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Modeling of the characteristics of the microstructure of the surface with strengthening of static-pulse treatment

Kokoreva Olga Grigoryevna

Name of institute: Murom Institute, branch of Federal state educational institution of higher professional education «Vladimir state University named Alexander and Nicholas Stoletovs»
Summary: analysis of the characteristics of the microstructure of the surface of samples of steel 110G13L hardened static-pulse treatment (SPT). The result of research is development of mathematical model of microstructure characteristics depending on the modes SPT represented by a polynomial of the second degree. The dynamics of the following parameters: diameter of grain, its area, number of grains per unit of area and surface hardness. Independent factors were: the impact energy, advanced statistical effort diameter and roller width, depth of hardening.

Studies have shown that the cause of hardening of high-manganese steel (HMS) when static-pulse treatment (SPT) is the fragmentation of corns of austenita in small blocks and blocking the slip planes that provides a significant increase in microhardness and durability. Microstructural study confirmed the results of tests on durability, microhardness and mechanical characteristics of the samples from the HMS, hardened SPT in production conditions.
Keywords: microstructure, mathematical model, modes and characteristics of the treatment, static-pulse hardening, static effort, the depth of hardening, geometrical parameters of the indenter, the crushing of grains, blocking the slip planes.

Research objective: to analyze the effect modes SPT, and create a mathematical model of microstructure characteristics depending on the modes SPT. For the studied microstructural characteristics taken following parameters: diameter of grain - dm , its area - S, number of grains per unit of area - N and surface hardness, the independent factors were: the energy of the impact - E, j (X1), preliminary statistical force - Fst, kN (x2), the diameter and width of roller - Dp and b, mm (X3,X4), the depth of hardening - h, mm (X5) (table. 1)

Table 1

Factors	Levels		
	-	0	+
X1	150	250	350
X2	20	30	40
X3	10	15	20
X4	15	25	35

Necessary data the results of the experiment are given in the form of a planning matrix. Using the program for data processing in Statistica 5.1 the company StatSoft Inc. We make the regression equation in the form:

$$y = b_0 + b \cdot X1 + b_2 \cdot X2 + ... + b_k \cdot XK + b_{12} \cdot X1 \cdot X2 +$$
$$+ b_{13} \cdot X1 \cdot X3 + ... + b_{k-1} \cdot X(K-1) \cdot XK$$

Defining the regression coefficients bO, b1, ... bK, we obtain the following dependencies: When X3=20, X4=15, X5=0...8

$$Y2_{x4,x5} = 0{,}009403 \cdot X3 + 0{,}000104 \cdot X4^2 + 0{,}002243 \cdot X5^2$$

when X3=10...20 X4=0...8

$$Y1_{x3,x5} = 0{,}016823 \cdot X5 + 0{,}002438 \cdot X3$$

when X3=10...20, X5=0

$$Y3_{x3,x5} = 0{,}126098 + 0{,}002243 \cdot X5^2 - 0{,}003475 \cdot X3$$

when X3=10...20, X4=15, X5=0...8

$$Y4_{x3,x5} = 4293{,}39 \cdot X3 + 0{,}83 \cdot X3 \cdot X5 + 284{,}11 \cdot$$

$$\cdot X5^2 - 3567{,}07 \cdot X5 - 2138{,}6 \cdot X4$$

The results of calculations and the obtained equations are presented depending on pictures 1-4. A number of summands in the model reflect the impact of individual factors, and mixed interaction effects: impact energy, static component of the load, the geometric parameters of the indenter and the depth of the hardened layer. From a mathematical model shows that the most complex nature of the dependence of grain size for steel 110G13L on the diameter of the indenter. Studies also indicate the need for optimization this parameter. Thus, using a mathematical model was found that most small grains fixed on the surface of samples of steel 110G13L, hardened SPT.

Testing the significance of the coefficients was performed by student's criterion: S{bj} = 2,57, at a significance level of 0.05, confidence interval Δbj =2,5; S{b} = 1,05. Largest regression coefficient conclude that the most significant factor is the diameter of the roller when processing CIO, the variance of the reproducibility of results S2(y) is 0,28, the variance of the adequacy of $S^2_{ад}$=1,0, $F_{\text{ÝÊÑ}} = \dfrac{1{,}0}{0{,}28} = 3{,}4,\ F_{\text{ÒÀÁË}} = 10{,}5$. Consequently, the model is adequate. Thus we obtain adequate model for which the level of significance is equal to 0.05.

Studies have shown that cause hardening of the HMS when static-pulse processing is crushing corns of austenita in small blocks and blocking the slip planes that provides a significant increase in microhardness and durability.

Mathematical model of the quantitative characteristics of the microstructure of steel 110G13L, which enabled to evaluate the significance of the modes of the static-pulse hardening.

Conclusions: as a result of metallographic research of samples of steel 110G13L, hardened, ICN, in terms of production, the analysis of influence of modes of SPT on the main characteristics of the microstructure. As a result of the implementation of full factorial experiment 24 and processing of data in the packet Statistics 5.1 the company StatSoft Inc. mathematical model of microstructure characteristics depending on the modes SPT, which is represented by a polynomial of the second degree.

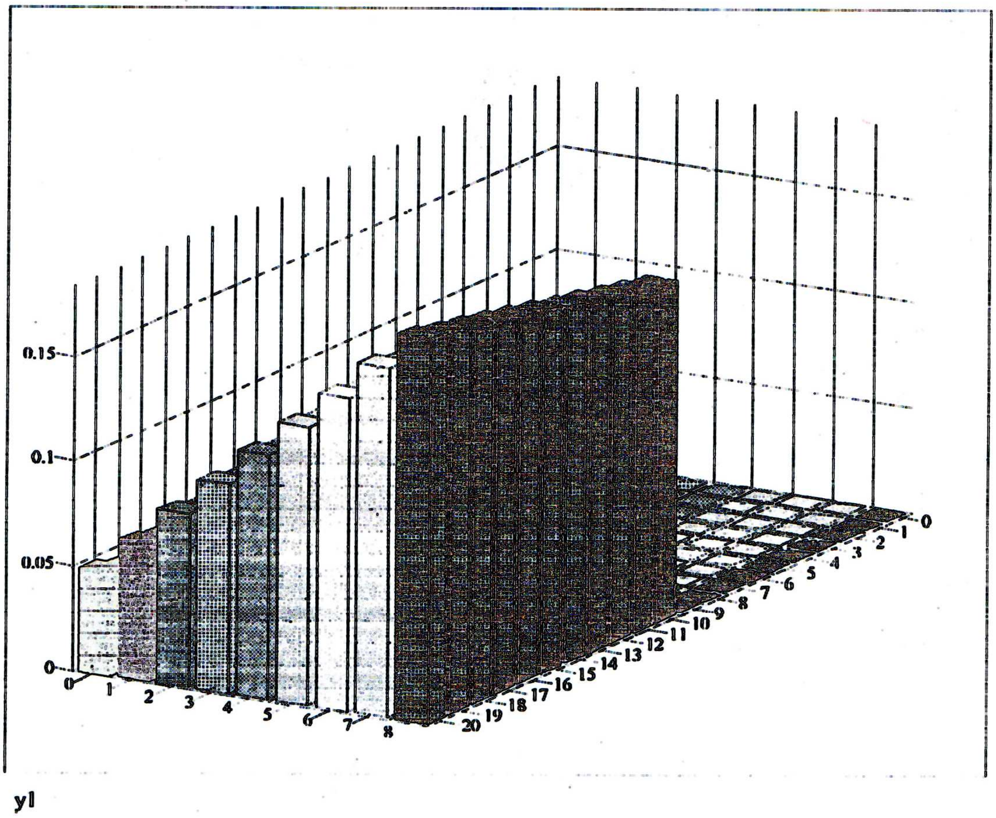
Microstructural study confirmed the results of tests on durability, microhardness and mechanical characteristics of the samples from the HMS, hardened SPT in production conditions.

$x5 := 0..8 \qquad x3 := 10..20$

$yl_{x3,x5} := 0.016823 \cdot x5 + 0.002438 \cdot x3$

yl =

	0	1	2	3	4	5	6	7	8
10	0.024	0.041	0.058	0.075	0.092	0.108	0.125	0.142	0.159
11	0.027	0.044	0.06	0.077	0.094	0.111	0.128	0.145	0.161
12	0.029	0.046	0.063	0.08	0.097	0.113	0.13	0.147	0.164
13	0.032	0.049	0.065	0.082	0.099	0.116	0.133	0.149	0.166
14	0.034	0.051	0.068	0.085	0.101	0.118	0.135	0.152	0.169
15	0.037	0.053	0.07	0.087	0.104	0.121	0.138	0.154	0.171
16	0.039	0.056	0.073	0.089	0.106	0.123	0.14	0.157	0.174
17	0.041	0.058	0.075	0.092	0.109	0.126	0.142	0.159	0.176
18	0.044	0.061	0.078	0.094	0.111	0.128	0.145	0.162	0.178
19	0.046	0.063	0.08	0.097	0.114	0.13	0.147	0.164	0.181
20	0.049	0.066	0.082	0.099	0.116	0.133	0.15	0.167	0.183



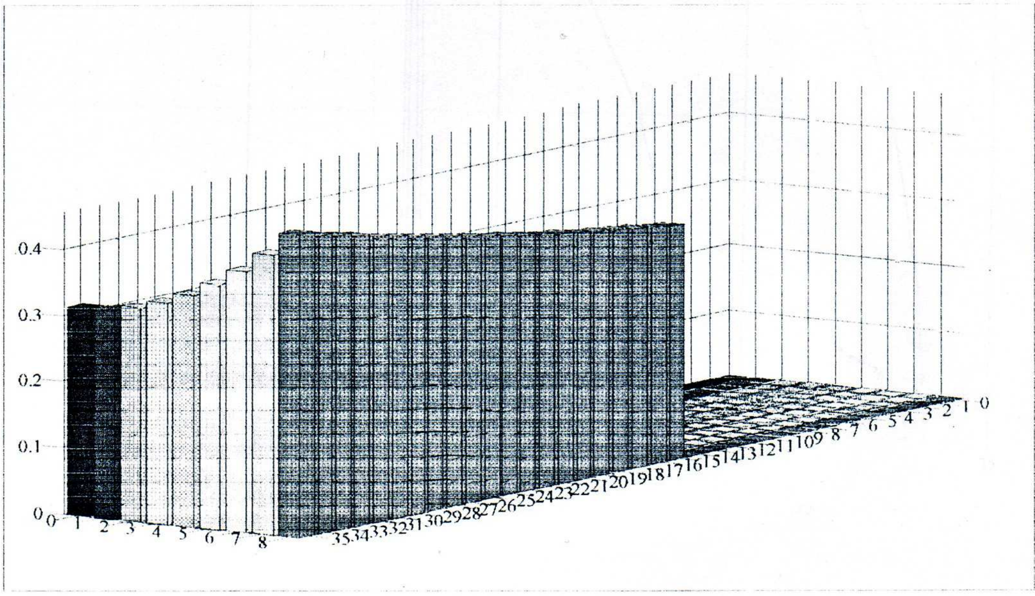
Picture 1.

$x3 := 20 \qquad x4 := 15..35 \qquad x5 := 0..8$

$$y2_{x4,x5} := 0.009403 \cdot x3 + 0.000104 \cdot x4^2 + 0.002243 \cdot x5^2$$

y2 =

	0	1	2	3	4	5	6	7	8
15	0.211	0.214	0.22	0.232	0.247	0.268	0.292	0.321	0.355
16	0.215	0.217	0.224	0.235	0.251	0.271	0.295	0.325	0.358
17	0.218	0.22	0.227	0.238	0.254	0.274	0.299	0.328	0.362
18	0.222	0.224	0.231	0.242	0.258	0.278	0.303	0.332	0.365
19	0.226	0.228	0.235	0.246	0.261	0.282	0.306	0.336	0.369
20	0.23	0.232	0.239	0.25	0.266	0.286	0.31	0.34	0.373
21	0.234	0.236	0.243	0.254	0.27	0.29	0.315	0.344	0.377
22	0.238	0.241	0.247	0.259	0.274	0.294	0.319	0.348	0.382
23	0.243	0.245	0.252	0.263	0.279	0.299	0.324	0.353	0.387
24	0.248	0.25	0.257	0.268	0.284	0.304	0.329	0.358	0.392
25	0.253	0.255	0.262	0.273	0.289	0.309	0.334	0.363	0.397
26	0.258	0.261	0.267	0.279	0.294	0.314	0.339	0.368	0.402
27	0.264	0.266	0.273	0.284	0.3	0.32	0.345	0.374	0.407
28	0.27	0.272	0.279	0.29	0.305	0.326	0.35	0.38	0.413
29	0.276	0.278	0.284	0.296	0.311	0.332	0.356	0.385	0.419
30	0.282	0.284	0.291	0.302	0.318	0.338	0.362	0.392	0.425
31	0.288	0.29	0.297	0.308	0.324	0.344	0.369	0.398	0.432
32	0.295	0.297	0.304	0.315	0.33	0.351	0.375	0.404	0.438
33	0.301	0.304	0.31	0.322	0.337	0.357	0.382	0.411	0.445
34	0.308	0.311	0.317	0.328	0.344	0.364	0.389	0.418	0.452
35	0.315	0.318	0.324	0.336	0.351	0.372	0.396	0.425	0.459



y2

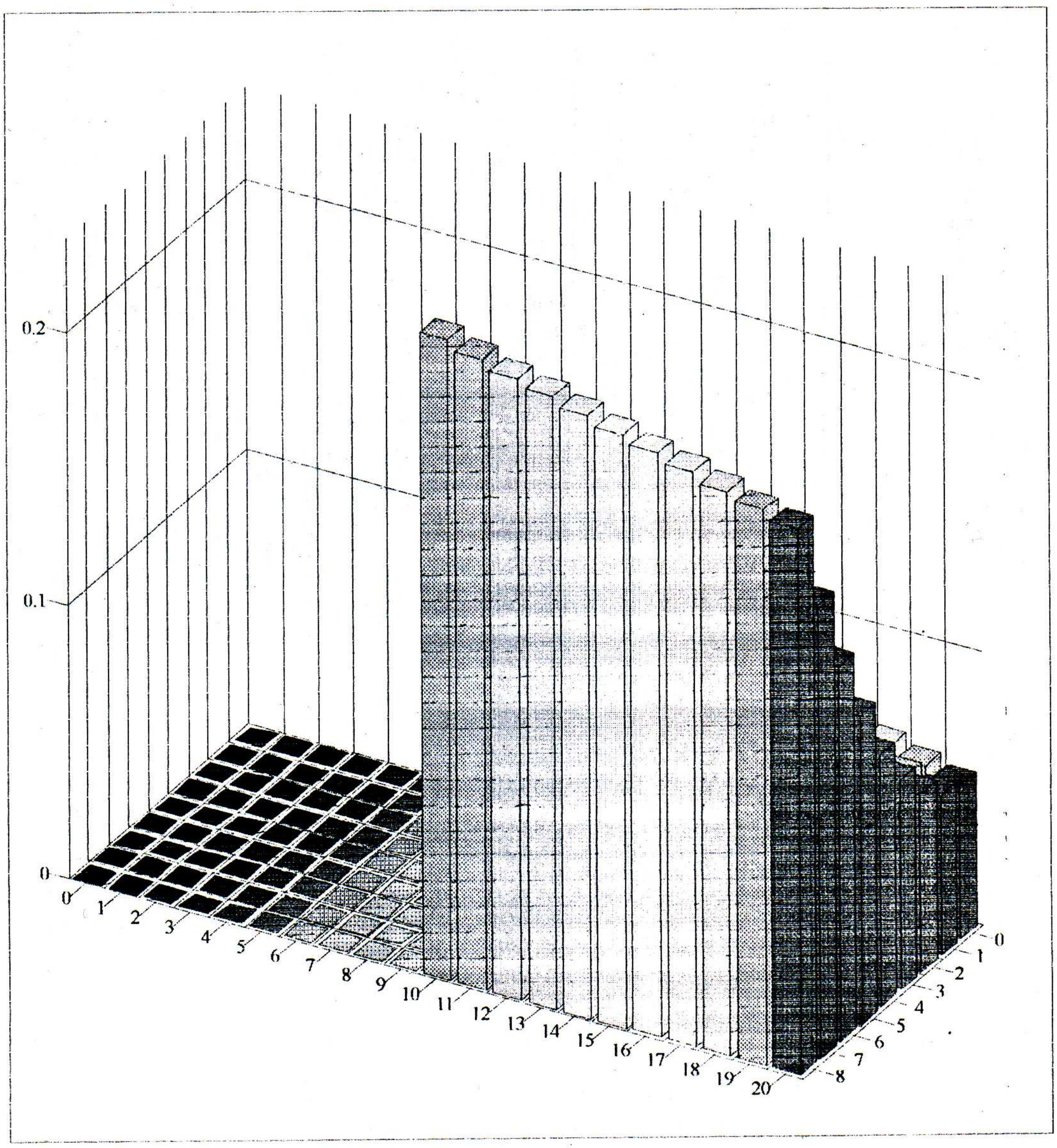
Picture 2.

$x5 := 0..8 \quad x3 := 10..20$

$$y3_{x5,x3} := 0.126098 + 0.002243 \cdot x5^2 - 0.003475 \cdot x3$$

y3 =

	8	9	10	11	12	13	14	15	16	17	18	19	20
0	0	0	0.091	0.088	0.084	0.081	0.077	0.074	0.07	0.067	0.064	0.06	0.057
1	0	0	0.094	0.09	0.087	0.083	0.08	0.076	0.073	0.069	0.066	0.062	0.059
2	0	0	0.1	0.097	0.093	0.09	0.086	0.083	0.079	0.076	0.073	0.069	0.066
3	0	0	0.112	0.108	0.105	0.101	0.098	0.094	0.091	0.087	0.084	0.08	0.077
4	0	0	0.127	0.124	0.12	0.117	0.113	0.11	0.106	0.103	0.099	0.096	0.092
5	0	0	0.147	0.144	0.14	0.137	0.134	0.13	0.127	0.123	0.12	0.116	0.113
6	0	0	0.172	0.169	0.165	0.162	0.158	0.155	0.151	0.148	0.144	0.141	0.137
7	0	0	0.201	0.198	0.194	0.191	0.187	0.184	0.18	0.177	0.173	0.17	0.167
8	0	0	0.235	0.231	0.228	0.224	0.221	0.218	0.214	0.211	0.207	0.204	0.2



y3

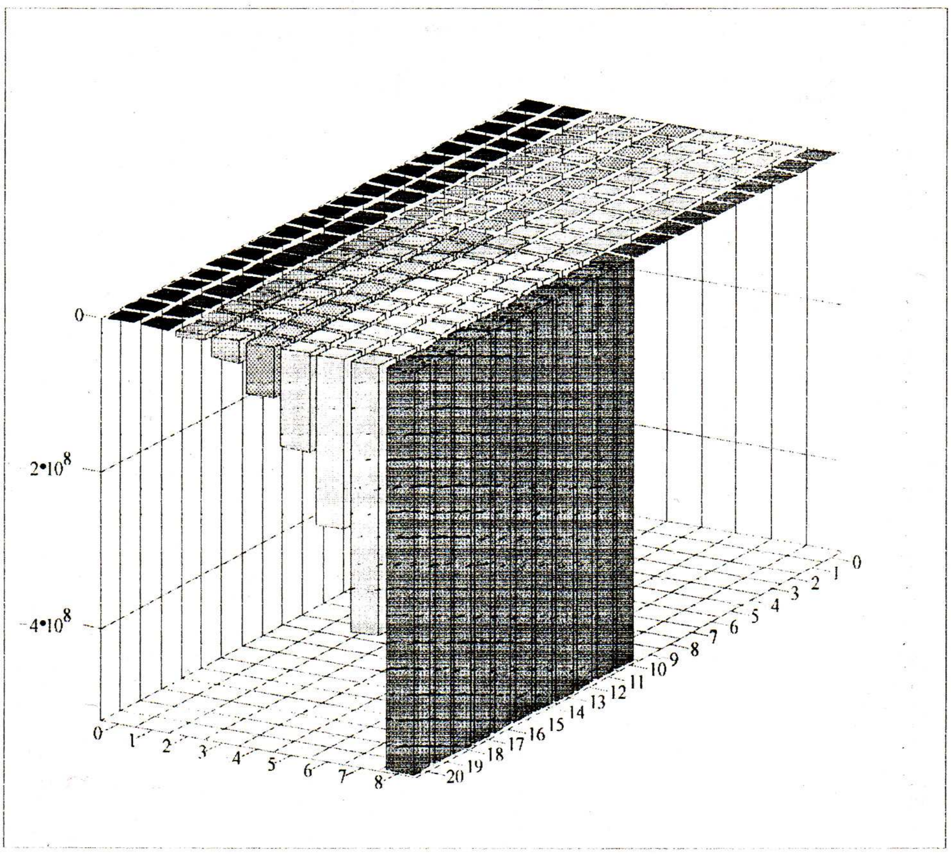
Picture 3.

$x3 := 10..20 \quad x4 := 15 \quad x5 := 0..8$

$y4_{x3,x5} := 4293.39 \cdot x3 + 0.83 \cdot x5 \cdot x3 + 284.11 \cdot x5^2 - 3567.07 \cdot x5 - 2138.6\, x4$

y4 =

	0	1	2	3	4	5	6	7	8
10	$1.085 \cdot 10^4$	$-1.003 \cdot 10^6$	$-8.097 \cdot 10^6$	$-2.735 \cdot 10^7$	$-6.485 \cdot 10^7$	$-1.267 \cdot 10^8$	$-2.189 \cdot 10^8$	$-3.476 \cdot 10^8$	$-5.189 \cdot 10^8$
11	$1.515 \cdot 10^4$	$-9.983 \cdot 10^5$	$-8.092 \cdot 10^6$	$-2.735 \cdot 10^7$	$-6.484 \cdot 10^7$	$-1.267 \cdot 10^8$	$-2.189 \cdot 10^8$	$-3.476 \cdot 10^8$	$-5.189 \cdot 10^8$
12	$1.944 \cdot 10^4$	$-9.94 \cdot 10^5$	$-8.088 \cdot 10^6$	$-2.734 \cdot 10^7$	$-6.484 \cdot 10^7$	$-1.267 \cdot 10^8$	$-2.189 \cdot 10^8$	$-3.476 \cdot 10^8$	$-5.189 \cdot 10^8$
13	$2.374 \cdot 10^4$	$-9.897 \cdot 10^5$	$-8.084 \cdot 10^6$	$-2.734 \cdot 10^7$	$-6.484 \cdot 10^7$	$-1.267 \cdot 10^8$	$-2.189 \cdot 10^8$	$-3.476 \cdot 10^8$	$-5.189 \cdot 10^8$
14	$2.803 \cdot 10^4$	$-9.854 \cdot 10^5$	$-8.079 \cdot 10^6$	$-2.733 \cdot 10^7$	$-6.483 \cdot 10^7$	$-1.267 \cdot 10^8$	$-2.189 \cdot 10^8$	$-3.476 \cdot 10^8$	$-5.189 \cdot 10^8$
15	$3.232 \cdot 10^4$	$-9.811 \cdot 10^5$	$-8.075 \cdot 10^6$	$-2.733 \cdot 10^7$	$-6.483 \cdot 10^7$	$-1.266 \cdot 10^8$	$-2.189 \cdot 10^8$	$-3.476 \cdot 10^8$	$-5.188 \cdot 10^8$
16	$3.662 \cdot 10^4$	$-9.768 \cdot 10^5$	$-8.071 \cdot 10^6$	$-2.733 \cdot 10^7$	$-6.482 \cdot 10^7$	$-1.266 \cdot 10^8$	$-2.189 \cdot 10^8$	$-3.476 \cdot 10^8$	$-5.188 \cdot 10^8$
17	$4.091 \cdot 10^4$	$-9.725 \cdot 10^5$	$-8.067 \cdot 10^6$	$-2.732 \cdot 10^7$	$-6.482 \cdot 10^7$	$-1.266 \cdot 10^8$	$-2.189 \cdot 10^8$	$-3.476 \cdot 10^8$	$-5.188 \cdot 10^8$
18	$4.52 \cdot 10^4$	$-9.682 \cdot 10^5$	$-8.062 \cdot 10^6$	$-2.732 \cdot 10^7$	$-6.481 \cdot 10^7$	$-1.266 \cdot 10^8$	$-2.189 \cdot 10^8$	$-3.476 \cdot 10^8$	$-5.188 \cdot 10^8$
19	$4.95 \cdot 10^4$	$-9.639 \cdot 10^5$	$-8.058 \cdot 10^6$	$-2.731 \cdot 10^7$	$-6.481 \cdot 10^7$	$-1.266 \cdot 10^8$	$-2.189 \cdot 10^8$	$-3.476 \cdot 10^8$	$-5.188 \cdot 10^8$
20	$5.379 \cdot 10^4$	$-9.596 \cdot 10^5$	$-8.054 \cdot 10^6$	$-2.731 \cdot 10^7$	$-6.481 \cdot 10^7$	$-1.266 \cdot 10^8$	$-2.188 \cdot 10^8$	$-3.476 \cdot 10^8$	$-5.188 \cdot 10^8$



y4

Picture 4.

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