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Self-Adjusting Handbrake Mechanism Design

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Abstract: Due to the wear of the brake linings of the rear brake, as well as due to the stretching of the steel rope of the handbrake control during the exploitation of the vehicle, the transmission mechanism of the handbrake increases the predefined clearances, that is, the free travel of the control lever increases. This free travel can increase to the extent that it compromises the normal functioning of the braking system. For this reason, all parking brake systems contain backlash adjustment mechanisms. On most vehicles, this adjustment is done manually, which means that the vehicle is periodically taken out of service for servicing. For this reason, the application of various mechanisms for self- adjustment of the handbrake, during the actual exploitation of the vehicle, began. This paper presents the process of design and construction of an innovative mechanism for continuous self-adjustment of the handbrake, without withdrawing the vehicle from operation.

Keywords: Vehicle; Braking system; Mechanism; Self-adjustment; Manual brake; Design for safety

1. Introduction

Traditionally, after setting up a component' design, it is further developed by evaluating the various production processes and the appropriate material. Then the practical aspects of the realization are defined, including the machine tools and the machining cycles. This traditional approach sees activities carried out in sequence, rather than simultaneously, and this often results in a relatively long time to set up the product. In particular, serious delays can occur when designers ignore production problems.

For years now designers tend to prefer the so-called *concurrent design* by what is now commonly recognized as *Design for X* (or *DFX*), where *X* stays for everything deserves to be investigated, designed and optimized [1]. This is the case, e.g., of design of cost [2], quality [3], safety [4], manufacturability [5], producibility [6], testability [7], reliability [8], maintainability [9], serviceability [10], recycling [11], sustainability [12] and so on.

During the product conception phase, in order for the product to be successful on the market, an innovative approach is desirable, and often indispensable, and this tends to make the approach required for an adequate design more complex and interdisciplinary [13]. Modern industry already tends to fully utilize the best technologies and equipment available in order to produce high quality products, in a short time and with competitive costs. Following some studies conducted in recent decades, more and more attention is being paid to the product design phase. As a guideline, it is believed that about 40% of the problems, related to the quality of a product, derive from an inadequate project [14] and that up to 70% of the final cost of a product can be influenced by the initial project [15], as well as about 70-80% of the total life cycle cost of the same can be determined during the design phase [16]. And this is what advanced training teaches by now [17, 18].

At the same time, the designers have gradually realized that such a list could be incredibly extended with new meanings, beyond the fact of going to involve intermediate aspects between each of the traditional categories.

This is, for example, the case discussed here where we, the designers, were forced to make a design intervention that took into account different aspects of the DFX simultaneously: safety, manufacturability, reliability, serviceability, testability between others. The final result is a new and complex product which nevertheless offers additional and unexpected functions aiming to achieve the general objective of *design for innovation*.

Actually, this is exactly what a good design process has to target to: offering innovativeness to products [19].

An important and representative sentence can fully explain the concept: “A product is an object, or system, or service made available for consumer use as of the consumer demand. It is anything that can be offered to a market to satisfy the desire or need of a customer " [20].

But let's move on to the design case: a self-adjusting handbrake mechanism.

Due to the need for occasional adjustment of the idle speed of the handbrake control lever, it is necessary to withdraw the vehicle from exploitation and refer it to the service. In order to avoid this criticality, improving the overall quality and saving resources, the design and production of several mechanisms that enable the adjustment of the handbrake during the vehicle's operation were started. The project assignment that preceded the design of the mechanism described in this paper, set requirements for: efficiency, reliability, compact construction, low cost.

The design solution, here proposed, met all the set requirements, so the design task was even improved, as the created structure enables continuous clearance adjustment during vehicle operation, which gives it a significant advantage in regulation precision, compared to mechanisms with discrete adjustment.

Then, an innovative mechanism for self-adjustment of the handbrake is the result of the present work.

2. Methodology

2.1 Design

The functionality of the mechanism according to the innovative design is based on the property of the threaded pair that the thread is not self-locking if the helix angle is greater than the friction angle. This is how the mechanism shown in Figure 1 was constructed.

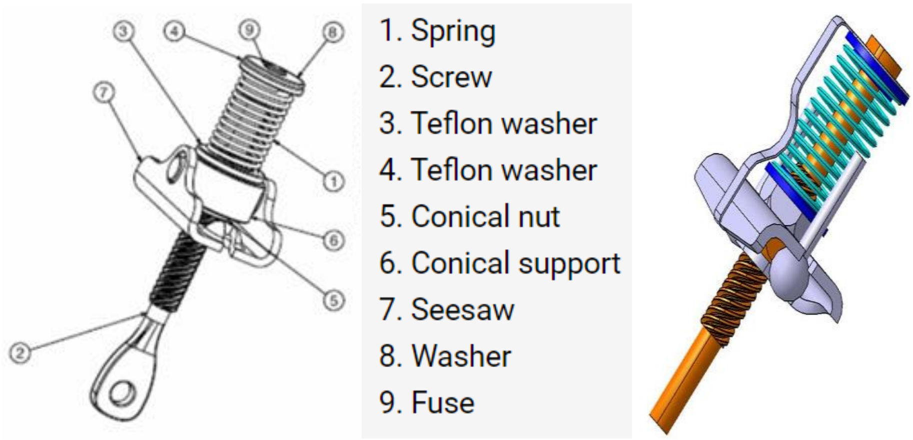


Figure 1. Assembly of the parking brake adjustment mechanism

The screw (2) and the conical nut (5) are connected via a multi-pass trapezoidal thread. The nut is inserted into the conical support (6), on which the "rocker" (7) is mounted. The screw is connected to the handbrake lever with an eye at its end, and the rocker is connected to the cables for activating the shoes.

When the handbrake lever is in the down position (unloaded), there is a balance of forces in the spring (1) and the return springs in the wheel. When there is a gap in the transmission mechanism, this balance is disturbed, so the spring separates the coupling of the conical pair and pushes the conical nut. Due to the small friction in the thread, the nut moves under the action of the axial force and thus compensates for the resulting gap. When pulling the handbrake lever, the cone nut is wedged in the cone carrier (6), so the nut cannot be re-screwed. In order to facilitate the operation of the mechanism, i.e. to ensure the easiest possible conversion of axial movement (spring) into rotary movement (nut), the spring is supported by sliding bearings (3 and 4).

Considering that the coupling of the conical pair is done only by friction, the mechanism will function continuously, reacting to the imbalance between the forces in the spring (1) and the return forces in the wheel of the vehicle.

2.2 Material and Methods

Even if the new brake design appears to be able to satisfy all functional requirements (and, in particular, adjustability), it is necessary to check the conditions to which all its parts are subject.

Specifically, it was decided to carry out finite element (FE) analyzes using the PAK software, a self-developed system of programs for linear and nonlinear structural analysis, heat conduction, fluid mechanics with heat transfer, coupled problems, biomechanics, fracture mechanics and fatigue [21].

It is of level of world known packages for structural analysis, with built-in finite elements and material models according to the state-of the art theoretical achievements. Its methodology is based on the up-to-date know-how, reported in journals and books by the program authors [22], that has already provided remarkable results in the field of elastoplastic analysis, thermo-plasticity, anisotropic material behaviour, element enhancements, original finite elements, coupled problems, biomechanics [23, 24]. In the present case, PAK-G. for graphical pre- and post-processing and PAK-S, for program for linear and geometrically and materially nonlinear structural analysis, modules were used.

Specifically, after the adoption of the mentioned conceptual solution, the mechanical analysis by finite elements of the construction elements was started. FEM was used to evaluate stress and displacement fields in the case of screw-nut assembly, with screw (pos. no. 2) and conical nut (no. 5), the conical support (no. 6) and seesaw (no. 7). As in other similar works by authors (e.g., [25-27]), finite elements permitted to validate the elastic and/or elasto-plastic behaviour of parts and their compliance with the resistance conditions of the materials. In the only case in which these safety conditions were not met, the study made it possible to introduce changes in the parts to guarantee the system safety.

3. Results and Discussion

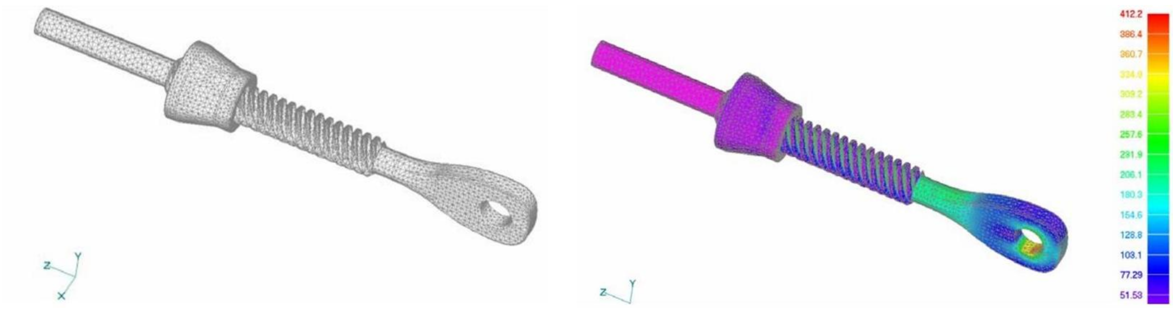
3.1 Numerical Analysis

3.1.1 Screw

Screw-nut system was modeled with 3D finite elements, using 21189 nodes and 83565 elements. This part was made of C1430 steel, reporting a yield stress of 415 MPa. The structure was loaded with a force of 7500N in the axial direction. The model discretization and effective stress field is shown in Figure 2. The maximum stress of 412.2 MPa is below the yield stress.

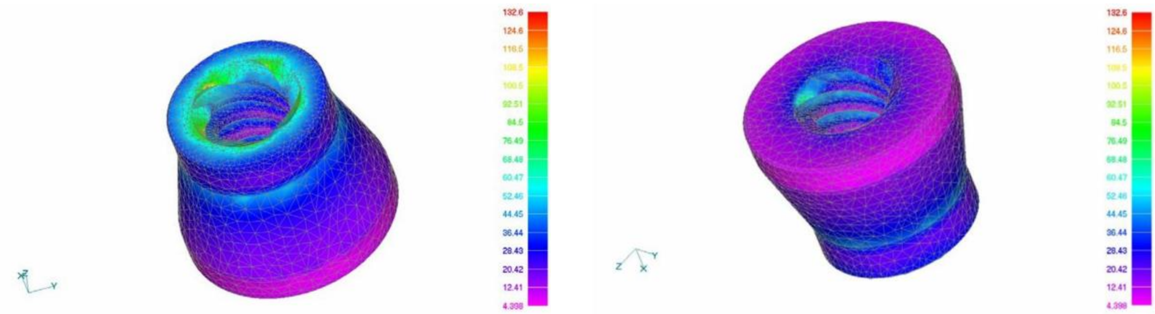
3.1.2 Nut

A deeper additional analysis of the nut was done as separate part using 12055 nodes and 51433 elements. A pressure was applied to the thread of the nut, causing an axial force of 7500 N. Discretization and stress field are shown in Figure 3. The maximum effective stress of 132.6 MPa is far below the yield stress.



(a) model discretization (b) stress field

Figure 2. Screw's finite element analysis



(a) model discretization (b) stress field

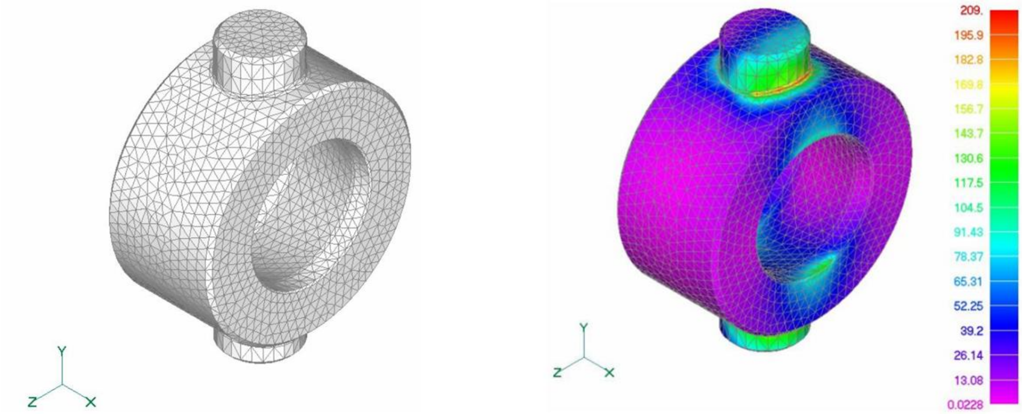
Figure 3. Nut's finite element analysis

3.1.3 Conical support

The 3D model of the conical support consists of 3750 nodes and 14354 elements. The material is Ch. 0545 with a yield stress of 285 MPa. A total force of 7500N is set on the lugs. Figure 4 shows the model discretization and the effective stress field. The maximum effective stress is 209 MPa, which is less than the yield stress.

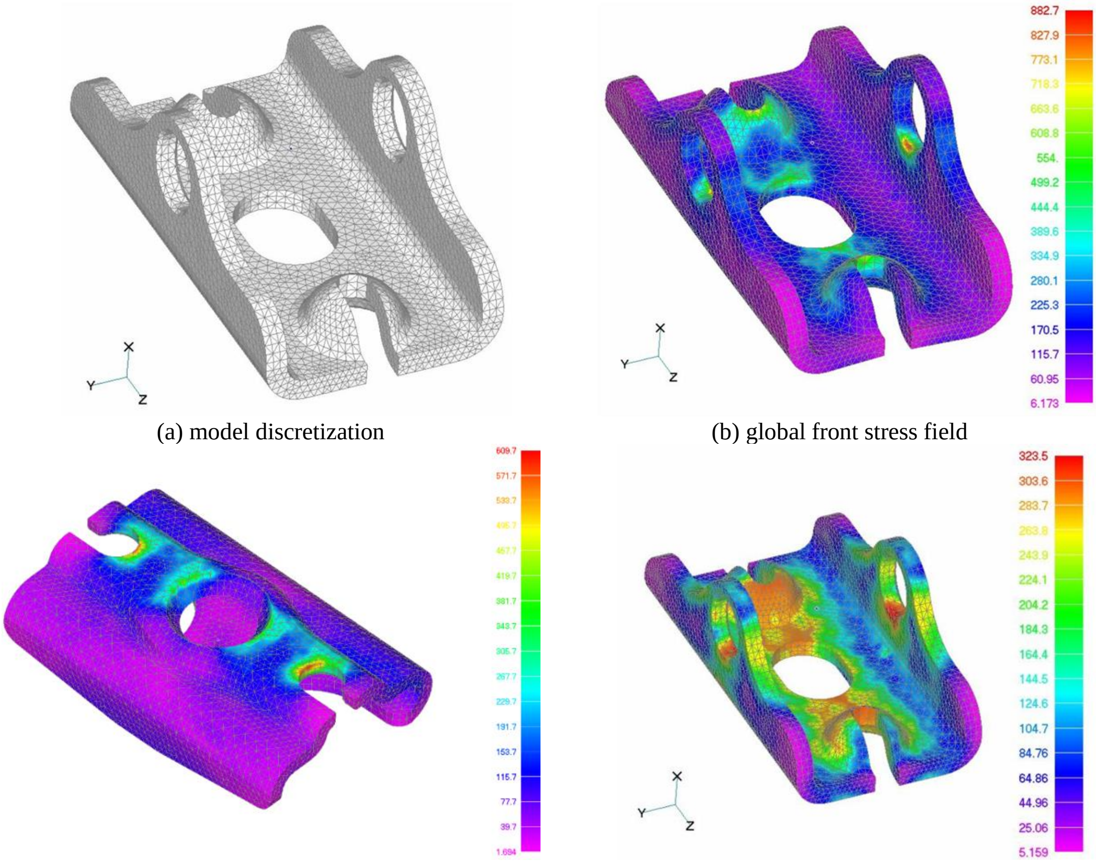
3.1.4 Seesaw

The seesaw was modeled by 6646 nodes and 20362 elements. The material was Ch. 0545 with a yield stress of 285 MPa. Figure 5 shows the model discretization (a) and the effective stress field (b). The maximum effective stress of 882.7 MPa is greater than the material yield stress and, therefore, it was necessary to additionally perform an elasto-plastic analysis. Results for such further analysis was shown in Figure 5 demonstrating as this component can be safely used.



(a) model discretization (b) stress field

Figure 4. Conical support's finite element analysis



(a) model discretization (b) global front stress field

(c) global back stress field (d) real stress field

Figure 5. Seesaw's finite element analysis

3.2 Redesign

Thanks to the numerical evidence, the necessary corrections were made during the mechanism's construction. The diameter of the screw (pos. 2) was increased and the shape of the rocker (pos. 7) was modified. Thus, the final design was achieved, on the basis of which the prototype of the mechanism, shown in Figure 6, was produced.

Figure 6. New handbrake adjustment mechanism, in the unfolded state and ready for assembly

3.3 Experiments

Prototypes typically made mechanism assemblies are subjected to laboratory testing: firstly, a function test and, then, a durability test. The conditions for durability testing (magnitude of load, characteristics of increase/decrease of load during the cycle, number of cycles...), set by CIMOS, conditioned the design and manufacture of a new electro- pneumatic test device. The device was designed so that it allowed setting the applied load, the gradient of the increase of the load, the holding time, the gradient of the decrease of the load and the pause time. Based on those requirements, the test was performed on the modified handbrake of the vehicle, where the handbrake control lever was not used (Figure 7).

(a) part of the test device for testing the durability of the mechanism

(b) test sample on the test table

(c) self-adjusting mechanism on the overload tester

Figure 7. Different phases of prototype testing

All test specimens of the mechanism withstood the intended number of load cycles, without plastic deformation of any element of the assembly and without loss of function. After the durability test, an overload test was performed. The test samples withstood the test not only without plastic deformation of any part of the assembly, but with complete preservation of the function of the mechanism. Figure 7(c), in particular, shows the test sample on the overload test device.

4. Conclusions

The use of modern engineering methods in all phases of design process (i.e., conceptual design, numerical analysis, manufacturing, laboratory tests, optimization) resulted in the design of an innovative mechanism for self-adjustment of the handbrake. This system met all the expected requirements: originality, reliability, functionality, mechanical durability, technology, low production cost. The final evaluation of system, beyond this initial prototype, will be given after the exploitation tests, which are in progress.

Author Contributions

Conceptualization, A.P.; methodology, S.V.; software, A.P. and S.V; validation, S.V. and A.P.; formal analysis, M.Z.; investigation, A.P. and S.V.; resources, M.Z.; data curation, A.P. and S.V.; writing—original draft preparation, A.P.; writing—review and editing, S.V.; visualization, M.P.; supervision, M.Z.; project administration, M.Z.; funding acquisition, M.Z.

Data Availability

The data, i.e., CAD/FEM models, supporting our research results may be released upon application to the corresponding author via e-mail.

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Conflicts of Interest

The authors declare no conflict of interest.

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