Materials Research Proceedings **24** (2022) 266-272 https://doi.org/10.21741/9781644902059-39

Locking Mechanism of a Slider with Self-Adjusting Backlash: Design and Dynamic Analysis

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Keywords: Locking Mechanism, Kinematic Analysis, Dynamic Analyses, Design Optimisation

Abstract. In mechanical designs which are to perform linear or rotary motion, there are forces resulting from the system inertia, speed, velocity of moving parts, friction resistance, etc. Therefore, the essence of modern design lies in predicting, in as much as possible, all the phenomena impacting the design and simulating them appropriately with the use of the available numerical tools. This paper presents both the modelling and kinematic and dynamic analyses for a mechanism blocking the linear movement of a slider connected to a movable element weighing approx. 1000 kg. The structure of the locking mechanism, essentially composed of two moving parts joined with the sliding element, was analysed. The developed mechanism consists in the use of moving parts to eliminate backlash (play), which during long-term operation, would be a disadvantage and lead to excessive dynamic forces and structural failure. The studies were performed in the "dynamic analysis" environment of the Inventor Professional 2021 3D CAD software.

Introduction

In the construction of mechanisms that implement movement based on linear guide rails, there is a need to lock the moving objects in specific, desired positions. For this purpose, engineers employ complex braking systems, as well as stoppers and locking mechanisms, simple in their construction. Stoppers restrict movement in one direction while locking mechanisms allow the movement to be limited in both directions thanks to the opening and closing mechanism. These mechanisms may be powered manually, electrically or using hydraulic or pneumatic systems. The drawbacks of such locking include difficulties in establishing the locking in both directions, which ensures a backlash-free connection, especially during operation [1-10]. This paper describes an innovative type of locking mechanism that performs its function with no backlash and a simulation was carried out to verify its operation. Simulation can not only replace costly practical tests and tests after the mechanism has been manufactured, but also the performance of multiple tests in a dedicated software environment.

Materials and Methods

Autodesk Inventor Professional 2021, version 2021.3.3 was used for the design works. This program contains the necessary standards and norms relative to mechanics and a number of useful calculation modules and wizards. The process of designing a given mechanism originally required the preparation of pre-designed components, and joining them together via nods at the later stage. This procedure allowed the authors to verify the matching of components and interconnections. For the purposes of the study, a dynamic simulation module was utilised, which enabled the simulation of the mechanism's operation, considering concurrent phenomena in the form of driving forces, forces in springs and friction in kinematic pairs. The results of the analyses conducted

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yielded the desired results in the form of the driving force runs as the function of the locking mechanism displacement and the spring forces as the function of time. Graphs in Figs. 1 and 2 serve as an illustration of these results.

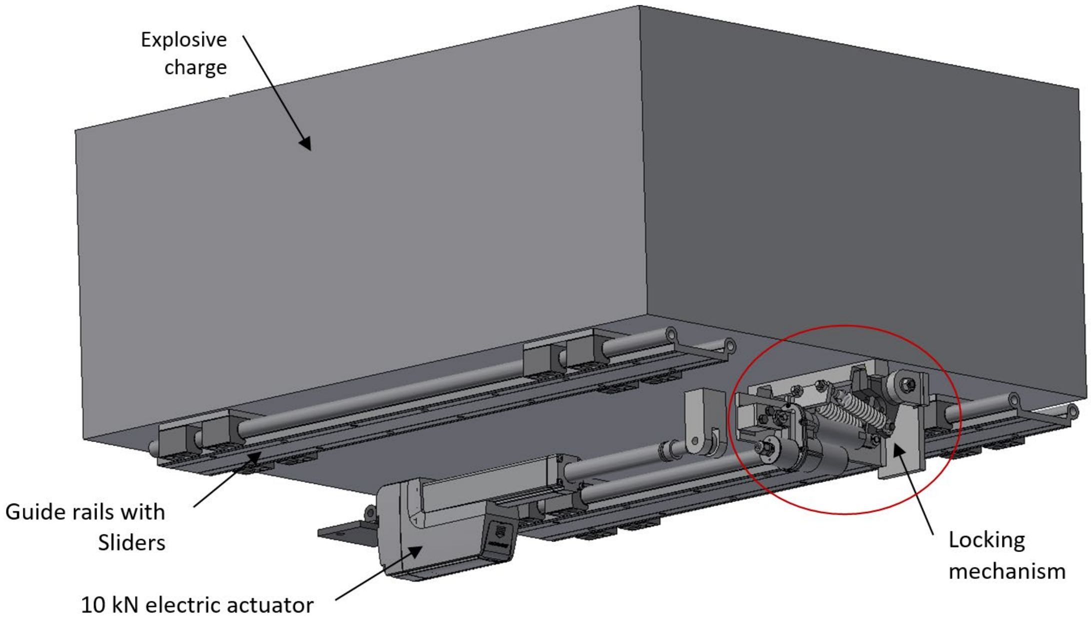

Fig.1. *General view of the studied mechanism.*

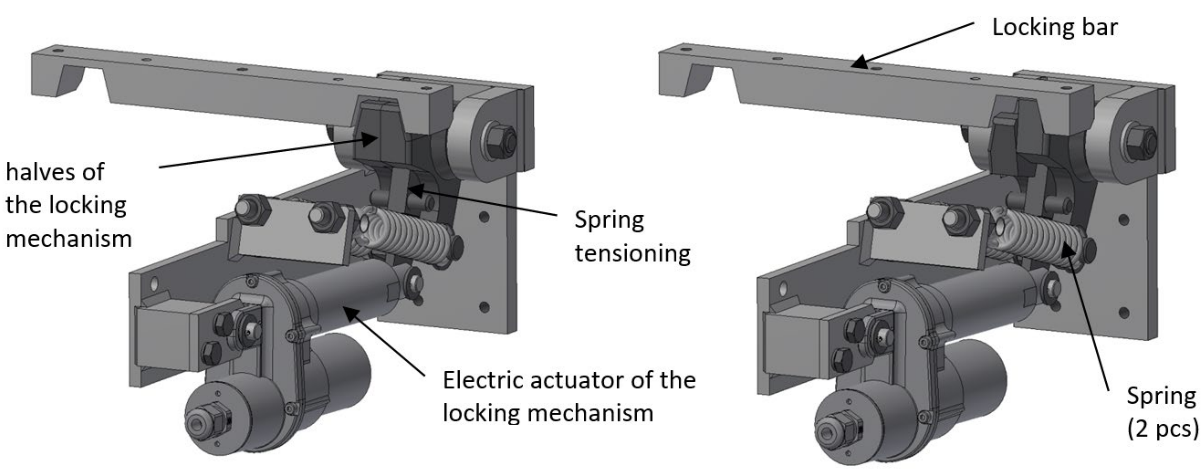

Fig.2. *Diagram of the designed locking mechanism.*

Results

The authors strived to verify the correct operation of the backlash-free locking mechanism. This generally takes place after the product has been manufactured and its operation – initiated. Autodesk Inventor's Dynamic Simulation module enables product testing at the digital prototype stage.

Design of the Backlash-Free Locking Mechanism. Consisting of two halves, the locking mechanism automatically compensates for any play resulting from inaccuracies of the slider braking distance (displacement) within the range of ± 1.5 mm. The wear and tear on the mating surfaces can also be compensated. The operation of the mechanism is presented in Fig. 3.

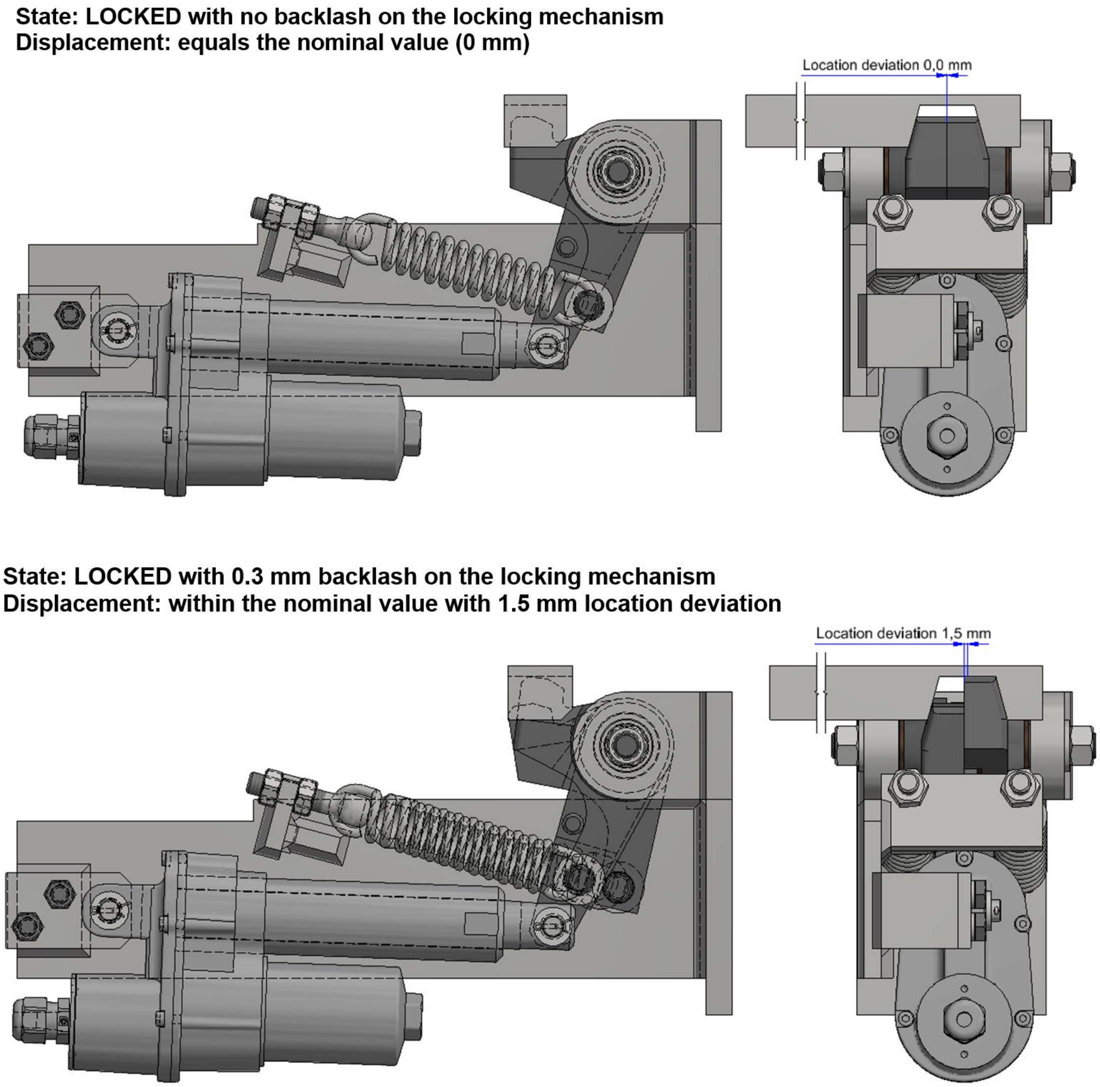

Fig.3. *Self-adjustment of a backlash-free locking mechanism.*

Such a mechanism should lock the position effectively and with no backlash, regardless of the location deviation within the range of ± 1.5 mm. In addition, the locking strength within this distance should be approximately the same. Such a solution has the advantages of applications based on brake mechanisms (brake blocks or brake shoes) while being simpler and more economic.

Verification of the Mechanism's Operation Using a Digital Model. The necessary elements of the locking mechanism were introduced into the digital model and the proper loads were applied. It was assumed that the mechanism operates correctly correct if the momentum of the slider's movement does cause the locking mechanism to disengage. This is an extreme case (e.g. an automation error), but certainly, such a force would not occur under normal operation and it is a safe assumption. In the structure under consideration, the drive used was an electric actuator with a nominal pulling force of 10 kN. The springs pressing the locking mechanism's halves were responsible for the effective operation of the mechanism, and hence the presence of these springs with the designed characteristics, presented in Fig. 4, in the dynamic simulation.

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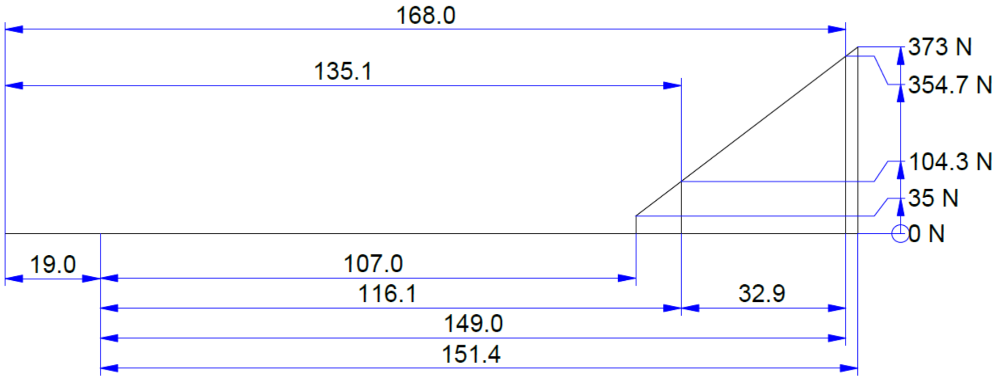

Fig.4. *Spring characteristics.*

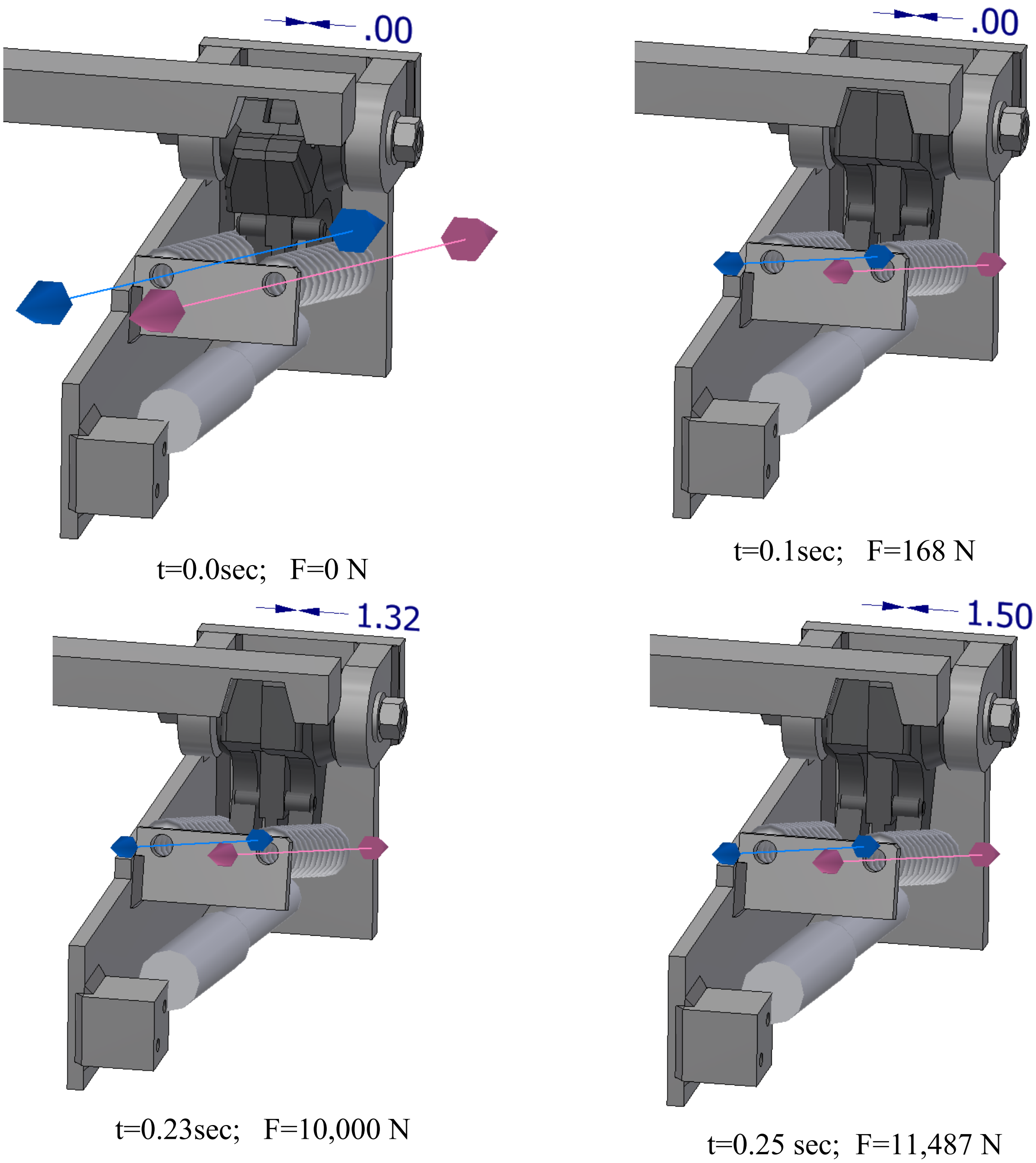

Fig.5. *Driving force as the function of time.*

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The dynamic simulation was carried out with the following assumptions in mind:

1. Simulation of the loading over time:
   - the time interval of 0.0 ÷ 0.6 sec,
   - the coefficient of friction equal $\mu = 0.2$ was assumed for the mating surfaces (steel/steel);

2. The locking mechanism halves (the P-block and the L-block) are pressed to the recess (cut out) by spring forces in accordance with their characteristics throughout the operating range;

3. The displacement of the locking bar was being applied across the slider in the range from 0 mm to 5 mm during 0.6 s. This movement, which generates the driving force necessary for the displacement, and is shown in Fig. 5 and on the graph in Fig. 6.

4. The displacement of the slider is monitored. A displacement of up to ± 1.5 mm is allowed, as it is within the range of position adjustment;

5. The slider displacement value for a driving force of 10 000 N is to be read out from Fig. 7;

6. The mechanism will work properly; the slider displacement needs to be under 1.5 mm if the driving force equals 10 kN.

Fig.5 illustrates the simulation at t = 0; 0.1; 0.23; 0.25 sec.

A graph of the driving force as the function of time was drafted based on the simulation (Fig. 6). What could be read out from the graph, is that the permissible slider driving force of 10 kN will occur at 0.23 sec.

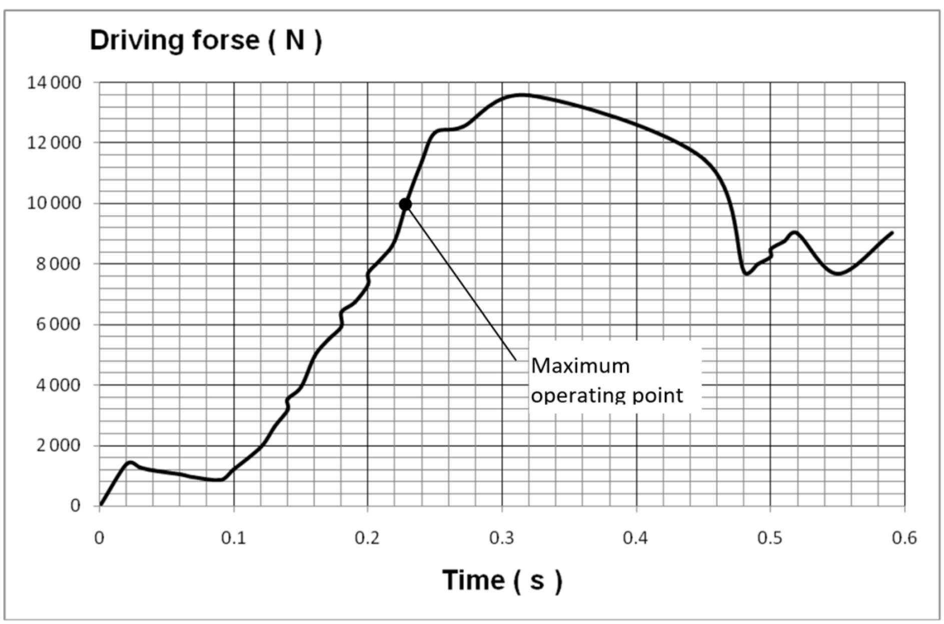

Fig.6. *Diagram of driving force as the function of time.*

A graph of the driving force as the function of time (Fig. 7) was drafted based on the simulation. What could be read out from the graph, is that the permissible slider driving force of 10 kN will occur at 1.23 mm of the locking bar movement.

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A graph of the driving force as the function locking mechanism displacement (Fig. 7) was also based on the simulation. The graph reveals that the permissible slider driving force of 10 kN will occur for the slider displacement equal 1.23 mm.

The spring force as the function of time is presented in Fig. 8. The graph was drafted based on the simulation conducted. It can be seen that for displacement of 1.5 mm the force of the P-spring equals 302 N, and that of the L-spring is 274 N, which is well within their performance characteristics.

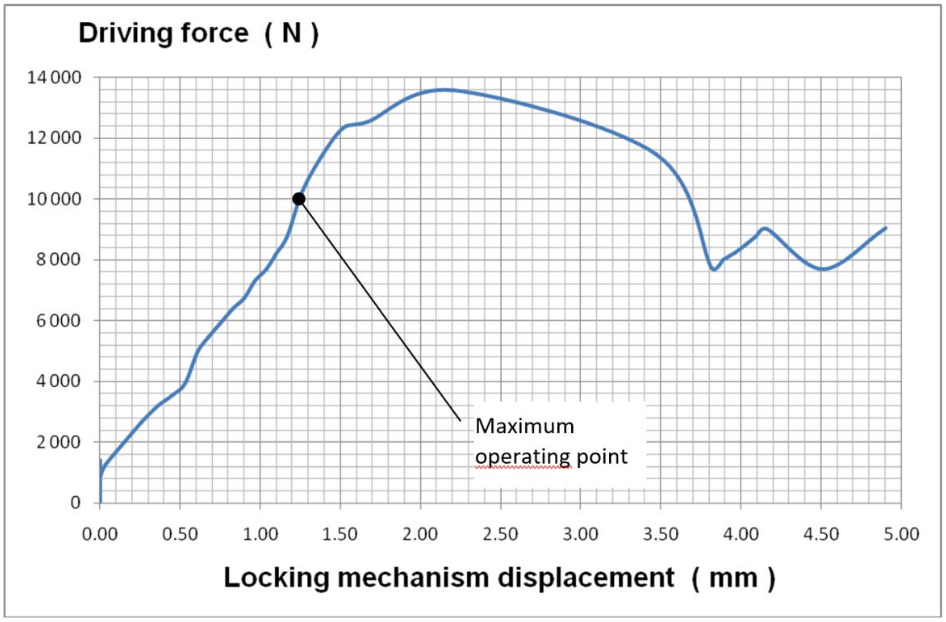

Fig.7. *Driving force in the function of the locking mechanism displacement.*

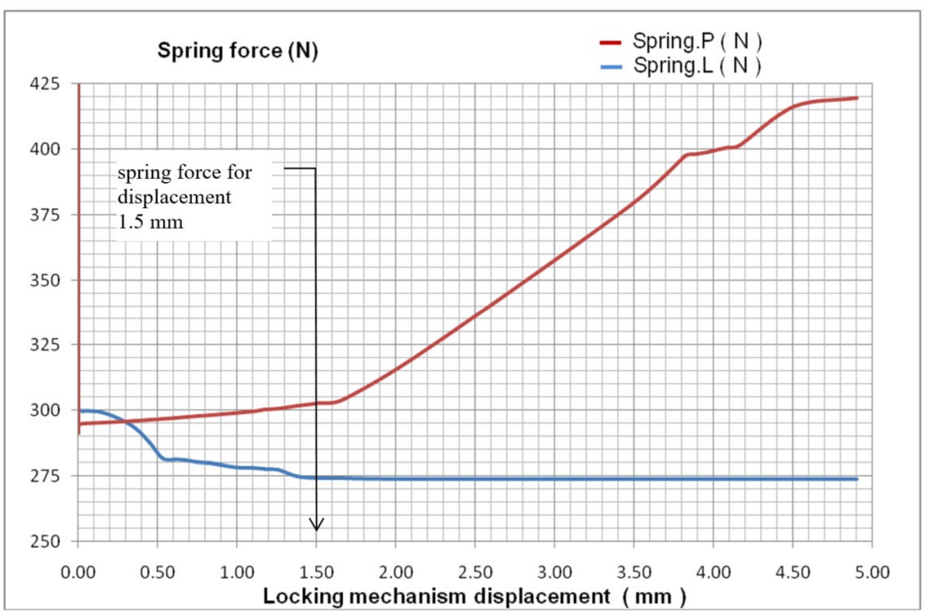

Fig.8. *Forces of springs as the function of time.*

The mechanism will work properly, as for a given slider driving force of 10 kN, the slider displacement value is 1.23 mm (Fig. 7), i.e. under 1.5 mm. Thus, the mechanism design can be considered correct.

Conclusion

Dynamic simulations bring undeniable benefits to the design practice. This study shows that the designed mechanism will function properly. The investigation was performed in a multifaceted manner, without the need for costly experimental tests, which will be performed on the final version of the designed product only, as part of the device prototype testing stage.

It should be noted that as in the case of all technical calculations, the value of the results obtained depends on the accuracy of the boundary conditions set. As even the most refined software tools will miscalculate when fed incorrect data, the use of advanced computational methods, such as dynamic simulations, should be reserved for experienced engineers, practicing in the field.

What also needs to be emphasized is that for simple mechanisms, that is with a low degree of complexity, where it is easier to formulate the input data, the calculation results will be more trustworthy, and such is the case examined in this article.

References

[1] A. Arian, B. Danaei, H. Abdi, S. Nahavandi. Kinematic and dynamic analysis of the Gantry-Tau, a 3-DoF translational parallel manipulator, Applied Mathematical Modelling 51 (2017) 217–231. https://doi.org/10.1016/j.apm.2017.06.012

[2] J. Frączek, M. Wojtyra. Kinematyka układów wieloczłonowych – metody obliczeniowe. WNT, Warszawa, 2008.

[3] M. Gawrysiak. Mechatronika i projektowanie mechatroniczne. Białystok University of Technology, Białystok, 1997.

[4] A. Gronowicz. Podstawy analizy układów kinematycznych. Wroclaw University of Technology, Wrocław, 2003.

[5] P. Hejma, M. Svoboda, J. Kampo, J. Soukup. Analytic analysis of a cam mechanism. Procedia Engineering 177 (2017) 3-10. https://doi.org/10.1016/j.proeng.2017.02.175

[6] S. Miller. Teoria maszyn i mechanizmów – analiza systemów kinematycznych. Wroclaw University of Technology, Wrocław, 1996.

[7] J. Ormezowski. Analiza dynamiczna mechanizmu hamującego. Archiwum Motoryzacji 1 (2010) 27-34.

[8] A. Sapietova, J. Bukovan, M. Sapieta, L. Jakubovicova. Analysis and implementation of input load effects on an air compressor piston in MSC.ADAMS. Procedia Engineering 177 (2017) 554-561. https://doi.org/10.1016/j.proeng.2017.02.260

[9] P. Sperzyński, J. Szrek, A. Gronowicz. Synteza geometryczna mechanizmu realizującego trajektorię prostoliniową ocechowaną. Acta Mechanica et Automatica 4 (2010) 124-129.

[10] J. Vavro Jr., J. Vavro, P. Kováčiková, R. Bezdedová. Kinematic and dynamic analysis of planar mechanisms by means of the SolidWorks software. Procedia Engineering 177 (2017) 476-481. https://doi.org/10.1016/j.proeng.2017.02.248