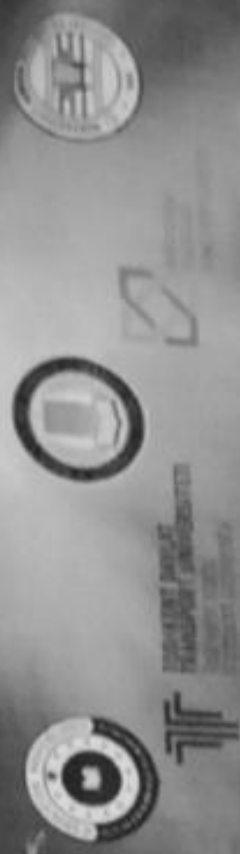




«AMALYI MATEMATIKA VA AXBOROT TEXNOLOGIYALARINING ZAMONAVIY MUAMMOLARI»
XALQARO ILMIY-AMALY ANJUMAN



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Muminov M.I., Khurramov A.M., Bozorov I.N. ON THE NUMBER OF EIGENVALUES OF A TWO-PARTICLE HAMILTONIAN ON THREE-DIMENSIONAL LATTICE	34
Muminov M.E., Jurakulova F.M. ON THE BRANCHES OF THE ESSENTIAL SPECTRUM OF OPERATOR MATRIX IN BOSONIC FOCK SPACE	36
Qushbaqov H., Muhammadjonov A., Ismoilova M. ABOUT ONE EQUALITY WITH EXPONENTIAL MATRIX	37
Rahmatullaev M.M., Tukhtabaev A.M. ON G_i^{∞} -PERIODIC p -ADIC GENERALIZED GIBBS MEASURE FOR ISING MODEL THE CAYLEY TREE	38
Rajabov Sh.Sh. PROPAGATION THEOREM FOR THE PROBLEM OF FINDING THE ORIGINAL FUNCTION IN MATRIX ARGUMENT FUNCTIONS	39
Rasulov T.H., Umirkulova G.H. BOUNDS OF THE ESSENTIAL SPECTRUM OF A THREE-PARTICLE MODEL HAMILTONIAN ON A 1D LATTICE	40
Rasulov T.H., Sharipova M.Sh. CUBIC NUMERICAL RANGE OF 3×3 BLOCK OPERATOR MATRICES	41
Rozikov U. A., Shoyimardonov S. K. A SET OF FIXED POINTS OF A COVID-19 SPREADING MODEL WITH VACCINATED CASE	42
Ruzieva D.S. STRONG LAW OF LARGE NUMBERS FOR RANDOM FIELDS WITH VALUES IN HILBERT SPACE	44
Sharipov O.Sh., Hamdamov A.H. GILBERT FAZOSIDA QIYMAT QABUL QILUVCHI U-STATISTIKALAR UCHUN KUCHAYTIRILGAN KATTA SONLAR QONUNI	45
Sharipov O.Sh., Kushmurodov A.A. MARCINKIEWICZ-ZYGMUND LAW OF LARGE NUMBERS FOR AUTOREGRESSIVE PROCEESS IN BANACH SPACES	46
Sharipov S. A LIMIT THEOREM FOR BRANCHING PROCESSES WITH IMMIGRATION	46
Shomalikova M.Sh. DARAXTSIMON METRIK GRAFLARDA ISSIQLIK TARQALISH TENGLAMASI UCHUN δ^r ULANISH SHARTLI MASALA	48
Tagaymurotov A.O. REPRESENTATION OF A MAX-PLUS-POLAR OF THE SET OF IDEMPOTENT PROBABILITY MEASURES BY THE POLAR OF THE SET OF PROBABILITY MEASURES	49
TALHA USMAN. A CLOSED FORM OF INTEGRAL TRANSFORMS IN TERMS OF LAURICELLA FUNCTION AND THEIR NUMERICAL SIMULATIONS	49
Tosheva N.A. FINITENESS OF THE NUMBER OF EIGENVALUES OF THE FAMILY OF 3×3 OPERATOR MATRICES: 1D CASE	50
Xalxujayev A.M., Khayitova K.G. ANALYTIC DISCRPTION OF THE ESSENSIAL SPECTRUM OF A OPERATOR MATRIX IN FERMIONIC FOCK SPACE	51
Xudayarov S.S. ON INVARIANT SETS OF A QUADRATIC NON-STOCHASTIC OPERATOR	52
Xurramov Y.S. $s-d$ MODELGA MOS SCHRÖDINGER TIPLI OPERATORNING SPEKTRAL XOSSALARI	53
Абдикалиров С.М. ОБ АНАЛОГЕ ТЕОРЕМЫ БЛАНШЕТА ДЛЯ α -СУБГАРМОНИЧЕСКИХ ФУНКЦИЙ	54
Актамов Ф.С. ПРИНЦИП РАВНОМЕРНОЙ ОГРАНИЧЕННОСТИ MAX-PLUS-ЛИНЕЙНЫХ ОПЕРАТОРОВ	55
Атамуратов А.А., Расулов К.К. МНОЖЕСТВО ОСОБЕННОСТЕЙ СЕПАРАТНО-АНАЛИТИЧЕСКИХ ФУНКЦИЙ	56
Бегижонов И. И. КРИТЕРИЙ ЦИКЛИЧЕСКОЙ КОМПАКТНОСТИ МНОЖЕСТВ В БАНАХОВЫХ МОДУЛЯХ	57
Бекназаров Дж.Х. ПРИБЛИЖЕНИЯ ФУНКЦИЙ СУММАМИ ФУРЬЕ-ЧЕБЫШЕВА В ПРОСТРАНСТВЕ $L_{2,\mu}$	59
Гадаев С. С-СВОЙСТВО α -СУБГАРМОНИЧЕСКИХ ФУНКЦИЙ	60
Ганиходжаев Р.Н., Эшмаматова Д.Б., Таджиева М.А. ДИНАМИКА КВАДРАТИЧНЫХ ОТОБРАЖЕНИЙ ЛОТКИ-ВОЛЬТЕРРА, ДЕЙСТВУЮЩИХ В ЧЕТЫРЕХМЕРНОМ СИМПЛЕКСЕ С ВЫРОЖДЕННОЙ КОСОСИММЕТРИЧЕСКОЙ МАТРИЦЕЙ	61
Икромов И.А., Баракаев А.М. ОБ ОГРАНИЧЕННОСТИ МАКСИМАЛЬНЫХ ОПЕРАТОРОВ В ПРОСТРАНСТВЕ $L2R3$	62
Икромова Д. И. ОБ ОЦЕНКАХ ПРЕОБРАЗОВАНИЯ ФУРЬЕ МЕР, СОСРЕДОТОЧЕННЫХ НА ПОВЕРХНОСТЯХ, ИМЕЮЩИХ ОСОБЕННОСТЬ ТИПА $E\mathbb{V}$	63

$$\mu_0 = \left(\max_{x \in \Lambda} \int_T \frac{v^2(t) dt}{u(x, t) - m} \right)^{-1}$$

We introduce two bounded and self-adjoint operators $H_\mu^{(1)}$ and $H_\lambda^{(2)}$ (so-called channel operators). They act in $L_2(T^2)$ by

$$H_\mu^{(1)} = H_0 - \mu V_1, \quad H_\lambda^{(2)} = H_0 - \lambda V_2$$

Set

$$E_{\mu, \lambda} = \min\{\xi \mid \xi \in \sigma_{\text{ess}}(H_{\mu, \lambda})\}$$

Then $E_{\mu, \lambda} \in \sigma_{\text{ess}}(H_{\mu, \lambda})$ is called the lower bound of the essential spectrum of $H_{\mu, \lambda}$.

The main result of the present note is the following theorem.

Theorem 1. For the essential spectrum of $H_{\mu, \lambda}$ we have

$$\sigma_{\text{ess}}(H_{\mu, \lambda}) = \sigma(H_\mu^{(1)}) \cup \sigma(H_\lambda^{(2)}).$$

For the lower bound $E_{\mu, \lambda}$ the following assertions hold.

(i) If $v(x') \neq 0$ for some $x' \in \Lambda$, then for all $\mu, \lambda > 0$ we have $E_{\mu, \lambda} < m$,

(ii) Let $v(x') = 0$ for all $x' \in \Lambda$.

(ii₁) For any $\mu > \mu_0$ and $\lambda > 0$ we have $E_{\mu, \lambda} < m$,

(ii₂) For any $\mu \leq \mu_0$ and $\lambda > 0$ we have $E_{\mu, \lambda} = \min \sigma(H_\lambda^{(2)})$.

Moreover, $\max(\sigma(H_{\mu, \lambda})) = M$ for any $\mu, \lambda > 0$.

This result plays a key role in the analysis of the discrete spectrum of $H_{\mu, \lambda}$. In [1] the discrete spectrum of $H_{\mu, 0}$ was discussed.

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CUBIC NUMERICAL RANGE OF 3×3 BLOCK OPERATOR MATRICES

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Block operator matrices are matrices the entries of which are linear operators between Banach or Hilbert spaces. They arise in various areas of mathematics and its applications. Let $\mathcal{H}_1, \mathcal{H}_2, \mathcal{H}_3$ be complex Hilbert spaces, and consider $\mathcal{H} = \mathcal{H}_1 \oplus \mathcal{H}_2 \oplus \mathcal{H}_3$. With respect to this decomposition, every bounded linear operator $\mathcal{A} \in L(\mathcal{H})$ has a 3×3 block operator matrix representation

$$\mathcal{A} = \begin{pmatrix} A_{11} & A_{12} & A_{13} \\ A_{12}^* & A_{22} & A_{23} \\ A_{13}^* & A_{23}^* & A_{33} \end{pmatrix} \quad (1)$$

with bounded linear entries $A_{ij} \in L(\mathcal{H}_j, \mathcal{H}_i), i, j = 1, 2, 3$ such that $A_{ii}^* = A_{ii}, i = 1, 2, 3$. In the following we denote by

$S_{\mathcal{H}_1 \oplus \mathcal{H}_2 \oplus \mathcal{H}_3} = S_{\mathcal{H}_1} \times S_{\mathcal{H}_2} \times S_{\mathcal{H}_3} = \{(f_1, f_2, f_3)^t \in \mathcal{H} \mid \|f_i\| = 1, i = 1, 2, 3\}$ the product of the unit spheres $S_{\mathcal{H}_i}$ in \mathcal{H}_i , we also write S^3 or $S_{\mathcal{H}}$ instead of $S_{\mathcal{H}_1 \oplus \mathcal{H}_2 \oplus \mathcal{H}_3}$ if the decomposition $\mathcal{H} = \mathcal{H}_1 \oplus \mathcal{H}_2 \oplus \mathcal{H}_3$ is clear (note the slight difference in notation between $S_{\mathcal{H}_1 \oplus \mathcal{H}_2 \oplus \mathcal{H}_3}$ and the unit sphere $S_{\mathcal{H}_1 \oplus \mathcal{H}_2 \oplus \mathcal{H}_3}$ in $\mathcal{H}_1 \oplus \mathcal{H}_2 \oplus \mathcal{H}_3$). In this case $S^3 = \{f = (f_1, f_2, f_3)^t \in \mathcal{H} \mid \|f_i\| = 1, i = 1, 2, 3\}$

Definition 1. For $f = (f_1, f_2, f_3)^t \in S_{\mathcal{H}_1 \oplus \mathcal{H}_2 \oplus \mathcal{H}_3}$ we introduce the 3×3 matrix

$$\mathcal{A}_f = \begin{pmatrix} (A_{11}f_1, f_1) & (A_{12}f_2, f_1) & (A_{13}f_3, f_1) \\ (A_{12}^*f_1, f_2) & (A_{22}f_2, f_2) & (A_{23}f_3, f_2) \\ (A_{13}^*f_1, f_3) & (A_{23}^*f_2, f_3) & (A_{33}f_3, f_3) \end{pmatrix} \in M_3(\mathbb{C}).$$

Then the set

$$W_{\mathcal{H}_1 \oplus \mathcal{H}_2 \oplus \mathcal{H}_3}(\mathcal{A}) = \bigcup_{f \in S^3} \sigma_p(\mathcal{A}_f)$$

is called cubic numerical range of \mathcal{A} (with respect to the block operator matrix representation (1)). For a fixed decomposition of \mathcal{H} , we also write

$$W^3(\mathcal{A}) = W_{\mathcal{H}_1 \oplus \mathcal{H}_2 \oplus \mathcal{H}_3}(\mathcal{A})$$

Let $a_{ij}(f) = (A_{ij}f_j, f_i)$ for $i, j = 1, 2, 3$ and

$$E_k(f) = \frac{1}{3}(a_{11}(f) + a_{22}(f) + a_{33}(f)), \text{ if } a_{11}(f) = a_{22}(f) = a_{33}(f),$$

$$a_{12}(f) = a_{23}(f) = a_{31}(f) = 0,$$

$$E_k(f) = \frac{1}{3}(a_{11}(f) + a_{22}(f) + a_{33}(f)) + 2\sqrt{-\frac{P(f)}{3}} \cos \frac{\Phi(f) + 2\pi k}{3} \text{ otherwise.}$$

where

$$P(f) = -\frac{1}{6}((a_{11}(f) - a_{22}(f))^2 + (a_{11}(f) - a_{33}(f))^2 + (a_{22}(f) - a_{33}(f))^2 - |a_{12}(f)|^2 - |a_{23}(f)|^2 - |a_{31}(f)|^2),$$

$$Q(f) = -\frac{2}{27}(a_{11}(f) + a_{22}(f) + a_{33}(f))^3 + \frac{1}{3}(a_{11}(f) + a_{22}(f) + a_{33}(f))(a_{11}(f)a_{22}(f) + a_{22}(f)a_{33}(f) + a_{11}(f)a_{33}(f) - |a_{12}(f)|^2 - |a_{23}(f)|^2 - |a_{31}(f)|^2) + a_{11}(f)a_{22}(f)a_{33}(f) + 2\operatorname{Re}(a_{12}(f)a_{23}(f)a_{31}(f)) + |a_{12}(f)|^2 a_{33}(f) + |a_{23}(f)|^2 a_{11}(f) + |a_{31}(f)|^2 a_{22}(f).$$

$$\Phi(f) = \arccos\left(-\frac{3Q(f)}{2P(f)} \sqrt{\frac{3}{P(f)}}\right).$$

The main result of this note is the following theorem.

Theorem 1. For the cubic numerical range of \mathcal{A} we have

$$W^3(\mathcal{A}) = \bigcup_{k=1}^3 \bigcup_{f \in S^3} \{E_k(f)\}.$$

This theorem plays a key role in the estimate of the bounds of \mathcal{A} in terms of cubic numerical range.

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A SET OF FIXED POINTS OF A COVID-19 SPREADING MODEL WITH VACCINATED CASE

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In the work [1] authors proposed SIARD epidemic model and based on this model we consider the following discrete-time SAIRVD model:

$$W = \begin{cases} S^{(t+1)} = S(1 - v_s) - (\beta_1 \alpha I + \beta_2 \alpha^2 A)S + \omega R + \rho V \\ A^{(t+1)} = A(1 - \mu - \gamma_a - d_a - v_a) + \beta_2 \alpha^2 AS \\ I^{(t+1)} = I(1 - \gamma_i - d_i) + \beta_1 \alpha IS + \mu A \\ R^{(t+1)} = R(1 - \omega - v_r) + \gamma_a A + \gamma_i I + \gamma_r V \\ V^{(t+1)} = V(1 - \rho - d_v - \gamma_v) + v_a A + v_s S + v_r R \\ D^{(t+1)} = D + d_a A + d_i I + d_v V \end{cases} \quad (1)$$

This model describes the interaction of susceptible population S , asymptomatic (unreported) infected population A , symptomatic (reported) infected population I , recovered population R , vaccinated population V and death population D . This system also closed system as many other systems, so for simplicity if we assume $S + A + I + R + V + D = 1$ then $S^{(t+1)} + A^{(t+1)} + I^{(t+1)} + R^{(t+1)} + V^{(t+1)} + D^{(t+1)} = 1$