TO‘RT O‘LCHAMLI NILPOTENT ALGEBRANING DIFFERENSIALLASHI LOKAL DIFFERENSIALLASHI

“University of Business and Science” universitetining matematika fani o‘qituvchisi:
Boydadayev Islomjon G‘anijon o‘g‘li,
“Namangan shahar 1-sonli ixtisoslashgan maktab internati” Matematika fani o‘qituvchisi
Abdusattarov Oxunjon Abdurauf o‘g‘li
“University of Business and Science” universitetining iqtisodiyot yo‘nalishi 1-kurs kunduzgi KIQ-24-01 guruh talabasi:
Mustapaqulova Mehribon Adxamjon qizi.
boydadayevislomjon06@gmail.com *Tel: 93 496 51 97*
Oxunjon1252@gmail.com *Tel: 91 182 12 52*

Annotation: *Differensiallash matematikaning fundamental tushunchalaridan biri hisoblanadi. Differensiallashlar algebra fanida ham muhim o‘rin tutadi. Differensiallashlarning turli umumlashmalari mavjud. Bular sarasiga antidifferensiallashlar, δ-differensiallashlar, ternar differensiallashlar va (α,β,γ)-differensiallashlar kiradi. Ushbu ishda to‘rt o‘lchamli nilpotent algebralarning differensiallashi lokal differensiallashi isboti bilan ko‘rsatilgan.*

Kalit so‘zlar: *Differensiallash, Algebra, lokal differensiallash, chiziqli akslatirish.*

Аннотатция. *ифференциация — одно из фундаментальных понятий математики. Дифференциации также играют важную роль в алгебре. Существуют различные обобщения дифференциаций. К ним относятся антидифференциации, δ-дифференциации, тернарные дифференциации и (α,β,γ)-дифференциации. В данной работе дифференциация четырехмерных нильпотентных алгебр демонстрируется путем доказательства локальной дифференциации.*

***Ключевые слова**: Дифференциация, алгебра, локальное дифференцирование, линейное отображение.*

***Abstract.** Differentiation is one of the fundamental concepts of mathematics. Differentiations also play an important role in algebra. There are various generalizations of differentiations. These include antidifferentiations, δ-differentiations, ternary differentiations, and (α,β,γ)-differentiations. In this paper, the differentiation of four-dimensional nilpotent algebras is shown by proving local differentiation.*

***Key words**: Differentiation, Algebra, local differentiation, linear mapping.*

Quyida biz to‘rt o‘lchamli nilpotent algebralarning differensiallashini keltiramiz.

R haqiqiy sonlar maydoni ustida aniqlangan $\{e_1, e_2, e_3, e_4\}$ bazisli nilpotent algebra N_1 berilgan. Bu algebrada ko‘paytirish jadvali quyidagicha aniqlanadi:

$$e_1e_1 = e_2 \qquad e_1e_2 = e_3 \qquad e_2e_1 = e_3$$

N_1 algebrada ixtiyoriy x vektorni

$$x = x_1e_1 + x_2e_2 + x_3e_3$$

ko‘rinishda yozish mumkin. $d : N_1 \rightarrow N_1$ akslantirishni qaraylik.

1-Ta’rif. Agar N algebaradan olingan ixtiyoriy x, y elementlar uchun

$$d(x \cdot y) = d(x) \cdot y + x \cdot d(y)$$

Tenglik bajarilsa d akslantirish qaralayotgan N algebrada differensiallash deb ataladi.

$d(x) = Ax$ chiziqli akslantirishni qaraylik, bu yerda A – 4×4 o‘lchamli kvadrat matritsa. Ravshanki, agar N_1 algebaradan olingan ixtiyoriy x, y elementlar uchun

$$A(xy) = (Ax)y + x(Ay) \qquad (1)$$

tenglik bajarilsa $d(x) = Ax$ akslantirish qaralayotgan N_1 algebrada differensiallashdan iborat bo‘ladi.

1-Teorema. $d(x) = Ax$ akslantirish N_1 algebrada differensiallashdan iborat bo‘lishi uchun A matritsa

$$A = \begin{pmatrix} a_{1,1} & 0 & 0 & 0 \\ a_{2,1} & 2a_{1,1} & 0 & 0 \\ a_{3,1} & 2a_{2,1} & 3a_{1,1} & a_{3,4} \\ a_{4,1} & 0 & 0 & a_{4,4} \end{pmatrix} \qquad (2)$$

ko‘rinishda bo‘lishi zarur va yetarli.

Isbot. Zarurligi. $d(x) = Ax$ akslantirish N_1 algebrada differensiallashdan iborat bo‘sin. U holda

$$A = \begin{pmatrix} a_{1,1} & a_{1,2} & a_{1,3} & a_{1,4} \\ a_{2,1} & a_{2,2} & a_{2,3} & a_{2,4} \\ a_{3,1} & a_{3,2} & a_{3,3} & a_{3,4} \\ a_{4,1} & a_{4,2} & a_{4,3} & a_{4,4} \end{pmatrix}$$

Matritsa ixtiyoriy x, y vektorlar uchun (1) tenglikni qanoatlantirishi kerak.

Xususan $e_1 e_1 = e_2$ tenglikdan foydalanib quyidagi ayniyatni

$$(Ae_1)e_1 + e_1(Ae_1) = A(e_2)$$

qaraylik:

$$Ae_1 \begin{pmatrix} a_{1,1} & a_{1,2} & a_{1,3} & a_{1,4} \\ a_{2,1} & a_{2,2} & a_{2,3} & a_{2,4} \\ a_{3,1} & a_{3,2} & a_{3,3} & a_{3,4} \\ a_{4,1} & a_{4,2} & a_{4,3} & a_{4,4} \end{pmatrix} \begin{pmatrix} 1 \\ 0 \\ 0 \\ 0 \end{pmatrix} = \begin{pmatrix} a_{1,1} \\ a_{2,1} \\ a_{3,1} \\ a_{4,1} \end{pmatrix} = a_{1,1}e_1 + a_{2,1}e_2 + a_{3,1}e_3 + a_{4,1}e_4$$

$$Ae_2 = \begin{pmatrix} a_{1,1} & a_{1,2} & a_{1,3} & a_{1,4} \\ a_{2,1} & a_{2,2} & a_{2,3} & a_{2,4} \\ a_{3,1} & a_{3,2} & a_{3,3} & a_{3,4} \\ a_{4,1} & a_{4,2} & a_{4,3} & a_{4,4} \end{pmatrix} \begin{pmatrix} 0 \\ 1 \\ 0 \\ 0 \end{pmatrix} = \begin{pmatrix} a_{1,2} \\ a_{2,2} \\ a_{3,2} \\ a_{4,2} \end{pmatrix} = a_{1,2}e_1 + a_{2,2}e_2 + a_{3,2}e_3 + a_{4,2}e_4$$

$$Ae_3 = \begin{pmatrix} a_{1,1} & a_{1,2} & a_{1,3} & a_{1,4} \\ a_{2,1} & a_{2,2} & a_{2,3} & a_{2,4} \\ a_{3,1} & a_{3,2} & a_{3,3} & a_{3,4} \\ a_{4,1} & a_{4,2} & a_{4,3} & a_{4,4} \end{pmatrix} \begin{pmatrix} 0 \\ 0 \\ 1 \\ 0 \end{pmatrix} = \begin{pmatrix} a_{1,3} \\ a_{2,3} \\ a_{3,3} \\ a_{4,3} \end{pmatrix} = a_{1,3}e_1 + a_{2,3}e_2 + a_{3,3}e_3 + a_{4,3}e_4$$

$$Ae_4 = \begin{pmatrix} a_{1,1} & a_{1,2} & a_{1,3} & a_{1,4} \\ a_{2,1} & a_{2,2} & a_{2,3} & a_{2,4} \\ a_{3,1} & a_{3,2} & a_{3,3} & a_{3,4} \\ a_{4,1} & a_{4,2} & a_{4,3} & a_{4,4} \end{pmatrix} \begin{pmatrix} 0 \\ 0 \\ 0 \\ 1 \end{pmatrix} = \begin{pmatrix} a_{1,4} \\ a_{2,4} \\ a_{3,4} \\ a_{4,4} \end{pmatrix} = a_{1,4}e_1 + a_{2,4}e_2 + a_{3,4}e_3 + a_{4,4}e_4$$

$$(Ae_1)e_1 = \big(a_{1,1}e_1 + a_{2,1}e_2 + a_{3,1}e_3 + a_{4,1}e_4\big)e_1 = a_{1,1}e_2 + a_{2,1}e_3$$

$$e_1(Ae_1) = e_1\big(a_{1,1}e_1 + a_{2,1}e_2 + a_{3,1}e_3 + a_{4,1}e_4\big) = a_{1,1}e_2 + a_{2,1}e_3$$

$$a_{1,1}e_2 + a_{2,1}e_3 + a_{1,1}e_2 + a_{2,1}e_3 = a_{1,2}e_1 + a_{2,2}e_2 + a_{3,2}e_3 + a_{4,2}e_4$$

bundan

$$a_{2,2} = 2a_{1,1}, \qquad a_{1,2} = 0, \qquad a_{3,2} = 2a_{2,1},$$

$$a_{4,2} = 0 \quad Ae_2 = 2a_{1,1}e_2 + 2a_{2,1}e_3$$

tengliklarni aniqlaymiz.

Endi $e_1 e_2 = e_3$ tenglikdan foydalanib quyidagi ayniyatni

$$(Ae_1)e_2 + e_1(Ae_2) = A(e_3)$$

qaraylik:

$$(Ae_1)e_2 = (a_{1,1}e_1 + a_{2,1}e_2 + a_{3,1}e_3 + a_{4,1}e_4)e_2 = a_{1,1}e_3$$

$$e_1(Ae_2) = e_1\left(2a_{1,1}e_2 + 2a_{2,1}e_3\right) = 2a_{1,1}e_3$$
$$a_{1,1}e_3 + 2a_{1,1}e_3 = a_{1,3}e_1 + a_{2,3}e_2 + a_{3,3}e_3 + a_{4,3}e_4$$

bundan

$$a_{3,3} = 3a_{1,1}, \qquad a_{1,3} = 0, \qquad a_{2,3} = 0, \qquad a_{4,3} = 0 \quad Ae_3 = 3a_{1,1}e_3$$

tengliklarni aniqlaymiz.

Endi $e_1e_3 = 0$ tenglikdan foydalanib quyidagi ayniyatni

$$(Ae_1)e_3 + e_1(Ae_3) = A(0)$$

qaraylik:

$$(Ae_1)e_3 = \left(a_{1,1}e_1 + a_{2,1}e_2 + a_{3,1}e_3 + a_{4,1}e_4\right)e_3 = 0$$

$$e_1(Ae_3) = e_1\left(3a_{1,1}e_3\right) = 0$$

$$0 = 0$$

bo‘ldi.

Endi $e_1e_4 = 0$ tenglikdan foydalanib quyidagi ayniyatni

$$(Ae_1)e_4 + e_1(Ae_4) = A(0)$$

qaraylik:

$$(Ae_1)e_4 = \left(a_{1,1}e_1 + a_{2,1}e_2 + a_{3,1}e_3 + a_{4,1}e_4\right)e_4 = 0$$
$$e_1(Ae_4) = e_1\left(a_{1,4}e_1 + a_{2,4}e_2 + a_{3,4}e_3 + a_{4,4}e_4\right) = a_{1,4}e_2 + a_{2,4}e_3$$
$$a_{1,4}e_2 + a_{2,4}e_3 = 0$$

bundan

$$a_{1,4} = 0, \qquad a_{2,4} = 0 \qquad Ae_4 = a_{3,4}e_3 + a_{4,4}e_4$$

tengliklarni aniqlaymiz.

Endi $e_2e_1 = e_3$ tenglikdan foydalanib quyidagi ayniyatni

$$(Ae_2)e_1 + e_2(Ae_1) = A(e_3)$$

qaraylik:

$$(Ae_2)e_1 = (2a_{1,1}e_2 + 2a_{2,1}e_3)e_1 = 2a_{1,1}e_3$$
$$e_2(Ae_1) = e_2(a_{1,1}e_1 + a_{2,1}e_2 + a_{3,1}e_3 + a_{4,1}e_4) = a_{1,1}e_3$$
$$2a_{1,1}e_3 + a_{1,1}e_3 = 3a_{1,1}e_3$$
$$3a_{1,1}e_3 = 3a_{1,1}e_3$$
$$0 = 0$$

bo‘ldi.

Endi $e_2e_2 = 0$ tenglikdan foydalanib quyidagi ayniyatni

$$(Ae_2)e_2 + e_2(Ae_2) = A(0)$$

qaraylik:

$$(Ae_2)e_2 = (2a_{1,1}e_2 + 2a_{2,1}e_3)e_2 = 0$$

$$e_2(Ae_2) = e_2(2a_{1,1}e_2 + 2a_{2,1}e_3) = 0$$
$$0 = 0$$

bo‘ldi.

Endi $e_2e_3 = 0$ tenglikdan foydalanib quyidagi ayniyatni

$$(Ae_2)e_3 + e_2(Ae_3) = A(0)$$

qaraylik:

$$(Ae_2)e_3 = (2a_{1,1}e_2 + 2a_{2,1}e_3)e_3 = 0$$
$$e_2(Ae_3) = e_2\big(3a_{1,1}e_3\big) = 0$$
$$0 = 0$$

bo‘ldi.

Endi $e_2e_4 = 0$ tenglikdan foydalanib quyidagi ayniyatni

$$(Ae_2)e_4 + e_2(Ae_4) = A(0)$$

qaraylik:

$$(Ae_2)e_4 = (2a_{1,1}e_2 + 2a_{2,1}e_3)e_4 = 0$$

$$e_2(Ae_4) = e_2(a_{3,4}e_3 + a_{4,4}e_4) = 0$$

$$0 = 0$$

bo‘ldi.

Endi $e_3e_1 = 0$ tenglikdan foydalanib quyidagi ayniyatni

$$(Ae_3)e_1 + e_3(Ae_1) = A(0)$$

qaraylik:

$$(Ae_3)e_1 = 3a_{1,1}e_3e_1 = 0, \;\; e_3(Ae_1) = e_3(a_{1,1}e_1 + a_{2,1}e_2 + a_{3,1}e_3 + a_{4,1}e_4) = 0$$

$$0 = 0$$

bo‘ldi.

Endi $e_3e_2 = 0$ tenglikdan foydalanib quyidagi ayniyatni

$$(Ae_3)e_2 + e_3(Ae_2) = A(0)$$

qaraylik:

$$(Ae_3)e_2 = 3a_{1,1}e_3e_2 = 0, \;\; e_3(Ae_2) = e_3(2a_{1,1}e_2 + 2a_{2,1}e_3) = 0$$

$$0 = 0$$

bo‘ldi.

Endi $e_3e_3 = 0$ tenglikdan foydalanib quyidagi ayniyatni

$$(Ae_3)e_3 + e_3(Ae_3) = A(0)$$

qaraylik:

$$(Ae_3)e_2 = 3a_{1,1}e_3e_3 = 0, \;\; e_3(Ae_2) = e_3 3a_{1,1}e_3 = 0$$

bo‘ldi.

Endi $e_3e_4 = 0$ tenglikdan foydalanib quyidagi ayniyatni

$$(Ae_3)e_4 + e_3(Ae_4) = A(0)$$

qaraylik:

$$(Ae_3)e_4 = 3a_{1,1}e_3e_4 = 0, \;\; e_3(Ae_4) = e_3(a_{3,4}e_3 + a_{4,4}e_4) = 0$$

$$0 = 0$$

bo‘ldi.

Endi $e_4e_1 = 0$ tenglikdan foydalanib quyidagi ayniyatni

$$(Ae_4)e_1 + e_4(Ae_1) = A(0)$$

qaraylik:

$$(Ae_4)e_1 = (a_{3,4}e_3 + a_{4,4}e_4)e_1 = 0,$$

$$e_4(Ae_1) = e_4(a_{1,1}e_1 + a_{2,1}e_2 + a_{3,1}e_3 + a_{4,1}e_4) = 0$$

$$0 = 0$$

bo‘ldi.

Endi $e_4e_2 = 0$ tenglikdan foydalanib quyidagi ayniyatni

$$(Ae_4)e_2 + e_4(Ae_2) = A(0)$$

qaraylik:

$$(Ae_4)e_2 = (a_{3,4}e_3 + a_{4,4}e_4)e_2 = 0, \;\; e_4(Ae_2) = e_4(2a_{1,1}e_2 + 2a_{2,1}e_3) = 0$$

$$0 = 0$$

bo‘ldi.

Endi $e_4e_3 = 0$ tenglikdan foydalanib quyidagi ayniyatni

$$(Ae_4)e_3 + e_4(Ae_3) = A(0)$$

qaraylik:

$$(Ae_4)e_3 = (a_{3,4}e_3 + a_{4,4}e_4)e_3 = 0, \;\; e_4(Ae_2) = e_4(3a_{1,1}e_3) = 0$$

$$0 = 0$$

bo‘ldi.

Endi $e_4e_4 = 0$ tenglikdan foydalanib quyidagi ayniyatni

$$(Ae_4)e_4 + e_4(Ae_4) = A(0)$$

qaraylik:

$$(Ae_4)e_4 = (a_{3,4}e_3 + a_{4,4}e_4)e_4 = 0,\ \ e_4(Ae_4) = e_4(a_{3,4}e_3 + a_{4,4}e_4) = 0$$

$$0 = 0$$

bo‘ldi.

Yetarliligi. Endi A matritsa (2) ko‘rinishda bo‘lsa $d(x) = Ax$ chiziqli akslantirish differensiallashdan iboratligini ko‘rsataylik.

$$xy = (x_1e_1 + x_2e_2 + x_3e_3 + x_4e_4)(y_1e_1 + y_2e_2 + y_3e_3 + y_4e_4) = \\ = x_1y_1e_2 + (x_1y_2 + x_2y_1)e_3$$

Tenglikka ko‘ra

$$A(xy) = \begin{pmatrix} a_{1,1} & 0 & 0 & 0 \\ a_{2,1} & 2a_{1,1} & 0 & 0 \\ a_{3,1} & 2a_{2,1} & 3a_{1,1} & a_{3,4} \\ a_{4,1} & 0 & 0 & a_{4,4} \end{pmatrix} \begin{pmatrix} 0 \\ x_1y_1 \\ x_1y_2 + x_2y_1 \\ 0 \end{pmatrix} =$$

$$= 2a_{1,1}x_1y_1 + 2a_{2,1}x_1y_2 + 2a_{2,1}x_2y_1 + 3a_{1,1}x_1y_2 + 3a_{1,1}x_2y_1 + a_{3,4}x_1y_2 \\ + a_{3,4}x_2y_1$$

boshqa tamondan

$$Ax = \begin{pmatrix} a_{1,1} & 0 & 0 & 0 \\ a_{2,1} & 2a_{1,1} & 0 & 0 \\ a_{3,1} & 2a_{2,1} & 3a_{1,1} & a_{3,4} \\ a_{4,1} & 0 & 0 & a_{4,4} \end{pmatrix} \begin{pmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{pmatrix} =$$

$$= a_{1,1}x_1e_1 + \big(a_{2,1}x_1 + 2a_{1,1}x_2\big)e_2 + (a_{31}x_1 + 2a_{21}x_2 + 3a_{1,1}x_3 + a_{3,4}x_4)e_3 \\ + (a_{41}x_1 + a_{4,4}x_4)e_4$$

$$(Ax)y = (a_{1,1}x_1e_1 + \big(a_{2,1}x_1 + 2a_{1,1}x_2\big)e_2 + (a_{31}x_1 + 2a_{21}x_2 + 3a_{1,1}x_3 \\ + a_{3,4}x_4)e_3 + (a_{41}x_1 + a_{4,4}x_4)e_4)(y_1e_1 + y_2e_2 + y_3e_3 + y_4e_4) = \\ = a_{1,1}x_1y_1e_2 + a_{1,1}x_1y_2e_3 + a_{2,1}x_1y_1e_3 + 2a_{1,1}x_2y_1e_3$$

$$Ay = \begin{pmatrix} a_{1,1} & 0 & 0 & 0 \\ a_{2,1} & 2a_{1,1} & 0 & 0 \\ a_{3,1} & 2a_{2,1} & 3a_{1,1} & a_{3,4} \\ a_{4,1} & 0 & 0 & a_{4,4} \end{pmatrix} \begin{pmatrix} y_1 \\ y_2 \\ y_3 \\ y_4 \end{pmatrix} =$$

$$= a_{1,1}y_1e_1 + \big(a_{2,1}y_1 + 2a_{1,1}y_2\big)e_2 + (a_{31}y_1 + 2a_{21}y_2 + 3a_{1,1}y_3 + a_{3,4}y_4)e_3 \\ + (a_{41}y_1 + a_{4,4}y_4)e_4$$

$$x(Ay) = (x_1e_1 + x_2e_2 + x_3e_3 + x_4e_4)(a_{1,1}y_1e_1 + \big(a_{2,1}y_1 + 2a_{1,1}y_2\big)e_2 \\ + (a_{31}y_1 + 2a_{21}y_2 + 3a_{1,1}y_3 + a_{3,4}y_4)e_3 + (a_{41}y_1 + a_{4,4}y_4)e_4) =$$

$$= a_{1,1}x_1y_1e_2 + a_{1,1}x_1y_2e_3 + a_{2,1}x_1y_1e_3 + 2a_{1,1}x_2y_1e_3$$

Yuqoridagi xisoblashlar (2) tenglik to‘g‘riligini ko‘rsatadi. **Teorema isbotlandi.**

Endi esa to‘rt o‘lchamli nilpotent algebraning lokal differensiallash tushunchasini keltiramiz.

2-Ta’rif. L algebra bo‘lib undagi har bir $x \in L$ element uchun $\Delta(x) = D_x(x)$ shartni qanoatlantiruvchi $D_x: L \to L$ differesiallash mavjud bo‘lsa, u holda

$\Delta: L \to L$ chiziqli akslantirish lokal differensiallash deb ataladi.

N_1 algebraning differensiallashini biz yuqorida 1-teoremada ko‘rib o‘tganmiz

$$A = \begin{pmatrix} a_{1,1} & 0 & 0 & 0 \\ a_{2,1} & 2a_{1,1} & 0 & 0 \\ a_{3,1} & 2a_{2,1} & 3a_{1,1} & a_{3,4} \\ a_{4,1} & 0 & 0 & a_{4,4} \end{pmatrix}$$

bu yerda quyidagi belgilashni kiritamiz

$a_{1,1} = \alpha,\ a_{2,1} = \beta,\ a_{3,1} = \gamma,\ a_{4,1} = \delta,\ a_{3,4} = \varepsilon,\ a_{4,4} = \epsilon$ u holda A matritsa bunday ko‘rinishga o‘tadi.

$$A = \begin{pmatrix} \alpha & 0 & 0 & 0 \\ \beta & 2\alpha & 0 & 0 \\ \gamma & 2\beta & 3\alpha & \varepsilon \\ \delta & 0 & 0 & \epsilon \end{pmatrix}$$

Quyidagi teoremada N_1 algebra uchun $\Delta: N_1 \to N_1$ akslantirishni qaraylik.

2-Teorema. N_1 algebraning har qanday chiziqli lokal differensiallashi differensiallashdan iborat.

Isbot. Δ ixtiyoriy lokal differensiallashi bo‘lsin. Barcha $x \in N_1$ uchun ta’rif bo‘yicha $\Delta(x) = D_x(x)$ differensiallashi mavjud.

2- teoremaga ko‘ra, D_x differensiallashi quyidagi matritsa ko‘rinishiga ega:

$$A_x = \begin{pmatrix} \alpha_x & 0 & 0 & 0 \\ \beta_x & 2\alpha_x & 0 & 0 \\ \gamma_x & 2\beta_x & 3\alpha_x & \varepsilon_x \\ \delta_x & 0 & 0 & \epsilon_x \end{pmatrix}$$

Xususan $\Delta(e_1) = D_{e_1}e_1, \Delta(e_2) = D_{e_2}e_2,\ \Delta(e_3) = D_{e_3}e_3,\ \Delta(e_4) = D_{e_4}e_4$

tengliklarni qanoatlantiruvchi $D_{e_1}, D_{e_2}, D_{e_3}, D_{e_4}$ matritsalar mavjud. A matritsani quyidagicha quraylik:

$$A = \begin{pmatrix} \alpha_{e_1} & 0 & 0 & 0 \\ \beta_{e_1} & 2\alpha_{e_2} & 0 & 0 \\ \gamma_{e_1} & 2\beta_{e_2} & 3\alpha_{e_3} & \varepsilon_{e_4} \\ \delta_{e_1} & 0 & 0 & \epsilon_{e_4} \end{pmatrix}.$$

Δ chiziqli bo`lgani uchun

$$\Delta(\mathrm{x}+\mathrm{y}) = \Delta(\mathrm{x}) + \Delta(\mathrm{y}), \quad \forall x, y \in N_1 \tag{3}$$

tenglik o`rinli.

Bu tenglikka ko`ra

$$\Delta(\mathrm{e}_1+\mathrm{e}_2) = \alpha_{\mathrm{e}_1+e_2} e_1 + \beta_{e_1+e_2} e_2 + \gamma_{e_1+e_2} e_3 + \delta_{e_1+e_2} e_4 + 2\alpha_{\mathrm{e}_1+e_2} e_2 + 2\beta_{e_1+e_2} e_3$$

$$\Delta(\mathrm{e}_1) + \Delta(\mathrm{e}_2) = \alpha_{\mathrm{e}_1} e_1 + \beta_{e_1} e_3 + \gamma_{e_1} e_4 + 2\alpha_{e_2} e_2$$

tengliklarga ega bo`lamiz. Bunda bazis elementlarining koeffitsientlarini taqqoslab, biz quyidagilarga erishamiz:

$$\alpha_{\mathrm{e}_1+e_2} = \alpha_{\mathrm{e}_1}, \qquad \beta_{e_1+e_2} = \beta_{e_1}, \qquad \gamma_{e_1+e_2} e_4 = \gamma_{e_1}, \qquad \alpha_{\mathrm{e}_1+e_2} = \alpha_{\mathrm{e}_2}.$$

Bundan esa $\alpha_{\mathrm{e}_1} = \alpha_{\mathrm{e}_2}$ bo`ladi.

Shunday qilib, biz Δ lokal differensiallash quyidagi shaklga ega ekanligini bilib olamiz:

$$\Delta = \begin{pmatrix} 0 & 0 & 0 & 0 \\ \alpha_{e_1} & 0 & 0 & 0 \\ \beta_{e_1} & 2\alpha_{e_1} & 0 & 0 \\ \gamma_{e_1} & 0 & 0 & 0 \end{pmatrix}$$

Teorema isbotlandi. Bulardan foydalanib 4 o‘lchamli nilpotent algebralarining ikki lakal differensiallanishini xam isbot qilishimiz mumkun.

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