Optimization of Edge Rounding with Elastic Abrasive Tools

Dimov Yuriy*[1], Podashev Dmitriy*[2]
*Engineering Design and Standardization Department,
Irkutsk National Research Technical University.
Russia, Irkutsk, Lermontov str., 83.
1 Dimov-Ura@yandex.ru
2 dbp90@mail.ru

Abstract - The article deals with the optimization of edge rounding with Scotch-Brite™ non-wooven elastic abrasive tools. The optimization criterion is the economic target function (ETF) which must be minimized. In order to determine the ETF, the target function (TF) (the basic machine time) and limiting functions (LF) (the potential surface roughness and edge size) have been developed. Based on the optimization results, the recommendations for selecting the machining conditions have been suggested.

Keyword-Elastic wheel, Scotch-Brite™ non-wooven material, economic target function, edge rounding, potential surface roughness, machining conditions, optimization system.

I. INTRODUCTION

The aircraft industry uses different parts with sharp edges. Those edges required rounding. At most factories, rounding is a manual operation. Mechanization and automation can help increase the efficiency of the process. One promising approach is machining with elastic abrasive wheels and brushes. These tools were classified and described in [1, 2].

In our research, we used such elastic abrasive tools as AK CF-FB-0,5A FIN, FS-WL-2SCRS, CB-ZS P180, FF-ZS ACRS, and BB-ZB Type C (granularity P400 (=40 µm) (Table 1).

Table 1. Tool Parameters and Machining Conditions

Tool	**External diameter D_t, mm**	**Width B_t, mm**	**Internal diameter d_t, mm**	**Abrasive**	**Grain size Z, µm**	**Feed S, mm/min**	**Speed V, m/min**	**Deformation ΔX, mm**
CF-FB-0,5AFIN	193	50	76.5	Al_2O_3	45÷50	50-1000	300-3000	3-4.5
FS-WL-2SCRS	147	26	25.4	SiC	≈200	50-1000	230-2300	1.5-3
BB-ZB Type C	150	13	25.4	SiC	40	50-1000	500-4000	2-5
CB-ZS P180	75	45	-	SiC	80	50-1000	150-1000	1-4
FF-ZS ACRS	75	45	-	SiC	~160	50-1000	150-1000	1-4

D_t is the tool diameter, mm; B_t is the tool width, mm; d_t is the external diameter, mm; d_0 is the internal diameter, mm.

The selection of optimal parameters can help increase the performance of production processes.

The method of parameter optimization for machining with elastic abrasive wheels (AW) depends on the manufacturing conditions. There are three ways of parameter optimization:

1) To increase the production performance ignoring the prime costs;
2) To minimize tool costs;
3) To minimize production costs.

Let us analyze the third type which is more cost-effective than others.

The optimization system for edge rounding with elastic abrasive tools is based on the mathematical models of:

- Relative edge removed – **ρ;**
- Position of the rounding radius - δ;
- Potential rounded edge surface roughness.

II. OPTIMIZATION SYSTEM

The economic target function (ETF) was selected as an optimization criterion for a specific tool. It is calculated based on the program below. The criterion for selecting an optimal tool is the minimum ETF value.

Figure 1 shows the optimization system for a specific tool.

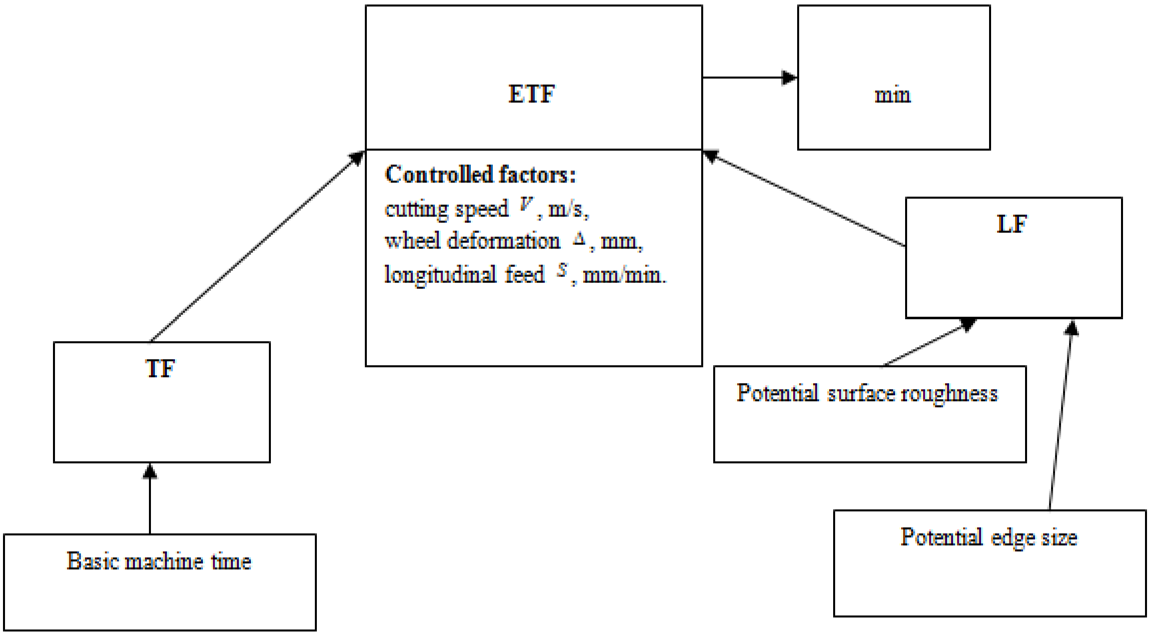

Fig. 1 Edge rounding optimization system

The economic target function is used to assess the costs of all options and to select the machining conditions with minimum costs.

$$ETF = T_r \bullet R_p + T_{n-p} \bullet R_p . \qquad (1)$$

The target function (TF) of the basic machine time T_r is a part of the ETF. Power consumption and tool wear were ignored because of their negligible effect on the prime costs by contrast to the labor costs.

The limiting functions (LF) are the equations of the potential surface roughness and edge size.

The ETF includes the parameters as follows:

For the target function (TF) of the basic machine time $T_{r,,}$ **measured and controlled input variables** are the cutting speed V, the wheel deformation ΔX, the longitudinal feed S.

For the target function (TF) of the basic machine time T_r, **measured and non-controlled input variables** are the required surface roughness (Ra_e), the required edge size, edge length (l_r), and wheel width B_w; for the ETF, they are the pay rate (P_T), the non-productive machine time (T_{n-p}).

For the ETF, **output parameters** are the costs of machining with elastic abrasive wheels.

The basic machine time, min.

$$T_r = l_r / S \tag{2}$$

where l_r is the edge length, mm; S is the longitudinal feed, mm/min.

The relative deviation δ of the center of the rounding radius from the symmetric position

$$\delta = \frac{X - Y}{X} \tag{3}$$

where X, Y are the coordinates of points A and B (Fig. 2, a).

The deviation from the symmetric position ($\delta = 0$ when $X = Y$) can be eliminated by optimizing the angle α (Fig. 2, b).

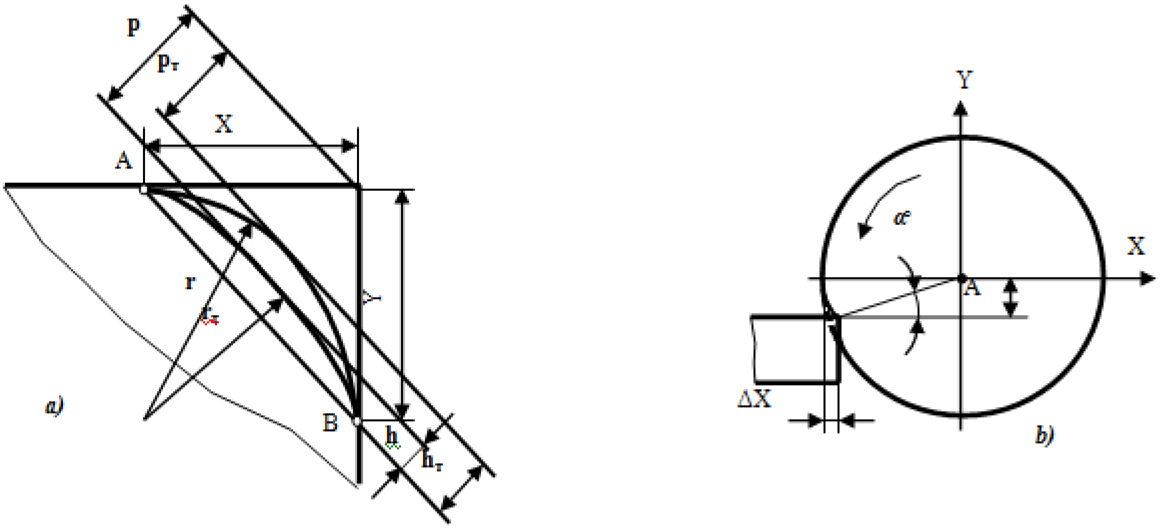

Fig. 2 Rounding parameters (*a*); parameters α and ΔX (*b*)

The position of the rounded radius dependent on the machining conditions was described in [3]. The observed data were approximated with a function (Table 2):

$$\boldsymbol{\delta = a_1 \cdot \alpha^2 + a_2 \cdot \Delta x^2 + a_3 \cdot \alpha + a_4 \cdot \Delta x + a_5 \cdot \Delta x \cdot \alpha + a_6} \tag{4}$$

where α is the wheel position angle relative to the edge, deg; ΔX is the tool deformation, mm.

When selecting the machining conditions, we have to ensure that $\delta = 0$.

Table 2

Coefficient	**CF-FB 0,5A FIN**	**FS-WL 2S CRS**	**BB-ZB Type**	**CB-ZS P180**	**FF-ZS ACRS**
a_1	$-2.2095 \cdot 10^{-4}$	$-2.4724 \cdot 10^{-3}$	$-1.8261 \cdot 10^{-3}$	-0.0706305	$-3.6853 \cdot 10^{-3}$
a_2	0.119885	0.398099	0.0689981	1.36642	0.0502261
a_3	-0.0249246	0.159299	0.0491029	3.41477	0.0751851
a_4	-1.21977	-2.14867	-0.648962	-6.04949	-1.33592
a_5	0.0165369	$8.8884 \cdot 10^{-3}$	$7.2605 \cdot 10^{-3}$	-0.048132	0.0667152
a_6	2.17522	-0.617307	0.770015	-31.3847	-0.0472628

A. The relative edge removed ρ

The relative edge removed is determined by the formula

$$\rho = p / B \tag{5}$$

where p = 0,414 r is the actual height of the edge removed (see Figure 1, *a*), B is the tool width, mm.

The relative edge removed is the actual size of the edge removed with 1 mm of the tool width.

Based on the results described in [3], we may derive a mathematical model for $\boldsymbol{\rho}$ in the form of a second-order polynomial

$$\rho = a_1\cdot\Delta x^2+a_2\cdot V^2+a_3\cdot S^2+a_4\cdot\Delta x+a_5\cdot V+a_6\cdot S+a_7\cdot\Delta x\cdot V+a_8\cdot\Delta x\cdot S+a_9\cdot V\cdot S+ a_{10}\cdot\Delta x\cdot V\cdot S +a_{11}, \tag{6}$$

where ΔX is the tool deformation, mm; V is the cutting speed, m/min; S is the longitudinal feed, mm/min.

Table 3 presents the values of the coefficients $\boldsymbol{a_1 – a_{10}}$ and the constant term $\boldsymbol{a_{11}}$.

Table 3

Coefficient	**CF-FB 0.5A FIN**	**FS-WL 2S CRS**	**BB-ZB Type C**	**CB-ZS P180**	**FF-ZS ACRS**
a_1	$2.85325\cdot10^{-5}$	$2.3\cdot10^{-3}$	$7.24638\cdot10^{-6}$	$8.82353\cdot10^{-4}$	0.001
a_2	$-6.3375\cdot10^{-10}$	$1.215\cdot10^{-8}$	$-4.61\cdot10^{-9}$	$2.45371\cdot10^{-8}$	$7.05867\cdot10^{-8}$
a_3	$-6.2625\cdot10^{-7}$	$-3.69625\cdot10^{-8}$	$-3.7137\cdot10^{-8}$	$-2.11216\cdot10^{-8}$	$3.3033\cdot10^{-10}$
a_4	$2.4631\cdot10^{-3}$	$-2.1125\cdot10^{-3}$	0.028985507	$4.9355\cdot10^{-5}$	$-6.66667\cdot10^{-7}$
a_5	$4.42\cdot10^{-6}$	$1.14838\cdot10^{-5}$	$2.53412\cdot10^{-4}$	$1.31943\cdot10^{-6}$	$5.055\cdot10^{-8}$
a_6	$-1.00275\cdot10^{-5}$	$-1.12238\cdot10^{-5}$	$-1.11543\cdot10^{-3}$	$-1.67901\cdot10^{-6}$	$-1.35134\cdot10^{-5}$
a_7	$4.725\cdot10^{-7}$	$9.8775\cdot10^{-7}$	$3.41538\cdot10^{-6}$	$2.73859\cdot10^{-7}$	$2.6732\cdot10^{-8}$
a_8	$2.6625\cdot10^{-6}$	$-2.47375\cdot10^{-6}$	$1.55343\cdot10^{-5}$	$-1.64831\cdot10^{-7}$	$-7.97608\cdot10^{-9}$
a_9	$-5.0925\cdot10^{-9}$	$5.54875\cdot10^{-9}$	$6.5769\cdot10^{-8}$	$1.98937\cdot10^{-9}$	$-1.3376\cdot10^{-10}$
a_{10}	$-2.0745\cdot10^{-10}$	$-2.71875\cdot10^{-9}$	$-2.73578\cdot10^{-8}$	$9.0522\cdot10^{-10}$	$-8.39\cdot10^{-12}$
a_{11}	0.001	0.006	0.0333333	$1.10294\cdot10^{-3}$	-0.003

The machining precision and performance results are the basis for edge rounding parameter optimization.

A. Rounded edge surface roughness

The rounded edge surface roughness depends on the type of machined parts (e.g., the surface roughness for aircraft parts must correspond to Ra 3.2).

Based on the observed results, we found that Ra is independent of the cutting speed V and the feed S. The dependence on the deformation ΔX can be presented as

$$\mathrm{Ra} = b / \Delta X + c \tag{7}$$

Table 4 shows the values of the coefficient b and the constant term c.

Table 4

Tool	Coefficient b	Constant term c
CF-FB 0,5A FIN	0.167	0.25
FS-WL 2S CRS	0.133	1.8
BB-ZB Type C	0.117	1.167
CB-ZS P180	0.25	0.75
FF-ZS ACRS	0.367	1.233

III. OPTIMALITY CALCULATION ALGORITHM FOR EDGE ROUNDING

Based on the observed results, we developed an optimality calculation algorithm for edge rounding. For each tool, the algorithm is different. The above-mentioned input parameters are entered into the system. The algorithm enables selection of the optimal cutting conditions using available equipment and tools, based on the basic edge surface roughness and the required edge surface roughness and size.

To calculate the optimal machining conditions, we developed a software using Borland C++ Builder 6.0.

The software is based on the exhaustive method. The input data are the data entered by the user. The output data include the wheel deformation, cutting speed, longitudinal feed, and the ETF value.

Figure 3 shows the optimality search algorithm for machining high-tensile aluminum alloy parts.

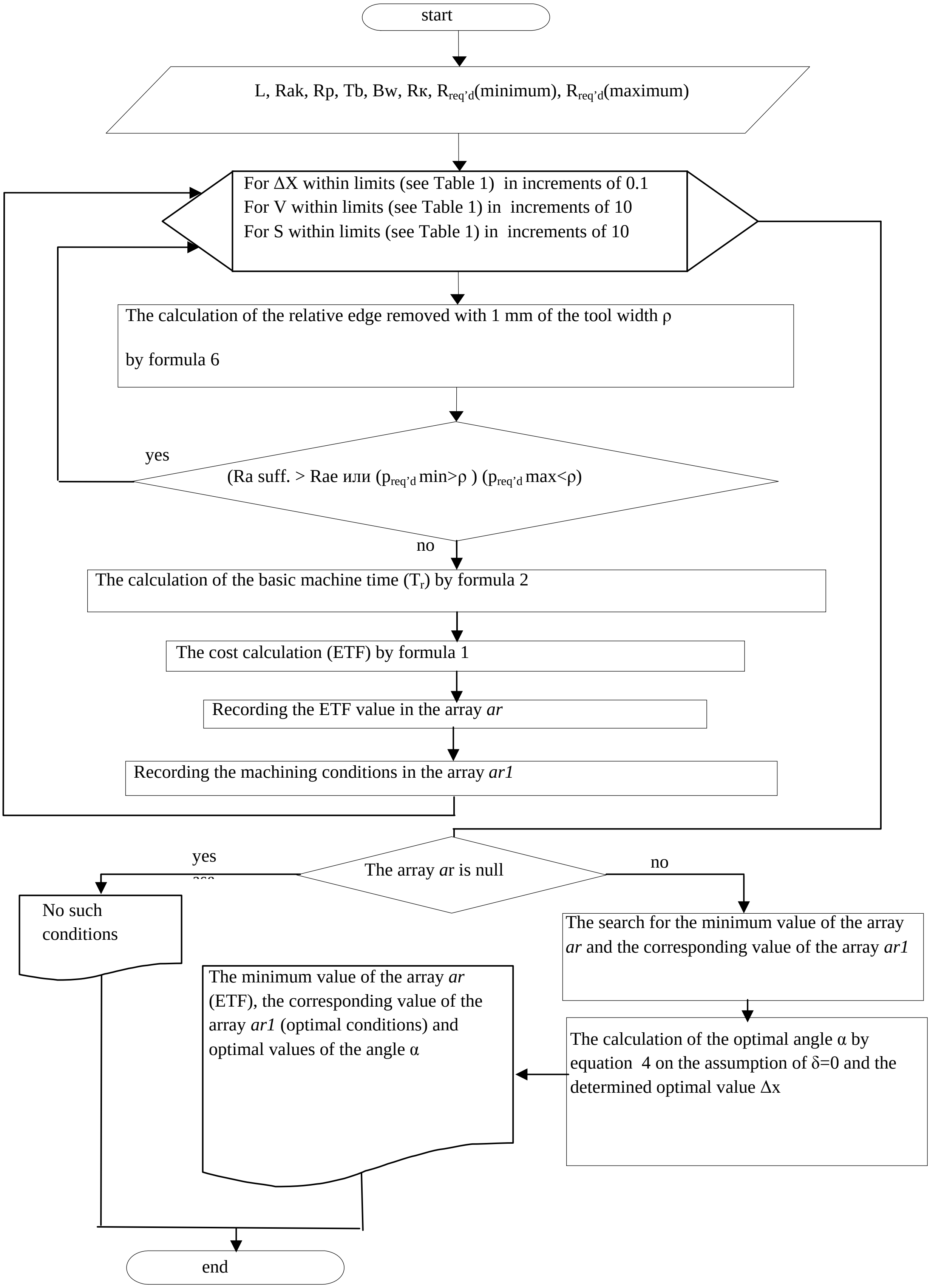

Fig. 3 Optimality calculation algorithm for edge rounding with elastic abrasive wheels

IV. MACHINING RECOMMENDATIONS

The program enables selection of the optimal tool and identifies the optimal conditions for machining aluminum alloy V95pchT2 parts with elastic abrasive tools. For this purpose, all the input parameters (edge length, mm; required minimum and maximum edge size, mm; required roughness, µm; pay rate, rubles; non-productive machine time, min.) must be entered.

The program was used to calculate the optimal machining parameters for V95pchT2 aluminum alloy (Table 5). These parameters are recommended for industries which implement machining with elastic abrasive wheels. The machining conditions for V95pchT2 shown in Table 5 are applicable to similar aluminum alloys: V950chT2, 1933T2, 1933T123, 1193T3, 1933T3-P, 1163T, 1163PDTV. All of them are widely used in the aircraft industry.

Table 5. Recommended cutting conditions of edge rounding with elastic wheels for aluminum alloy V95pchT2 machine parts

Required edge size, mm	**Required Ra_e, µm**	**Recommended tool**	**V, m/min**	**ΔX, mm**	**S, mm/min**	**α°**
0.25±0.15	1.0	CF-FB-0.5AFIN	1000	4.4	170	23.98
	1.6	CB-ZS P180	480	3.4	970	18.76
	2.5	FF-ZS ACRS	300	3.4	1000	16.97
	3.2	FF-ZS ACRS	240	3.7	1000	16.77
0.5±0.2	1.0	CF-FB-0.5AFIN	1000	4.4	180	23.98
	1.6	CB-ZS P180	480	3.4	1000	18.76
	3.2	FF-ZS ACRS	230	4	1000	16.56
	6.3	FF-ZS ACRS	230	4	1000	16.56

V. CONCLUSION

1. The economic target function as an optimization criterion can help increase the production efficiency.
2. The optimization system can help select the cost-efficient machining conditions using available equipment and tools.
3. The machining recommendations may find wide applications in the aircraft industry.

Acknowledgment

The information presented in this article is carried out with the financial support of the Government of the Russian Federation (Russian Ministry of Education) for the integrated project 2012-218-03-120 "Automation and efficiency of manufacturing processes and manufacture of products of new generation aircraft, the Scientific Production Corporation "Irkut" with the scientific support of the Irkutsk State technical University ", according to the decision of the Government of the Russian Federation, April 9, 2010 № 218.

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AUTHOR PROFILE

Yuriy Dimov, Doctor of Engineering Sciences, Professor. Irkutsk National Research Technical University, Engineering Design and Standardization Department, Professor. Affiliation address: 83 Lermontov St., Irkutsk, 664074, phone: (3952) 40-51-46. Home address: 53 Pervomayskiy Distr., Apt. 8, Irkutsk, 664058 (P.O.B. 355), phone: (3952) 36-62-70, mobile phone: 89645427169, e-mail: Dimov-Ura@yandex.ru

Dmitriy Podashev, Candidate of Engineering Sciences. Irkutsk National Research Technical University, Engineering Design and Standardization Department, Professor. Affiliation address: 83 Lermontov St., Irkutsk, 664074, phone: (3952) 40-51-46. Home address: 55, Volzhskaya St., Apt. 48, phone: (3952) 23-15-30, mobile phone: 89086558744, e-mail: dbp90@mail.ru