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NUMERICAL AND EXPERIMENTAL ANALYSIS OF THE PROGRESSIVE GEAR BODY WITH THE USE OF FINITE-ELEMENT METHOD

BADANIA NUMERYCZNE I DOŚWIADCZALNE KONSTRUKCJI CHWYTACZA PROGRESYWNEGO Z WYKORZYSTANIEM METODY ELEMENTÓW SKOŃCZONYCH*

The article presents the results of experimental and numerical simulations of the braking process of new type CHP 2000 progressive gear roller. The gear which is a main element of the friction drive lift safety during braking is exposed to over-loading connected with changeable weight loading the gear. Reliable operation of the braking system of the lift, especially in emergency situations, is the basis for the safe operation of these devices. Presented in this paper progressive gear design solution was subjected to tests on test stand and simulations numerical aimed at confirming the required strength and proper functionality of structures subjected to operational loads. Numerical analysis simulation was gear roller displacement during braking from the neutral position to the maximum displacement and the impact load on the alternating stress levels in the gripper elements. The results of numerical calculations verified by experimental studies, analyzing braking distance. The instrument used was a commercial numerical package for calculations using the finite element method – a program Abaqus®.

Keywords: *friction drive lift, progressive gears, safety, numerical simulation, FEM.*

W artykule zaprezentowano wyniki badań eksperymentalnych oraz symulacji numerycznych procesu hamowania rolki chwytacza progresywnego nowego typu CHP 2000. Chwytacz będący głównym elementem bezpieczeństwa dźwigu ciernego podczas hamowania narażony jest na przeciążenia związane ze zmienną masą obciążającą układ hamowania. Niezawodna praca układu hamowania dźwigu, zwłaszcza w sytuacjach awaryjnych, stanowi podstawę bezpiecznej eksploatacji tych urządzeń. Zaprezentowane w artykule rozwiązanie konstrukcyjne chwytacza progresywnego poddane zostało próbom stanowiskowym oraz symulacjom numerycznym, mającym na celu potwierdzenie wymaganej wytrzymałości oraz właściwej funkcjonalności konstrukcji poddanej obciążeniom eksploatacyjnym. Analizie numerycznej poddano symulację przemieszczenia rolki chwytacza w trakcie hamowaniaz pozycji neutralnej do pozycji maksymalnego przemieszczenia oraz wpływ zmiennego obciążenia na poziom naprężeń w elementach chwytacza. Wyniki obliczeń numerycznych weryfikowano badaniami eksperymentalnymi, poddając analizie długość drogi hamowania. Zastosowanym narzędziem numerycznym był komercyjny pakiet do obliczeń z wykorzystaniem metody elementów skończonych – program Abaqus®.

Słowa kluczowe: *dźwig cierny, chwytacze progresywne, bezpieczeństwo, symulacje numeryczne, metoda elementów skończonych.*

1. Introduction

Passenger and freight lifts are commonly used devices for vertical transport both in public buildings and residential buildings. The universality of this type of construction dictates sanctioned meet the stringent requirements of the building regulations of safety, imposing a strict manner of operation. The basic components of these devices include braking systems, to ensure proper functionality, and above all, the safety of the structure. Despite the high demands placed on these types of devices the current state of the literature on the issues of the construction and operation of the braking and progressive safety gear is not exhaustive. Issues presented in the literature relate to two main lines of research - issues and issues of dynamic load-bearing components of strength. Lifting dynamics issues dealt with, among others, Taplak [16] and Filas and Mudro [6]. In [16], the authors present the issues associated with the use of neural networks to analyze the vibration of the lift, as a result of variable mass of the traffic load. Used neural networks have been used by the authors to assess symptoms of vibration, which show that the failure of the lift or the entire device. The authors of reference [6] described the use of methods reduce the problem of the evaluation of the dynamics of the crane. In their analysis of the lift cab model reduced to a flat system with one vertical degree of freedom. The presented methodology for reducing the authors used to describe a specific mechanism cargo lift, defining the problem mathematically. In addition made an assessment of the lift operating parameters and their effect on the characteristics of the acceleration of the entire system. Issues related to the dynamics of the braking system of the lift, the analysis of the materials and construction of the progressive gears are further discussed in publications [9, 10, 11, 12, 13]. The authors of these studies focused mainly their attention on the analysis of the brake system, compare the construction and operation of the progressive gears European producers to the newly developed solution.

A different class of problems are lifts used in high-rise buildings, over 40 floors. An example of the analysis of these devices was mentioned in [19] in which the authors have examined issues related to the impact of weight lift car power cords and cables on the work of the crane. In such devices, a significant height requires a compensatory belt, which compensates for the weight of the ropes and wires power, causing relief other components of the lift. The authors describe in an exemplary manner belt compensatory behavior and its impact on the linear model of the lift. Also examine the impact of horizontal displacements countervailing belt natural frequency of the system.

In the process of design and operation of lifts are more widely used numerical tools using the finite element method (MES) [20]. This applies above all stress analysis and optimization of structural elements [5, 7] lifting equipment. Example of using the finite element method to simulate the stresses and displacements of the hook body immediately during braking is shown in [8], in which the results of numerical calculations successfully verified with experimental studies.

The results of the performance tests are presented in the publication [3], where the author presents own research on the application of the coating NiCrBSi-60 applied to the gripper jaws of the wedge and the impact is applied to the coating on the braking parameters with respect to the jaws made from steel C45. A new type of progressive gears, characterized by different performance characteristics with respect to existing solutions used in freight elevators are presented in the work [18]. The authors describe a mathematical model and the structure of your model together with an analysis of the results obtained experimentally. Patent new design solutions progressive roller gear developed for KONE published in [17], in which the original structure was presented progressive roller gear and the characteristics of its activities.

In publications [4, 14] authors describe the use of the finite element method to evaluate the stiffness and the strength of the cabin frame in different types of lifts, including the construction of a progressive gear. The finite element method in the described issues, we used to optimize the design of the support frame, for reduced beam sections of the frame structure, leading to a significant reduction in the weight of the device and determine the coefficients of safety. The results of calculations possible to identify the sensitive areas of the lift frame system on the occurrence of damage.

Presented the results of numerical analysis show a great possibility of using FEM for the design and optimization of structural elements of lifting equipment. In this context, the authors of this article have attempted to extend the issues related to the modeling and simulation of the braking process, based on the author's lift concept of progressive safety gear CHP 2000 presented results of numerical simulations were verified bench test results conducted on the physical model of the structure of the progressive gear.

2. Construction and operation of the braking system and progressive gear

The newly compiled construction of the progressive gears of CHP 2000 type was designed and intended for the lifts with nominal load capacity from 8000 to 20000 N, constituting app. 75% of manufactured devices. Estimated annual production of that type of gears with changeable braking configuration is approximately 2000 sets per year. The braking system consisting of a kinematic connection between CHP 2000 type gears has been presented in Figure 1.

The lift gear is located in the cabin frame under the lift cabin. The release lever 2 is mounted to the gear. The lever ends are connected with the speed limiter line. At the top part of the lift shaft there is the speed limiter which controls the lift operation and at its bottom part there is a weighting agent responsible for proper pull of the speed limiter line. The speed limiter initiates the braking process when the nominal speed of the lift cabin increases by 0.3 m/s. Once the nominal
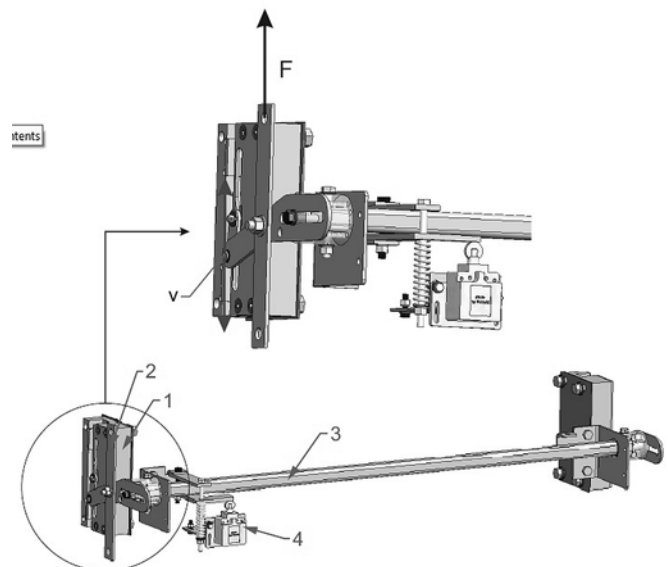

Fig. 1. Kinematic scheme of the friction drive lift braking system. 1 – a gear, 2 – a release lever, 3 – the gears coupler, 4 – controlling and compensating system

speed is exceeded, the speed limiter is blocked, at that time the line via properly selected friction coefficient is blocked as well. During the lift cabin movement with blocked subassys, the lever is dislocated in the direction opposite to the direction of a moving cabin as a result of which the gear braking roller is lifted. The roller is pushed to the guide causing its elastic deformation in the direction of the base plate which is on the other side of the set of Belleville springs as a result of which the energy loss of speeding mass is obtained. Thus, the set of Belleville springs is responsible for creating changeable force which pushes the roller to the guide, dependent on the mass which is transported in the cabin once the braking process is initiated.

CHP 2000 type gear presented in Figure 2 consists of the body 1, where the cam 5 was located, along the cam the braking roller 2 with knurled surface moves. Between the cam and the body there are the packets of Belleville springs 4 with changeable configuration dependent on the nominal loading capacity of the lifting device. During the operation the gear moves along the lift guide which is located in the gear body between the braking roller and the base plates 3 placed in the opposite sides of the Belleville springs packets.

The changeable setting of the gear is connected with changeable mass which is inside the lift cabin. With respect to the above, the nom-
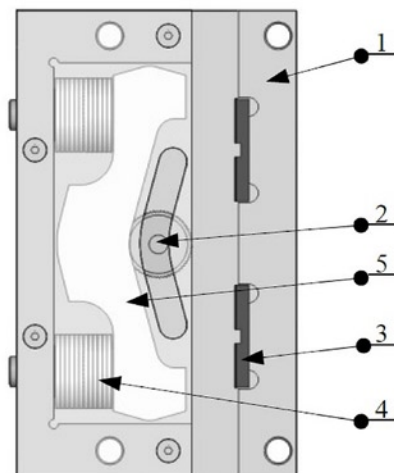

Fig. 2. Diagram of CHP2000 type progressive gears: 1 – a body, 2 – a braking roller, 3 – a braking plate, 4 – Belleville springs, 5 – a cam [11]

inal load is the sum of the weight of progressive gear cab, the cab frame, the cabin door and the nominal load capacity [11].

The design of the progressive safety gear is designed to provide effective braking lifting device. This results in a substantial burden of its individual elements, which depends on the strength of the safety passenger lift. The research will be to examine the strength of the entire team catcher permissible load that may occur during emergency braking.

3. The gear discrete model

Numerical analysis of the hook during emergency braking process was carried out in the case of the maximum static load acting on the elements of the structure. The scope of research included analysis of the steady-state mechanism, so the description of the system is independent of the variable of time. The numerical model of interaction of contact type used in the ABAQUS® defined as Surface-to-Surface, which contact constituting defining the interaction between mating components of the system to normal and tangential direction with friction coefficient of 0.3.

The characteristics of the individual elements of the hook progressive summarized in Table 1. For all of the elements defined by the steel material model elasto-plastic properties of isotropic reinforcement.

Table 1. Elements material features [2]

	Material	Young's Modulus E [MPa]	Poisson's coefficient v	Yield point Re [MPa]	Resistance limit Rm [MPa]
The braking roller and plates	18HGT steel	210000	0.3	850	1000
The guide	S235JRG2 steel	210000	0.3	235	520
The body, the cam, the remaining elements	C45 steel	210000	0.3	360	610

Boundary conditions attached to the system will enable the simulation of the progressive gear in the process of emergency braking. Model of progressive gear is fully fixed in places mounting screws by blocking in area the holes all degrees of freedom. The guide roller is received, and able to move along the Y axis, and further blocked roll rotatable about an axis Z and X – Figure. 3.
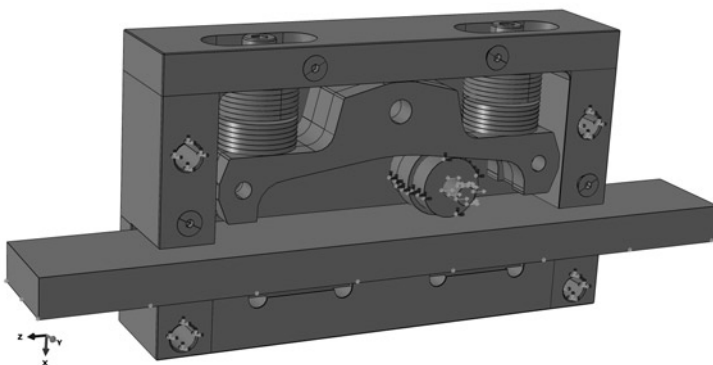

Fig. 3. Boundary conditions

The system works due to the displacement of the braking roller along the path which is determined by the cam and in the opposite direction to Z axis. The cam cooperates with the Belleville springs pressing the roller to the guide, and then respectively the guide is pressed to the base plates in the X axis direction. Elements that map
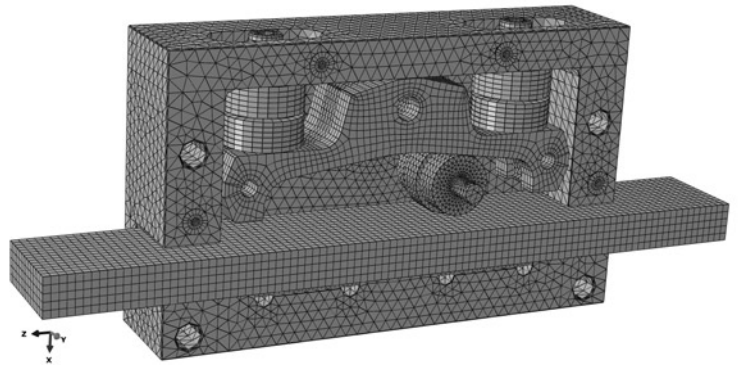

Fig. 4. Finite element mesh used

disc springs are shaped in such a way as to obtain the particular characteristics of elastic deformation by them during emergency braking process.

Discretization of individual elements of the hook was carried out using two types of volume elements: hexagonal - C3D8R and tetragonal type – C3D4 [1]. In both cases the element type has been used first order, and in the case of components used be reduced integrating of eight-node elements [20].

In the case of a four node elements in order to ensure adequate accuracy of the calculations, the high density of the mesh elements of tetragonal (progressive gear roll), as compared to the overall size of the mesh FEM model numerical.

FEM calculations carried out as a static calculation (Static procedure, General) taking into account non-linear problems. The load consisted of the constraint in the form of a displacement of the braking applied to the rollers of the 23.5 mm, acting in the opposite direction to return the Z axis. The total number of finite element numerical model was developed more than 131000.

4. Results of numerical analysis

FEA analysis results are presented on the basis of the gear roller dislocation simulation. In the article the attention is mainly focused on the determination of the stresses level H-M-H (Huber-Mises-Hencky) in the key points of the whole system as well as on the determination of the maximum stresses level and displacements of the guide nodes at the braking stage. The maximum level of stresses is demonstrated by the roller element where R_m resistance limit is reached. The level of stresses in the roller has the nature of nearly symmetrical layout versus its axis, whereas the maximum stress appears in the central part of the subassy which has been presented in Figure 5.

Achieving the level of the breaking of the roller elements R_m=1000 MPa due to the adopted too stringent working conditions of the numerical model of the progressive gear. In a real system roll movement in the analyzed period would be difficult to achieve, at the same time would cause the actual effort of the roller elements below the strength of the material. However, this is one of the critical elements of the progressive gear, who as a result of the emergency braking sustains permanent deformation. Reduced stress levels in the remaining elements of progressive safety gear (excluding items roll) is shown in Figure 6.

Stresses that occur in parts of the outside roller, do not show a level exceeding the limit strength of the material. In addition to the cam and the guide, none of the components does not reach the yield point. Cam suffered a small crossing yield strength (360 MPa) C45 steel. In fact, the force generated by a passenger lift, do not lead to a displacement of the roll to the end of the road, which determines the
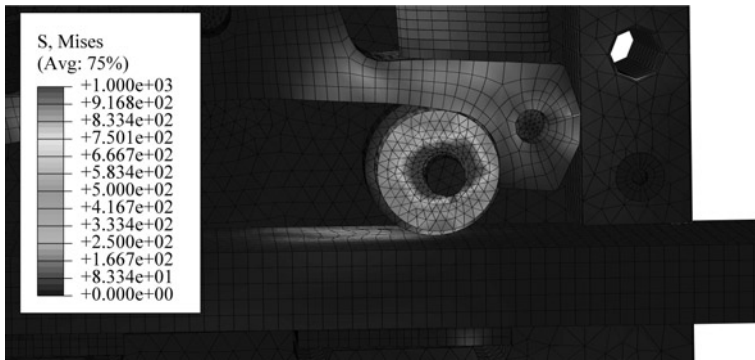
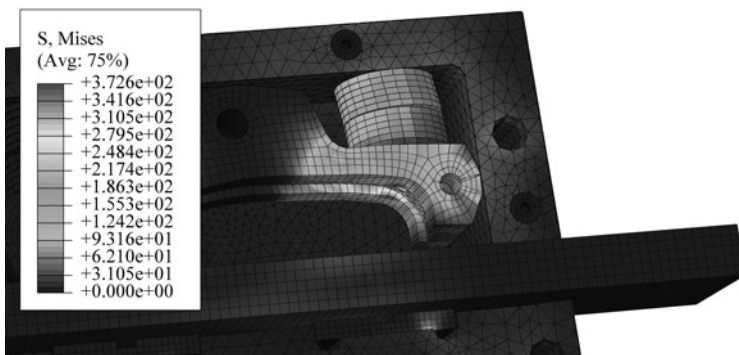*Fig. 5. Stress distribution occurring in the roll replacement [MPa]*

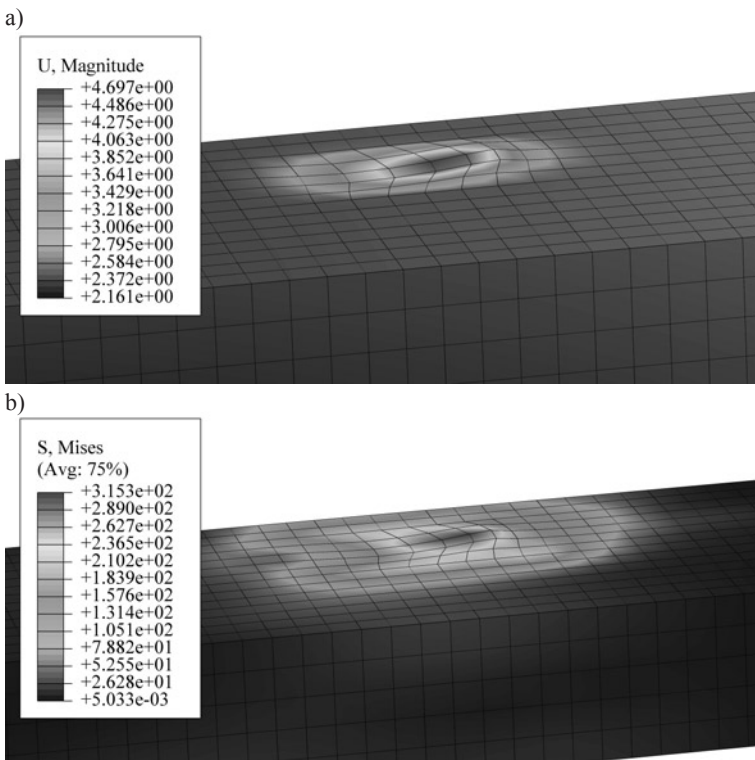*Fig. 6. Stress distribution in other parts of substitute ingredients [MPa]*

a)

b)

Fig. 7. The results of numerical studies of the guide: a) substitute the stress distribution [MPa], b) the distribution of displacements [mm]

cam. Cam stress level would therefore be much lower than presented in the results of numerical analysis. The most important component of the research was the hook guide. After the performed analysis, numerical and experimental presents the level of the plastic deformation of

the guide piece of material, under pressure originating from the roll. FEM studies have shown that exceeded the guide material yield and there was a significant displacement of the nodes. The maximum value of stress at a critical location substitute track was 315.3 MPa, which means exceeding the yield stress of 80 MPa guide. Figure 7 shows the maximum displacement of the tension elements and nodes of the guide.

The maximum displacement nodes at the place pressing of the guide rollers moving was nearly 4.7 mm. The material is permanently laminated to the approximate length of approximately 18 mm, determined on the basis of an area including six nodal displacements of finite elements with an edge length of a single member to be (in the track) of 3 mm.

5. Experimental studies

Experimental studies were carried out on a specially designed position for enabling the free fall test method with variable load traps - Figure 8.

In the design of the test bench guides are placed, after which she moved aggravating frame of progressive gear, coupled with the supervising system of free fall speed. The main task of this system was to initiate the process of braking at speeds above par on the value of 0.3 m/s.

In order to protect against uncontrolled hit the ground test bench, the height at which the system had to be lifted was determined based on the relationship between potential and kinetic energy, determining the amount of free fall. Initiate free fall test system implemented by releasing the lock placed in the frame position. After crossing the speed of 1.25 m/s speed initiated watchdog triggering traps, starting with emergency braking process. After stopping the system under study was performed measurements of braking distances, which was the main parameter of construction associated with the correct evaluation of the work progressive gears.

We also evaluated the technical condition of the structural elements of progressive gears, as among state of the braking rollers and the state of the plastic deformation of the guide, which has been deformed by the roller as a result of braking.

The study confirmed the required bench strength and proper operation of the safety gear developed progressive structure, which is the main element lift safety during emergency braking.

Experimentally determined characteristics of the work progressive gear CHP 2000, defining the relationship of braking distances as a function of load compared with the analogous characteristics of the existing solutions - Figure 9. The present work progressive gear CHP 2000 reaches the lowest value of braking distances in different load cases, compared to previously commonly used in such devices. The resulting performance characteristics translate into significantly to local plastification of the guide, reducing the length of the plastic deformation region. A significant reduction in emergency braking if used design solution improves the safety of use of lifts, which is the main idea of this device design.

The actual level of the plastic deformation of the guide obtained from experimental studies performed on a physical model of the structure is almost progressive gear representation of numerical simulation. The result of the experimental study are shown in Figure 10.

The resulting high that the results of numerical calculations with measurements carried out stand length of the plastic deformation area guide - the difference does not exceed 10 %, providing the basis to confirm the adequacy of the developed numerical model, both in qualitative and quantitative terms. Development

Fig. 8. The test stand: a) general view of the stand for experimental test, b) the progressive gear with the loading system in the neutral position, c) the progressive gear with the loading system at a given load
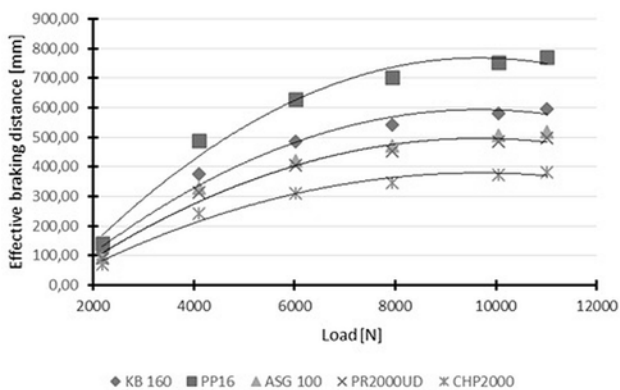

Fig. 9. Performance characteristics of selected types of traps

Fig. 10. Area guide plastification observed in the experiment

of experimentally verified numerical models allows while conducting a thorough analysis of the effort and strain individual components of the test device, providing a range of relevant information about the importance of structural and operational. The numerical simulation
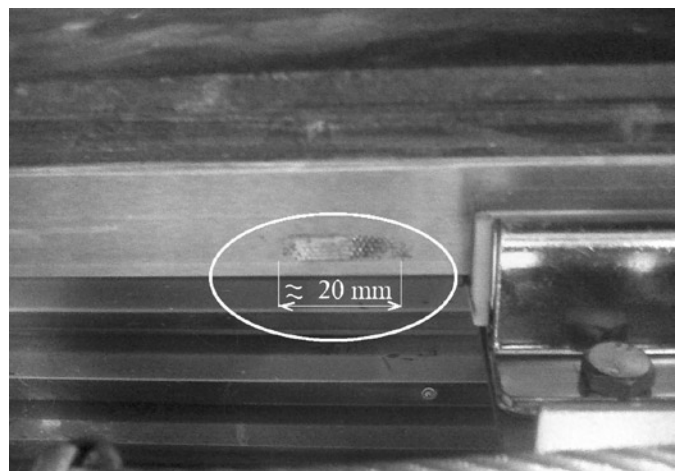
performed in this case allows an assessment of the gripper elements progressive effort, while the sample bench confirm proper functional-

ity and reliability of structures in braking, as well as exhibit improved structural efficiency of the proposed solution compared to the other devices of this type (Figure 9).

6. Conclusions

The paper presents an original concept of progressive safety gear, which is the primary mechanism for the inhibition of passenger and freight elevators for general use. The developed concept is characterized by a difference of a constructional solution as compared to existing devices of this type. Results of this study confirmed the sufficient strength and reliability of the emergency braking system developed.

Numerical analysis has been carried out strength structural components progressive gear using the finite element method. The performed numerical calculations allowed the evaluation of the degree of effort and strain on the hook mechanism to simulate the load case of emergency braking. The calculation results confirmed the correctness of the designed system, while exhibiting critical elements of the test structure. Proved to be a critical component of the braking roller, which received a reduced stress level close to the breaking point of the material. This means that in the event of emergency braking element is the most vulnerable part of the structure, limiting its strength. The level of effort of the other structural elements of the progressive gear does not endanger the operation of the mechanism.

Performed numerical analysis showed quantitative and qualitative consistency of results with the results of experimental studies conducted on the physical model of the structure. The plastic deformation zone were verified guide progressive gear after emergency braking simulation. Plasticizing FEM simulated testing, resulting in breaking subassembly reflects the nature of the deformation occurring in the way of actual experiment. This is confirmed by the results of experimental studies, in which the guide element area of the plastic deformation of the material obtained due to contact with the surface of the guide roll to a large extent similar to the deformation of the numerical model. The resulting high compatibility with the results of numerical simulations of the experiment indicates a high simulation capabilities similar issues, supporting the important field of research and design processes.

The study of experimental and numerical include important issues concerning the operation of passenger and freight elevators. The devices of this type have a strict conditions laid down building regulations concerning safety requirements to be met by a device that can be put into service. These requirements relate primarily to ensure safety in critical situations to which include lift emergency braking case. As previously mentioned, the crucial element is progressive gear braking system, which directly implement elements of the braking process. The efficiency of this process is primarily determined braking distance, which for safety reasons should be as short as possible, taking into account the different value system load. Conducted research in this area focused on improving therefore the characteristics of these devices, consisting of a crane shorter braking distances. The results presented in the article studies confirm the effectiveness of the proposed solution progressive gear CHP 2000, which also meets the requirements of BS EN 81-1 A3: 2010 [15].

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