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Obuna indeksi – yakka tartbidagi obunachilar uchun **- 5583,**
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M U N D A R I J A
C O N T E N T S

№	Maqola nomi	Article title	Bet/ page
1	Yemirilishni hisobga olgan holda ikki zonali g‘ovak muhitda degradatsiyalanuvchi modda ko‘chishi **Xo‘jayorov B., Fayziev B., Sagdullaev O., Haydarov O.**	Transport of a degrading solute in a two-zone porous medium taking into account the decay **Khuzhayorov B., Fayziev B., Sagdullaev O., Khaydarov O.**	**5-11**
2	Fizik-kimyoviy usullar yordamida kadmiy ionlarini aniqlovchi ion-selektiv elektrod membranasining tuzilishi **Abduraxmanov E., Salimova Sh., Jumanova G.**	Membrane structure of ion-selective electrode for determining cadmium ion, analyzed by physicochemical methods **Abdurakhmanov E., Salimova Sh., Jumanova G.**	**12-17**
3	Tasodifiy qo‘zg‘alishlarda elastik sterjenning chiziqlimas ko‘ndalang tebranishlarini so‘ndirish masalasi **Dusmatov O., Kasimova F.**	Problem of absorber nonlinear transverse vibrations of an elastic rod under random impacts **Dusmatov O., Kasimova F.**	**18-22**
4	Birjinsli tekis-radial muhitda anomal filtratsiya **Xo‘jayorov B., Maxmudov J., Akramov Sh.**	Plane-radial anomalous filtration of liquid in homogeneous porous medium **Khuzhayorov B., Makhmudov J., Akramov Sh.**	**23-28**
5	Parasetamolning molekulyar xususiyatlariga erituvchining ta’siri **Holikulov U., Jumabaev A., Xudaykulov B., Yormatov Sh., Safarov A.**	Solvent effect on the molecular properties of paracetamol **Holikulov U., Jumabaev A., Khudaykulov B., Yormatov Sh., Safarov A.**	**29-35**
6	Tibbiy tasvirlar asosida teri kasalliklarini tasniflashning mashinaviy o‘qitish va chuqur o‘qitish yondashuvlari **Boboxonov A., Xuramov L., Rashidov A.**	Machine learning and deep learning approaches to classify skin diseases based on medical images **Bobokhonov A., Khuramov L., Rashidov A.**	**36-48**
7	Urbanizatsiya jarayonlarini hududiy tashkil etilishida xorijiy davlatlar tajribasi **Ibragimov L., Baratova G.**	The experience of foreign countries in the territorial organization of urbanization processes **Ibragimov L., Baratova G.**	**49-55**
8	Singulyar sirtlar uchun transversallik sharti **Usmanov S.**	Transversality condition for singular surfaces **Usmanov S.**	**56-60**
9	Tuproq namligini o'lchovchi avtonom sensorlar uchun $KPbBr_3$ nanokompoziti **Rahmonova M., Muxamadiev N., Galyamitdinov Y.**	$KPbBr_3$ nanocomposite for autonomous agro soil moisture sensors **Rahmonova M., Mukhamadiev N., Galyamitdinov Y.**	**61-67**
10	Fotoelektrik modul yuzasi ifloslanishi jarayonining matematik modeli **Muminov R., Utamuradova Sh., Dyskin1 V., Tukfatullin O., Butunbaev B.**	Mathematical model of the soiling process of a photovoltaic module surface **Muminov R., Utamuradova Sh., Dyskin1 V., Tukfatullin O., Butunbaev B.**	**68-74**
11	Landshaft komplekslarini tadqiq etishda landshaft-meliorativ yondashish va baholash **Eshquvvatov B., Xurramova N., Saydullayeva S.**	Landscape-ameliorative approach and assessment in the study of landscape complexes **Eshkuvvatov B., Khurramova N., Saydullaeva S.**	**75-80**
12	Yuklangan Hirota tenglamani sochilish nazariyasining teskari masalalari usulida integrallash **Hoitmetov U., Musoyeva F.**	Integrating the loaded Hirota equation via the inverse scattering method **Hoitmetov U., Musoeva F.**	**81-91**
13	Tebranishlardan himoyalanuvchi mexanik sistemaning chiziqlimas tasodifiy parametrik tebranishlari **Dusmatov O., Xodjabekov M., Ashurov B.**	Nonlinear random parametric oscillations of a vibration-proofed mechanical system **Dusmatov O., Xodjabekov M., Ashurov B.**	**92-100**
14	Qisman-izospektral Shturm-Liuvill operatorlari va ularning tatbiqlari **Mirzaev O., Abdunazarov R., Nosirova G.**	Partially-isospectral Sturm-Liouville operators and their applications **Mirzaev O., Abdunazarov R., Nosirova G.**	**101-111**
15	Texnogen omillarning Ohangaron daryo havzasi landshaftlari ifloslanishiga ta'siri **Fozilov A.**	The influence of technogenic factors on the pollution of landscapes of the Akhangaran river basin **Fozilov A.**	**112-116**
16	Trisiklik 7-дезапуринлар синтези **Kuryazov R.Sh., Shonazarov A.R., Zhao J., Bozorov Kh.A.**	Synthesis of tricyclic 7-deazapurines **Kuryazov R.Sh., Shonazarov A.R., Zhao J., Bozorov Kh.A.**	**117-121**
17	Trisiklik pirrolo[2,3-*D*]pirimidin tizimida karbonil-amin kondensatsiyasi orqali iminlar sintezi **Kuryazov R.Sh.**	Synthesis of imines via carbonyl-amine condensation in the tricyclic pyrrolo[2,3-d]pyrimidine system **Kuryazov R.Sh.**	**122-126**

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TRANSVERSALITY CONDITION FOR SINGULAR SURFACES

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Abstract. The paper analyzes some parametrized singular surfaces in three dimensional Euclidean spaces. It is investigated a transversality condition for these surfaces.

Key words: fractional power series, regular point, singular point, singular surface, transversality condition.

Singulyar sirtlar uchun transversallik sharti

Annotatsiya. Maqola uch o'lchovli Evklid fazolarida ba'zi parametrlangan singulyar sirtlarni tahlil qiladi. Bu singulyar sirtlar uchun transversallik sharti tadqiq qilinadi.

Kalit so'zlar. kasr darajali qator, regulyar nuqta, singulyar nuqta, singulyar sirt, transversallik sharti.

Условия трансверсальности для сингулярных поверхностей

Аннотация. Статья анализирует некоторые параметризованные сингулярные поверхности в трехмерных евклидовых пространствах. Исследуется условия трансверсальности для этих поверхностей.

Ключевые слова: дробно-степенной ряд, регулярная точка, сингулярная точка, сингулярная поверхность, условия трансверсальности.

I. Introduction. The problems of boundedness of maximal operators associated with hypersurfaces are related to geometric properties of surfaces in Euclidean spaces [1]. Therefore, studying properties of surfaces is an important for verifying of these problems. Also, exploration geometric properties of surfaces plays an important role for investigation of Fourier transforms of measures and Fourier restriction problems on hypersurfaces (see for details [1]-[10]).

To study properties of curvatures of surfaces is important for investigating boundedness problem for maximal operators and Fourier transforms on hypersurfaces. Essentially, the boundedness problem for maximal operators associated with hypersurfaces depends on the condition of transversality of the surfaces (see [6]). In particular, transversality condition for singular surfaces is an important for investigating maximal operators associated with such kind of surfaces. This paper is devoted to study the transversality condition for some singular surfaces in R^3 which have singularities on the coordinate planes.

II. Problem statement. In the paper we will study singular surfaces in $\boldsymbol{R^3}$ given by the following parametric equations

$$x_1(u_1,u_2)=u_1^{a_1}u_2^{a_2}g_1(u_1,u_2), x_2(u_1,u_2)=u_1^{b_1}u_2^{b_2}g_2(u_1,u_2), x_3(u_1,u_2)=u_1^{c_1}u_2^{c_2}g_3(u_1,u_2), \quad (1)$$

where a_1,a_2,b_1,b_2,c_1,c_2 are non negative rational numbers, $u_1\geq 0, u_2\geq 0$, $\{g_i(u_1,u_2)\}_{i=1}^3$ are fractional power series in a small neighborhood of the origin in R^2 (see Definition 1, in [11]).

By B, B_1 and B_2 we define the following determinants

$$B = \begin{vmatrix} a_1 & b_1 \\ a_2 & b_2 \end{vmatrix}, B_1 = \begin{vmatrix} b_1 & c_1 \\ b_2 & c_2 \end{vmatrix}, B_2 = \begin{vmatrix} a_1 & c_1 \\ a_2 & c_2 \end{vmatrix}.$$

Note that if at least one of the numbers B, B_1 and B_2 is non-zero, then all points of the surfaces (1), lying in a small neighborhood of the origin out of the coordinate planes, are regular. Points of these surfaces lying on the coordinate planes may be singular (see [11], Lemma 1).

The paper [11] is devoted to investigate properties of curvatures of the singular surfaces (1) in a small neighborhood of the origin in R^3. More precisely, it was proved that at least one of the principal curvatures does not vanish at each regular point of these surfaces.

In this paper we will continue studying properties of the singular surfaces (1). We will show that under some assumptions the condition of transversality for singular surfaces is fulfilled.

III. Main results. In this section we will state main results of this paper.

We will investigate the following condition of transversality for the surfaces (1): for any point $x \in S \subset R^3$ affine tangent plane $x + T_x S$ to S at the point x does not pass through the origin [6].

Suppose that $u_1 > 0, u_2 > 0$ and points (u_1, u_2) lie in a sufficiently small neighborhood of the origin in R^2.

First we consider the singular surfaces (1) in a small neighborhood of the point $(0,0,r)$, where r is any non-zero real number. In this case we investigate the transversality condition for these surfaces.

Main result of the present paper is the following theorem.

Theorem. Let rB $\neq 0, (c_1, c_2) \neq (0,0)$ and $\{g_i(u_1, u_2)\}_{i=1}^3$ be fractional power series in a small neighborhood of the origin in R^2, satisfying the conditions $g_i(0,0) \neq 0$. Then for the surfaces (1) in a sufficiently small neighborhood of the point $(0,0,r)$, at regular points of these surfaces the transversality condition is satisfied.

Proof. Denoting by X_1, X_2, X_3 coordinates of the tangent plane to the surface (1) at its non-singular point (x_1, x_2, x_3), we take its equation in the form (see [12], p. 225)

$$\begin{vmatrix} X_1 - x_1(u_1,u_2) & X_2 - x_2(u_1,u_2) & X_3 - x_3(u_1,u_2) \\ \frac{\partial x_1(u_1,u_2)}{\partial u_1} & \frac{\partial x_2(u_1,u_2)}{\partial u_1} & \frac{\partial x_3(u_1,u_2)}{\partial u_1} \\ \frac{\partial x_1(u_1,u_2)}{\partial u_2} & \frac{\partial x_2(u_1,u_2)}{\partial u_2} & \frac{\partial x_3(u_1,u_2)}{\partial u_2} \end{vmatrix} = 0. \qquad (2)$$

By calculating the first minor of second order of this determinant we have

$$\frac{\partial x_1(u_1,u_2)}{\partial u_1}\frac{\partial x_2(u_1,u_2)}{\partial u_2} - \frac{\partial x_1(u_1,u_2)}{\partial u_2}\frac{\partial x_2(u_1,u_2)}{\partial u_1} =$$

$$u_1^{a_1+b_1-1}u_2^{a_2+b_2-1}\left(b_2 g_2(u_1,u_2) + u_2\frac{\partial g_2(u_1,u_2)}{\partial u_2}\right)\left(a_1 g_1(u_1,u_2) + u_1\frac{\partial g_1(u_1,u_2)}{\partial u_1}\right) -$$

$$-u_1^{a_1+b_1-1}u_2^{a_2+b_2-1}\left(a_2 g_1(u_1,u_2) + u_2\frac{\partial g_1(u_1,u_2)}{\partial u_2}\right)\left(b_1 g_2(u_1,u_2) + u_1\frac{\partial g_2(u_1,u_2)}{\partial u_1}\right) =$$

$$\left(\mathrm{B}g_1(u_1,u_2)g_2(u_1,u_2) + w_3(u_1,u_2)\right)u_1^{a_1+b_1-1}u_2^{a_2+b_2-1},$$

where

$$w_3(u_1,u_2) = a_1 u_1 u_2^2 g_1(u_1,u_2)\frac{\partial g_2(u_1,u_2)}{\partial u_2} + b_2 u_2 u_1^2 g_2(u_1,u_2)\frac{\partial g_1(u_1,u_2)}{\partial u_1} +$$

$$+u_1^2u_2^2\frac{\partial g_1(u_1,u_2)}{\partial u_1}\frac{\partial g_2(u_1,u_2)}{\partial u_2}-a_2u_2u_1^2g_1(u_1,u_2)\frac{\partial g_2(u_1,u_2)}{\partial u_1}-$$

$$-b_1u_1u_2^2g_2(u_1,u_2)\frac{\partial g_1(u_1,u_2)}{\partial u_2}-u_1^2u_2^2\frac{\partial g_1(u_1,u_2)}{\partial u_2}\frac{\partial g_2(u_1,u_2)}{\partial u_1}$$

is fractional power series in a small neighborhood of the origin in R^2, satisfying the condition $w_3(0,0)=0$.

Analogously, other minors of second order can be represented as follows

$$\frac{\partial x_1(u_1,u_2)}{\partial u_1}\frac{\partial x_3(u_1,u_2)}{\partial u_2}-\frac{\partial x_1(u_1,u_2)}{\partial u_2}\frac{\partial x_3(u_1,u_2)}{\partial u_1}=$$

$$\big(B_3g_1(u_1,u_2)g_3(u_1,u_2)+w_2(u_1,u_2)\big)u_1^{a_1+c_1-1}u_2^{a_2+c_2-1},$$

$$\frac{\partial x_2(u_1,u_2)}{\partial u_1}\frac{\partial x_3(u_1,u_2)}{\partial u_2}-\frac{\partial x_2(u_1,u_2)}{\partial u_2}\frac{\partial x_3(u_1,u_2)}{\partial u_1}=$$

$$\big(B_2g_2(u_1,u_2)g_3(u_1,u_2)+w_1(u_1,u_2)\big)u_1^{b_1+c_1-1}u_1^{b_2+c_2-1},$$

where

$$w_1(u_1,u_2)=b_1u_1u_2^2g_2(u_1,u_2)\frac{\partial g_3(u_1,u_2)}{\partial u_2}+c_2u_2u_1^2g_3(u_1,u_2)\frac{\partial g_2(u_1,u_2)}{\partial u_1}+$$

$$+u_1^2u_2^2\frac{\partial g_2(u_1,u_2)}{\partial u_1}\frac{\partial g_3(u_1,u_2)}{\partial u_2}-b_2u_2u_1^2g_2(u_1,u_2)\frac{\partial g_3(u_1,u_2)}{\partial u_1}-$$

$$-c_1u_1u_2^2g_3(u_1,u_2)\frac{\partial g_2(u_1,u_2)}{\partial u_2}-u_1^2u_2^2\frac{\partial g_2(u_1,u_2)}{\partial u_2}\frac{\partial g_3(u_1,u_2)}{\partial u_1}$$

$$w_2(u_1,u_2)=a_2u_2u_1^2g_1(u_1,u_2)\frac{\partial g_3(u_1,u_2)}{\partial u_1}+c_1u_1u_2^2g_3(u_1,u_2)\frac{\partial g_1(u_1,u_2)}{\partial u_2}+$$

$$+u_1^2u_2^2\frac{\partial g_1(u_1,u_2)}{\partial u_2}\frac{\partial g_3(u_1,u_2)}{\partial u_1}-a_1u_1u_2^2g_1(u_1,u_2)\frac{\partial g_3(u_1,u_2)}{\partial u_2}-$$

$$-c_2u_2u_1^2g_3(u_1,u_2)\frac{\partial g_1(u_1,u_2)}{\partial u_1}-u_1^2u_2^2\frac{\partial g_1(u_1,u_2)}{\partial u_1}\frac{\partial g_3(u_1,u_2)}{\partial u_2},$$

and $w_1(u_1,u_2), w_2(u_1,u_2)$ are fractional power series in a small neighborhood of the origin in R^2, satisfying the conditions $w_1(0,0)=0, w_2(0,0)=0$.

Consequently, calculating the value of the determinant in (2) we have

$$\big(X_1-x_1(u_1,u_2)\big)\big(B_2g_2(u_1,u_2)g_3(u_1,u_2)+w_1(u_1,u_2)\big)u_1^{b_1+c_1-1}u_2^{b_2+c_2-1}+$$

$$+\big(X_2 - x_2(u_1,u_2)\big)\big(B_3 g_1(u_1,u_2)g_3(u_1,u_2) + w_2(u_1,u_2)\big)u_1^{a_1+c_1-1}u_2^{a_2+c_2-1} + \quad (3)$$

$$+\big(X_3 - x_3(u_1,u_2)\big)\big(\mathrm{B}g_1(u_1,u_2)g_2(u_1,u_2) + w_3(u_1,u_2)\big)u_1^{a_1+b_1-1}u_2^{a_2+b_2-1} = 0.$$

If we suppose $X_1 = X_2 = X_3 = 0$, then we can rewrite the equation (3) as

$$\mathrm{rB}g_1(u_1,u_2)g_2(u_1,u_2) + rw_3(u_1,u_2) +$$

$$+g_1(u_1,u_2)w_1(u_1,u_2) + g_2(u_1,u_2)w_2(u_1,u_2) + g_3(u_1,u_2)w_3(u_1,u_2)u_1^{c_1}u_2^{c_2} = 0.$$

Thus, from the conditions $\mathrm{rB} \neq 0, (c_1,c_2) \neq (0,0)$ and $g_i(0,0) \neq 0$ it is clear that the expression on the left side of this equation is non-zero in a small neighborhood of the origin in R^2. This finishes the proof of Theorem.

Now we consider the singular surfaces (1) in a small neighborhood of the origin in R^3.

Corollary 1. Let $B + B_1 + B_2 \neq 0$ and $\{g_i(u_1,u_2)\}_{i=1}^3$ be fractional power series in a small neighborhood of the origin in R^2, satisfying the conditions $g_i(0,0) \neq 0$. Then for the surfaces (1) in a sufficiently small neighborhood of the origin in R^3 the transversality condition is hold.

Proof. It is clear that at least one of the numbers B, B_1 and B_2 is non-zero. Therefore, all points of the surfaces (1), lying in a small neighborhood of the origin in R^3 out of the coordinate planes are regular. Denote by X_1, X_2, X_3 coordinates of the tangent plane to the surface (1) at its non-singular point (x_1, x_2, x_3).

Assume that $X_1 = X_2 = X_3 = 0$, then from the equation (3) we get

$$+g_3(u_1,u_2)w_3(u_1,u_2)u_1^{b_1+a_1+c_1-1}u_2^{b_2+a_2+c_2-1} = 0.$$

Thus, from this equality it is clear that under the conditions $B + B_1 + B_2 \neq 0$ and $g_i(0,0) \neq 0$the left side of this equation does not vanish in a small neighborhood of the origin in R^2. This finishes the proof of the corollary 1.

Consider now a different corollaries in connection with Theorem.

Corollary 2. Assume that $B \neq 0, (c_1,c_2) \neq (0,0)$ and $\{g_i(u_1,u_2)\}_{i=1}^3$ are real analytic functions in a small neighborhood of the origin in R^2, satisfying the conditions $g_i(0,0) \neq 0$. Then for the surfaces (1) in a sufficiently small neighborhood of the point $(0,0,r)$, at regular points of these surfaces the transversality condition is hold.

Corollary 3. Let $B_1 \neq 0, (a_1,a_2) \neq (0,0)$ and $\{g_i(u_1,u_2)\}_{i=1}^3$ be fractional power series in a small neighborhood of the origin in R^2, satisfying the conditions $g_i(0,0) \neq 0$. Then for the surfaces (1) in a sufficiently small neighborhood of the point $(r,0,0)$, at regular points of these surfaces the transversality condition is satisfied.

Corollary 4. Suppose that $B_2 \neq 0$, $(b_1,b_2) \neq (0,0)$ and $\{g_i(u_1,u_2)\}_{i=1}^3$ are fractional power series in a small neighborhood of the origin in R^2, satisfying the conditions $g_i(0,0) \neq 0$. Then for the surfaces (1) in a sufficiently small neighborhood of the point $(0,r,0)$, at regular points of these surfaces the transversality condition is hold.

Remark. If $\{g_i(u_1,u_2)\}_{i=1}^{3}$ are real analytic functions in a small neighborhood of the origin

in R^2, satisfying the conditions $g_i(0,0) \neq 0$, then the corollaries 3 and 4 will be true.

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