frac{1}{a}\operatorname{arctg}\frac{x}{a}+C.$$

Xuddi shunday tarzda

$$\int\frac{dx}{\sqrt{a^2-x^2}}=\arcsin\frac{x}{a}+C$$

ekanligini ko‘rsatish mumkin. Bu natijalar asosiy integrallar jadvaldagi 15-16 integrallarni umumlashtiradi.

3. Bo‘laklab integrallash usuli. Faraz qilaylik, $u=u(x)$ va $v=v(x)$ funksiyalar differentsiallanuvchi funksiyalar bo‘lsin. Bu funksiyalar ko‘paytmasining differentsialini yozamiz:

$$d(uv) = vdu + udv.$$

Bu yerdan

$$udv = d(uv) - vdu$$

tenglikka ega bo‘lamiz. Bu tenglikning ikkala tomonini hadma-had integrallab, quyidagi natijani hosil qilamiz:

$$\int udv = \int d(uv) - \int vdu.$$

Bu yerdan, integralning oldingi paragrafda ko‘rsatilgan IV xossasiga asosan, ushbu formulaga ega bo‘lamiz:

$$\int udv = uv - \int vdu. \qquad (4)$$

Bu natija ***bo‘laklab integrallash formulasi*** deyiladi. Ayrim hollarda (4) formulaning chap tomonidagi integralni hisoblash murakkab, o‘ng tomondagi integral esa osonroq hisoblanadi.

Demak, berilgan $\int f(x)dx$ integralni (4) formula orqali bo‘laklab integrallash usulida hisoblash quyidagi algoritm asosida amalga oshirilishi mumkin:

- ❖ Integral ostidagi $f(x)dx$ ifodani ikki bo‘lakka ajratamiz;
- ❖ Hosil bo‘lgan bo‘laklardan dx qatnashganini dv , ikkinchisini esa u orqali belgilaymiz;
- ❖ Hosil qilingan dv differensial bo‘yicha biror v boshlang‘ich funksiyani topamiz. Buning uchun $v = \int dv$ aniqmas integralni hisoblab, unda ixtiyoriy C o‘zgarmas sonni C=0 deb olish mumkin;
- ❖ Hosil qilingan u funksiya bo‘yicha du differensialni hisoblaymiz;
- ❖ (4) tenglikni o‘ng tomonidagi $\int vdu$ integralni hisoblaymiz;
- ❖ Berilgan $\int f(x)dx = \int udv$ integralni (4) tenglikning o‘ng tomoni orqali topamiz.

Bunda $f(x)dx=udv$ bo‘laklashda u va dv shunday tanlanishi kerakki, (4) formuladagi $\int vdu$ jadval integrali yoki hisoblanishi osonroq bo‘lgan integraldan iborat bo‘lsin.

Bo‘laklab integrallash usuliga misol sifatida $\int xe^x dx$ integralni hisoblaymiz. Bunda ikki holni qaraymiz.

1-hol. Integral ostidagi $xe^x dx$ ifodani $u=e^x$, $dv=xdx$ ko‘rinishda bo‘laklaymiz. Bu holda

$$du = de^x = (e^x)'dx = e^x dx, \quad v = \int dv = \int x dx = \frac{x^2}{2} + C$$

bo'lgani uchun, C=0 deb, (4) formuladan

$$\int x e^x dx = \frac{x^2}{2}e^x - \frac{1}{2}\int x^2 e^x dx$$

tenglikka kelamiz. Ammo bunda hosil bo'lgan o'ng tomondagi integral berilgan integralga nisbatan murakkabroq ko'rinishga ega. Demak, bunday bo'laklash maqsadga muvofiq emas.

2-hol. Bu holda $u=x$, $dv=e^x dx$ deb olamiz. Bunda

$$du = dx, \quad v = \int dv = \int e^x dx = e^x + C$$

bo'ladi. Bu yerda C=0 deb va (4) formuladan foydalanib, berilgan integralni quyidagicha oson hisoblaymiz:

$$\int x e^x dx = x e^x - \int e^x dx = x e^x - e^x + C = (x-1)e^x + C.$$

Ayrim integrallarni hisoblash uchun bo'laklab integrallash formulasini bir necha marta qo'llashga to'g'ri keladi. Bunga misol sifatida ushbu integralni

qaraymiz:

$$\int x^2 \sin x dx = \left[\begin{matrix} u = x^2, \quad dv = \sin x dx, \\ du = 2x dx, \quad v = \int \sin x dx = -\cos x \end{matrix}\right] = -x^2 \cos x + 2\int x \cos x dx =$$

$$= \left[\begin{matrix} u = x, \quad dv = \cos x dx, \\ du = dx, \quad v = \int \cos x dx = \sin x \end{matrix}\right] = -x^2 \cos x + 2(x \sin x - \int \sin x dx) =$$

$$= -x^2 \cos x + 2(x \sin x + \cos x) + C.$$

Shunday qilib, bu yerda (4) bo'laklab integrallash formulasidan ikki marta foydalandik.

Izoh: Yuqoridagidek mulohaza yuritib, $\int x^n \sin x dx$, n=1,2,3, … , integral bo'laklab integrallash formulasini n marta qo'llash orqali hisoblanishini ko'rish mumkin.

Ba'zi integrallarni hisoblash uchun dastlab bo'laklab integrallash orqali ularga nisbatan tenglama hosil qilinib, so'ngra bu tenglamani yechib ko'zlangan maqsadga erishiladi. Misol sifatida $I = \int \sqrt{1-x^2}dx$ integralni hisoblaymiz.

$$I = \int \sqrt{1-x^2}dx = \left[\begin{matrix} u = \sqrt{1-x^2}, \quad dv = dx, \\ du = \dfrac{-x dx}{\sqrt{1-x^2}}, \quad v = x \end{matrix}\right] = x\sqrt{1-x^2} + \int \frac{x^2 dx}{\sqrt{1-x^2}} =$$

$$= x\sqrt{1-x^2} - \int \frac{1-x^2-1}{\sqrt{1-x^2}}dx = x\sqrt{1-x^2} - \int \sqrt{1-x^2}dx + \int \frac{dx}{\sqrt{1-x^2}} =$$

$$= x\sqrt{1-x^2} - I + \arcsin x + C.$$

Shunday qilib izlanayotgan *I* integral uchun

$$I = x\sqrt{1-x^2} - I + \arcsin x + C \Rightarrow 2I = x\sqrt{1-x^2} + \arcsin x + C$$

chiziqli tenglamani hosil qildik. Bu tenglamani yechib,

$$\int \sqrt{1-x^2}\,dx = I = \frac{x\cdot\sqrt{1-x^2} + \arcsin x}{2} + C$$

natijaga erishamiz.

Bo'laklab integrallash usulida

$$\int x^n \cos axdx, \quad \int x^n \sin axdx, \quad \int \sqrt{a^2 - x^2}\,dx, \quad \int x^n a^x dx, \quad \int x^n \ln xdx,$$

$$\int e^{ax} \cos bxdx, \quad \int e^{ax} \sin bxdx, \quad \int x^n \arccos xdx, \quad \int x^n \mathrm{arctg} xdx, \quad \int \sin \ln xdx$$

va shularga o'xshash integrallarni hisoblash mumkin.

XULOSA

Differensiallash amaliga nisbatan integrallash amali ancha murakkabdir. Hatto ayrim elementar funksiyalarning aniqmas integrallari elementar funksiyalar sinfida mavjud bo'lmasdan, ular maxsus (noelementar) funksiyalar orqali ifodalanadi. Bundan tashqari ixtiyoriy aniqmas integralni hisoblashga imkon beradigan universal, umumiy usul mavjud emas. Shu sababli faqat ayrim , ma'lum bir xususiyatlarga ega bo'lgan, aniqmas integrallarni hisoblash usullarini ko'rsatish mumkin. Ularga yoyish, differensial ostiga kiritish, o'zgaruvchilarni almashtirish va bo'laklab integrallash usullari kiradi.

Ko'rsatilgan usullardan foydalanib kvadrat uchhad qatnashgan ayrim aniqmas integrallarni hisoblash mumkin.

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