

flexible coupling; virtual modelling; simulations

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## **KINEMATIC AND DYNAMIC SIMULATION OF THE FUNCTIONING OF TORSIONALLY FLEXIBLE METAL COUPLING**

**Summary.** The article presents the process of visualization and the accuracy of performance of the prototype of bidirectional torsionally flexible metal coupling using Autodesk® Inventor® Professional 2009. Selected figures from the simulations are presented and discussed on the basis of a virtual model of the coupling.

## **KINEMATYCZNA I DYNAMICZNA SYMULACJA DZIAŁANIA METALOWEGO SPRZĘGŁA PODATNEGO SKRĘTNIE**

**Streszczenie.** W artykule omówiono proces wizualizacji i poprawności działania prototypu metalowego sprzęgła podatnego skrętnie dwukierunkowego działania z wykorzystaniem programu Autodesk® Inventor® Professional 2009. Zostały zaprezentowane i omówione wybrane wyniki z przebiegu tych symulacji na modelu wirtualnym sprzęgła.

### **1. INTRODUCTION**

The tendency to increase the effectiveness of technological processes and at the same time the efficiency of machines through growth of power with simultaneous optimisation of their size and mass often leads to the increase of dynamic interactions of particular units of the machines. The dynamic interactions taking place in the power transmission system components are definitely disadvantageous. Broad research has shown that even relatively small dynamically affecting force can cause considerably bigger internal forces and displacements to appear than significantly bigger statistically affecting force.

From the experiments regarding exploitation and the information of machine shops stems the fact that the level of knowledge about constructing and the insufficiently examined problems with the process of utilization need further research. The efficacy and reliability of machines are shaped during the processes of construction, manufacturing and exploitation. Sufficient knowledge about working load affects the decisions made at all three of those phases and that has a close link to the durability of particular elements and units of the machines. In the process of construction nominal external load is taken into account with a certain reserve, e.g. with the aid of the factor of implementation  $K_A$  (formerly overload  $K_p$ ). However, assessing other factors that have influence on the load of the elements of the machine, like e.g. those stemming from faulty performance and assembly as well as the interaction between cooperating elements, is hampered because of their random character and unspecified synergism in generating dynamic loads.

Decreasing the dynamic loads between particular elements of the power transmission system components of a mill, which usually include engine, mechanical gear and actuator can be accomplished through the accurate selection of couplings linking those respective elements. Thanks to couplings it is possible to considerably reduce the dynamic loads in the power transmission system components caused by both external and internal factors. This function is best fulfilled by torsionally flexible couplings characterised by adequate resilient and deadening features.

In the majority of the machines used in mining, building and road industry most of the power transmission system components is liable to random loads both in the phase of start and steady flow as well as stop. Those power systems are prone to be affected by overloads, shock loads and frequent starting under great load. An excellent instance of the above is the power system of a drag chain conveyor. Difficult operating conditions require the usage of couplings with great flexibility susceptibility. Currently the most loaded power transmission systems of mining machines employ one or two liner flexible couplings, liquid couplings of various kinds (e.g. SH, TV produced by Voith Turbo GmbH, etc.) or different types of integrated power transmission systems, like WB/CST DBT, that comprise of epicyclic gearbox and multiple-plate coupling. The aforementioned examples of couplings are characterised by specific advantages and disadvantages described in technical literature [5, 6].

The Institute of Mining Mechanization developed a completely new construction, namely torsionally flexible metal coupling, which fulfils most of the requirements of application as regards to the considerably loaded power transmission systems of mills [1 - 4].

Through the mitigation of torque alterations this coupling causes the absorption of energy, which affects the stabilisation of torsional vibration and the beneficial change of its flow. This contributes to a significant reduction of dynamic loads and thereby ensures the accurate performance of the power transmission system of a mill. And this means the increase of durability and reliability of its constituents.

## **2. THE NATURE OF TORSIONALLY FLEXIBLE METAL COUPLING'S FUNCTIONING**

One of the structural forms of bidirectional torsionally flexible metal coupling is shown in fig. 1.

The tenet of torsionally flexible metal coupling rests in the operating torque affecting the active part of the coupling directly through the shaft (1) and then being conveyed to the sliding sleeve (2) with the aid of a multi-start thread. The increasing value of the torque causes the rotation of the shaft (1) against the sliding sleeve (2) and at the same time the torque converter housing (3). The axial force that is thus produced in the multi-start thread initiates plane motion of the sliding sleeve alongside the crankshaft centreline (release lever axle).

The limitation of the motion of the sliding sleeve to plane motion is achieved through motor splined coupling positioned between the sleeve (2) and the torque converter housing (3). Plane motion of the sliding sleeve causes simultaneously the compression of a set of dished plate springs (4) that is especially selected to match the assumed qualities of the coupling. The compression of the springs causes the internal elastic strain force to affect the set. This force in every temporal, fixed location of the sliding sleeve counterbalances the axial force produced in the multi-start thread, which is the result of the external insert momentum operating. Every temporal overload of the power system with the insert momentum triggers additional compression of the resilient elements of the coupling and decreasing the load causes their annealing.

Detailed information about the construction and the tenet of functioning of the coupling can be found in publications [1 - 4].

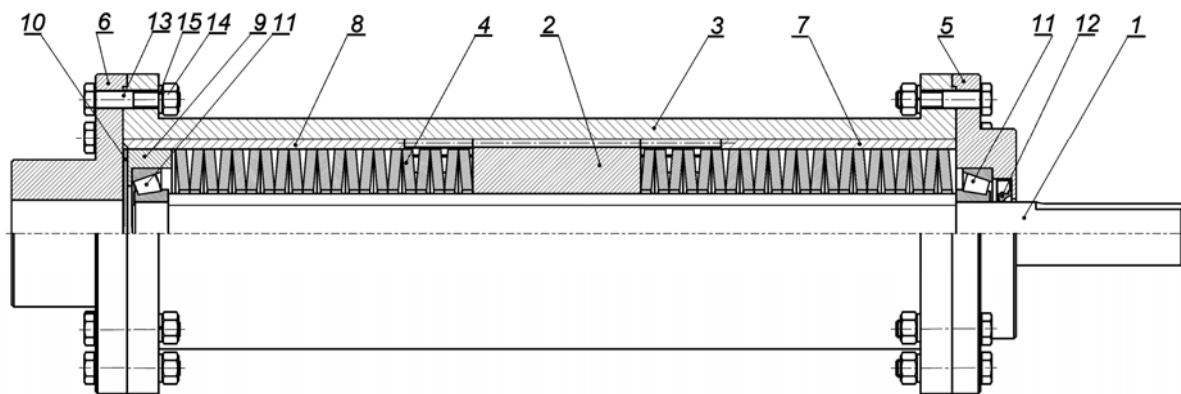


Fig. 1. Two-way-flexible torsional metal coupling prototype construction: 1 – screw-threaded coupling shaft, 2 – splined sliding sleeve with internal screw thread, 3 – housing with cut splines, 4 – disk spring set, 5 – cover plate, 6 – coupling hub, 7,8 – sleeves locating the disk spring set, 9 – sleeve locating the bearing, 10 – sealing element, 11 – cone bearings, 12 – sealing ring, 13,14,15 – screw joint elements

Rys. 1. Budowa prototypu metalowego sprzęgła podatnego skrętnie dwukierunkowego działania, gdzie: 1 – wał sprzęgła z wykonanym gwintem, 2 – tuleja przesuwana z wykonanym gwintem wewnętrznym i wielowypustami, 3 – obudowa z naciętymi wielowypustami, 4 – zestawy sprężyn talerzowych, 5 – pokrywa zamykająca, 6 – piasta sprzęgła, 7,8 – tuleje ustalające sprężyny, 9 – tuleja ustalająca łożysko, 10 – element uszczelniający, 11 – łożyska stożkowe, 12 – pierścień uszczelniający, 13,14,15 – elementy połączenia śrubowego

### 3. EXAMPLES OF KINEMATIC AND DYNAMIC ANALYSIS OF TORSIONALLY FLEXIBLE METAL COUPLING

In modern machines designing computer programs come into play making it possible not only to visualise the object in three-dimensional form, but also to check how the designed construction will act both kinematically and dynamically even before the actual prototype has been constructed. Currently programs like e.g. SolidWorks®, Pro/ENGINEER®, Solid Edge, Catia or Autodesk Inventor® that serve such purposes are in common use.

In this publication Autodesk® Inventor® Professional 2009 was used to both visualise and check the accuracy of functioning of the torsionally flexible metal coupling construction. With the aid of the so-called solid modeller provided by the program particular elements of the coupling were built and then composed to make a functional coupling mechanism (fig. 2) by block capabilities.

Built-in dynamic simulation module of Autodesk® Inventor® Professional 2009 enables both kinematic and dynamic analysis of the performance of the coupling. The relations between cooperating elements of the coupling were fixed thanks to dynamic capabilities, usage there of is shown in fig. 3.

The capabilities determine kinematic relationships in the linkage found in the screw joint between the shaft of the coupling and the sliding sleeve. The effect of geometrical connection of the elements of the coupling with the capabilities is the creation of virtual dynamic links that simulate the links that appear in the actual object. Direct visualisation of the simulation of motion of the elements of the coupling enables to check the accuracy of the kinematic links and the constructional assumptions and thereby foresee how they will behave in real conditions, which are in the prototype of the coupling.

In order to simplify the computer kinetic and dynamic analysis of the coupling the sets of the dished plate springs were substituted with virtual elastic and dumping linkage presented in the computer model in the form of a spiral spring corresponding to the qualities of the sets of dished plate springs used (Fig. 4). Thanks to this trick it was possible to make an accurate simulation of the movement of the sliding sleeve of the coupling produced when the torque affects the shaft of the coupling. The created move matched the deformation of both the sets of dished plate springs.

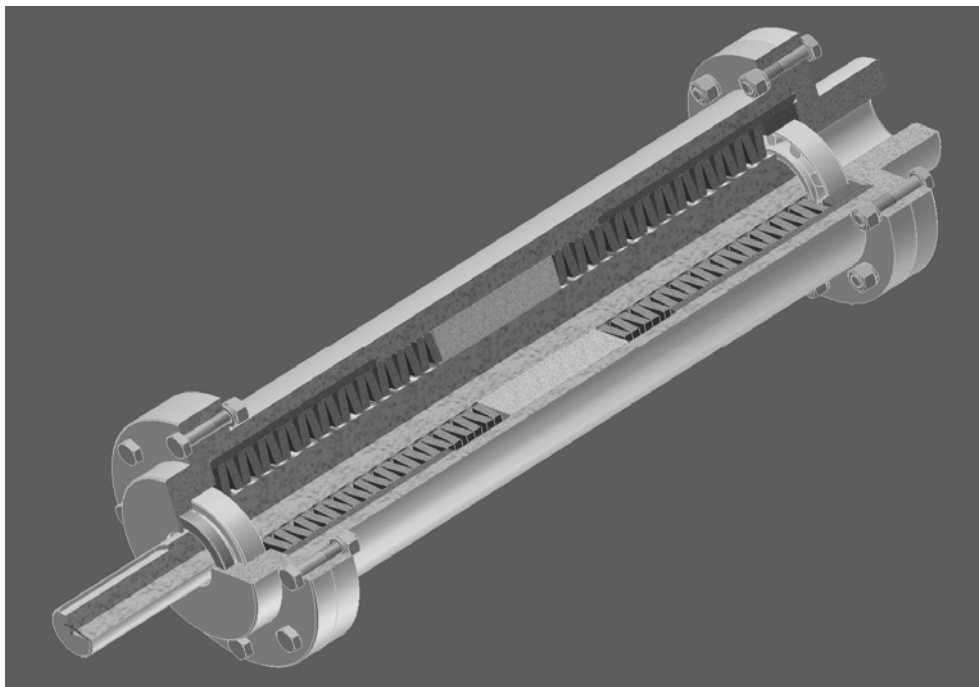


Fig. 2. View of the two-way prototype of the metal flexible torsional coupling  
Rys. 2. Widok prototypu metalowego sprzęgła podatnego skrętnie dwukierunkowego działania

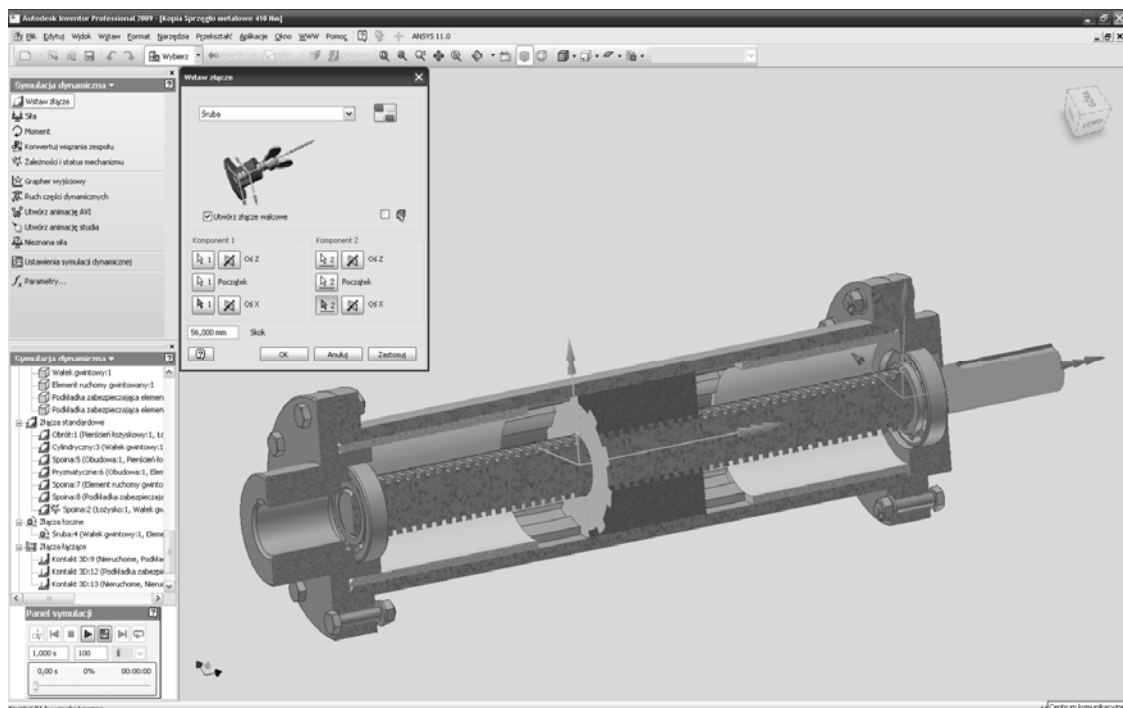


Fig. 3. Estimation of the „screw thread” bound type between sliding sleeve and coupling shaft  
Rys. 3. Określanie wiązania typu „śruba” pomiędzy tuleją przesuwaną i wałem sprzęgła

The substitution of the set of springs with such linkage eliminated the problem of modelling the contact between the particular dished plate springs in a block and the contact between the peripheral dished plate springs, the bearing ring and the sliding sleeve.

The application of this technique was determined by the program limitations characterising the version used for these analyses.

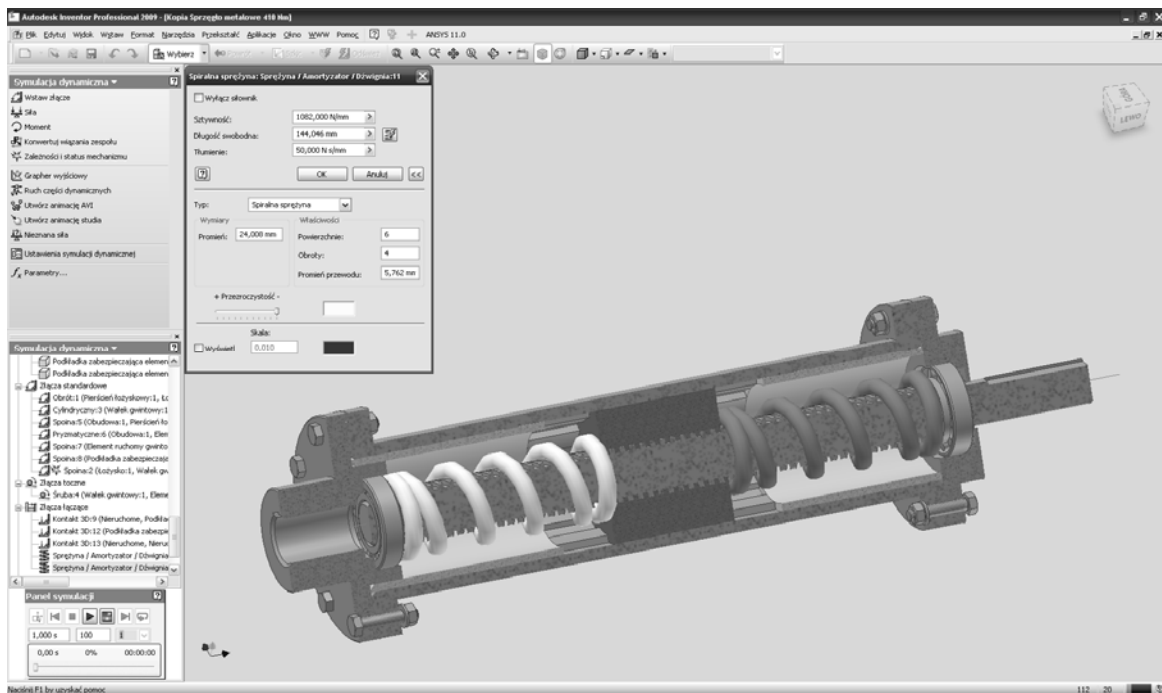


Fig. 4. Estimation of the “elastic and dumping” bound type, simulation of disk spring set  
 Rys. 4. Określanie wiązania sprężysto – tłumiącego, symulującego zestaw sprężyn talerzowych

The friction factors were fixed for all of the cooperating kinematic pairs. Their values are determined for all assumed dynamic capabilities (fig. 5).

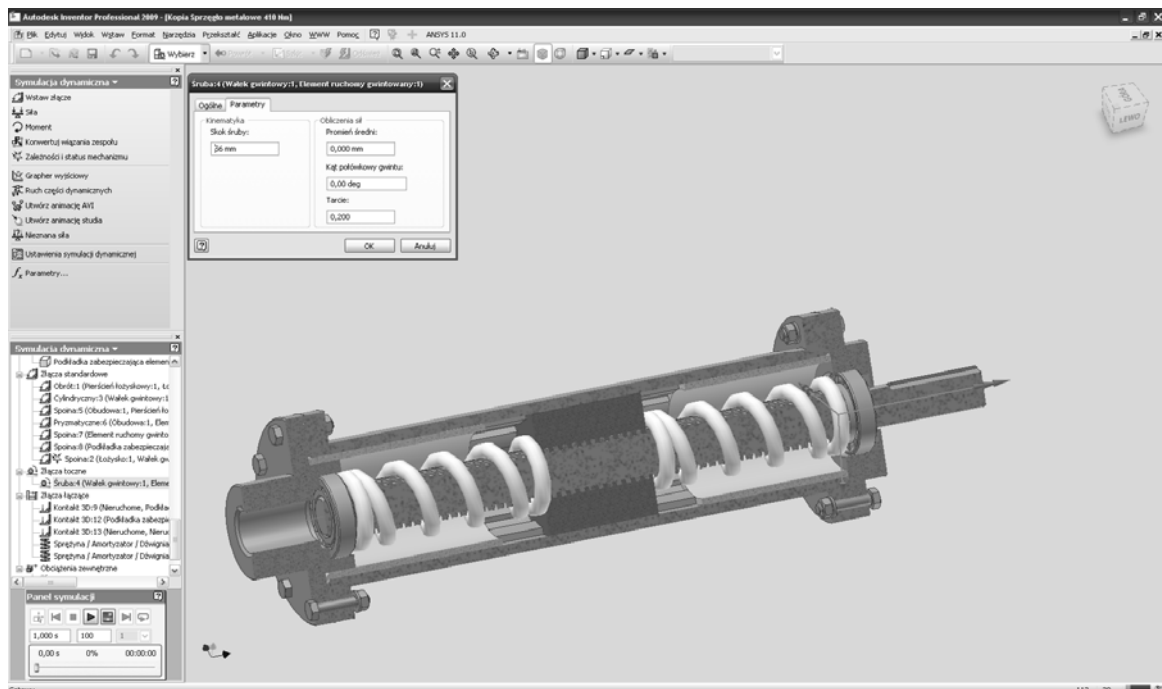


Fig. 5. Example estimation of friction factors between sliding sleeve and coupling shaft  
 Rys. 5. Przykład określenia współczynnika tarcia pomiędzy tuleją przesuwaną i wałem sprężną

The extraction in the form of motion of any movable element of the coupling can be constant or can change in the time function thanks to the application of the so-called “input grapher” of the program. An example of its implementation is shown in fig. 6.

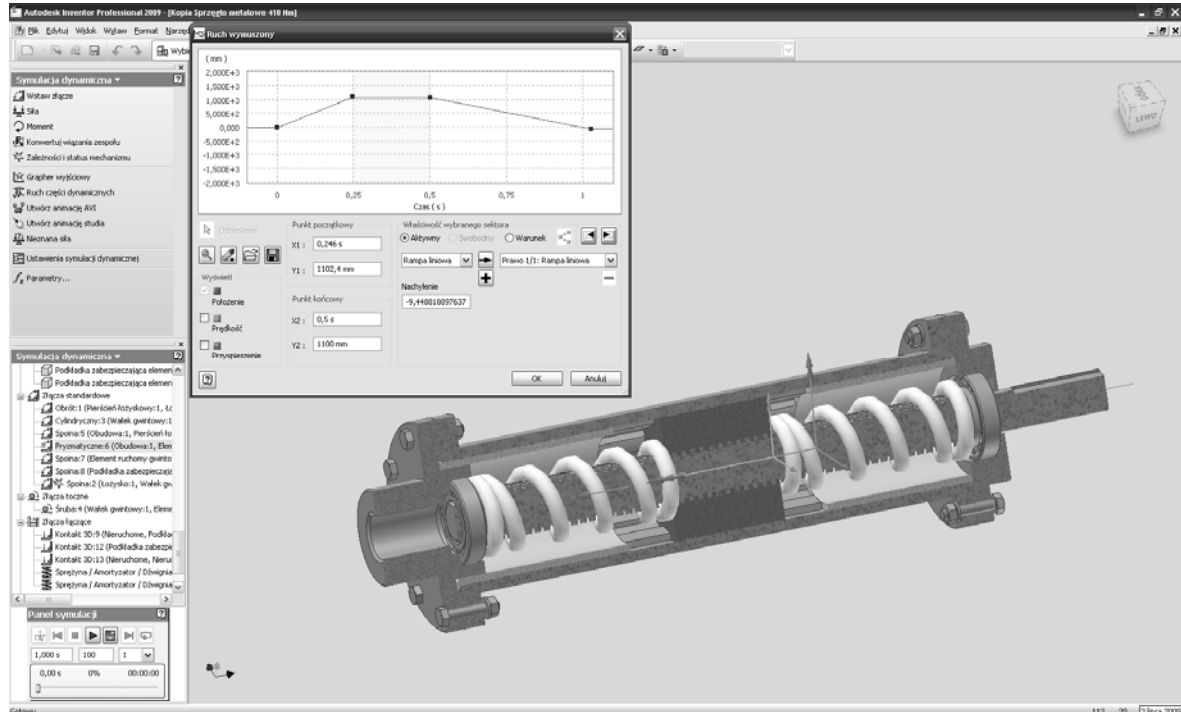


Fig. 6. Example using “input grapher” in dynamic simulation of the Autodesk® Inventor® 2009 program  
Rys. 6. Przykład wykorzystania „graphera wejściowego” do symulacji dynamicznej w programie Autodesk® Inventor® 2009

In this case the input grapher was employed to determine extraction variables affecting the sliding sleeve of the torsionally flexible metal coupling. The changing value of the offset of this element alongside the axis of the coupling in the time function was determined. It is possible to stipulate any number of load brackets for a given time of simulation in the object analysis.

After the modelling of all the elements of the coupling, linking them with dynamic capabilities to create a functioning mechanism and applying extraction in the form of the torque on the input shaft of the coupling the simulation of its performance was launched. The simulation proved the accuracy of torsionally flexible metal coupling’s functioning in terms of kinematics.

In the next stage a dynamic analysis was launched. This produced information about the features characterising the dynamics of selected constituents. The “output grapher” of the program enables to visualise the results of the dynamic analysis in the form of graphs. Thanks to this module it is possible to present the results of the conducted dynamic analysis both swiftly and precisely. It is also possible to obtain the flow of analysed dynamic and kinematic parameters in the time function, e.g. force and momentum that affect the loaded elements of the coupling and the displacement, speed and acceleration of the movable elements of the examined construction.

An example of the presentation of the results of the dynamic analysis using the output grapher is shown in fig. 7. The graph presents the value of displacement of the sliding sleeve in the time function as an outcome of constant torque affecting the shaft of the coupling. In the initial phase the sliding sleeve relocates rapidly along the axis of the coupling. Next the speed of the displacement of the sleeve is decreased until the value of the displacement is pegged or in other words the sleeve completely stops to a halt. This dependence is strictly related to the modelled characteristics of the set of the dished plate springs.

Another example of the dynamic analysis of the coupling is presented in fig. 8. Constant torque was put against the input shaft of the coupling. The graph shows how the value of the torque (axis of ordinates in the graph) changes in the screw joint between the shaft of the coupling and the sliding sleeve in the time function during the conducted simulation.

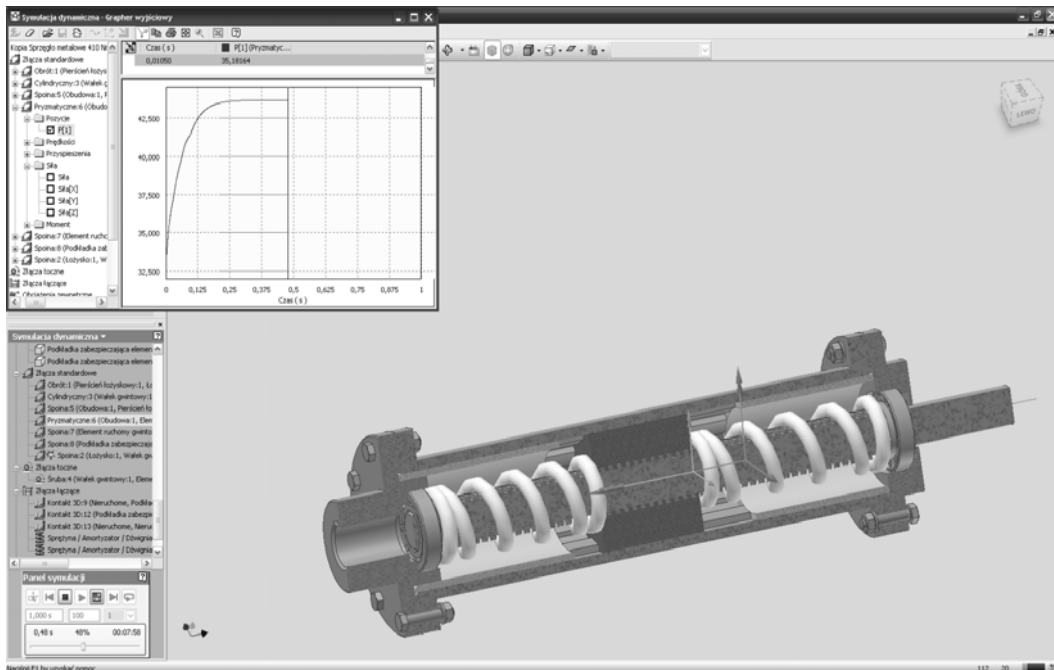


Fig. 7. Example of the visualization results of the dynamic simulation using the "output grapher" Autodesk® Inventor® 2009 program – displacement sliding sleeve coupling

Rys. 7. Przykład wizualizacji wyników symulacji dynamicznej za pomocą „graphera wyjściowego” programu Autodesk® Inventor® 2009 – przemieszczenie tulei przesuwnej sprzęgła

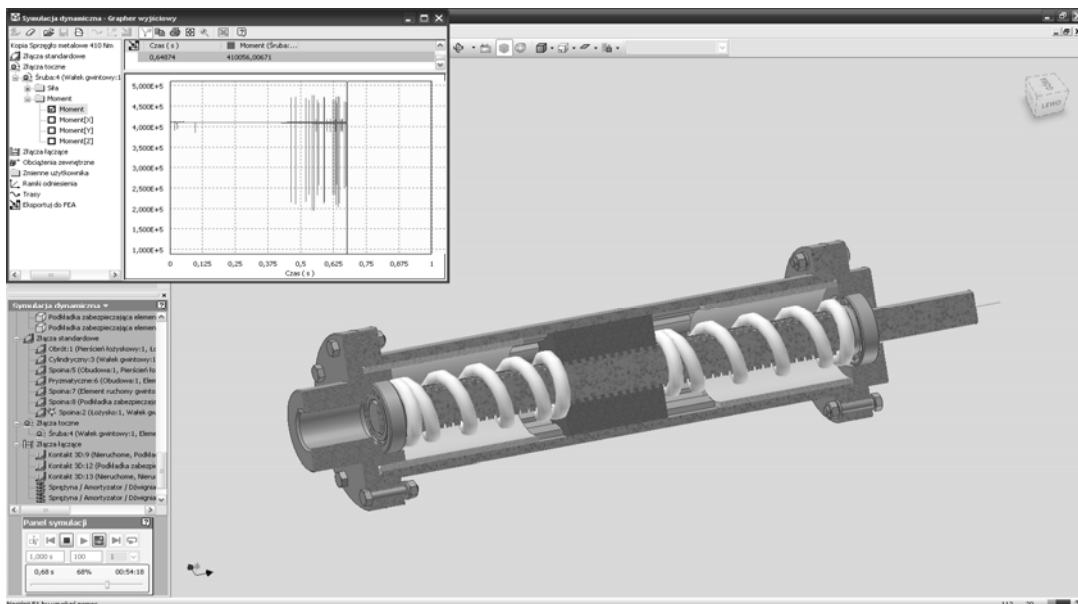


Fig. 8. Example of the visualization results of the dynamic simulation using the "output grapher" Autodesk® Inventor® 2009 program – torque acting value between coupling shaft and sliding sleeve

Rys. 8. Przykład wizualizacji wyników symulacji dynamicznej za pomocą „graphera wyjściowego” programu Autodesk® Inventor® 2009 – wartość momentu obrotowego pomiędzy wałem sprzęgła i tuleją przesuwną

For comparative purposes it is possible to place many curves in the same graph, to control and read the results in any given moment of the simulation cycle. The additional possibility to export the results to Microsoft® Excel® spreadsheet allows conducting further inference and presenting the results of computer research in other forms.

#### 4. SUMMARY

In the process of creating new constructive solutions computer tools in the form of advanced CAD-type engineer programs that enable the analysis of the machine before building its actual prototype are of great help.

Torsionally flexible metal coupling was fashioned in Autodesk® Inventor® 2009 as three-dimensional solid model. This allowed to launch kinematic and dynamic analysis through the performance simulation of the coupling under working load.

The results of the conducted dynamic analysis are the program-generated flow of the value of force, displacement, speed and acceleration of the specific movable elements of the coupling in the time function.

Thanks to the computer simulation results it was proved that this construction works accurately as regards to kinematics in the linkage of shaped elements of the coupling. It was also possible to check the reaction of particular elements of the coupling to extortions by motion owing to the application of the report compliance used for the analyses.

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