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LABORATORY STUDIES OF THE FORMATION OF A WOOD BUNDLE BY LEVELING DEVICES

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Abstract: *The main development trend of the logging industry is the continuous improvement of existing equipment, the manufacturing application of prospective technological processes, and the use of effective technical solutions that will increase labor productivity and reduce production costs. About 150 million m^3 of wood is harvested annually in Russia. The harvested wood is supplied to consumers by road 54.7%, rail 39%, and water 6.3% transport [11]. Each type of vehicle has its own rules for the transportation of goods. In order to load round timber into transport as efficiently as possible, it is necessary to align the ends of the round timber. The problem of alignment of the ends of round timber is widespread in the logging industry. Often, this problem is solved individually at each enterprise. To form a pack of logs before loading on the timber transport, various end-leveling devices are used. Gravity levelers are the most common, they are easy to manufacture and economical. The principle of their work is to use the gravity of the load lowered by the crane onto the alignments equipment. The currently existing and previously developed designs of such devices have a number of disadvantages: long alignment time, large friction forces, and the need to repeat the operations. Therefore, the purpose of our research is to improve the design of gravity levelers for the qualitative formation of the bundle, which is an urgent task today. This will increase the efficiency of loading wood raw materials into logging transport, and labor productivity.*

Key words: *leveling devices, alignment of the ends, cargo beams, leveler, logging transport.*

1. Introduction

To date, there is a lot of different equipment for leveling timber. For example, Yoma GmbH has developed a device for making timber piles and for their transportation [4], Nikolenko D.I. – an invention for the alignment of the ends of the pads [8]. In Russia the Volga-Kama research Institute of the forestry industry has developed mobile gravity levelers TGPK-1, K-127, K-153; Perm Design Bureau

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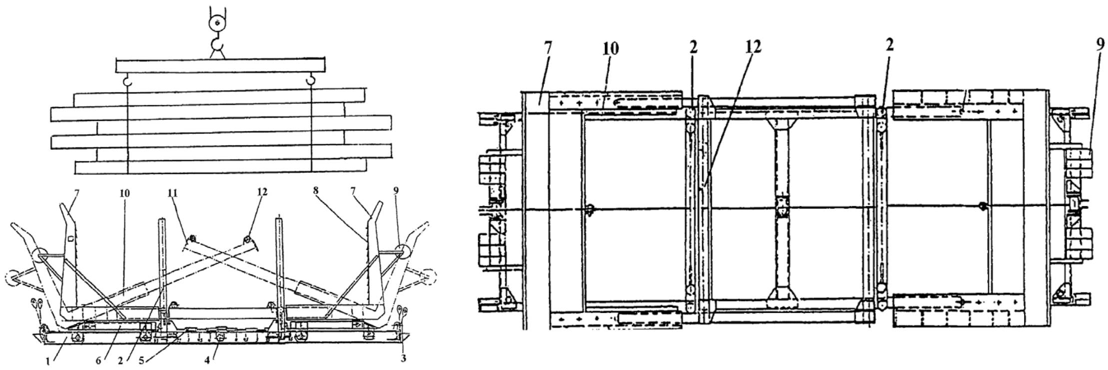
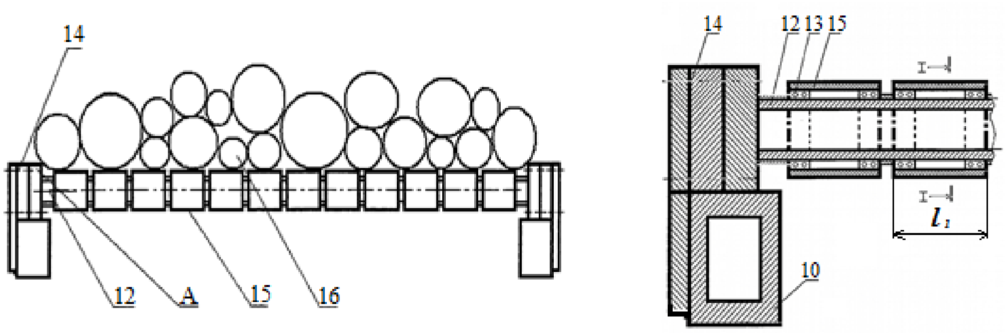
- mobile gravity equipment LT-106; Northern research Institute of industry - stationary gravity devices L-460, LT-105; Irkutsk branch of the central research Institute of mechanization and energy of the forestry industry - invention LV-126 [3, 13, 16]. The disadvantage of these Russian gravitational inventions is a long cycle of alignment of the ends associated with the presence of high friction forces and the need to repeatedly lower a bundle of logs onto the leveler using a crane. Each such device is developed by the enterprises themselves and meets the conditions of their enterprise, which excludes their wide application in production. Also, the Volga-Kama research Institute of water forest transport (VKNIVOLT) has developed the K-142 leveler [2]. Its main disadvantage is the presence of large friction forces between the receiving cross-beams and a timber bundle. When attempting alignment of the timber ends, there is sliding friction between them and the crossbeams of the leveling devices. It increases the overall leveling force of the logs and reduces the quality of the alignment of the timber ends. Consequently, labor productivity slackens.

To eliminate the shortcomings of existing end levelers, a new design is proposed [6]. The prototype of the new invention is a gravitational device K-142 [2]. In the proposed invention (Figure 1), self-rotating cylinders on ball bearings are mounted on cargo beams. The section of the cargo beam is shown in Figure 2.



a. b.

Fig. 1. *Portable modernized device for leveling the ends of a bundle of logs:*
1 - metal frame; 2 - stands-catchers; 3 - cable block system; 4 - intermediate support; 5 - adjusting chain; 6 - mobile carriage; 7 - L-shaped swivel end shield; 8 - horizontal ribs; 9 - counterweight; 10 - telescopic beam; 11 - stops; 12 - removable cargo beam
(Source: Compiled by the authors)



a. b.

Fig. 2. *Cargo beam of the gravity leveling device (a.) and cargo beam in section (b.): 10 - telescopic beam; 12 - removable cargo beam; 13 - ball bearings; 14 - bolted connections; 15 - self-rotating cylinders; 16 - timber (Source: Compiled by the authors)*

The width of these cylinders l1 is equal to the minimum diameter of the logs. When leveling, the rotating cylinders allow the round timber to move independently of each other on the cross-beams in opposite directions, and also to reduce the friction forces between the cargo beams and the lower row of timber.

In the proposed design, the sliding friction of the timber against the cargo beams will be replaced by rolling friction. The rotating cylinders on the load beams (Figure 2) when interacting with a timber pack roll on the surface of the logs and create a slight rolling resistance. The rolling friction is many times much less than the sliding friction, because the rolling friction coefficients (wood-steel) 0.03 are 20 times less than the sliding friction (steel-oak) 0.6 [7]. Therefore, this invention will reduce the friction forces between the cargo beams of the device and a timber bundle, intensify the process of alignment of the logs, improve the quality of the timber ends and the performance of the equipment, and reduce the power consumption of the cranes.

To verify this statement, it is necessary to conduct experimental studies, make models of a laboratory installation for the formation of wood loads, compare the values of time, quality, and leveling effort obtained in the experiment on the model of an existing and upgraded device.

2. Materials and Methods

To test our claim about the effectiveness of the new invention, experiments? were carried out in the laboratory conditions of the Department of Forestry and Chemical Technologies of the Volga State Technological University on physical models of the mechanism of lowering timber by a tower crane and a gravity leveler [1], [5].

The analysis of theoretical and experimental studies allowed us to establish that the magnitude of the leveling force of logs with a gravitational device is significantly influenced by: the weight of the load P, the mass of the wood *m*, the coefficient of friction of the logs along the fibers *f*, the dimensions of the bundle of timber: the height *H* and the length *L*, the average diameter of the logs *d*, the ratio of the protruding logs to their total number *k*, the end thrust coefficient *λ*, the acceleration of gravity *g*, and the rate of lowering of the load *v* (Equation (1)):

$$F_T = f(P, m, f, H, L, d, k, \lambda, g, \upsilon) \qquad (1)$$

In accordance with the similarity theory [12], out of 10 dependence parameters, among which three factors *m*, *g*, *f* are chosen as the main ones, 7 dimensionless complexes can be formed, which are similarity criteria (Equation (2)):

$$F_T = f\left(\frac{P \cdot L}{m \cdot \upsilon^2}; \frac{\upsilon^2}{g \cdot H}; f; k; \lambda; \frac{H}{L}; \frac{d}{H}\right) \qquad (2)$$

To conduct experimental studies, a laboratory installation was made on a scale of 1:10 (Figure 3). It included:

- A tower-type lifting mechanism with a capacity of 0.5 kW and a load capacity of 0.6 kN;
- A gravity leveler K-142 of the basic and modernized design with a load capacity of 0.11 kN;
- Models of forest goods of various sizes, shapes, and breeds;
- A set of measuring instruments and recording equipment;
- A converter;
- A computer.

Fig. 3. *Laboratory installation for studying the process of timber alignment*

Methods of mathematical and physical modeling were used in the manufacture of the installation. The two-mass crane-leveler system was adopted as the initial one for modeling when designing, which is sufficient to ensure the similarity of the parameters included in this system. The measurement of the loads and stresses in the nodes of the leveling device was carried out by the strain gauge method. The recalculation of the main parameters from the model to nature was carried out according to the Newton criterion [14].

A model of the basic and upgraded design of the K-142 device was made (Figure 4). To measure the force, sensors were installed between the leveling shields. To conduct a laboratory experiment to determine the force of alignment of the ends of the logs with leveling equipment, 4 significant parameters: the weight of the timber *P*, the ratio of the protruding logs to their total number *k*, the diameter of the logs *d*, and the length of the timber *L,* were selected. They varied at five levels (Table 1).

Levels of variation of significant factors Table 1

Parameters	Levels of variation				
	-2	-1	0	+1	+2
1. The weight of the timber P [kN]	50	65	80	95	110
2. The ratio of the protruding logs to their total number, k	0.1	0.2	0.3	0.4	0.5
3. The diameter of the logs, d [m]	0.1	0.18	0.24	0.3	0.38
4. The length of the timber, L [m]	4.0	4.5	5.0	5.5	6.0

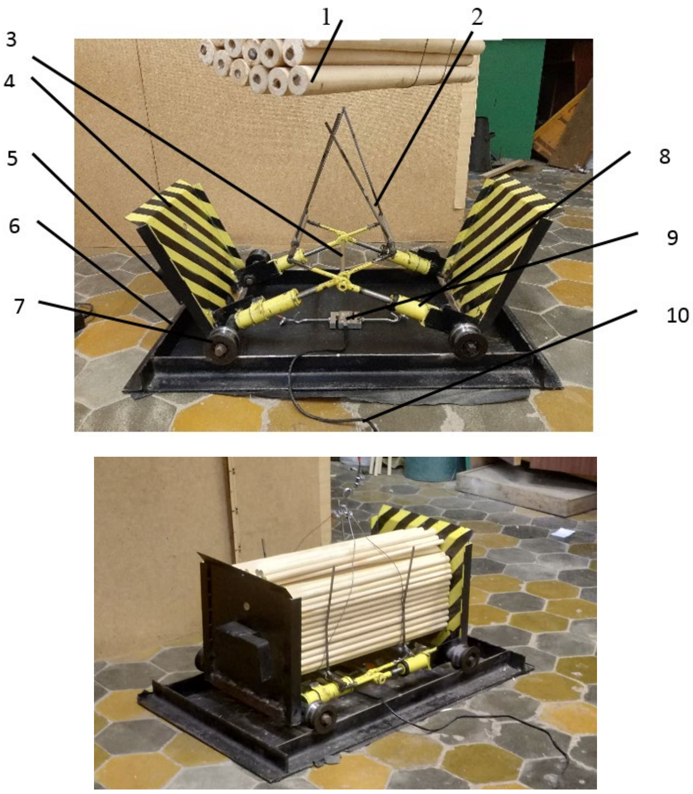


Fig. 4. *Model of gravity device:*
1 - a pack of model logs; 2 - stand-catchers; 3 - removable cargo beam; 4 - end-leveling shield; 5 - counterweight; 6 - frame; 7 - mobile roller; 8 - telescopic retractable beam; 9 – force load cell; 10 - connecting wire
(Source: Compiled by the authors)

An arithmetic progression was chosen as a rational sequence of variation of the significant parameters. To improve the efficiency of the studies, a rational experiment planning technique based on the idea of the Latin square was chosen [9], which allowed to reduce the number of observations by 25 times. A total of 600 experiments were performed. Laboratory research was carried out on an experimental setup (Figure 4). The order is as follows. The investigated model of a bundle of logs of given dimensions was placed on a measuring table by a crane. After measuring the weight, volume, and geometric parameters, a bundle of timber with a given number of protruding ends of the logs was lowered by a lifting mechanism onto the load beams of the equipment. Also, the time of the end alignment was measured (the time of lowering the timber bundles onto the device, the time of the alignment of the ends of the logs with rotary shields, the time of lifting the timber bundles from the device) and the effort of leveling the bundle of the model logs. A ruler measured the distances between the leveling shields. Next, a bundle of model logs was lifted by a crane from the device to a measuring table, the quality of alignment was determined, and the run-up of the ends of the logs along the perimeter of the pack was measured on both sides. The repeatability of each experiment was established by calculation. The alignment force of the bundles of logs was measured with a tensile force sensor UU-K10, UU-K50. To process the signals received from the force sensors, an NI 9219 analog signal conversion module was used. To control the measuring equipment, a computer with the LabVIEW program was used. First, the leveling forces of the wood were experimentally measured on the basic model of the K-142 device. Then the experiment was repeated on the upgraded equipment.

3. Results

The experimental values of the leveling forces of the timber ends on the basic and upgraded structures of the levelers, depending on each of the primary parameters, are presented in Tables 2 to 5. Graphs of the dependence of the average values of the alignment force on each parameter for the basic F_b and the modernized device designs F_m (Figures 5 to 8) are constructed.

Table 2

The values of the alignment force of the timber with a basic leveler $F_b = f_1 (P, k)$

k / P [kN]	0.1	0.2	0.3	0.4	0.5	Total value of force	Average value
50	32.65	59.74	46.64	70.87	105.46	315.36	63.07
65	106.31	64.48	87.02	62.81	85.24	405.86	81.17
80	108.29	112.02	85.61	106.32	106.48	518.72	103.74
95	174.13	82.24	154.41	97.26	114.76	622.80	124.56
110	176.67	181.43	169.87	181.17	124.91	834.05	166.81
Total value of force	598.05	499,91	543.55	518.43	536.85	1995.05	539.36
Average value of force	119.61	99.98	108.71	103.69	107.37	539.36	107.87

Table 3

The values of the alignment force of the timber with a modernized leveler
Fm = f_2 (P, k)

P [kN] \ k	0.1	0.2	0.3	0.4	0.5	Total value of force	Average value of force
50	30.77	56.11	44.65	67.01	55.34	253.88	50.78
65	79.46	61.32	85.46	61.85	82.33	370.42	74.08
80	102.37	108.77	81.09	95.18	91.51	478.93	95.79
95	135.89	80.26	133.58	95.31	111.25	556.28	111.26
110	114.95	135.81	103.98	125.63	83.35	563.72	112.74
Total value of force	463.45	442.27	448.78	444.97	423.78	2223.24	444.65
Average value of force	92.69	88.45	89.76	88.99	84.76	444.65	88.93

The values of the alignment force of the timber with a basic leveler $F_b = f_3$ (d, L) Table 4

d [m] \ L [m]	0.1	0.2	0.3	0.4	0.5	Total value of force	Average value of force
0.10	124.91	32.65	106.31	64.48	85.61	413.96	82.79
0.18	70.87	85.24	169.87	108.29	82.24	516.51	103.30
0.24	174.13	181.43	106.48	46.64	62.81	571.49	114.30
0.30	87.02	106,32	59.74	114.76	176.67	544.51	108.90
0.38	112.02	154.41	106.31	181.17	105.46	659.37	131.87
Total value of force	568.95	560.05	548.71	515.34	512.79	2705.84	541.17
Average value of force	113.79	112.01	109.74	103.07	102.56	541.17	108.23

Table 5

The values of the alignment force of timber with a modernized leveler
$F_m = f_4$ (d, L)

d [m] \ L [m]	0.1	0.2	0.3	0.4	0.5	Total value of force	Average value of force
0.10	67.01	30.77	56.11	44.65	81.09	279.64	55.93
0.18	85.46	82.33	79.46	61.32	80.26	388.83	77.77
0.24	108.77	95.18	91.51	102.37	61.85	459.68	91.94
0.30	135.89	133.58	95.31	111.25	65.34	541.37	108.27
0.38	83.35	135.81	103.98	125.63	114.95	563.72	112.74
Total value of force	480.49	477.67	426.38	445.21	403.49	1995.07	446.65
Average value of force	96.10	95.53	85.28	89.04	80.70	446.65	89.33

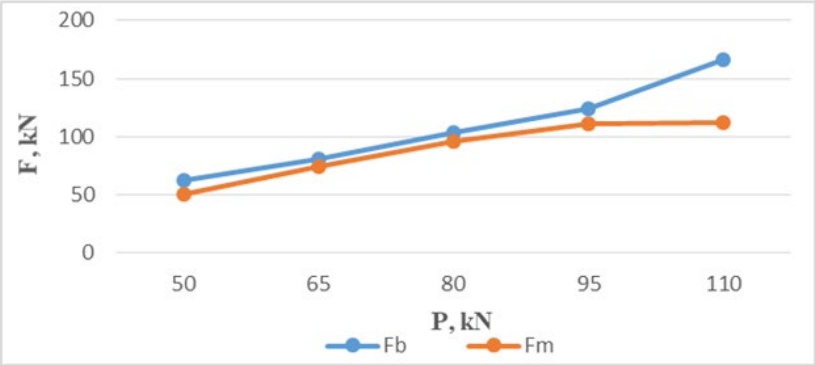


Fig. 5. *Graphs of the dependence of the average values of the alignment forces by the basic F_b and modernized F_m levelers on the weight of a bundle of timber P*

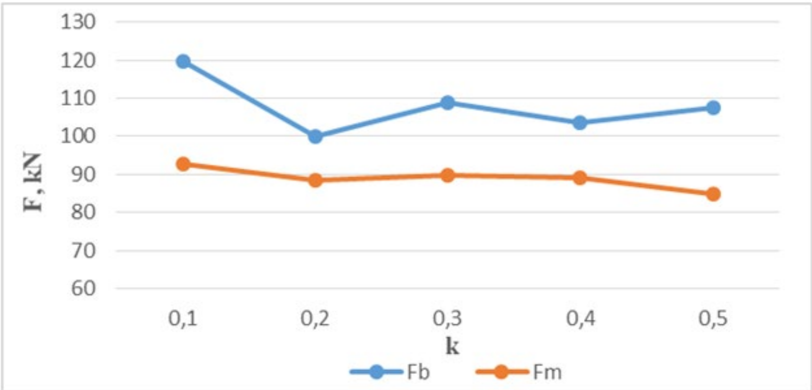


Fig. 6. *Graphs of the dependence of the average values of the alignment forces by the basic F_b and modernized F_m levelers on the ratio of protruding logs to their total number k*

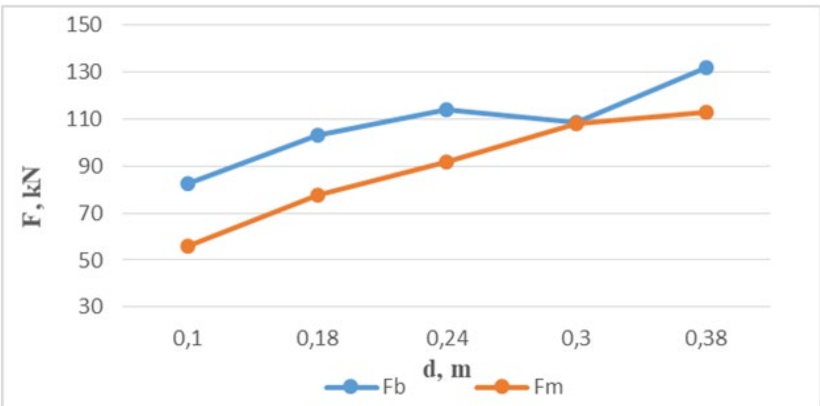


Fig. 7. *Graphs of the dependence of the average values of the alignment forces by the basic F_b and modernized F_m levelers on the diameter of the logs d*

Based on the results of the laboratory experiments in the Statistica program, graphs of the leveling force of the timber bundles by the basic (Figure 9) and modernized (Figure 10) devices from the parameters *P*, *k*, *d*, *L* are constructed.

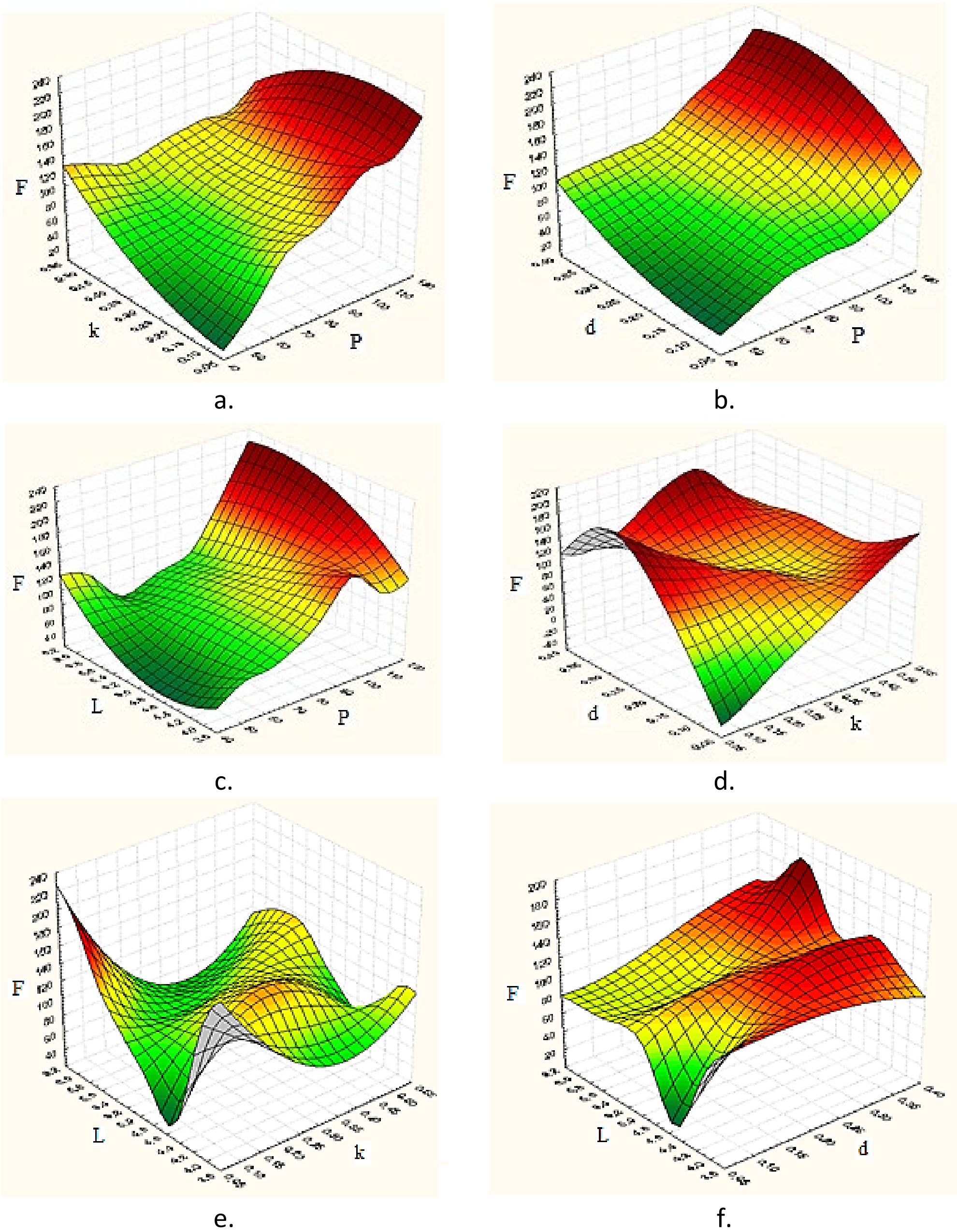


Fig. 9. *Dependence of the leveling force of the ends of the timber by the basic device* $F_b=f_1\ (P,k,d,L)$

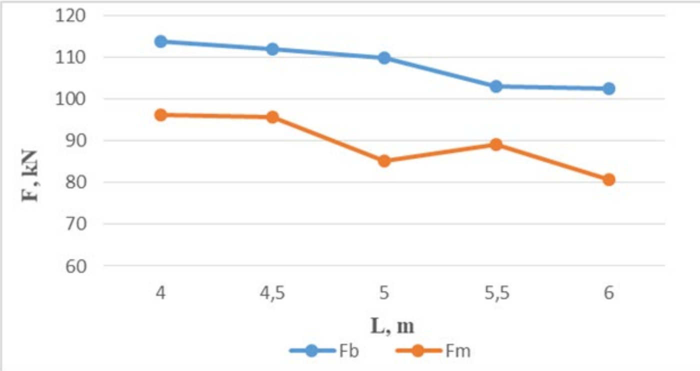


Fig. 8. *Graphs of the dependence of the average values of the alignment forces by the basic F_b and modernized F_m levelers on the length of the timber L*

The analysis of the experimental data obtained [10] for the modernized equipment showed that the force of alignment of the bundles of logs increases with increasing weight from 50 to 110 kN and the diameter from 0.1 to 0.38 m. When the length of the logs changes from 4 to 6 m, the force of alignment decreases. With a decrease in the ratio of the number of protruding logs, the leveling force of the timber also decreases. The reduction of the forces when leveling the ends of the logs on the designed structure, depending on the parameters, is presented in Tables 6 to 9 and Figures 11 to 14.

Table 6

Comparison of the force of alignment for the basic and modernized levelers depending on the weight of the timber $F=f_1$ (P)

P / F [kN]	50	65	80	95	110	Sum	Average value
Basic leveler F_b	63.07	81.17	103.74	124.56	166.81	539.36	107.87
Modernized leveler F_m	50.78	74.08	95.79	111.26	112.74	444.65	88.93
Reduction force F_b- F_m	12.30	7.09	7.96	13.30	54.07	94.71	18.94
Reduction [%]	19.49	8.73	7.67	10.68	32.41	78.99	15.80

Table 7

Comparison of the force of alignment for the basic and modernized levelers depending on the ratio of the protruding logs to their total number $F=f_2$ (k)

P / F [kN]	0.10	0.20	0.30	0.40	0.50	Sum	Average value
Basic leveler F_b	119.6	100.0	108.7	103.7	107.4	539.4	107.9
Modernized leveler F_m	92.7	88.5	89.8	89.0	84.8	444.6	88.90
Reduction force F_b- F_m	26.9	11.5	19,0	14.7	22.6	94.7	18.90
Reduction [%]	22.5	11.5	17,4	14.2	21.1	86.7	17.30

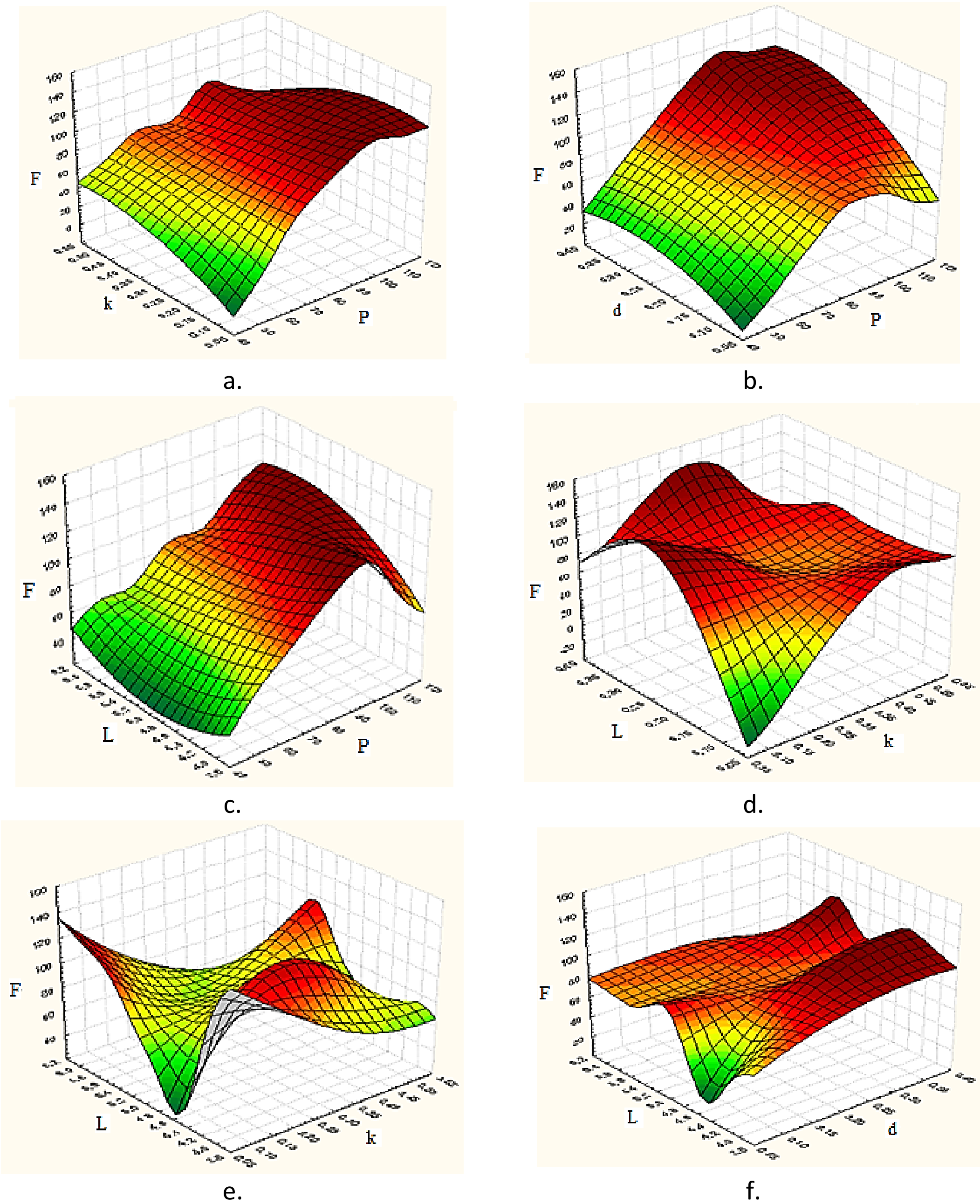


Fig. 10. *Dependence of the leveling force of the ends of the timber by the modernized device* $F_m = f_2\ (P, k, d, L)$

Table 8

Comparison of the force of alignment for the basic and modernized levelers depending on the diameter of the timber F=f_3 (d)

P / F [kN]	0.10	0.18	0.24	0.30	0.38	Sum	Average value
Basic leveler F_b	82.79	103.30	114.30	108.90	131.87	541.17	108.23
Modernized leveler F_m	55.93	77.77	91.94	108.27	112.74	446.65	89.33
Reduction force F_b- F_m	26.86	25.54	22.36	0,63	19.13	94.52	18.90
Reduction [%]	32.45	24.72	19.56	0.58	14.51	91.82	18.36

Table 9

Comparison of the force of alignment for the basic and modernized levelers depending on the length of the timber F=f_3 (L)

P / F [kN]	4.0	4.5	5.0	5.5	6.0	Sum	Average value
Basic leveler F_b	113.79	112.01	109.74	103.07	102.56	541.17	108.23
Modernized leveler F_m	96.10	95.53	85.28	89.04	80.70	446.65	89.33
Reduction force F_b- F_m	17.69	16.48	24.47	14.03	21.86	94,52	18.90
Reduction [%]	15.55	14.71	22.29	13.61	21.32	87.48	17.50

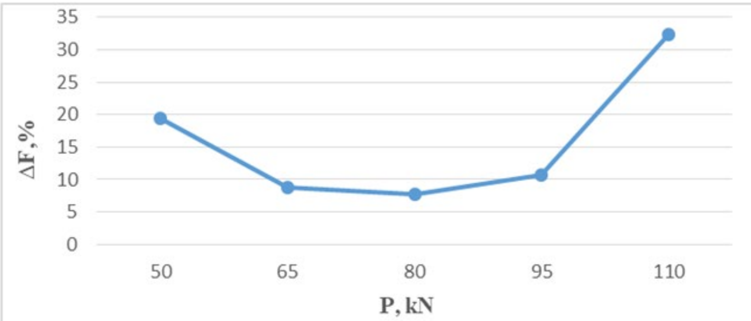


Fig. 11. *The graph of the reduction of the force of alignments of the timber Δ F = f_1 (P)*

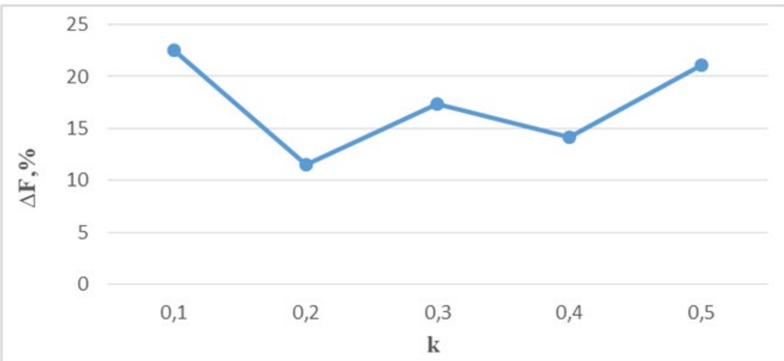


Fig. 12. *The graph of the reduction of the force of alignments of the timber Δ F= f_2 (k)*

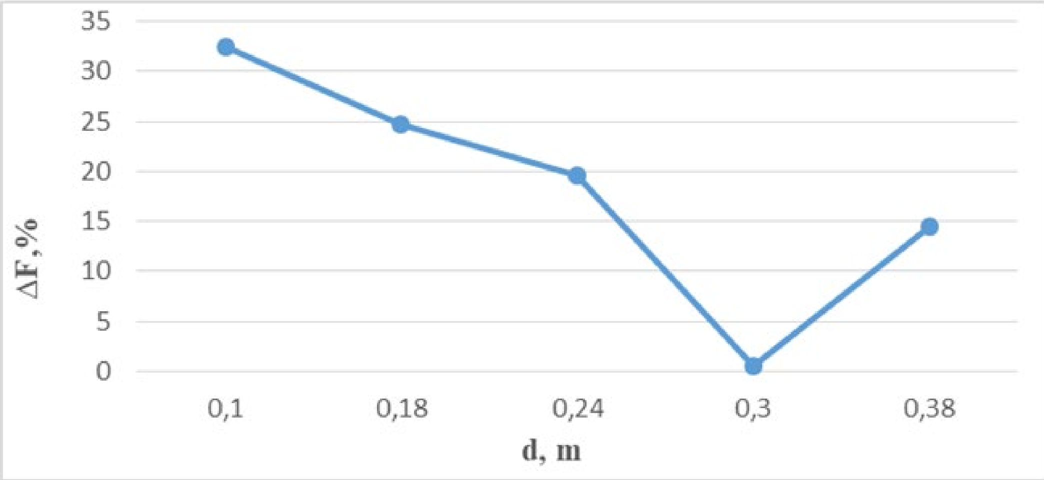


Fig. 13. *The graph of the reduction of the force of alignments of the timber* $\Delta F = f_3 (d)$

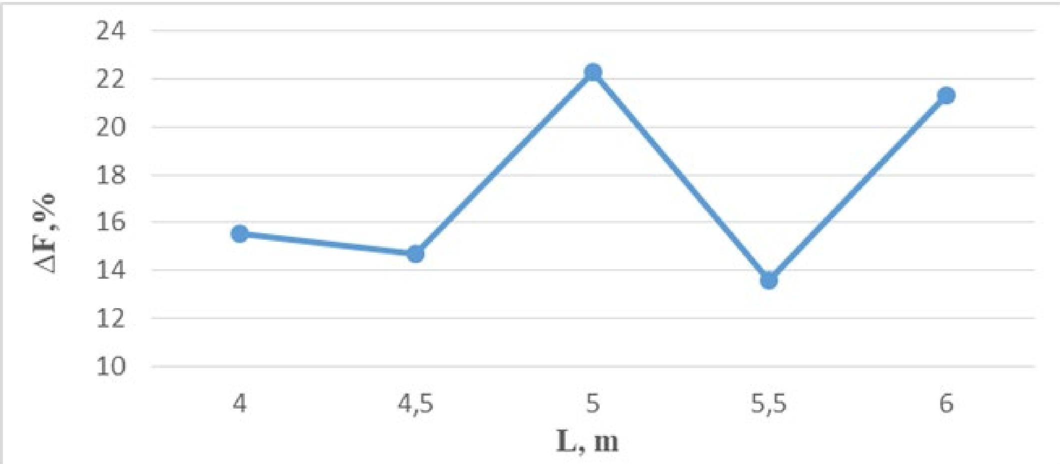


Fig. 14. *The graph of the reduction of the force of alignments of the timber* $\Delta F = f_4 (L)$

The alignment forces for the timber loads weighing from 50 to 110 kN by the modernized device decreased by an average of 18.94 kN or 15.8% compared to the base one. The reduction in the force of leveling timber by the modernized invention occurred by 17.3%, depending on the ratio of the protruding logs to their total number in the range from 0.1 to 0.5. When changing the length of the logs from 4.0 m to 6.0 m, the reduction in the efforts of alignment of the timber loads was on average 17.5%. The decrease in the efforts of leveling timber loads by 18.6% occurred when varying the diameters of round timber in the range from 0.10 m to 0.38 m. The duration of the formation of timber loads decreased by 9.7% by the modernized invention compared to the basic one.

Production tests of K-142 were performed at the industrial site of the experimental production plant of the Volga-Kama Research Institute of Water Forest Transport, equipped with a lifting crane KKS-10, a gravity device K-142 and various types of bundles of round timber [3]. The results of the laboratory and production experiment of the basic leveler K-142 are presented in Table 9.

Table 9

Results of laboratory and production studies

Indicators	Laboratory research	Production research (VKNIIVOLT)
1. Weight of a bundle of logs, *P* [kN]	50.0	50.0
2. Volume of wood, *W* [m^3]	6.37	9.83
3. Length of timber, l_1 [m]	4.0	4.0
4. Average log diameter, d_0 [m]	0.18	0.2
5. Number of logs, *n*	63	78
6. Width of the bundle, *B* [m]	1.92	2.2
7. Bundle height, *H* [m]	1.88	2.99
8. Coefficient of protruding logs, *k*	0,4	0.5
9. The spread of the ends, *ΔL* [m]	±0.7	±0.7
10. The speed of lowering the bundle onto the leveler, *υ* [m/s]	KB-572 0.33	KKS-10 0.25
11. Number of observations	10	20
12. Average alignment force, *F* [kN]	88.93	83.40

A comparison of the results of the efforts of the K-142 gravitational device obtained during laboratory (F_l) and production (F_p) research (Table 9), shows that the discrepancy between the values of the leveling forces of the logs was 6% (Equation (3)):

$$P[\%] = \frac{\left(F_p - F_l\right) \cdot 100}{F_p} = \frac{\left(88.93 - 83.40\right) \cdot 100}{88.93} = 6\% \quad (3)$$

4. Discussion

We have proposed a new leveler design, which is an upgrade of the existing device [2] and conducted laboratory tests for it for the first time. The developed program and methodology of research [1, 5], the laboratory experiment on physical models allowed us to confirm the results obtained theoretically [15] and compare the results presented in the article with the results of research conducted by A.S. Fadeev at the industrial site of the experimental production plant of the Volga-Kama Research Institute of Water Forest Transport [3]. The present study, the reliability of the similarity criteria found for the process of leveling round timber with an upgraded gravity device, the formulas for recalculating the results of the laboratory studies in nature and their compliance with the manufacture of laboratory equipment and models of wood loads, were verified by conducting comparative tests of the basic leveler K-142 in laboratory and production conditions [3], which allow us to note that the discrepancy in the effort values is negligible. This means that the obtained results of the laboratory studies are quite satisfactory and suitable for practical use. This research can be used to create the equipment proposed by the authors and to plan a production experiment.

5. Conclusions

Laboratory samples of inventions were created and an experiment was conducted to determine the leveling forces. Conducted laboratory studies of the proposed design of the leveler [6] made it possible to compare the efforts of alignments on the model of the basic and modernized design of the levelers. A comparative analysis of the obtained results of the laboratory studies was also carried out with previously obtained production studies, which showed a slight discrepancy (6%). These tests confirmed the technical result of the invention: reduction of the friction force by an average of 18% (Figures 11 to 14) between the load beams of the modernized device and the bundles of logs due to the installation of removable self-rotating load beams (Figure 2) and the replacement of sliding friction by rolling friction. Compared to the basic one, the proposed invention will reduce the force of alignments and the time of this process, improve the alignments quality and, thus, increase labor productivity when loading timber into timber transport. This invention is recommended for use at logging enterprises engaged in the transportation of round wood.

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