Use of the iLogic Autodesk Inventor tool in the process of designing self-propelled drilling rigs

Author's affiliations and addresses:

[1] AGH University of Science and Technology, Faculty of Mechanical Engineering and Robotics, Department of Machinery Engineering and Transport, al. Mickiewicza 30, 30-059 Krakow, Poland

* Correspondence:

e-mail: boloz@agh.edu.pl

Łukasz BOŁOZ iD [1*]

Abstract:

In the article, a practical example of using the Autodesk Inventor Professional iLogic tool for designing self-propelled drilling rigs has been presented. Self-propelled drilling rigs are advanced mining machines with a complex structure. At the design stage, most of the structural changes affect the stability, manoeuvrability and coverage area of the machine. Working on detailed machine models is time-consuming and unnecessary in the initial phase of the project. Therefore, a parametric 3D model of a two-boom drilling rig has been developed. It enables a quick analysis of selected machine properties depending on a number of significant parameters. The most important dimensions, masses and centres of gravity of each subassembly are entered by transparent editing windows. Next, model tests are carried out taking into account the pass through a face end of a given width as well as the coverage area of a face with specific dimensions. At each stage of model tests, the location of the machine's centre of gravity against the stability triangle background is analysed. In addition, the model allows entering the longitudinal and transverse angles of inclination of the working as well as determining the distance of the centre of gravity from the tipping edge. The model is a practical tool that makes it possible to easily determine the inner and outer turning radius as well as the working area of the machine while constantly controlling its stability. Due to the use of simplified geometry of subassemblies, the changes in parameters result in an instantaneous change of the model and allow a quick analysis of their impact.

Keywords: self-propelled drilling rigs, machine stability, parametric modelling, iLogic, Autodesk Inventor Professional

1. Introduction

Self-propelled mining machines are the machines commonly used in many underground mines. These machines work in the mining of metal ores, precious stones or salt. Changing in working conditions and growing customer expectations force constant changes. For many years, there has been a demand for advanced control systems, including automation and diagnostics as well as remote operation. In recent years, the first battery-powered machines have also appeared. Advanced, closed and air-conditioned operator's cabins are increasingly used. Rapid changes and small-lot or almost one-off manufacture require quick and efficient designing process. Manufactured machines, often prototypes, are almost immediately intended for operation in the mine. Any design or assembly errors are unacceptable and entail financial implications. Advanced CAx programs, supporting the design work, satisfy the high demands of the current market. CAD (Computer Aided Design) and CAE (Computer Aided Engineering) are the essential programs used by the designers on daily basis.

CAD programs, such as Catia, NX, Creo, Inventor, support design work, including parametric design. CAD programs often have CAE components allowing to analyse load or strength [1, 2]. CAx programs are powerful tools with great possibilities. Numerical methods of solving physical models concern various issues, not only the strength of materials and kinematic and dynamic simulations, but also the analysis of bulk materials, heat flow, fluid flow and magnetism.

This article describes how to use the Autodesk Inventor Professional iLogic tool to design self-propelled drilling rigs. The parameterized, automatic generator of self-propelled drilling rigs allows for quick creation and modification of the conceptual model. It enables the verification of the machine's mobility and a preliminary assessment of its stability. Face Master 2.8 ATEX drilling rig by Mine Master, was the object of the described research work.

The use of advanced design methods is the subject of research work by various authors. There is an article about computer simulations and virtual reality applied in redesigning process of underground transportation routes [3]. The next ones are related to CAD systems in testing the collision of underground transportation means [4] and a train wagon in a narrow tunnel [5]. Another one is about using computer-aided design in Virtual Reality versus traditional 3D designing [6].

There are articles presenting the application of various IT tools used in the design of machines for ore mining [7-9]. The next ones concern the design of shearer loader's cutter head with the use of iLogic [10-11]. In the following article, the authors presented the use of modelling to develop a concept of a unique machine for securing the roofs of roadways with roof support [12].

The theoretical model for assessing the stability of self-propelled drilling rigs with single and double booms is known from the literature [13]. The cited article presents all the formulas and discusses the spreadsheet that allows for the evaluation of the stability of the drilling rigs. Moreover, the results of empirical research work confirming the correct operation of the spreadsheet are presented.

The article presents the use of CAD software, namely the iLogic tool of the Autodesk Inventor program, for the design of drilling rigs. The use of the iLogic tool allows for a quick assessment of working area and turning circle with simultaneous, continuous control of the position of the center of gravity.

2. Materials and Methods

2.1. Parametric 3D model of the drilling rig

Self-propelled mining machines, such as wheel-tyre drilling rigs, are of an articulated structure which, due to the use of booms, working conditions and requirements for turning circle, is prone to loss of stability. Drilling rigs are designed for specific user requirements that depend on the target workplace. The development of parametric iLogic models in Autodesk Inventor Professional allows you to quickly modify the geometry of the machine and verify the movement capabilities, the working area, while controlling the location of the center of gravity of the machine. The use of such a tool

speeds up conceptual work and allows for a relatively short time to specify the dimensions of each component of the machine, thanks to which it meets the user's requirements and is stable at the same time.

A parametric model was developed in the Autodesk Inventor Professional environment on the basis of the initial structure of the Face Master 2.8 ATEX twin-boom drilling rig by Mine Master. The machine combines parameterized subassemblies made with classical modelling and with the use of iPart parts (hydraulic cylinders). Everything is primarily controlled by the iLogic tool. In addition to the machine model, the selected components of the working creating the area simulating the face and the face-end were developed. The developed models were simplified as much as possible to enable quick change of parameters of the machine, without overloading the workstation. However, they still allow for a precise analysis of both the work area and the ability to pass face-end. The tool developed in this way allows to analyse the relationships among all machine parameters as well as the turning parameters and the position of the working parts on the work area and turning circle. During these analyses, the model enables continuous tracking of the location of the machine's gravity centre, including taking into account the workings inclinations. The FM 2.8 ATEX machine is divided into a drivetrain, a platform and working parts consisting of a boom and a guide frame with actuators, turntables and connectors. The machine as a parametric 3D model is shown in Fig. 1.
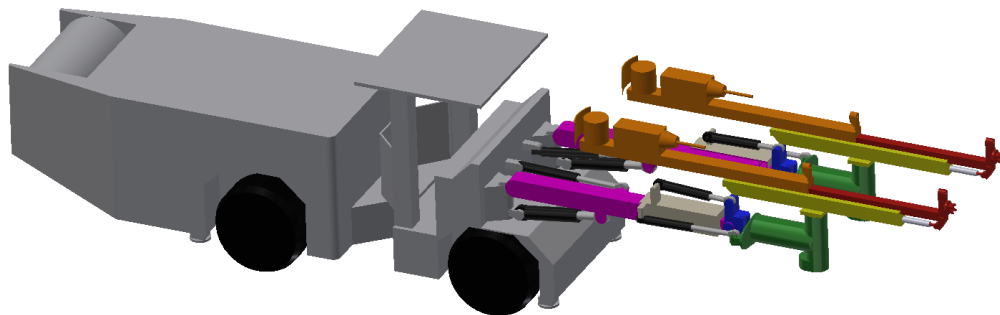

Fig. 1. View of the parametric model of FM 2.8 ATEX rig

All these components were parameterized taking into account also the mass and the coordinates of the gravity center of these components. The following figures show the parameters adopted for the drivetrain (Fig. 2), platform (Fig. 3) and the working part (Fig. 4). The gravity centres are marked with red dots.
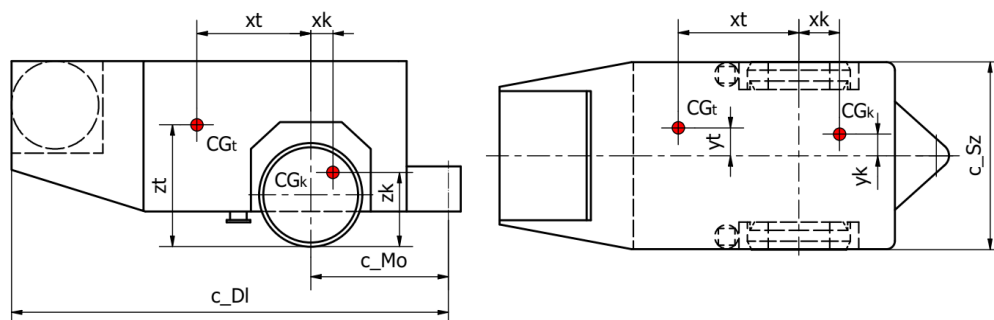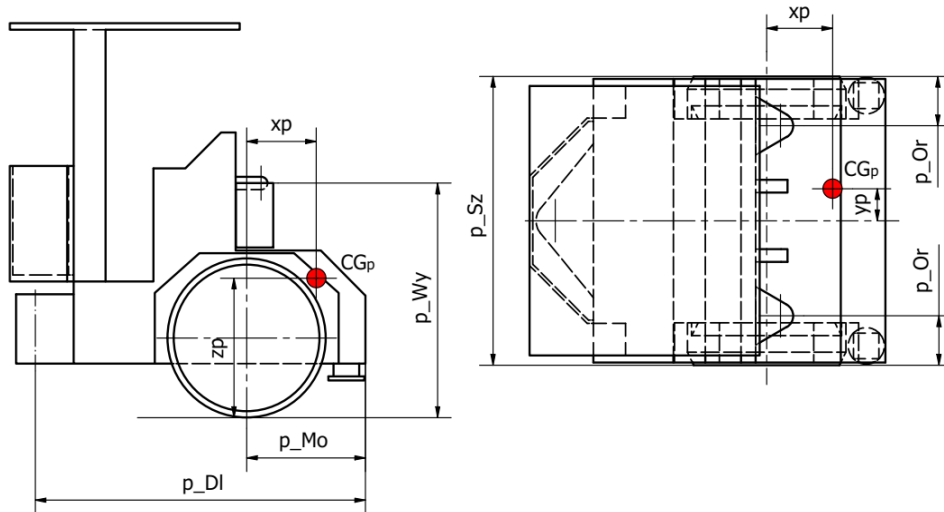

Fig. 2. FM 2.8 ATEX drivetrain with parameters
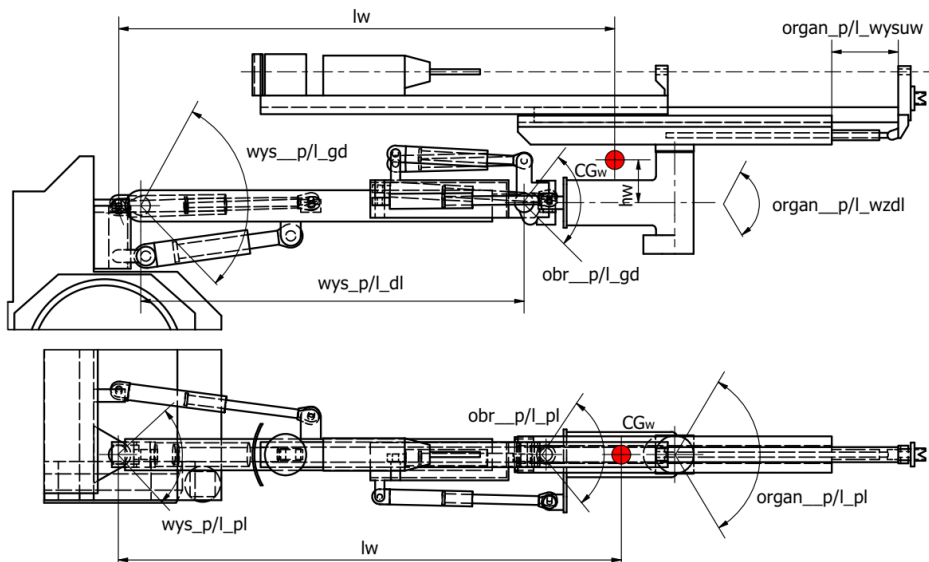
Fig. 3. FM 2.8 ATEX platform with parameters

Fig. 4. FM 2.8 ATEX working part with parameters (original language of the schemes and forms)

The 3D model of subassemblies is fully parameterized and its geometry depends only on the provided dimensions. The rest of the geometry is related to the proper relationships. The masses, on the other hand, were modelled with spheres of constant density and diameters resulting from the mass of each component. Scripts convert the size of the spheres, so that the total weight and the position of gravity centre of the machine correspond to reality (Fig. 5).
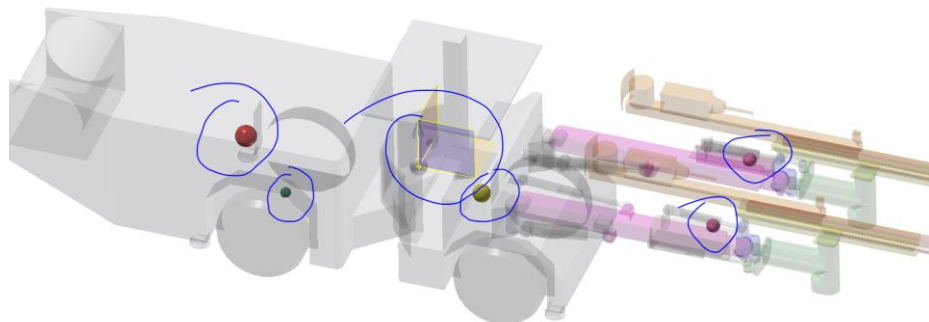

Fig. 5. Model 3D FM 2,8 ATEX with masses and the gravity centre

2.2. Parametric 3D model of the working

Apart from the machine, the parameterized face (Fig. 6) and the face end with turning circle (Fig. 7) were modelled. In the case of a face, the machine is at a level marked as "floor under the machine" and from this position it can make the entire contour creating a new floor below the level marked as "floor made by the machine"
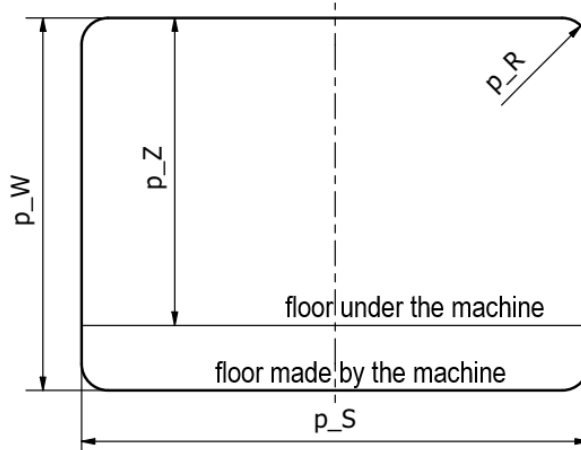

Fig. 6. Face cross-section with the parameters

In the case of a face end, two perpendicular roads with the width s_Sz were marked. Regardless of that, the inner radius s_Rw and the outer radius s_Rz are plotted. Taking into account the possibility of cutting the corner of the working by s_Sc, we obtain the withdrawal of the internal arc by the value marked as "gain", which results in the possibility of reducing the external turning circle.
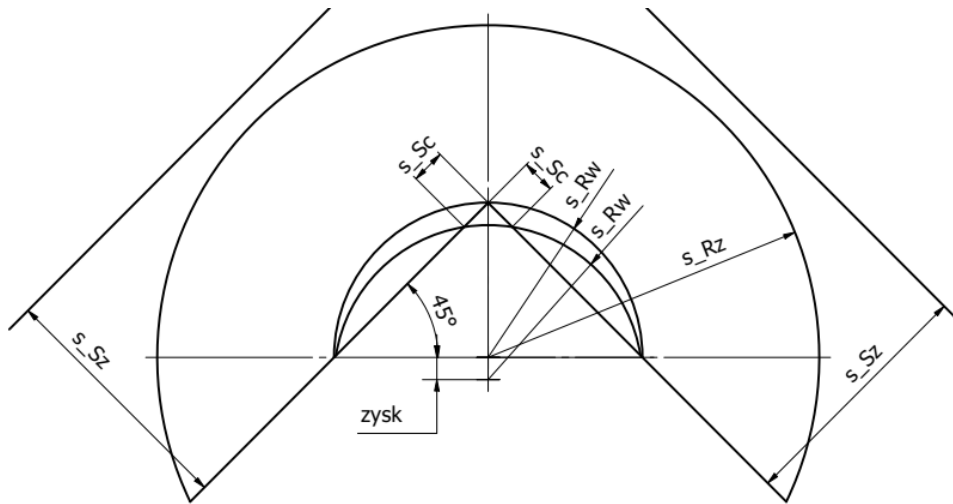

Fig. 7. Top view of a face end with marked turning radii and parameters

The location of the centre of gravity of the machine is independent of the pit inclination. From the stability point of view, only the vertical projection of the centre of gravity on the ground can be considered. The coordinates of the projections depend on the zc coordinate of the centre of gravity and the longitudinal (α) and transverse (β) inclination. Knowing the coordinates of the centre of gravity and the inclination of the working, the following can be written:

$$x_{cn} := x_c - z_c \cdot \tan(\alpha) \tag{1}$$

$$y_{cn} := y_c + z_c \cdot \tan(\beta) \tag{2}$$

In the 3D environment a graphical method based on the given relationships can be used. The graphical method allows to determine the impact of the inclination on the stability of the machine by analysing the distance of the centre of gravity from the tipping edge, without calculations. Fig. 8 shows a machine with a prism of a triangle base defined by the tipping edges of the machine.
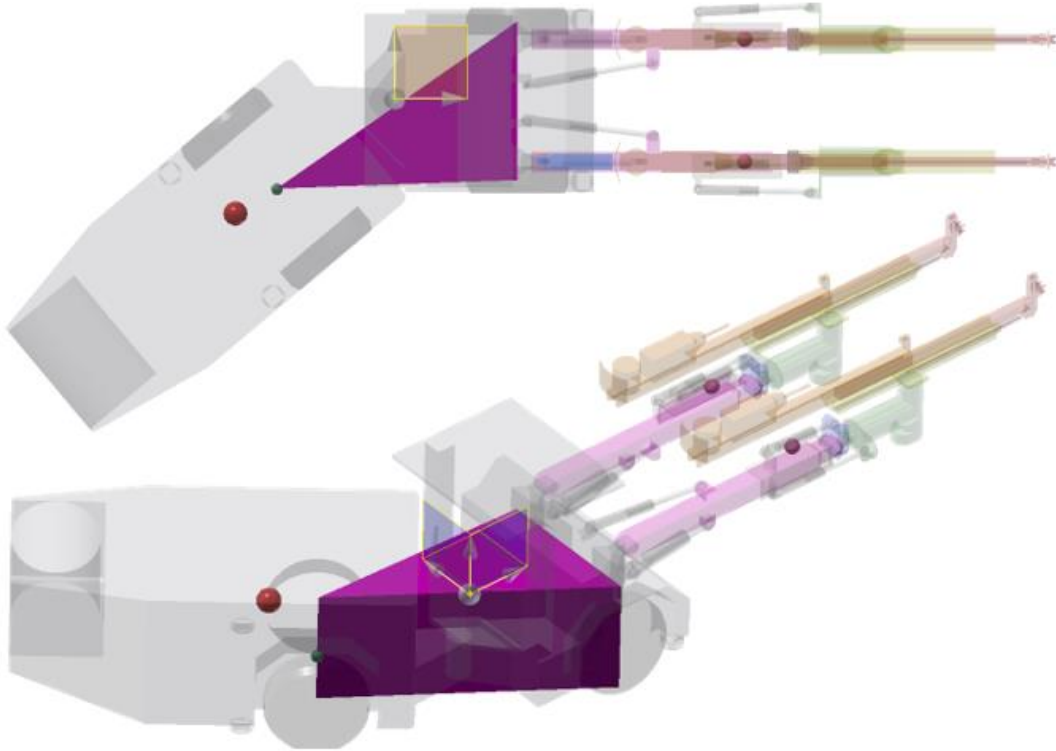

Fig. 8. A prism defining the stability in a horizontal working – machine in a turning position

Regardless of whether the working is inclined or not, the lower base of this prism is marked by the same three points delineating the triangle of the tipping edges (Fig. 9). On the other hand, its upper base runs at the height of the centre of gravity of the machine and is determined by three points shifted by the values described earlier, and resulting from the working inclination angles. So in an inclined working, the centre of gravity remains unchanged and the stability triangle moves. By analysing such a model in a plan view from above, you can easily determine the distances from the edge of the tipping in a horizontal and inclined working.
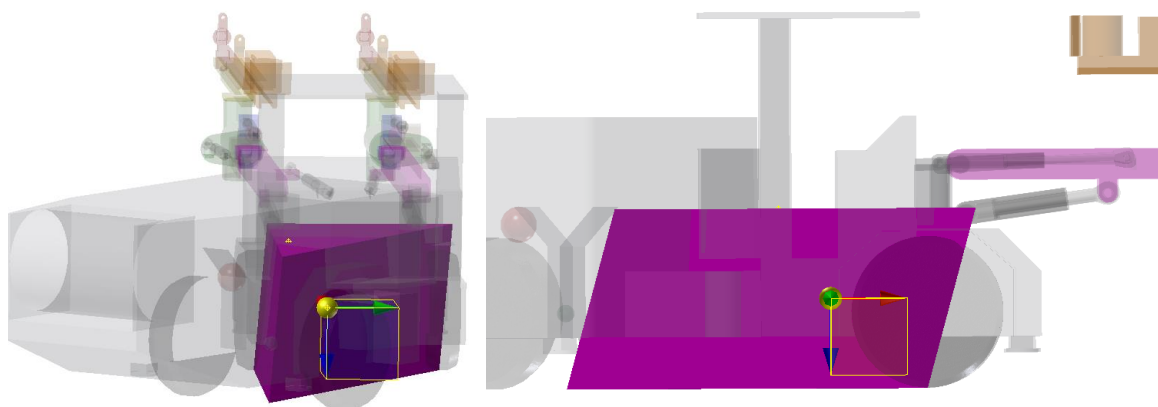

Fig. 9. Modification of the prism in an inclined working

2.3. Modification of the model using the iLogic

Using the parameters of the machine models required the creation of appropriate scripts and forms. Such possibilities are given by the iLogic tool. The scripts realize the simple commands and operations such as mass updating, arithmetic calculations, changing the machine geometry, controlling the turning of the machine and booms. Generally, the scripts allow determining the necessary relationships, calculate the indispensable quantities and superior control of the entire assembly. Forms are a tool that allows the user to enter each value. Four forms were created to operate the machine: "Chassis Geometry" and "Booms Kinematics" (Fig. 10), and "Global Settings" (Fig. 11) and "Stability" (Fig. 12). Geometry of the chassis allows setting the dimensions of the drivetrain and the platform, while the kinematics of the booms on two tabs determining the angles of rotation and extension of the left and right working component. The Global Settings form allows turning on or off the face and face end view, restore the machine geometry and kinematics to default values, turn on the left head copy position, straight line function, and including the tangency for inside turn radius analysis. In addition, the global settings form has two tabs that enable setting the turning parameters of the machine and the dimensions of the face and face end depending on the previous analysis.
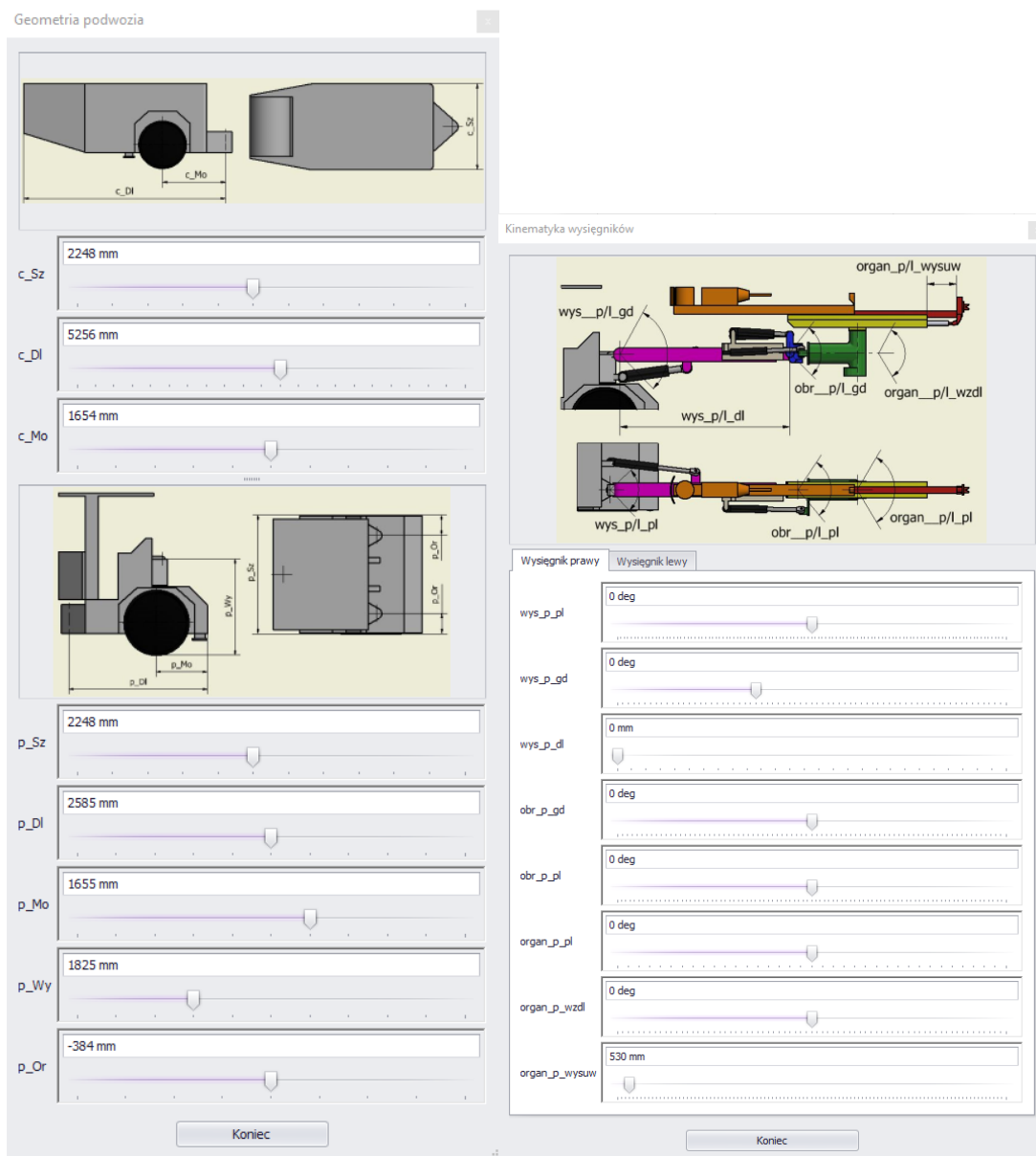

Fig. 10. The forms: chassis geometry and booms kinematics (original language of the forms)

The Stability form allows determination of the coordinates of the location of all centres of gravity and the mass of each component. In addition, it is possible to set the longitudinal and transverse inclination angles of the working. After selecting the boom extended or retracted option, the stability form needs to be updated with the "Update booms" button ("Update wysiegniki" in Polish shown in Fig. 12, on the left side. Any change in this form that affects the position of the centre of gravity must be updated with the "Update GC" button shown in Fig. 12 (the right form). After updating, the current coordinates of the machine's gravity centre can be read. The model is related to a 2D drawing with a top view, in which the distances of the centre of gravity from the tipping edges are constantly updated for the horizontal and inclined workings.
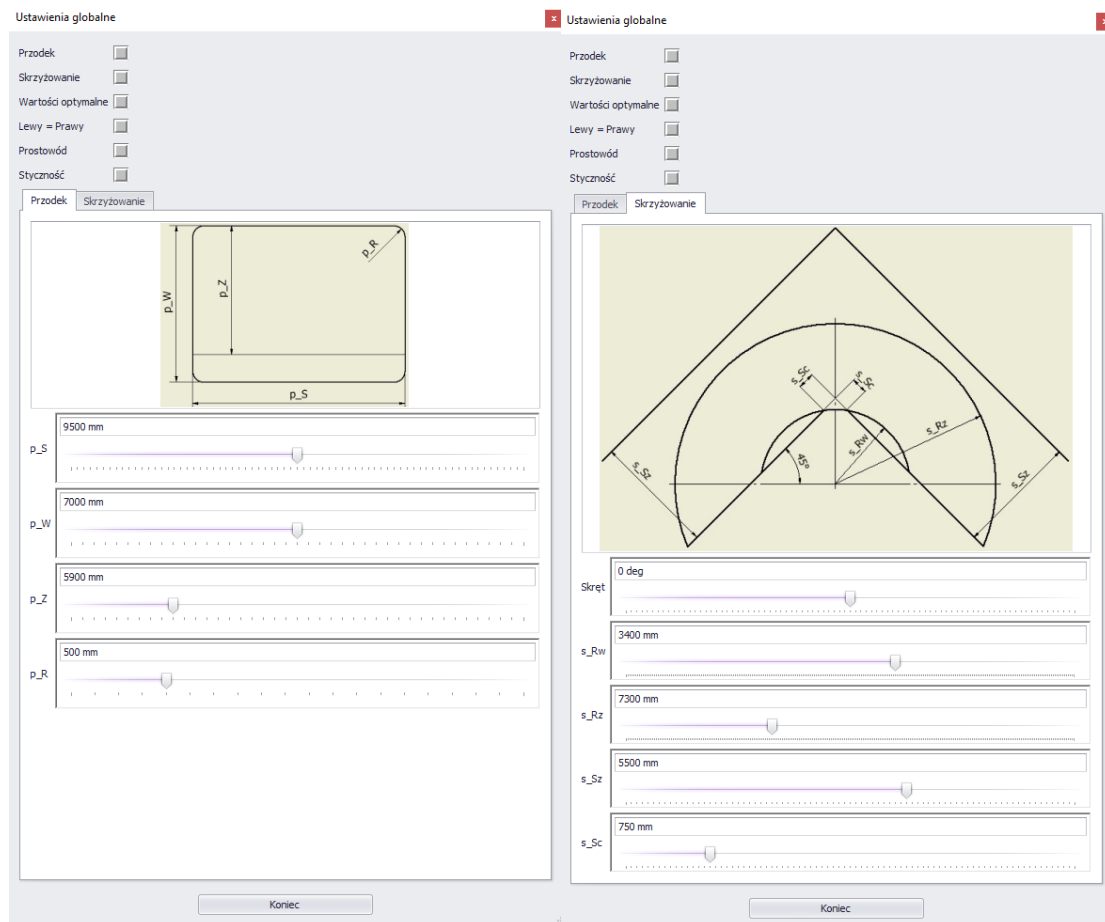

Fig. 11. Form of global settings: face, face end (original language of the forms)

Fig. 12. Stability form (original language of the forms)

2.4. Model tests of work area and a turning circle

The developed parametric model allows generating the unlimited number of configurations of each parameter. For each configuration, the working area and turning circle can be verified. During the model tests of the FM 2.8 ATEX machine, a set of parameters developed during the preliminary tests was used, which are presented in Table 1 and in Fig. 13.

Table 1. Maximum turning circles as well as telescope articulation
and extension for FM 2.8 ATEX

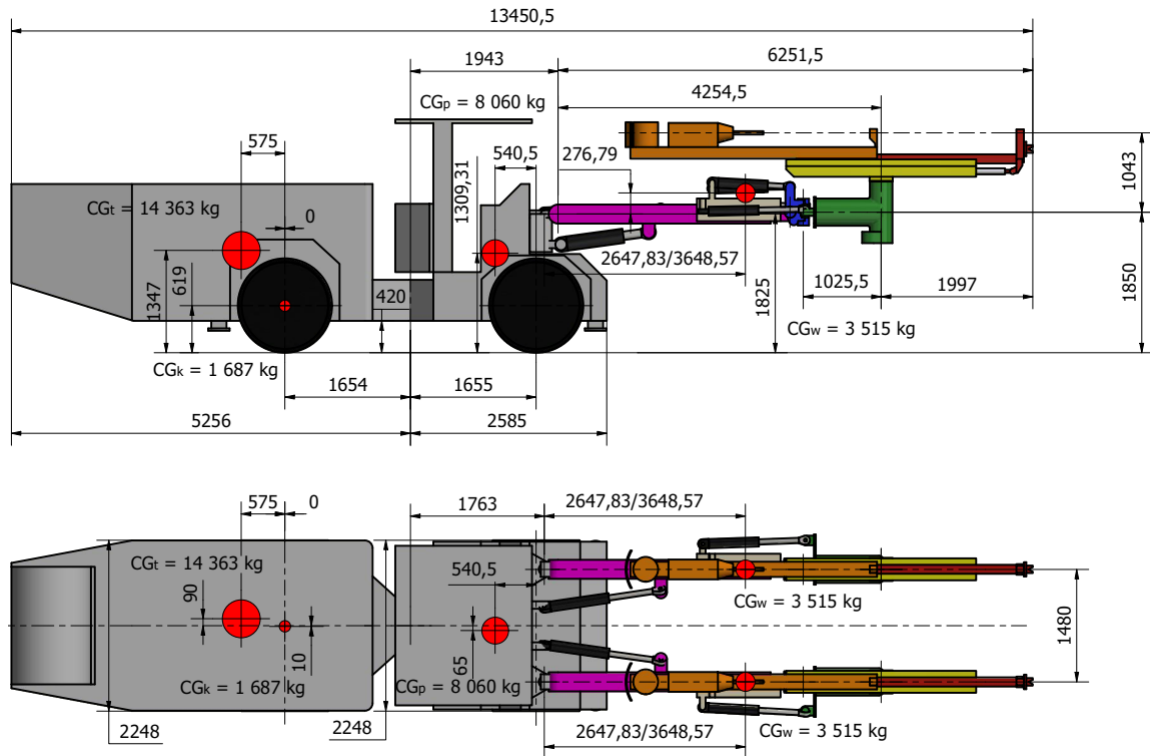| Machine kinematics		
Parameter	**Symbol**	**Range**
Machine turning angle	γ	$-40° \div +40°$ $-42° \div +42°$
Booms articulation - vertical	α_w	$-25° \div +45°$
Booms articulation - horizontal	β_w	$-35° \div +35°$ $-55° \div +55°$ - for $\alpha_w+ = $ max
Extension of the telescope boom	Δw	0 mm $\div 1350$ mm

Fig. 13. Key dimensions of FM 2.8 ATEX assumed in iLogic

The machine model, according to the previously mentioned parameters, was simulated to verify the possibility of achieving the assumed working area and turning circle. This is one of the possibilities of using the parametric iLogic model, which is used at the end of the conceptual work. At the earlier stages, it is possible to search for the working area and turning circle for specific machine parameters or vice versa. Fig. 14 shows he selected views from the working area analysis, and Fig. 15 shows the turning circle analyses.
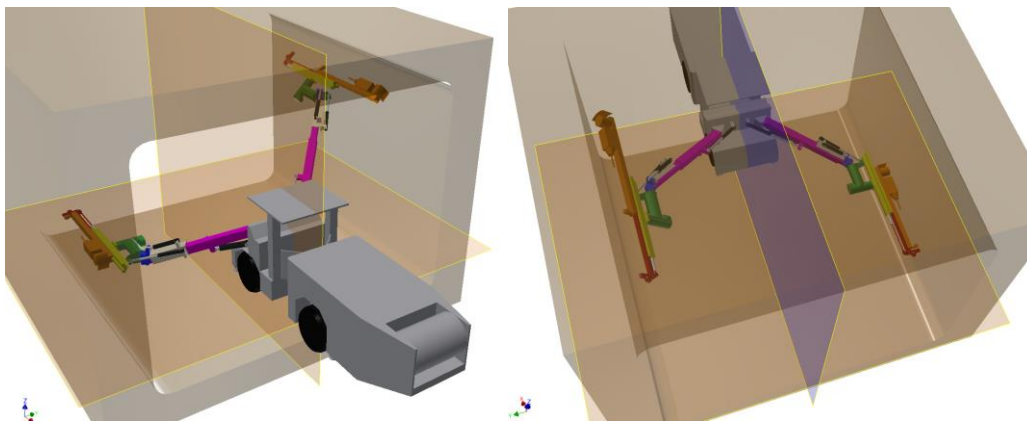

Fig. 14. Selected views of one of the working area FM 2.8 ATEX analyses
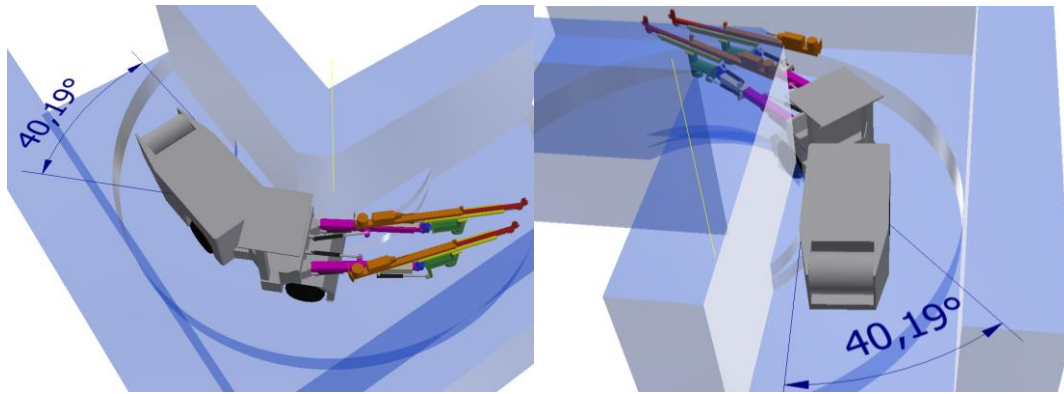
Fig. 15. Selected views of one of the vehicle passing the face end FM 2.8 ATEX analyses

Analysis of the work area confirmed the possibility of obtaining the work area assumed by the user, 9150 mm wide and 7000 mm high, of which 5900 mm at the height from the floor (Fig. 16). Areas of this size are obtained by deflecting the booms to the extreme positions and by extending the booms by 1350 mm.
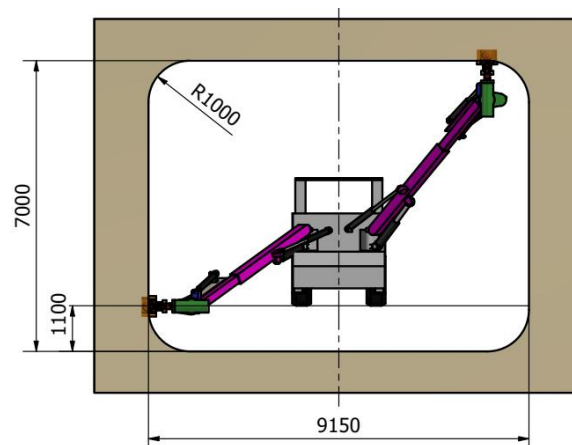

Fig. 16. Analysis of work area for FM 2.8 ATEX – full area – front view

Initially developed chassis and working components covering the assumed work area were used for further analyses of passing the workings. For FM 2.8 ATEX, several dozen analyses of passing the perpendicular workings were performed. Various positions of the car and the working components were simulated to obtain the assumed and required by the future user the turning circle of 3400 mm inside and 7300 mm outside. A series of analyses were performed to obtain the outer radius of 7300 mm. The assumed effect was achieved for the booms articulated by 10° and 5° and guide frames turned by 15° and 20° (Fig. 17).
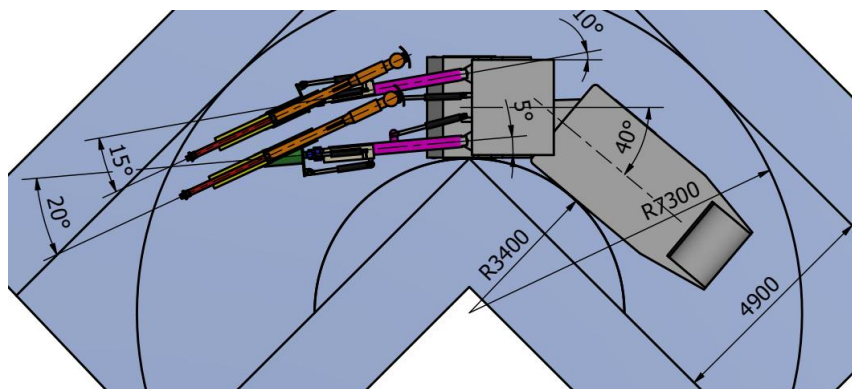

Fig. 17. Analysis FM 2.8 ATEX – booms articulated by 10° and 5°, frames turned by 15° and 20°

Assuming the possibility of cutting the working corner, its size can be selected so that the machine can pass the assumed excavation without manoeuvring the working parts. A corner rounding allowing the straight pass with the booms (Fig. 18) in a results in gaining 1400 mm. This is a borderline situation, i.e. for a 3400 mm cut, the machine can pass with the booms straight ahead. However, the cutting area is large and amounts to 2.47 m². By a slight articulation of the booms, the required area of cutting can be significantly reduced.
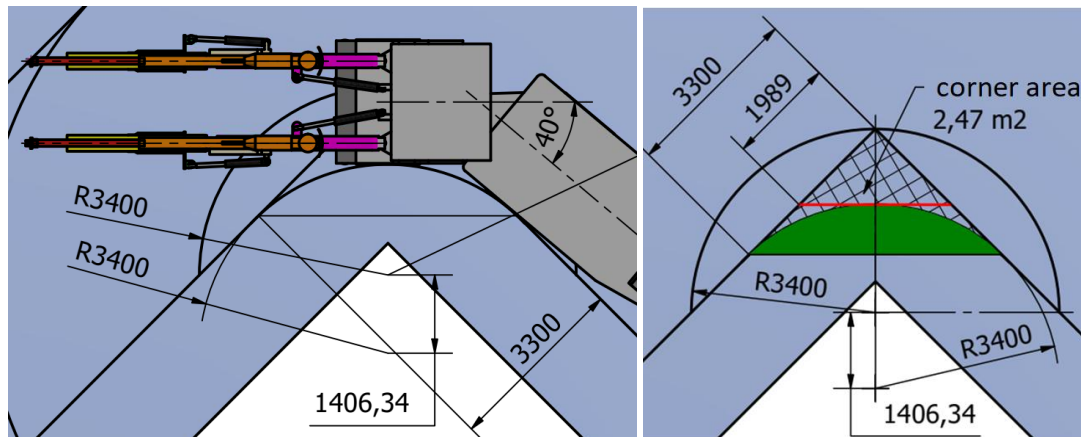

Fig. 18. FM 2.8 ATEX analysis – cutting the corner enable passing the machine with the booms straight ahead

3. Results – machine stability control

During the model tests, position of the machine's gravity centre against the background of tipping edges was verified. Each scenario, during the machine is turning or with the booms articulated was analysed. Sample results of the analysis of the distance of the gravity centre from the tipping edges during assessing the turning circle are shown in Fig. 19.
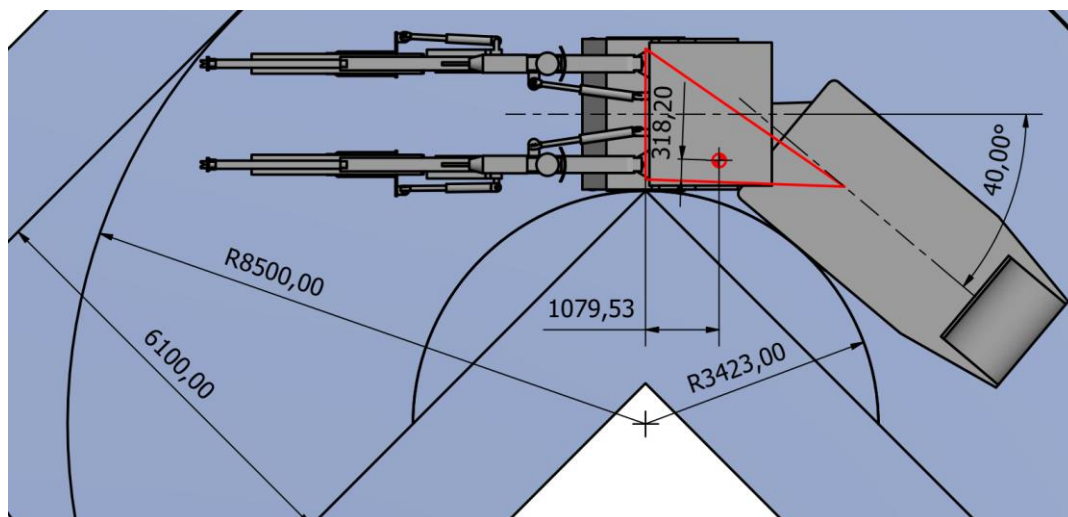

Fig. 19. FM 2.8 ATEX – Rw 3423 mm, Rz 8 500, Sz 6 100 mm, analysis of turn

Using the previously described graphical method, the impact of workings inclination on the stability, the distance of the gravity center from the modified tipping edges was determined. Sample analysis for a -15° longitudinal inclination and a 6° transverse inclination was shown in Fig. 20. The gravity center of the machine remains the same, but the tipping edges shift. The analysis was carried out simultaneously for two stability triangles, the red one defines the tipping edges for the horizontal working, and the green one for the inclined one. As a result, the figure shows the impact of specific workings inclinations on the change in stability of the machine.
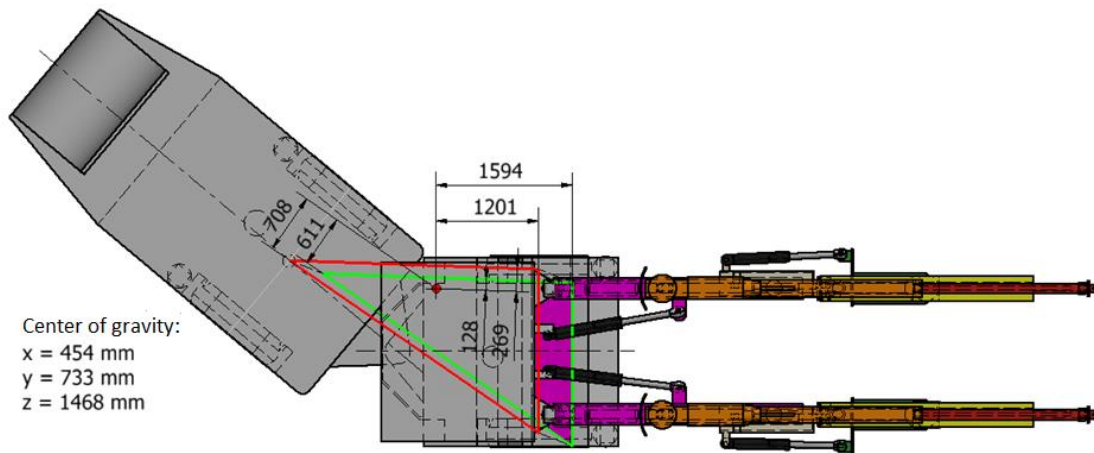
Fig. 20. A sample analysis of graphical interpretation of the impact of workings inclination

4.   Conclusions

Confirmation of the parametric iLogic model correct operation was the key element in the work on its creation. At the stage of verification of the iLogic model, all results were checked against the theoretical model saved as a spreadsheet. Due to the different nature of both tools, the global coordinates of the rear wheels and rocker as well as the gravity centre of the drivetrain, rocker and booms were checked and compared. The rear end of the machine only turns, so the verification was limited only to changing one angle. The booms, on the other hand, are the complex mechanism where the position of their centre of gravity is affected by two boom angles and min/max extension. Fig. 21 shows an exemplary comparison of the results from the theoretical model and iLogic for the same variables. The results are identical.

Data to be verified CG$_{wp}$:		
α$_{wp}$	β$_{wp}$	l$_w$
-30.0 deg	55.0 deg	2 647.8 mm

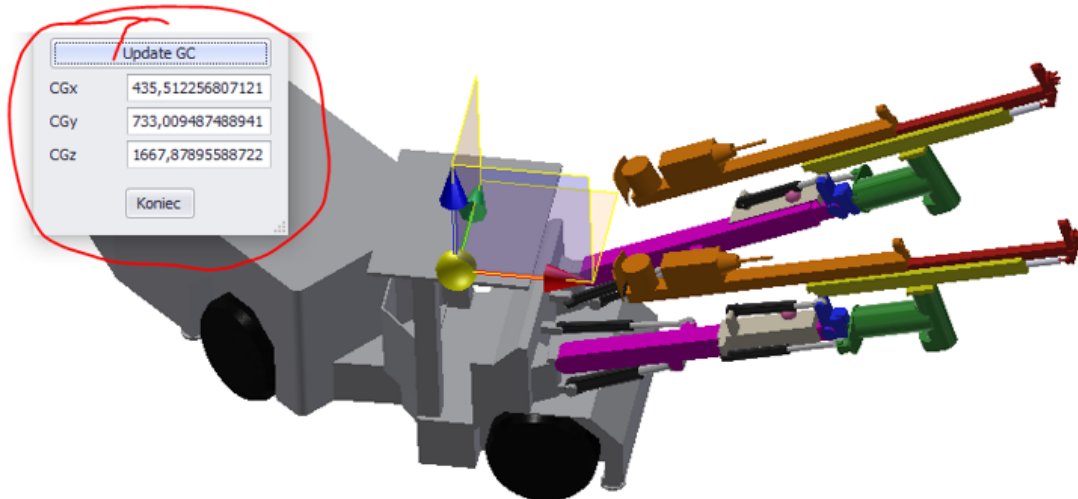| Boom centre of gravity:		
x	y	z
3 260.89 mm	-2 879.20 mm	740.79 mm

Fig. 21. Exemplary comparison of global coordinates of the iLogic model and the theoretical model – boom extended (original language of the properties window)

Similarly, the coordinates of the machine were compared for several selected situations, while different turning and deflection angles of the booms as well as the min/max extensions of the working parts from the straight-ahead position, but with the max extension of the working parts were checked. Comparison is shown in Fig. 22. During the verification, the turning circle and the distance of the gravity centre from the tipping edge were also checked. The results were identical.

The use of parametric modelling speeds up the design work, especially at the stage of concept development or preliminary design. Self-propelled drill rigs are the complex machines. Almost every

change in their geometry affects the working area, turning circles and changes the position of the machine's centre of gravity. The issue of stability of the machines, especially articulated machines, is a serious problem that requires an appropriate approach from the very beginning of the designing process. In the case of drilling rigs, we are dealing not only with an articulated structure of the body, but also with long booms extending significantly beyond the undercarriage. Due to the way of manoeuvring in the workings and the arrangement of the booms, the machine moves or works on the verge of stability. Thanks to the developed parametric model, it is possible to modify the geometry of the machine in order to obtain the possibilities assumed and required by the user, while simultaneously controlling the position of its of gravity centre against the background of the tipping edge, both for horizontal and inclined workings. The forms are clear and easy to use, which significantly speeds up the creation of subsequent combinations of parameters.

Data for verification of the machine centre of gravity:					
γ	α_{wl}	β_{wl}	α_{wp}	β_{wp}	I_w
-40.0 deg	25.0 deg	0.0 deg	15.0 deg	0.0 deg	2 647.8 mm

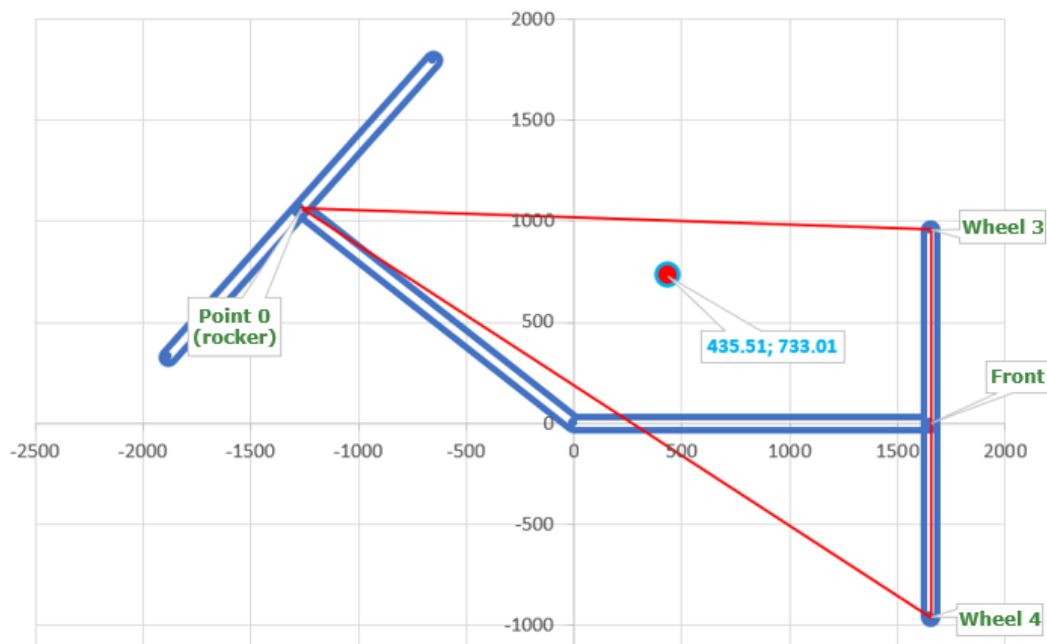| Machine centre of gravity:		
x	y	z
435.51 mm	733.01 mm	1 667.88 mm

Fig. 22. Exemplary comparison of the center of gravity in the iLogic model and in the theoretical model

Funding:

References

[1]   Wang S.H., Melendez S., Tsai C.S., Wu C.W.: Parametric Design and Design Associability in 3D CAD. Advanced Manufacture: Focusing on New and Emerging Technologies. Vol. 594, 2008, pp. 461-468, DOI: 10.4028/www.scientific.net/MSF.594.461

[2]   Zhang ASJ.: Teaching computer aided product design with aesthetic considerations. Proceedings of the ASME International Design Engineering Technical Conferences and Computers and Information in Engineering Conference 2005, vol. 3, 2005, s. 581-584

[3]   Rozmus M., Tokarczyk J., Michalak D., Dudek M., Szewerda K., Rotkegel M., Lamot A., Roser J.: Application of 3D Scanning, computer simulations and virtual reality in the redesigning process of selected areas of underground transportation routes in coal mining industry. Energies 2021, nr 14(9) 2589, s. 1-21

[4]   Dudek, M.: Use of CAD Systems in Testing the Collision of Underground Transportation Means. Arch. Min. Sci. 2013, 58, s. 411–432

[5]   Schauer, J.; Nüchter, A. Collision detection between point clouds using an efficient k-d tree implementation. Adv. Eng. Inform.2015, 29, 440–458

[6]   Feeman S.M., Wright L.B., Salmon J.: Exploration and evaluation of CAD modeling in virtual reality. Comput. Aided Des. Appl.2018, 15, 892–904.

[7]   Bołoz Ł.: Digital prototyping on the example of selected self-propelled mining machines. Multidisciplinary aspects of production engineering: monograph. Pt. 1, Engineering and technology, ed. Jacek Sitko, Warszawa, Sciendo, 2020

[8]   Bołoz Ł., Ostapow L.: Prototypowanie cyfrowe na przykładzie wybranych samojezdnych maszyn górniczych. Transport Przemysłowy i Maszyny Robocze: przenośniki, dźwignice, pojazdy, maszyny robocze, napędy i sterowanie, urządzenia pomocnicze, nr 4, 2020, s. 59–66

[9]   Vališ D., Gajewski J., Forbelská M., Vintr Z., Jonak J.: Drilling head knives degradation modelling based on stochastic diffusion processes backed up by state space models. Mech. Syst. Signal Process., 2022, Vol. 166, 108448, https://doi.org/10.1016/j.ymssp.2021.108448

[10]   Bołoz Ł.: Generowanie parametrycznych modeli organów frezujących kombajnów ścianowych. Modelowanie Inżynierskie, Wydział Mechaniczny Technologiczny Politechniki Śląskiej, t. 40 nr 71, s. 13–18, 2019

[11]   Bołoz Ł., Castañeda L. F.: Computer-aided support for the rapid creation of parametric models of milling units for longwall shearers, Management Systems in Production Engineering, vol. 26, iss. 4, 2018, pp. 193–199, DOI: 10.1515/mspe-2018-0031

[12]   Bołoz Ł., Mendyka P.: Koncepcje wozów samojezdnych do zabezpieczania stropów wyrobisk korytarzowych obudową powierzchniową. Transport Przemysłowy i Maszyny Robocze: przenośniki, dźwignice, pojazdy, maszyny robocze, napędy i sterowanie, urządzenia pomocnicze, nr 2, 2018, s. 42–46

[13]   Bołoz Ł., Kozłowski A.: Methodology for assessing the stability of drilling rigs based on analytical tests. Energies, 14, 24, 8588, 2021, pp. 1-29, https://doi.org/10.3390/en14248588