Detection and Change of Tension Forces Operating on Elevator Hoist Ropes

Leopold Hrabovsky¹, Peter Koscak²

¹VŠB - Technical University of Ostrava, Faculty of Mechanical Engineering, 17. listopadu 2172/15, 708 33 Ostrava - Poruba, Czech Republic
²Technical University of Kosice, Faculty of Aeronautics, Department of Air Transport Management, Rampova 7, 041 21 Kosice, Slovak Republic

¹ leopold.hrabovsky@vsb.cz, ² peter.koscak@tuke.sk

Abstract. The Decree on Technical Requirements for Buildings stipulates that all the new residential buildings with entrances to flats at the fifth and higher floors, or attics at the same level, must have an elevator installed. The applicable standards in the Czech Republic so that, for the electric elevators with friction discs that use two or more hoist ropes, the weight of the applied load was evenly distributed over all the cross-sections of the hoist ropes for the given layout of the elevator. Rope tension equalizers used in elevators are usually designed to allow sensing of the acting tensile forces in an uninterrupted cross-section of the hoist cable. They are usually installed on hoist ropes only in the newly-installed elevators and during regular inspections. The paper describes the basic principles of devices currently in use, the so-called rope tensioners, which allow detecting and adjusting primarily different tensile forces in the hoist ropes to the same value. The paper refers to two, already published design variants of portable rope straighteners, which use foil strain gauges or strain gauge sensors to detect the acting tensile forces in the hoist ropes. The constructional solution and the principle of operation of the “hydraulic rope tensioner”, which were created at the VŠB-Technical University of Ostrava, are described in more detail.

1. Introduction

Most elevators in the Czech Republic were installed before 1993 and their current states do not meet the European standard ČSN EN 81-80 [1]. Such elevators should be replaced or renovated.

Rope-driven traction elevators are most often installed in buildings with a higher number of stations where the lift height is not limited, and a high cabin start-up frequency is required. These are elevators suspended on ropes with a counterweight. The machine room of these elevators is mostly located above the shaft or under the shaft. In the case of a building that does not have machine room space, the solution of an elevator without a machine room can be used.

The contractor must incorporate newly-introduced standards applicable during the reconstruction or building of elevators. The customer will thus avoid the unpleasant fact that in case of failure to observe or neglecting of any safety standard, the building will not pass its final inspection.

Effective as of August 31, 2017, the standard [2], which is the Czech version of the European Standard EN 81-20: 2014 (the European Standard EN 81-20: 2014), came into force. The translation
was provided by the Office for Standards, Metrology and Testing. (It was translated by the Czech Office for Standards, Metrology and Testing.). Standard [2] together with standard [3] replace EN 81-1 + A3 [4] ČSN EN 81-2+A3 [5].

The standard [3] establishes safety rules for the construction and installation of permanently installed new passenger and passenger and freight elevators with traction drive, kinematic-coupled drive or hydraulic drive, serving designated stations and having a car intended for the transport of persons or persons and freight, which is hung on ropes or chains and guided by guides that are do not deviate from the vertical plane by more than 15°.

The Standard sets out the design regulations, calculations, checking and testing of elevator components referred to in other standards for the construction of passenger elevators, passenger and freight elevators, freight only elevators and other similar types of lifting equipment. The subject [3] is the establishment of safety rules for elevators with regard to the safety of persons and objects against the risk of accidents related to the activities of users, maintenance personnel and emergency rescue operations for elevators.

Amongst other things, standards [2] and [3] require suppliers and service technicians for elevators with traction sheaves to achieve a uniform load distribution when installing new elevators or during regular service inspections; acting from the weight of the elevator car, load and counterweight, to all elevator hoist ropes used. The uniform distribution of the applied load into the partial cross-sections of the hoist ropes used in the particular elevator installation must be documented by the measurement record, the so-called protocol, which the service technician (elevator installer) is obliged to submit to the elevator operator.

Along with this requirement, arose a requirement for equipment that would enable detection, recording, storing, evaluating and graphically presenting the acting load determined by measurements in the component sections of uninterrupted hoist elevator ropes.

2. Load Distribution Equipment Currently in Use in Hoist Ropes

Over the past years, several device variants have been put on the consumer market, for example, [6, 7], which allow sensing of the actual tensile force in an uninterrupted cross section of steel rope. These devices allow the tensile force in a particular steel rope to be compared to the tensile forces of adjacent ropes and to achieve even, identical increases in tensile forces of all hoist ropes (with the prescribed deviation tolerance).

![Figure 1. Sensors detecting the tensile force in the steel rope](image)

Devices that can detect the tensile force in a steel rope are based on three basic principles.

The first principle is based on the knowledge of the bending of a straight rod. Rope weighing
sensors [6] are essentially beams (rectangular or square cross-sections) of the specified length. The sensors are placed on one of the longitudinal sides of the beam body at its ends, fastened with two pins, which represent the supports. In the center, between these pins, a third pin is attached to the sensor body. In determining the tensile force in a steel rope by this principle, the respective rope is guided over the pins as shown in figure 1. The tensile force in the rope exerts a force on the center pivot in the plane of symmetry of the sensor body and this causes a planar bending of the beam (i.e., the sensor body bends in one plane without the effects of twisting the beam), for more details, see [8].

The second principle is based on the direct sensing of the acting tensile force in the rope by tensometric sensors. To sense the tensile force in the rope, tensometric sensors are used, either so-called “load cells” for measuring axial forces, see figure 2, and in greater detail [9].

The third principle is based on Pascal’s law of fluid mechanics, or Pascal's law, which defines the transfer of pressure, made possible by the movement of liquid particles and the dissipation of mutual forces between them in all directions, to any point in the liquid. In general, if an external pressure force acts on an ideal fluid, then the pressure at each liquid location increases by the same value. However, real fluids are not completely incompressible and the pressure changes in them spread through the final velocity.

Pascal’s Law is the basis for hydraulic equipment making use of pressure transfer, and thereby also pressure forces from one piston to another, see figure 3, in more detail [10]. The pressure force can also be influenced by the size of the piston.

3. Devices for Load Distribution in Hoist Ropes
Specific design and technical solutions of devices that allow detection and equalizing tensile forces in elevator hoist ropes, named “mobile mechanical tension equalizers” are thoroughly described in [8, 11, 12].

This device is able to continuously record the time progression of instantaneous tensile forces acting in the elevator car ropes. For the device [8], the tensile force acting on the axis of the
suspension bolt, to which one free end of the hoisting rope is mechanically attached, is detected by the tensile force strain gauge and its progression over time is recorded on the PS monitor in the DEWESoft X2, SP5 Dewetron hardware environment.

The design and technical solution of the device, which is also capable of sensing and recording the time course of instantaneous tensile forces in the elevator hoist ropes, is described in [11-13]. Different values of tensile forces resulting from different prestressing of coiled compression cylindrical springs are, in this construction variant, sensed by foil tension gauges, which are glued on outer surfaces of cylindrical bodies of devices intended for balancing tensile forces in ropes.

The construction of a mobile hydraulic tensile force equalizer, which can compensate for different tensile forces in two or more load-bearing cross-sections of steel ropes, is shown in figure 4. In the case of a real electric elevator with friction sheave, the free end of the supporting rope is mechanically connected to the eye of the suspension bolt by means of rope clamps.

![Figure 4. Construction design for mobile hydraulic tensile force equalizer](image)

The suspension bolt (represented by a threaded rod in figure 5) 12, provided with a metric thread passes through an opening in the clamping bracket 7. The suspension bolt 12 over the upper surface of the clamping bracket 7 extends through a cylindrical opening of the cup 7a into which one end of the cylindrical coiled compression spring fits 6.

The other end of the spring is covered by the opposite cup 5b, see figure 5. Above the cup 5b, a spacer 4 is inserted on the suspension bolt 12. The suspension bolt 12 is secured against ejection from the opening in the clamping bracket 7 (due to the load of the hoisting rope which is attached to the suspension bolt by the rope clamps through the eyelet) and the fall of the suspension bolt 12 into the elevator shaft with a hexagonal nut 3. These components form one unit - the suspension of the supporting steel cable.

The main components of the described device, the so-called mobile hydraulic tensile force equalizer, are the double-action rectilinear hydraulic motor 1, the outer cylindrical body of the tensile force equalizer 2 and the inner body (which forms the threaded coupling piece) 8, the Tensile forces 9 tensometric strain sensor and the coupling piece 10.

The double-acting rectilinear hydraulic motor (hydraulic cylinder) 1 (see figure 4 and figure 5), consists of the piston rod 14, piston 13, body of the hydraulic motor 16 and flanges 17. The flange 17 is fitted with four openings, each with internal M5 thread, whose axis is perpendicular to the axis of the hydraulic motor body 16.

The outer cylindrical body of the equalizer consists of two detachable parts - the lower part 2b and the upper part 2a. The lower part 2b of the outer cylindrical body of the equalizer is, on one of its sides, provided with an internal mount (see figure 5, mounting on the left side) of 36 mm by which it fits against the spacer 4. On this side, there is an opening in the lower section 2b, of the outer cylindrical body of the equalizer, which allows turning the nut 3. Section 2b has two opposed elliptical
grooves on its housing to limit the maximum insertion of the piston rod of the hydraulic motor $I_3$ into the body $I_5$. This restriction is provided by a screw $I_8$ which passes through the said grooves in the body $2b$ and the through the regular hole in the threaded part $8$. The bolt $I_8$ is secured by a nut $2I$ and washers $22$.

The part $2b$ terminates the outer fitting of the selected diameter which is used for insertion of the opposite inner fitting in the upper part $2a$ of the equalizer body. The elliptical cut-out in the lower section of the upper part $2a$ enables access to the tension sensor $9$ and at the same time allows the sensor data output in a vertical direction. The subsequent, opposed elliptical grooves are used to mount the support pin $I_11$. The mounting of the upper part of the body $2a$ serves to engage the flange $I_17$ of the hydraulic motor $I$. In this fitting, four horizontal elliptical grooves are provided to secure the relative position of the hydraulic motor $I$ and the equalizer body $2$ by the bolts $I_9$ of the washers $I_8$.

![Figure 5. Detail of construction design for a mobile hydraulic tension equalizer](image)

The inner body consists of three components mechanically connected to each other by a threaded joint. The first threaded connection piece $8$ has a metric thread M16 on one side for connecting the suspension bolt (see figure 4, threaded rod $12$) and connecting piece $8$ and a second metric thread M10 for connection to the tensometric sensor $9$, which is the second component of the inner body. The second connecting part $10$ is also provided with a metric thread M10 for mechanical connection with a sensor $9$ and a cylindrical bore of a diameter of 16 mm for insertion of the piston rod $I_3$, with which it is mechanically connected by means of a support pin $I_11$ which passes through the piston rod $I_3$ and part $10$ through holes perpendicular to the axis of the equalizer.

A coil spring $6$, see figure 4, is placed on both sides in the retainer cups $5a$ and $5b$. The bottom part of the cup $5a$ contacts the base plate $7$. One of the ends of the coil spring $25$ abuts against the opposite side of the base plate $7$, the other end of which is supported in the cup $5c$. The threaded rod $I_2$ is threaded through the opening in the cup $5c$ and is secured against slipping out by the nut $23$ and the spacer $24$.

4. Description of Action of Mobile Hydraulic Tension Equalizer

In the design of the mobile hydraulic tension equalizer, see figure 4, the threaded rod $I_2$ simulates a suspension bolt with an eyelet, which is used to attach the loose ends of the carrying ropes in rope elevator installations. In the described functional prototype, the tensile force acting in the axis of the suspension bolt (in practice, this force is exerted by the relative distribution of the load of the weight of the car or counterweight to the individual hoisting ropes) is applied in the axis of the threaded rod $I_2$ by means of a compression coil spring $25$ (in a deformed state). The desired compression of the compression spring $25$ can be adjusted using the nut $23$. Upon achievement of the desired axial force in one threaded rod $I_2$, a tensile force of different size is applied in the axis of the second threaded rod...
The tensile forces exerted in the individual threaded rods 12, which are exerted by the prestressing of the coil compression springs 25, are sensed by tensometric force sensors 9. The sensor 9 is connected to the threaded rod 12 by a threaded connection part 8 and by a piston rod 13 of the hydraulic cylinder 1 by means of a connecting part 10 and a support pin 11.

By bringing the pressurized fluid under the piston 14 of the hydraulic cylinder by means of the neck 17 of the hydraulic motor 1, the piston rod of the hydraulic motor 13 is inserted into the body 15 of the hydraulic cylinder. As a result, the distance between the connecting piece 10 and the flange 16 of the hydraulic cylinder 1 begins to shorten as they are connected to each other by a support pin 11.

Subsequently, this causes the hydraulic cylinder flange 16 to start to press against the fitting in the body of the equalizer 2a and the cup 5b is moved away through the spacer 4 engaging in the fitting in the lower part of the equalizer body 2b, thereby simultaneously compressing the compression coil spring 6. The course of the tensile force, which is created in the inner body of the equalizer, as a reaction to the force required to compress the spring 6, is sensed by a tensometric sensor 9. At a certain stage, the bolt 20 abuts the end of the groove in the body 2b, thereby limiting the subsequent compression of the spring 6.

The working spaces of the linear hydraulic motors 1 of the two tension equalizers which are connected to the threaded rod 12 by means of the inner body of the equalizer and rest against the spacer with their flanges 16 through the outer cylindrical body 2 above the cup 7b, see figure 4, are connected to each other together with the pressure energy generator (hand pump) via a hydraulic system.

After pressurization of the cylinders using the pressure energy generator through the neck of the hydraulic motor 17, the cup 5b, based on Pascal’s Law, begins to move away in the above-described manner, according to the different tensile forces in the individual strand cross-sections due to unequal load distribution and identical cross-sectional areas on which pressure energy is applied in the cylinders. In this way, the compression coil spring 6 is then deformed, whereas the compression coil springs 6 are deformed at the individual mountings by different lengths, due to the unequally adjusted prestressing of the coil springs 25. By sensing the value of the compressive force applied by the sensor
9, the progress can be monitored, and the correct tensile force compensation is verified in the threaded rods 12 of the individual suspensions.

After equalization of the tensile forces (biasing of the individual compression coil springs 25), the compressed or released compression spring 6 can be fixed in the desired position by tightening (or loosening) the nut 3 located above the cup 5b and the shim 4.

5. Conclusion
An apartment building that has five or more floors and its number of housing units does not change, does not have to install an elevator. If it is decided to add a floor or carry out construction modifications that will change the number of housing units, it is necessary to build an elevator. In this way, additionally installed elevators are built into all the buildings concerned, if their structural design permits.

Rope-driven elevators are most often installed in buildings with a higher number of stations where the lift height is not limited, and a high frequency of cabin start-ups is required. These are elevators suspended on ropes with counterweight. The machine room of these elevators is mostly above the shaft or under the shaft. In the case of a building that does not have space for a machine room, an elevator that does not require a machine room can be used.

Rope lifts without machine rooms are installed in buildings where it is not possible to place a machine room. They are designed for installation in a classic brick shaft or into a self-supporting steel structure. The machine room is a part of a single space containing the elevator shaft and the drive unit is located in the elevator shaft without additional space requirements. A specially-designed elevator drive can be placed at any height level of the elevator shaft, along with the elevator distribution cabinet on the respective platform, from which the rescue and emergency operations can then be performed. This type of elevator is suitable for most residential buildings and its parameters make it an ideal solution for replacing existing obsolete elevators, or for new buildings.

Elevators suspended on ropes with a counterweight use a friction sheave to move the car. Rope drive elevator cars must be suspended on at least two hoist ropes. According to the applicable standards [3, 4], it is ordered that the load on the hoist ropes be evenly distributed over all cross sections of the hoist ropes used in the installed elevator. How to achieve this and what possible devices can be used for this is outlined in the submitted paper.

The action principle of the mechanical balancers of tension in the ropes developed at VŠB - Technical University of Ostrava is described in [8, 13]. The construction design and principle of operation of the hydraulic tension equalizer in the ropes are described in this paper (see [12] for more details). Due to the limited number of pages, this paper does not describe a hydraulic aggregate that distributes hydraulic pressure fluid to the space beneath or above the pistons of double-acting hydraulic cylinders that are used in the described “hydraulic rope tensile force equalizers”.

Acknowledgments
This work has been supported by The Ministry of Education, Youth and Sports of the Czech Republic from the Specific Research Project SP2019/101.

References
[1] V. Vaněk, F. Jaroš and J. Dvořák, ČSN EN 81-20 (27 4003) Safety rules for the construction and installation of lifts - Lifts for the transport of persons and goods - Part 20: Passenger and goods passenger lifts. CTN Unie výtahového průmyslu ČR, 2015 (in Czech).
[2] J. Dvořák, ČSN EN 81-50 (27 4003) Safety rules for the construction and installation of lifts - Examinations and tests - Part 50: Design rules, calculations, examinations and tests of lift components. CTN Unie výtahového průmyslu ČR, 2015 (in Czech).
[3] J. Dvořák, ČSN EN 81-1+A3 (274003) Safety rules for the construction and installation of lifts - Part 1: Electric lifts. CTN Unie výtahového průmyslu ČR, 2010 (in Czech).

[4] J. Dvořák, ČSN EN 81-2+A3 (274003) Safety rules for the construction and installation of lifts - Part 2: Hydraulic lifts. CTN Unie výtahového průmyslu ČR, 2010 (in Czech).

[5] Liftec Group, “Snímače vážení na lana” [Online] 2019 Available at: http://www.liftecggroup.com/lana.html. (in Czech).

[6] Micro Epsilon, “Snímač MC100 pro kontrolu zatižení kabiny výtahu” [Online] 2018 Available at: https://www.micro-epsilon.cz/tenzometricke/Na_lana/ (in Czech).

[7] L. Hrabovský and M. Maslarić, Device designed for detection and setting the required tensile force in ropes. Advances in Science and Technology Research Journal Issue: 1, Pages: 200-206, MAR 2018.

[8] Micelect, “HPS - Load weighing sensor” [Online] 2018 Available at: http://www.micelect.es/en/micelect-load-weighting-sensors/hps-elevator-hitch-plate-sensor.

[9] Brug Lifting, “Tensile forces in steel ropes equalized by hydraulic cylinders”, [Online] 2018 Available at: https://www.brugglifting.com/elevator/images/downloads/manu/RLE_Manual.pdf.

[10] L. Hrabovský and P. Michalik, A tension equalizer in lift carrying ropes. Advances in Science and Technology Research Journal. Volume: 11, Issue: 4, Pages: 326-332, DEC 2017.

[11] Utility model, “Vyrovnávač tahů v nosných lanech výtahů”, No. 29 336, U1, Office of Industrial Property, Czech Republic. [Online] 2018 Available at: https://isdv.upv.cz/doc/FullFiles/UtilityModels/FullDocuments/FDUM0029/uv029336.pdf (in Czech).

[12] Patent application, “Vyrovnávač tahů v nosných lanech výtahů”, No. 2015-876, A3, Office of Industrial Property, Czech Republic. [Online] 2018 Available at: https://isdv.upv.cz/doc/FullFiles/Applications/2015/PPVCZ2015_0876A3.pdf (in Czech).

[13] V. Vaněk, ČSN EN 81-80 (274003) Safety rules for the construction and installation of lifts - Existing lifts - Part 80: Rules for the improvement of safety of existing passenger and goods passenger lifts. TNK 107 Výtahy, pohyblivé schody a pohyblivé chodníky, 6/2004 (in Czech).