



Volume 110

2021

p-ISSN: 0209-3324

e-ISSN: 2450-1549

DOI: <https://doi.org/10.20858/sjsutst.2021.110.3>

Journal homepage: <http://sjsutst.polsl.pl>



Article citation information:

Hrabovský, L. Tension force equalizer in a rope system using a proximity sensor. *Scientific Journal of Silesian University of Technology. Series Transport*. 2021, **110**, 35-44.
ISSN: 0209-3324. DOI: <https://doi.org/10.20858/sjsutst.2021.110.3>.

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TENSION FORCE EQUALIZER IN A ROPE SYSTEM USING A PROXIMITY SENSOR

Summary. Different values of tension forces in the load-bearing ropes of elevators, which push the rope into the grooves of the traction discs with different pressure, are the cause of uneven wear of the grooves of the traction discs under operating conditions. Current technical standards in the EU stipulate that the load suspended on load-bearing ropes be evenly distributed to all ropes used, using one of the many construction designs for tension force equalizers in the rope system. The main subject and primary objective of this paper are to present the construction design, 3D model and produced device of one of four produced prototypes, which were constructed in the “Research and Testing Laboratory”, and allow setting of differing values of tension forces in the system of ropes of a traction elevator, to values of the same size. Laboratory measurements were performed on the produced device, which enables the detection of tension forces in ropes and the magnitude of these forces in the required period to be graphically displayed on a PC. The prototype tension force equalizer can show the functionality and practical applicability of the procedure of balancing the levels of tension forces, which are of unequal strengths at the start of the laboratory measurement.

Keywords: tension force equalizer, rope elevator, load-bearing rope, ring load cell

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1. INTRODUCTION

In practice, the elevator car must be allowed to travel as high as possible in the elevator shaft. This is ensured by installing the load-bearing rope bracket at the shortest possible distance from the ceiling of the elevator shaft. The minimum distance of the upper surface of the bracket from the ceiling of the elevator shaft places a fundamental requirement on the design height of tension force equalizers, which are installed at the ends of the threaded parts of the suspension bolts. Mobile tension force equalizers have relatively large heights and their use to balance varying tension forces to the same magnitude in a rope system is not always suitable in cases where there is a lack of operating space and the construction height is limited.

This paper presents a sequence of activities and a description of the operations, which when using a tension force equalizer, result in the weight of the load (in the more loaded branch of the rope system of the elevator) in the final phase of the experiment being evenly distributed in all cross-sections of the load-bearing ropes.

The principles of tension force equalizers suitable for use in cases of restricted operating spaces and low ceiling height in the elevator shaft are introduced in [3,5].

2. CONSTRUCTION DESIGN OF THE DESCRIBED DEVICE

A 2D construction design (created in AutoCAD) is presented in Fig. 1a. Fig. 2 shows a 3D model created in the SolidWorks 2012 x 64 SP 5.0 environment, one of four variants of a tension force equalizer in a rope system, which was designed and assembled at the Institute of Transport, Faculty Mechanical Engineering, VSB - Technical University of Ostrava, based on a requirement for its production by LIFTCOMP, a. s.

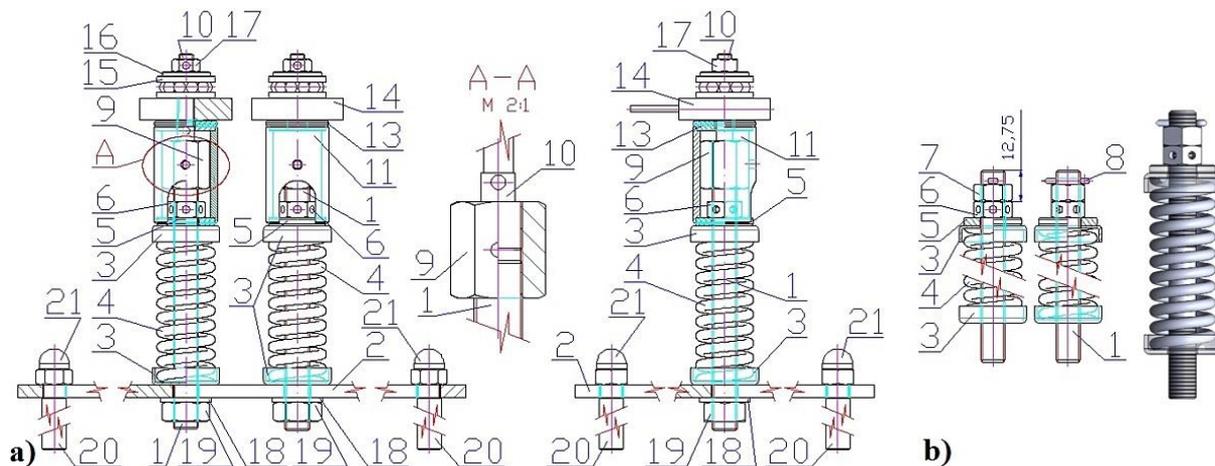


Fig. 1. a) 2D construction design for a tension force equalizer in a system of ropes,
b) terminal point of the suspension bolt in practice

The shanks (ϕ 10 or 12 mm) of the suspension eyebolts 1 [1] pass through (ϕ 11 or 13.5 mm) in the bracket, which under laboratory conditions is replaced by a steel plate (300 x 200 x 5 mm) 2, Fig. 1a. A bowl 3 and a compression coil spring 4 [7] are slid on the threaded part of each of the eyebolts 1, which are threaded through the holes in the plate 2. A bowl 3, a washer 5 and a hexagonal nut 6 are mounted on the upper end face of the coil spring 4. In practice, unscrewing the nut 6 is prevented by the lock nut 7 and the cotter pin 8 (Fig. 1b).

Holes (2.5 mm) are drilled in the shank of the suspension bolts 1, their horizontal axes are spaced at least 4.5 mm from the end faces of the shanks of the suspension bolts 1 (Fig. 1b). The minimum distance between the upper surface of the nut 6 and the upper surface of the shank of the hinge screw 1 (after removing the cotter pin 8 from the hole in the shank of the hinge screw 1 and unscrewing the lock nut 7) is $L_{min} = 12.75$ mm, Fig. 2b. The space L_{min} [m] is sufficient to install the tension force equalizer.

A nut 9 (M10), which has a hole (3 mm) formed on one of its vertical surfaces in the middle of its height of 20 mm, is screwed onto the threaded part of the shank of the suspension bolts 1. A threaded part (length 10 mm) of the pin 10 is screwed onto the internal thread M10 of the opposite hole in the nut 9. A tubular part 11 is threaded on the pin 10 to form concentric holes (3 mm in the nut and 4 mm in the tubular part 11). In the upper and lower part of the tubular part 11 (with an inner/outer diameter of 20/26 mm), an inner fitting is formed, the so-called inner ϕ 24 mm to a depth of 2 mm. The tubular part 11 is threaded at the bottom onto the outer diameter (ϕ 24 mm) of the washer 12 (height 3 mm). A ring 13 (with an inner hole of ϕ 8 mm for the pin 10) is threaded on the inner fitting (ϕ 24 mm, depth 2 mm). A tension force sensor (Ring Load Cell) 14 (with an inner/outer diameter of 7/38 mm) is threaded on the pin 10.

An axial bearing (type 51100 ČSN 024730) 15 and a ring 16 (with an inner hole 6 mm for the pin 10, with an outer 10 mm lower part 5 mm long, which is pushed into the hole of the upper ring of the axial bearing 15) are mounted on the shaft of the pin 10. Part of the height of the 2-mm ring 16 is 20 mm). An M6 nut 17 is screwed onto the thread M6 in the end part of the pin 10.

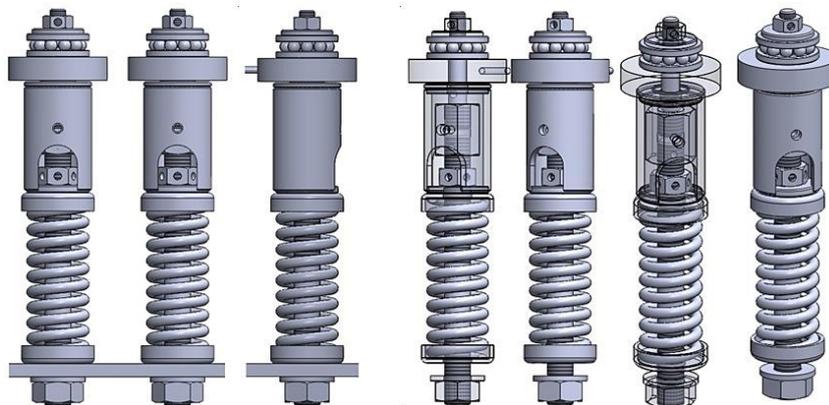


Fig. 2. 3D model a tension force equalizer in a system of ropes

The test device, Fig. 1 and Fig. 4, uses compression coil springs 4 [7] with wire diameter $d = 4$ mm, outer diameter $D_1 = 24$ mm, length in free state $L_0 = 63$ mm, length in retracted state $L_8 = 48.5$ mm, total number of turns $z = 10.5$., number of active coils $n = 8.5$, spring force in retracted state $F_8 = 549$ N and stiffness (spring force when compressed by 1 mm) $c = 37.88$ N/mm.

3. ASPECTS EQUALIZING TENSION FORCES IN A ROPE SYSTEM

The load capacity Q [kg] of a passenger elevator is determined according to the table in ČSN EN 81-20 [2]. The basic indicator for determining the load capacity of a passenger elevator is the floor area of the cage, from which the load capacity and the number of people who can use the elevator at one time are calculated.

Elevator cages must be suspended on either steel ropes, gall or roller chains. Steel wire ropes must meet the requirements [2]: the nominal diameter must be at least 8 mm; the nominal tension strength of the wires must be $1570 \text{ N}\cdot\text{mm}^{-2}$ or $1770 \text{ N}\cdot\text{mm}^{-2}$ for ropes with wires of the same tension strength, or $1370 \text{ N}\cdot\text{mm}^{-2}$ for outer wires and $1770 \text{ N}\cdot\text{mm}^{-2}$ for inner wires for ropes with two nominal tension strengths; at least two ropes must be used. The safety factor k_s [-] (is the ratio between the guaranteed load capacity of the rope N_L [N] and the maximum force F_L [N] in this rope when the cage with the rated load is at the lower end station) must not be less than 12 for a drive with friction discs with three or more supporting ropes; 16 for a drive with friction discs with two support ropes.

If the load capacity of the lift is Q [kg], the actual weight of the cage P [kg], the height of the lift of the cage H [m], the rope gear r [-], the weight of the rope m_L [$\text{kg}\cdot\text{m}^{-1}$], the number of load-bearing ropes n_L [-], then the greatest force F_L [N] acting in one rope can be expressed according to (1).

$$F_L = g \cdot \left(\frac{Q + P}{r \cdot n_L} + m_L \cdot H \right) \text{ [N]} \quad (1)$$

If the coefficient of the minimum breaking force k_u [-] and the minimum breaking force of the rope is N_L [N], then the safety factor of the rope k_s [-] can be expressed by the relation (2).

$$k_s = \frac{k_u \cdot N_L}{F_L} \text{ [-]} \quad (2)$$

By modifying the relationships (1) and (2), it is possible to calculate the required number of load-bearing ropes n_L [-], relationship (3).

$$k_s \cdot F_L = k_u \cdot N_L \Rightarrow n_L = \frac{k_s \cdot g \cdot (Q + P)}{r \cdot (k_u \cdot N_L - m_L \cdot H \cdot g \cdot k_s)} \text{ [-]} \quad (3)$$

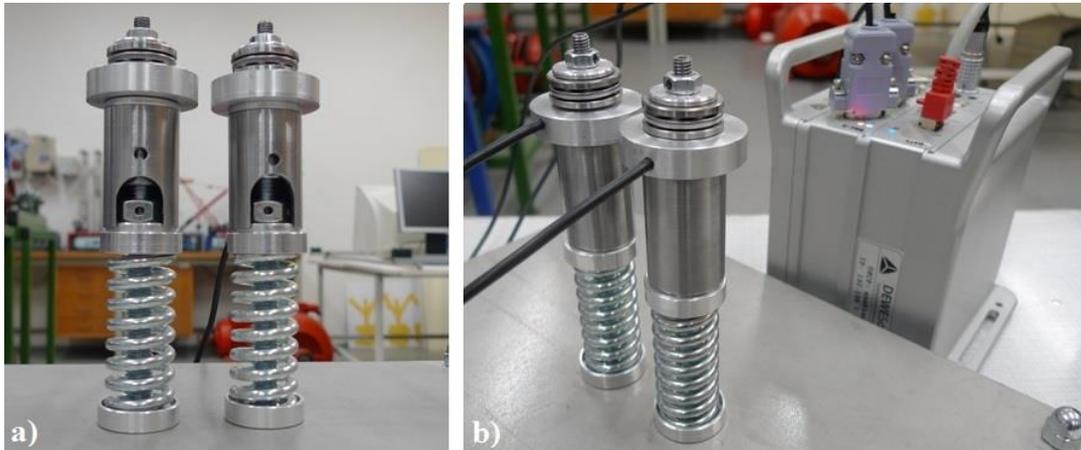


Fig. 3. Laboratory model of described variants of a tension force equalizer in a system of ropes, a) front view, b) rear view

The principle, presentation and verification of the correct functionality of equalizing tension forces in the system of ropes (which consists of two or more ropes) is performed on devices assembled in the Research and Testing Laboratory of the Institute of Transport, VSB-Technical University of Ostrava, the equalizers tension forces in the rope system, Fig. 3 and Fig. 5. The executed device is designed so that it has (for reasons of reduction of economic costs used for the building of the laboratory model and the purchase of a larger number of tension force sensors 14) only two suspension bolts 1.

The cable ends of both tension force sensors 14 are soldered to the connectors of the “D Sub” connector plug. The connector plugs are plugged into two of the four sockets in the DEWESoft DS-NET [6] measuring system. The DEWESoft DS-NET measuring apparatus is connected to a PC with a network cable (with an “RJ45” connector at both ends). In the DEWESoft X2 SP5 software environment in the PC, the curves of the applied forces $F_{L(i)}$ [N] (initially different tension force magnitudes to tension forces balanced to equal magnitudes) in the suspension bolts 1 were displayed (detected by force sensors 14), Fig. 5.

The different magnitudes of the initial values of the tension forces $F_{L(i)}$ [N] in the load-bearing ropes are derived by the different tightening of the nuts 19, Fig. 1 and Fig. 4. Varied tightening of the nuts 19 causes a different deformation (that is, compression $H_{1(i)}$ [m]) of the compression springs 4. Compression $H_{1(i)}$ [m] of the compression springs 4 is of the same magnitude as the vertical displacement $y_{1(i)}$ [m] of the nut 19. The magnitude of the displacement $y_{1(i)}$ [m] of the nut 19 can be expressed by the relation (4), where d_s [m] is the mean thread diameter of the hinge screw 1, α [deg] is the pitch angle of the thread of the suspension bolt 1, β [deg] is the angle of rotation of the nut 19, P [m] is the pitch of the thread of the suspension bolt 1 and the nut 19.

$$y_{1(i)} = \frac{\pi \cdot d_s \cdot \text{tg} \alpha \cdot \beta}{360^\circ} = \frac{P \cdot \beta}{360^\circ} [m] \quad (4)$$

The lengths $L_{1(i)}$ [m] ($L_{1(2)}$) on Fig. 4) compressed springs 4 (loaded by forces $F_{L(i)}$ [N]) can be expressed according to (5).

$$L_{1(i)} = L_0 - y_{1(i)} = L_0 - H_{1(i)} = L_0 - \frac{F_{L(i)}}{c} = L_0 - \frac{F_{1(i)}}{c} [m] \quad (5)$$

Compressive forces $F_{1(i)}$ [N] acting in the springs 4; equal to the values of tension forces $F_{L(i)}$ [N] in the load-bearing ropes (6); are transmitted to the lower surfaces of the tension force sensors 14 via the washers 5, the tubular parts 11 and the rings 13.

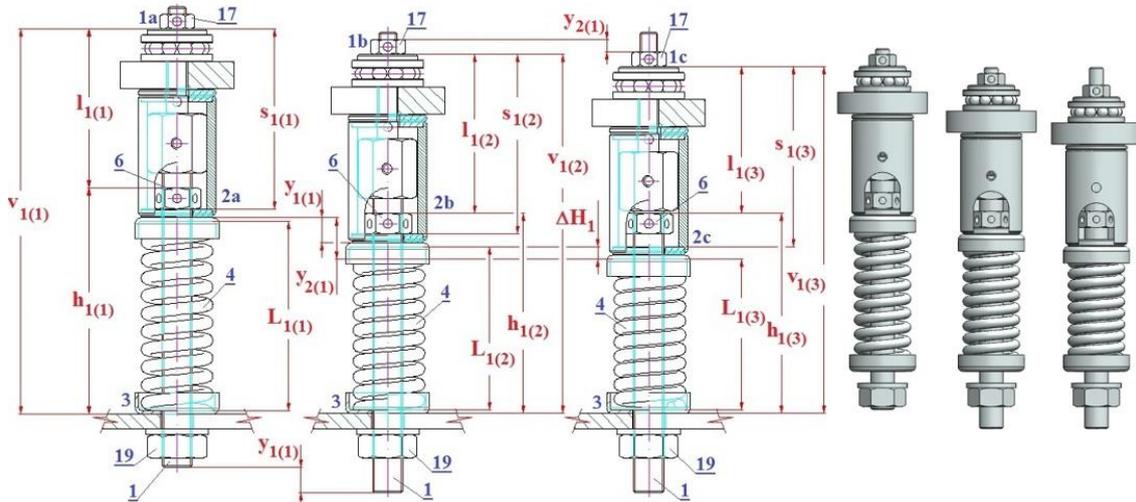


Fig. 4. Visualisation of the action of balancing differing tension force magnitudes in the ropes to a unified value.

$$F_{1(i)} = (L_0 - L_{1(i)}) \cdot c = H_{1(i)} \cdot c = y_{1(i)} \cdot c = F_{L(i)} [N] \quad (6)$$

Compressive forces $F_{c(i)}$ [N], which are the same magnitude as the compressive forces $F_{1(i)}$ [N], are applied to the upper surfaces of the tension force sensors 14 (tension forces $F_{L(i)}$ [N] (1) are transmitted from the load-bearing ropes via pin 10) (assuming tightened nuts 6).

If the nuts 17 are tightened, the distance $l_{1(i)}$ [m] is shortened (from the initial value $l_{1(2)}$ [m] to the value $l_{1(3)}$ [m], Fig. 4) and there is a vertical displacement (relative to the upper surface of the suspension bracket, section “3” in Fig. 4) of the suspension bolt 1 (provided that the nut 19 is not screwed onto the threaded part of the suspension bolt 1). In practice, each of the suspension bolts 1 is subjected to a proportional part of the load (ideally $F_{L(1)} = F_{L(2)} = F_L$ [N] (1)) and these loads (tension forces in ropes $F_{L(i)}$ [N]) compress the springs 4. Further, if the magnitudes of the forces in the ropes $F_{L(i)}$ [N] are not the same, the springs 4 are deformed differently. The spring 4 which is most compressed $H_{1(i)}$ [m] (that is, which has the smallest height $L_{1(i)}$ [m]) generates the highest compressive force $F_{1(i)}$ [N] (6).

By tightening the nut 17 of the least compressed $H_{1(i)}$ [m] spring 4, in the practical use of the elevator, the vertical screw 1 is first shifted vertically, to which is attached (least loaded by the force $F_{L(i)}$ [N] (6)) load-bearing rope. In this load-bearing rope, the tensile force $F_{L(i)}$ [N] increases (because by shortening the length of the rope, this rope is loaded with a larger proportion of the load distributed into the rope system) and the spring 4 is compressed.

4. ACTION OF THE LABORATORY MODEL OF THE TENSION FORCE EQUALIZER

Tightening the nut 17 of the least compressed $H_{1(i)}$ [m] spring 4 in the laboratory model (Fig. 3) results in (as a result of the vertical shift $y_{2(i)}$ [m] (4) (Fig. 4) of nut 17, where d_s [m] is the mean thread diameter of the hinge screw 10, α [deg] is the pitch angle of the thread of the suspension bolt 10, β [deg] is the angle of rotation of the nut 17, P [m] is the pitch of the thread of the suspension bolt 10 and the nut 17) the transfer of the derived compressive force $F_{2(i)}$ [N] on the spring 4, which, due to increasing compressive forces $F_{2(i)}$ [N], is compressed (relative to the uncompressed length $L_{1(i)}$ [m] of the spring 4 compressed by the force $F_{1(i)}$ [N]) after the completion of the tightening phase of the nut 19 by the total size $y_{2(i)}$ [m] (7), and with respect to the uncompressed length L_0 [m] of the spring 4 compressed by the total size $s_{p(i)}$ [m] (8).

$$y_{2(i)} = H_{2(i)} = \frac{F_{2(i)}}{c} [m] \quad (7)$$

The increase in compression $\Delta H_{(i)}$ [m] of the spring 4 (at the moment of terminating the tightening of the nut 17) is equal to the vertical shift $y_{2(i)}$ [m] of the nut 17 being tightened.

The total compression $s_{p(i)}$ [m] (8) of the spring 4 is equal to the sum of the vertical shift $y_{1(i)}$ [m] of the nut 19 being tightened and the vertical shift $y_{2(i)}$ [m] of the nut 17 being tightened.

$$s_{p(i)} = y_{1(i)} + y_{2(i)} = \frac{F_{1(i)} + F_{2(i)}}{c} [m] \quad (8)$$

The resulting lengths $L_{v(i)}$ [m] ($L_{1(3)}$ on Fig. 4) of the compressed springs 4 (weighted with the forces $F_{2(i)}$ [N]) can be expressed according to (9).

$$L_{v(i)} = L_0 - s_{p(i)} [m] \quad (9)$$

By tightening the nut 17, the distance $l_{1(i)}$ [m] ($l_{1(3)}$ on Fig. 4) is shortened. For the distance $l_{1(i)}$ [m] according to Fig. 4, (10) applies.

$$l_{1(3)} = l_{1(1)} - y_{2(i)} = l_{1(2)} - y_{2(i)} = l_{1(2)} - H_{2(i)} = l_{1(2)} - \frac{F_{2(i)}}{c} [m] \quad (10)$$

Given the unchanging heights of the machine parts 6, 11 to 16 (Fig. 1a), when the nut 17 is tightened, a vertical shift of the nut 6 takes place (since the pin 10 is of a constant and unchanging length) as well as the compression of spring 4 by a value of $y_{2(i)}$ [m].

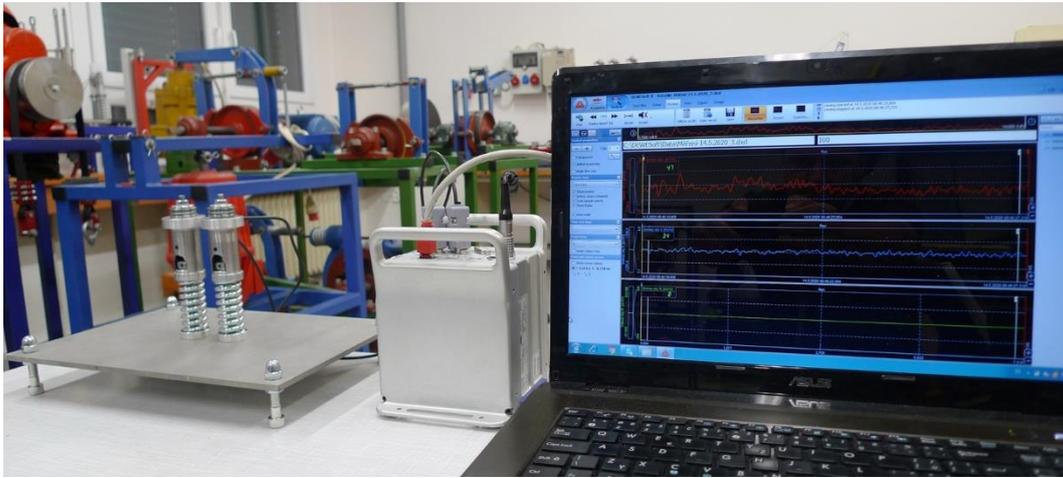


Fig. 5. Physical execution of the model on a tension force equalizer in a system of ropes

If the nut 6 is rotated in the desired direction, at some point, the nut 6 rests on the washer 5. By further turning the nut 6, the spring 4 is compressed by the value $H_{3(i)}$ [m]. Compressing the spring 4 by the value $H_{3(i)}$ [m] produces a tension force $F_{3(i)}$ [N] in the suspension screw 1 and the pin 10, which is transmitted to the upper surface of the force sensor 14. Vertical displacement $y_{3(i)} = H_{3(i)}$ [m], derived by turning the matrix 6, causes the points “1c - 2c” to be delayed, that is, extension of the length $l_{1(i)}$ [m], which is given by the sum of the heights of the machine parts 6, 11 to 16, and reduction of the compressive force $F_{1(i)}$ [N] acting on the force sensors 14. Sizes of compressive forces $F_{1(i)}$ [N] acting on the force sensors 14, which are mounted on the suspension bolts 1 of all load-bearing ropes for the given traction lift, are displayed on the PC monitor. By gradually turning the nuts 6, the tension forces in the ropes are balanced.

5. EXPERIMENTAL TESTS

Cables terminated with connectors of both tension force sensors 14 of the tension force equalizer (Fig. 3b) for the test device (Fig. 5) were connected to the measuring apparatus.

The data (detected by the force transducers 14) was transferred to the PC via network cable.

In the DEWESoft X2 SP5 software environment, the waveforms of the detected compressive force magnitudes $F_{L(i)}$ [N], (Fig. 6) were displayed on the PC monitor.

Tab. 1 shows the theoretically calculated compression force magnitudes $F_{l(i)}$ [N] according to the relationship (6), during the compression $H_{1(i)}$ [N] of springs 4 for both tension force equalizers.

Tab. 1 simultaneously gives the tensile force magnitudes $F_{L(i)}$ [N] that were detected by the tension force transducers 14 during the gradual compression of the springs 4 and subtracted from the PC monitor.

Fig. 6 shows the waveforms of the measured forces $F_{L(i)}$ [N] detected by the force transducers 14. From Fig. 6, it is clear that the initially different magnitudes of tensile forces in the ropes $F_{L(i)}$ [N] can be set to magnitudes of the same size by the tensile force compensator, using the procedure described in the section “Action of the laboratory model of the tension force equalizer”.

Tab. 1
Theoretically calculated and measurement-obtained compression forces

$F_{1(1)}$	$F_{1(2)}$	$H_{1(1)}$	$H_{1(2)}$	$L_{1(1)}$	$L_{1(2)}$	$F_{L(1)}$	$F_{L(2)}$
N		mm				N	
75.76	151.52	2	4	61	59	78.16	147.93
151.52	227.28	4	6	59	57	157.37	232.44
227.28	303.04	6	8	57	55	223.28	310.34
303.04	378.80	8	10	55	53	305.63	365.88
378.80	454.56	10	12	53	51	382.35	462.11
454.56	530.32	12	14	51	49	467.71	526.59

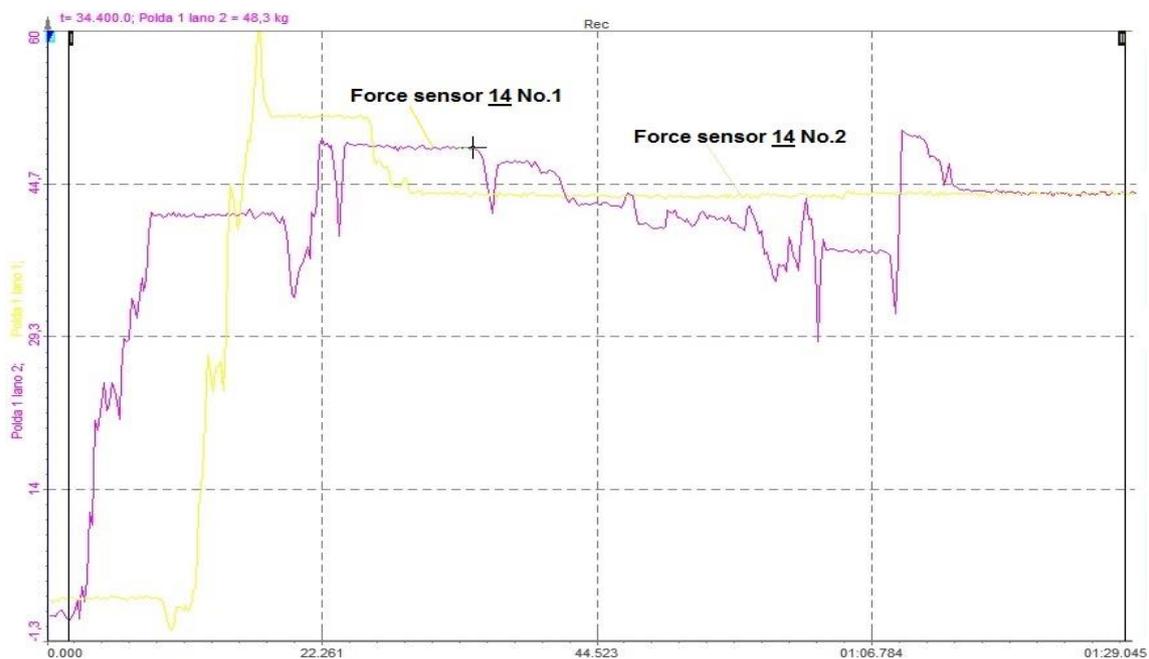


Fig. 6. The holding force of the electromagnet depending on the distance from ferromagnetic plate

6. CONCLUSION

Construction designs and principles of operation of technical devices as well as the sequence of work procedures, by which the total weight of the load can be evenly distributed into the partial cross-sections of load-bearing ropes, which form the system of ropes in traction elevators, are presented in several researches. These technical devices are called “elevator rope tension force equalizers”.

The possible way of achieving uniform load distribution into two or more carrier ropes in the traction lift using a tension force equalizer in a rope system with a proximity sensor is given in this paper.

This device is portable and is mounted on suspension bolts only when it is necessary to set the same tensile forces in carrier ropes. After carrying out its activities, it is possible to remove the device from the suspension bolts and move it to another traction rope lift.

In contrast to the known principle of the hydraulic compensator [8], the described device can be provided with strain gauge load cells that can detect instantaneous tensile forces in carrier cables, record them and use them for certificate processing purposes.

This paper presents a technical design of a mobile, mechanical equalizer, which uses a tensile force sensor (transducer) to detect tension forces in the ropes.

More so, this paper presents a construction design and specifications of individual basic components from which the equalizer is assembled. A 3D model of the tension force equalizer in a system of ropes was presented as well.

The described device can adjust the tension forces in the cross-sections of load-bearing ropes, either during the installation of new elevators or reconstructions and upgrades of existing elevators. This tension equalizer helps to extend the life of elevator parts, that is, the load-bearing ropes and the rope friction disc.

The actual prestressing in the ropes is measured by a sensor, which allows even distribution of the weight of the load, and thus, distribute it appropriately into the partial cross-sections of the load-bearing elevator ropes used. The measurement of the magnitude of tension forces in ropes and their equalization can similarly take place even during the operation of the elevator car. Tension compensation in load-bearing ropes of elevators can be achieved using a mobile device to which the cross-sections of the load-bearing ropes are attached.

The main advantage of the device is the continuous measurement of the tension of all ropes of the elevator system during the operation of the elevator. Other advantages include a non-destructive method of monitoring the tension in the ropes, that is, a method that does not require interruption of the final length of the load-bearing rope on which the elevator car is suspended. Further advantages are the simplicity of installation, affordability, low weight, the possibility of various forms of measurement and the fact that the device has its own battery power source.

Acknowledgements

This work was supported by the Ministry of Education, Youth and Sports of the Czech Republic from the Specific Research Project SP2020/90.

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Received 26.07.2020; accepted in revised form 30.10.2020



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