19
Safety-Oriented Virtual Prototyping of Mining Mechanical Systems

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19.1
Introduction

The term *prototype* in technology means the original, the first working prototype of a machine or device that was made in accordance with the relevant technical documentation. At the same time, it is the basis for manufacture. The word *prototype* comes from the Greek *prōtótypon*, ''original,'' and *typos*, ''type, model'' (De Agostini, 2011). In mechanical engineering, until recently this term referred only to the first manufactured copy of a machine, designed for laboratory tests (stand tests) or *in situ* tests.

In relation to mechanical systems, a ''virtual prototype is a computer simulation of a physical product that can be presented, analyzed, and tested from concerned product life-cycle aspects such as design/engineering, manufacturing, service, and recycling as if on a real physical model. The construction and testing of a virtual prototype is called virtual prototyping (VP)'' (Wang, 2002).

Nowadays, VP is commonly used in industries such as the aviation industry (McConnell, 2007; Jameson and Ou, 2011) and the space industry, in road (Sun, Ren, and Zhang, 2011) and rail (Seron *et al.*, 2004) transportation, in medicine (Feng *et al.*, 2010), in electronics, household goods, and even in fashion design (Cugini, Bordegoni, and Mana, 2008; Lu *et al.*, 2010) and archeology (Benazzi *et al.*, 2009). At present the elements of VP and virtual reality are used in open-cast mining (Rusiński, 2004) and in underground mining (Tokarczyk *et al.*, 2010; Tokarczyk, 2011).

The process of VP is characterized by multiple modifications, both geometric features and modification of technical parameters of the virtual prototype (power, pressure supply, etc.). The process is realized in a dispersed software environment and each software package is designed for testing only to a certain extent. Ensuring the transfer of criteria models between each software and defining reliable criterial states are the key issues (Winkler, 2001). The following methods, which are used in VP of mechanical systems, belong to the most common approaches:

- computer-aided design (CAD)

Handbook of Loss Prevention Engineering, First Edition. Edited by J. M. Haight.

- finite element method (FEM) (Zienkiewicz, Taylor, and Zhu, 2005)
- multi-body system (MBS)
- discrete element method (DEM) (Williams, Hocking, and Mustoe, 1985)
- design of anthropometric models (Winkler, 2005; Jung, Kwon, and You, 2009)
- reverse engineering (RE) – especially used to create 3D geometric models of irregular shapes (Zhang *et al.*, 2010; Curtis, Harston, and Mattson, 2011)
- computational fluid dynamics (CFD) (Zienkiewicz, Taylor, and Zhu, 2005).

Examples of the use of CAD, FEM, and CFD methods in the process of VP considering safety aspects are presented in this chapter.

19.2
Introduction to Polish Underground Coal Mine Working Conditions

The Polish coal mining industry is extracting coal from deeper and deeper seams, which results in an increasing number of hazards in the miners' workplace. The risk of hazards can be limited by controlling both technical hazards with regard to the operation of machines and equipment and natural hazards, including bumps, fires, and methane explosions.

The term ''hazard'' includes a situation characterized by an increased probability of loss of health, life, or appreciated values.

Such understood hazards precede a dangerous event, which is an called an accident. Unwanted events (situations) that occur during production processes can be the reason for accidents at work. Elimination of hazards is the essence of prevention of accidents at work.

Traditional hazards in the mining industry are as follows:

- natural hazards associated with mining and geological conditions of the seam (methane hazards, rock and gas outbursts, bumps, water hazards, etc.)
- technical hazards associated with machines and equipment
- organizational and human hazards.

According to the Polish State Mining Authority (Wyższy Urząd Górniczy, 2011), as of 31 December 2010, 42 underground mining plants were in operation in Poland, 32 of them being hard coal mines employing about 112 000 workers. Total production of hard coal in Poland in 2010 was more than 76 million tons. The main producers of hard coal in Poland are Coal Company JSC, Jastrzebska Coal Company JSC, and Katowicki Coal Holding JSC. The Polish underground mining industry is characterized by difficult geological and mining conditions subject to practically all natural hazards that are known in the world mining industry. The main natural hazards in the underground mining industry include bumps, roof falls, fires, methane hazards, coal dust explosion hazard, rock and gas outbursts, and water hazards.

Worsening of the working environment conditions and increased risk levels during realization of mining operations are features in hard coal mining plants. The present level of safety in Polish hard coal mines is shaped by the following:

- Location of almost all mines in the Upper Silesian Coal Basin, resulting in a concentration of mining operations on both local and regional scales.
- The long period of mine operations, often over 100 years, leads to the extraction of huge volumes of the seam and disturbance of the rock mass structure.
- Multi-layer seams (problem of remains, pillars, edges, and their interactions).
- Great and constantly increasing depth of mining (5–8 m per year). At present the deepest mines operate at depths of 900–1150 m.
- Use of a "sub-level" extraction model in a broader scale. Sub-level extraction and concentration of mine development work and production with increasing depth of mining increase the exposure to hazards. In a majority of sub-level operated longwalls, the temperature of rocks exceeds 30 °C, which causes an increase in climatic hazards.

The creation of prototypes was used in the process of construction of mining machines. It is the only method for verifying the correctness of the design, especially with regard to strength and reliability requirements. In Europe, hard coal is extracted by the so-called longwall system method. Three main machines make up the longwall system (Figure 19.1):

a) longwall shearer
b) powered roof support
c) armored face conveyor (AFC)

Since restructuring of the Polish mining industry, the average number of operated longwall panels (Staroń, 1995) in underground mine plants has been reduced. A breakdown of mining operations in one of the longwall panels has an impact on the production rate in the whole mine. This is why the designed mining machines have to be reliable, but there is no possibility of testing the prototypes in *in situ* conditions. Among others, the following cause difficulties in the manufacture of material prototypes:

- great complexity of mechanized mining systems
- large size and weight of machines
- use of individual or small series production
- required short time between design and manufacture
- difficulty of assembly of the prototype in *in situ* conditions due to:
  – confined working space

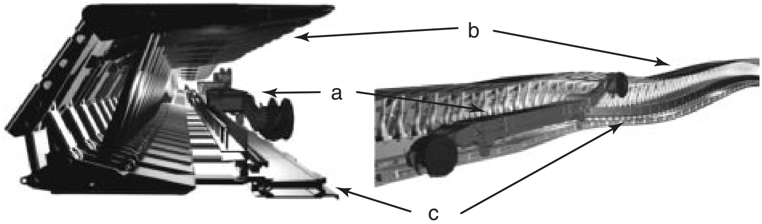

Figure 19.1 Geometric model of a longwall system (Michalak, 2004).

– poor lighting
– uneven and slippery floor with high inclination
– unfavorable climatic conditions such as high temperature and humidity
– difficult use of hoists and other lifting devices.

The above factors and increasing concentration of production, while reducing the number of operating longwall panels, prompt the use of VP, which allows simulation of the operation of mining machinery in selected criterial states, taking into account the working environment in which they are located. This procedure, however, requires the determination of the assessment criteria and the development of VP scenarios (Tokarczyk and Winkler, 2011).

19.3 Introduction to Technical Hazards

Technical hazards are present in all underground mining plants and they are associated with machines and equipment that are used in these plants, the operation of which can cause mechanical, electrical, thermal, and noise hazards, and hazards caused by mechanical vibrations. Technical hazards can occur during the use of machines and equipment by employees at the workplace.

Examples of technical hazards include the failure of the whole machine or its sub-system, loss of stability, and the possibility of collision during use of the machine (Dudek *et al.*, 2003).

Regarding the control of technical hazards, detailed analyses of the reasons for and circumstances of accidents and other dangerous events have shown that not obeying the basic safety rules by employees operating machines and equipment and also a lack of effective supervision by mine managing and supervisory boards are likely to be contributing reasons for most events.

The following rules are used during the selection of the most appropriate methods for elimination of any occupational risks associated with the operation of machines or equipment:

- elimination or minimization of hazard occurrence as far as possible
- applying necessary protective measures against hazards that cannot be eliminated.

These rules are obligatory not only for manufacturers of machines and equipment, but also for employers who deliver these machines to personnel in the workplace. The employer also has to ensure proper selection of machines and equipment for the prevailing conditions in which they will be used, to ensure proper technical conditions and that employees are trained to operate them safely.

Analyzing the reasons for accidents associated with the use of machines and equipment it should be said that, in many case, they do not result from design failure of these machines and equipment, but from improper maintenance, improper technical condition, and the workers not obeying basic rules of safe work organization during their use as well as from lack of effective supervision by management and supervisory staff.

Analyses of reasons for and circumstances of accidents and dangerous events, conducted by appropriate supervisory authorities, showed the following to be contributory factors (Wyższy Urząd Górniczy, 2011):

- presence of employees on transportation routes during the movement of transportation means or in the close vicinity of moving machine components
- not obeying underground railway and road transportation regulations
- carrying out of maintenance and repair operations during movement of conveyors
- lack of effective supervision by the supervisory personnel of work carried out on machines and equipment.

The following procedures should be adopted to reduce technical hazards in underground mining plants (Wyższy Urząd Górniczy, 2011):

- control and application of suitable technical conditions for machines, equipment, and installations in mining plants and obeying the rules for their safe use
- control of knowledge of the design of the machine and of the use of devices with an anti-explosive design by workers in underground mining plants
- control of design rules and development of transportation systems and technical documentation of the systems for transportation of people.

19.4 Graphical Methods of Technical Hazards Assessment in Underground Mechanical Systems

19.4.1 Introduction to the CAD/CADD Systems and Graphical Methods of Technical Hazards Assessment

CAD, also known as computer-aided design and drafting (CADD), is the use of computer technology in the process of design and design documentation. This is the design process, in which a computer together with the appropriate software is a designer's tool at each stage of their work (from the initial design until the design of each individual component and the production of the final design documentation). CAD is also used to support conceptual work and to aid in making decisions (modeling, optimization and assessment problems, and advisory systems). CAD covers, first of all, the possibility of saving the design documentation and its modifications in the computer memory.

There are hundreds of CAD/CADD software programs available in the industry today. Most of them are simply drafting programs, whereas others offer certain engineering analysis, design, or database capabilities. Some parts of the software are more comprehensive than others. This is called low-end software and it is commonly used for general drawing work. Typical low-end CAD/CADD software include AutoCAD LT (Autodesk, 2011), Bricscad (Bricsys, 2011), and DraftSight (Dassault Systèmes, 2011).

Other CAD/CADD software is in the mid-range category. This category offers advanced drafting techniques such as layers, 3D modeling, basic database capabilities, advanced dimensioning, and many automated drawing features. Architecture and engineering design firms commonly use mid-range software. About 80% of all the CAD/CADD software falls into this category. Typical mid-range CAD/CADD software includes AutoCAD and Inventor (Autodesk, 2011), ArchiCAD (Graphisoft, 2011), MicroStation (Bentley, 2011), and SolidWorks (Dassault Systèmes SolidWorks, 2011).

There are a few advanced high-end CAD/CADD software programs available, which are commonly used by large corporations in high-volume production. This software includes integrated features such as solid modeling, engineering analysis, and design, database, and project management. This is so called high-end software. Most of them are customized to meet the specific requirements of the corporation. Typical high-end CAD/CADD software includes CATIA (Dassault Systèmes, 2011) and NX Unigraphics (Siemens, 2011).

Note that often it is difficult to determine whether software is in the low-end, mid-range, or high-end category. Low-end software sometimes claims to be mid-range, and mid-range software sometime claims to be high-end.

CADD's 3D modeling abilities allow the creation of 3D images that are as realistic as the real objects. These images are called 3D models because, just like a physical model, they can be rotated on the screen. One can display views from a 3D model, such as isometrics or perspectives, from any angle using a few simple steps.

Analysis of technical risk consists in the use of all available information about technical risks to evaluate the risk of a given system of technical equipment. Hence there is a need for continuous identification and assessment of potential technical hazards to which the users of technical systems (mining mechanization systems) are exposed. Identification and assessment of technical hazards are made both at the stage of the design of technical means/main and auxiliary production processes and at the stage of their operation/realization.

The use of computers in engineering activities, from designing through strength calculation until the simulation of product operation, has completely changed the engineer's work. Traditional drawing board and laborious calculations have been replaced by an integrated environment in which corrections, changes in the concept, and calculations are realized very quickly and the results can be presented in a clear form. This results of in shortening of the following cycle: design – analysis of operation – corrected design – product. At the same time, digital analysis of the behavior of designed equipment and objects (simulation of technical means operation, strength calculations by the FEM or boundary element method, calculation of vibration intensity, flow intensity, etc.) enables the number of prototypes required to be reduced. The resulting cost associated with the manufacture of the product is lower and the product is of better quality.

CAD software is commonly used at the stage of designing the machines and processes. The software meets most of the requirements of today's designers. There are a number of separate software programs available that can extend the power of a CAD/CADD system. The add-on software works as an extension of CAD/CADD to accomplish specific tasks. The software permits, for example, determination of the standard stability coefficient of the machine, which is required in designing its sub-assemblies or is needed for the certification process of the final product. It also allows the design of an underground transportation system regarding potential collisions on transportation routes.

19.4.2
Detection of Collisions During Transport Operation

Collision detection is one of the most important geometric queries, with diverse engineering applications in areas such as robotics, mechanical engineering, computer graphics, animation, computer games, virtual reality, simulation, and haptic rendering.

A basic problem in collision detection is to produce an object's continuous motion from its starting point to its end point, avoiding collisions with known obstacles. The motion of an object and an obstacle's geometry are described in a 2D or 3D workspace, whereas the motion path is represented mainly as a continuous line, within a 2D or 3D workspace.

The collision detection method typically refers to the computational problem of detecting the intersection of two or more objects. While the problem is most often associated with the use of the method in video games and other physical simulations, it also has applications in mechanical engineering and robotics. In addition to determining whether two objects have collided, collision detection systems may also calculate time of impact (TOI), and report a contact manifold (the set of intersecting points). Collision response deals with simulating what happens when a collision is detected. Solving collision detection problems requires the comprehensive use of concepts from linear algebra and computational geometry.

The problem of collision detection or determination of contact between two or more objects is fundamental for computer animation, physical-based modeling, molecular modeling, computer-simulated environments (e.g., virtual environments), and robot motion planning. Depending on the content of applications, it is also called many different names, such as interference detection, clash detection, and intersection tests.

Collision detection is also an integral part of many new technological developments. VP systems create electronic representations of mechanical parts, tools, and machines, which need to be tested for interconnectivity, functionality, and reliability. The aim of these systems is to reduce processing and manufacturing costs by avoiding the actual physical manufacture of prototypes. This is similar to the main goal of CAD tools, where collision detection is an essential component of such environments.

The objective of the collision detection method is to report automatically a geometric contact when it is about to occur or has actually occurred. It is typically used in order to simulate the physics of moving objects, or to provide the geometric information that is needed in future work, for example, planning of the path for robots or other transportation vehicles.

A solid model is an enclosed 3D body that has such features as mass, volume, center of gravity, and moments of inertia. Almost every CAD software program has the ability to create complex 3D solid models and to perform Boolean operations among them. There are three main types of Boolean operations:

- **Union** – In a union operation, two objects are put together, so from CAD's point of view they become a single physical object. Actually, a more correct term would be "addition," since one of the objects retains its identity and the other is added to that.
- **Subtract** – In subtraction, one of the objects functions as a "negative" one that is used to subtract geometry from the other.
- **Intersect** – In intersection, a geometric object is created from the common volume of two or more existing objects.

Transportation of materials in underground mine workings inside mining areas is realized mainly with the use of suspended monorails. The ability of a suspended monorail to pass by obstacles such as conveyors, drives, and other underground equipment that can be found in roadways on the transportation routes is its advantage. Suspended monorails are especially used in the roadways of weak floor rocks, which are prone to be deformed. Further, suspended monorails facilitate reloading of materials in the transferring stations. Suspended monorails are very popular in Polish underground coal mines. Floor-mounted railways are an important aid in the case when it is necessary to re-equip longwalls fitted with powered-roof supports of high weight or in the case of high inclination of the transportation track. Owing to traction possibilities, floor-mounted railways provide an excellent complement to other transportation systems. An increased size of transported equipment requires the design of transportation systems on the basis of analyses of the railway tracks regarding the possibility of collision of transported loads with the support and roadway equipment, especially during transportation of large or long materials.

Collision-free passage of the load during transportation depends on the proper design of the track and the selection of the transportation system. Work aimed at the development of tools aiding verification of designs of transportation systems in the light of safety criteria was conducted at the KOMAG Institute of Mining Technology within the MINTOS European project (Winkler *et al.*, 2009; MINTOS, 2010). Analyses of the potential for collision of large or long loads that are transported with suspended monorails and floor-mounted railways are a significant part of verification procedures. Analysis of the possibility of collision on transportation routes is especially important in the case of the design of a transportation system when a decrease in the roadway cross-section as a result of a reaction of the surrounding rock mass should be considered.

In Poland, designs of transportation system are developed by the Division for Preparation of Production in Mines and many of them are prepared with the use of the AutoCAD designing system. Most of the drawing documentation of a design is developed in that system. A tool for designers of transportation systems was developed at KOMAG in the form of an add-on program running in the AutoCAD environment. It enables designers of transportation systems to obtain a quick verification of selected sections of tracks of floor-mounted railways and suspended monorails regarding the possibility of collision during transportation operations. Formulation of input data is realized by the final user in AutoCAD software and any Internet browser, which is also used for the transfer of input data to a computational server and takes part in receiving simulation results.

Results of exemplary simulation tests – determination of an outline of transported load – are presented in Figure 19.2. A method of transportation of a powered-roof support by a rack-and-pinion diesel floor-mounted railway along a selected distance of roadway is presented illustrated. The powered-roof support is transported as an entire machine on a transportation platform. In this example, two simulations of the passage of the transportation platform with the powered-roof support load on the track of a floor-mounted railway were made: (a) forward-facing and (b) rearward transportation.

The simulation software automatically realizes the passage of the transportation platform with the load on a railway track in previously set simulation steps. After each step, it leaves a ‘‘trace’’ of the transported load. After the simulation, all ‘‘traces’’ of the load are combined in one outline, which shows the surface that is covered in a roadway by the transported load during a passage of the transportation platform.

An analysis of 2D simulations demonstrates that during forward-facing transportation of the powered-roof support there is a possibility of collision. Additionally,

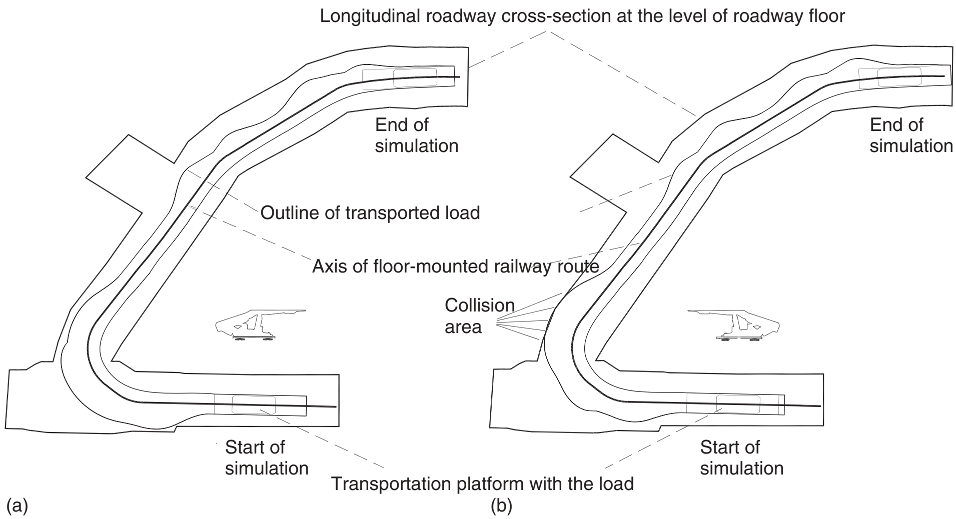

Figure 19.2 Exemplary simulation tests. Determination of outline of transported load. Simulation step = 0.1 meter (Winkler *et al.*, 2011).

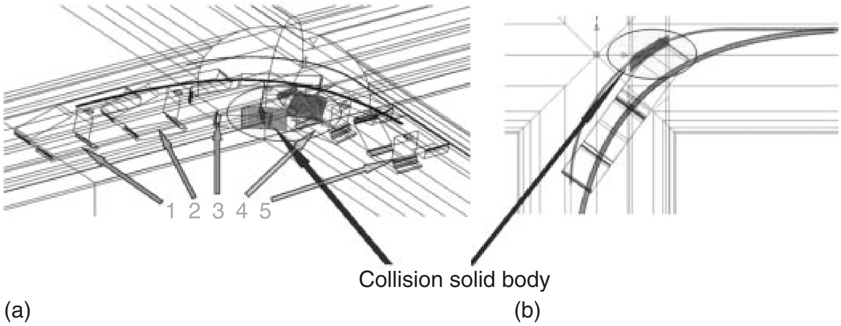

Figure 19.3 Collision detection in a 3D CAD environment.

in an analysis of the possibility of collision developed by the computer software (add-on program), it is possible to take into account a reduction of the roadway cross-section. The above-mentioned analyses can also be made in 3D modeling. Figure 19.3 shows the results of simulation of the transportation of a powered roof support with an MZN-252-252kN modular carrying unit: (a) selected steps of simulation of passing the curve of the route and (b) top view of an exemplary simulation step, namely collision with a solid body between the support and AFC.

The presented method of analysis of the possibility of collision on tracks of floor-mounted railways and suspended monorails can be also used for loads transported by means of railway locomotives.

19.5 Virtual Prototyping of FOPS

FEM is used in many cases for the purpose of VP, especially for the assessment of technical criteria. Assessment of FOPSs (falling object protective structures) and ROPSs (roll-over protective structures) is an example. In the mining industry, these protective structures are used in self-propelled vehicles. FOPS structures protect against falling objects, whereas ROPSs protect against crushing if the vehicle overturns. These structures are subjected to non-destructive tests according to relevant standards (Polish Standard (PKN), 1992; ISO, 2009a,b). FOPS structures can be divided into two groups: those protecting against impacts of energy up to 11 600 J and those protecting against impacts of energy up to 60 000 J – the latter group is most frequently used in the underground mining industry. ROPS protective structures are also used in the automotive industry and in special vehicles. The process of VP is most frequently restricted to simulation tests, the aim of which is strength verification (Karliński, Rusiński, and Smolnicki, 2008). An exemplary FOPS protective structure is presented in Figure 19.4 (KOMAG, 2003). Such a design can have a multilayer structure equipped with ribbing between the upper and lower sheathing of the FOPS structure, which absorbs impact energy.

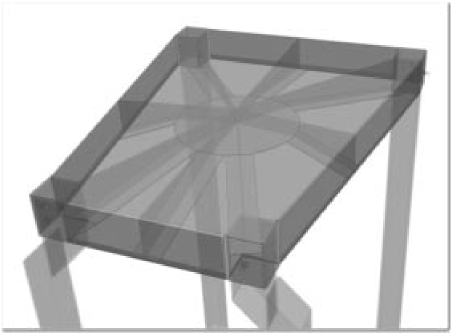

Figure 19.4 Example of falling object protective structure (KOMAG, 2003).

VP of FOPS as regards safety criteria is realized with the use of numerical methods, most frequently FEM. This method is becoming increasingly common and is often used by designers. Static/dynamic calculations in a linear range are possible in most commercial CAD software, such as AutoDesk Inventor in the Professional version. However, more advanced calculations, which include geometric and material non-linearities and belong to tasks of the multiphysics class, require the use of dedicated commercial software, such as SimExpert (MSC Software, 2011), Abaqus Multiphysics (Dassault Systèmes SolidWorks, 2011), and ANSYS (ANSYS, 2011). Creation of a computational task in software based on FEM begins with establishing finite elements meshing. Pre-processors, that is, software for the preparation of data for calculations, have their own generators of finite element meshing. The process of discretization of the geometric model (division into finite elements) is automatic. More frequently, computational models consist of spatial components. Their number can exceed 1 million. In a described task, the computational model was extended by a dead weight of suitable mass and initial speed to obtain minimal impact energy. A computational model of dead weight and FOPS structure is presented in Figure 19.5.

On the basis of calculations, the designer obtains information about zones of plastic deformation and displacements, especially within a protected zone already at the stage of the design process. The obtained results of calculations can be sent to a software environment, enabling an anthropotechnical system to be created, which consists of a model of a material object and a man (Figure 19.6). In this way, multi-criteria assessment of suggested design solutions becomes possible.

Determination of the position of an operator's seat in a machine body, which is already partly occupied by operational instrumentation, was also one of the design tasks in the discussed example. The task consisted of optimization of the seat position, which is determined by the operator's field of vision. The setting of anthropotechnical features of "seated persons" of different dimensions on seats inside the protective structure of a model allows the precise determination of the

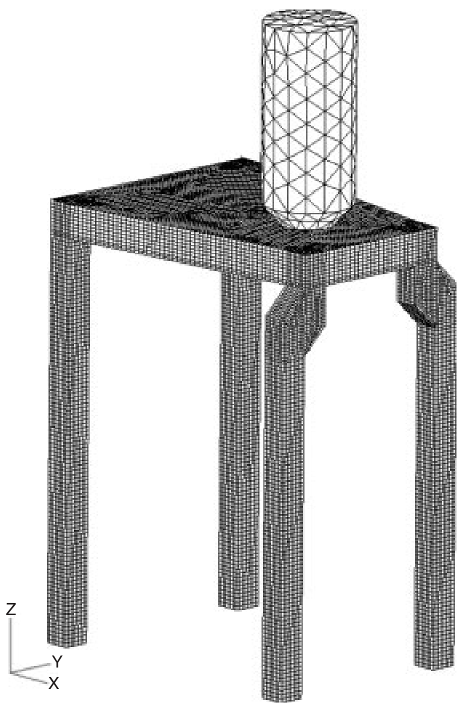

Figure 19.5 Example of computational model of FOPS structure and dead weight.

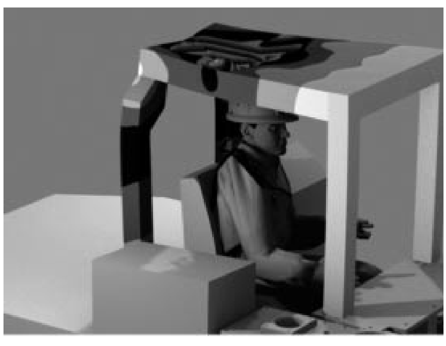

Figure 19.6 Example of an anthropotechnical model.

position of an operator's head inside the upper outline of the FOPS sheathing and determination of the length of the FOPS supports. The use of VP methods for values exceeding the load-bearing capacity of the FOPS structure permits the determination of the shape of the necessary survival space in damaged material structures.

19.6
Application of Computational Fluid Dynamics (CFD) Analyses in Virtual Prototyping of Mining Machines

Transportation of materials and people by suspended monorails in mines is one of the rapidly developing branches of transportation systems. At present, the majority of locomotives for suspended monorails have their own diesel drive. A diesel drive has many advantages compared with a cable drive, such as a significantly greater range and improvement of mobility between different regions of the mine. The constantly increasing weight of machines and equipment used in longwall panels (longwall shearers, flight-bar conveyors, powered roof supports) forces the manufacturers of suspended monorails to use higher pulling forces and the manufacturers of transportation assemblies need to ensure higher and higher load capacities. That means the use of diesel engines of higher power and thus increased emission of harmful gases to the atmosphere. The use of the CFD method in the process of VP of new locomotives for suspended monorails permits simulation of the passage of a transportation set to calculate the concentration of the exhaust gases emitted by diesel engines during operation. The problem of exhaust gases especially concerns roadways with poor ventilation in which people are transported by a diesel railway.

The above represents only a small selection of the possibilities of using the CFD method in industry. New versions of software now available and the high computational power of PCs enable more complex computational tasks to be solved, including multi-phase analyses (Xiang and Lee, 2005; Ren and Balusu, 2010; Tratnig and Brenn, 2010).

Use of the CFD method in underground mine transportation is presented with the example of a diesel suspended monorail. Determination of the field of air and exhaust gas flow rates and the concentration of each component of the exhaust gases with special regard to carbon monoxide and dioxide was the objective of numerical calculations. The analysis was carried out for an unsteady state, that is, the calculation process also included movement of the transportation set. In Figure 19.7, the spatial calculation model of part of the roadway with a suspended monorail is shown.

The calculation model also included models of the anthropometric features of transported employees. Most frequently the employees are carried on so-called benches (Figure 19.8).

In the calculation process, it was assumed that fresh air is a mixture of three components, nitrogen, oxygen, and carbon dioxide, and the exhaust gases are mixtures of nitrogen, oxygen, carbon monoxide, and carbon dioxide. Simulation of the suspended monorail passage was possible by description of the movement of each component of the transportation set. The assumed speed of the transportation set was $v = 0.3\ \mathrm{m\,s^{-1}}$.

Inlet of fresh air to the roadway was defined by the air flow rate u at the inlet in a direction normal to the inlet surface, by parameters of turbulence k and ε, and

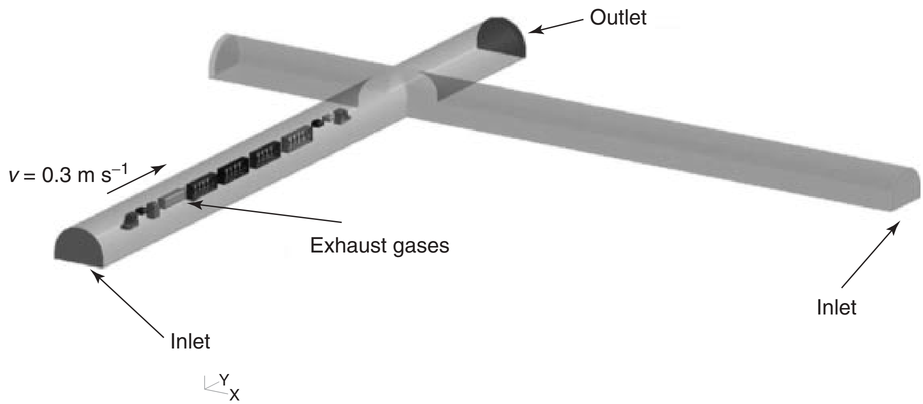

Figure 19.7 Numerical model of the analyzed part of roadway (MINTOS, 2010).

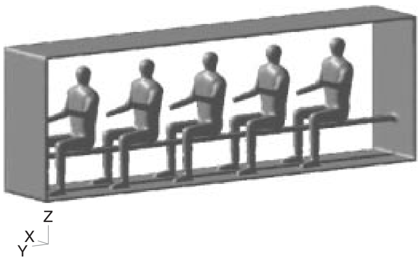

Figure 19.8 Geometrical model of the bench for transportation of people (MINTOS, 2010).

also by the mass contents of oxygen, carbon monoxide, and carbon dioxide with the following constant parameters:

$u = 1.45$ and $0.62\ \mathrm{m\,s^{-1}}$
$k = 0.01\ \mathrm{m^2\,s^{-2}}$
$\varepsilon = 0.001\ \mathrm{m^2\,s^{-3}}$
Concentrations: 22.843% O_2, 0.057% CO_2, 0% CO.

Emission of exhaust gases was modeled as a stream of a mass of constant intensity Q_m, constant parameters k and ε and chemical composition with the following parameters:

$Q_m = 0.06\ \mathrm{kg\,s^{-1}}$
$k = 0.01\ \mathrm{m^2\,s^{-2}}$
$\varepsilon = 0.001\ \mathrm{m^2\,s^{-3}}$
Concentration: 18.275% O_2, 5.686% CO_2, 0.43% CO.

The outlet of the mixture of air and exhaust gas was defined as free outflow.

The distribution of flow rates and concentrations for steady-state analysis calculated with the assumption that the speed of the monorail in the starting position is $0\ \mathrm{m\,s^{-1}}$ was assumed as the initial condition.

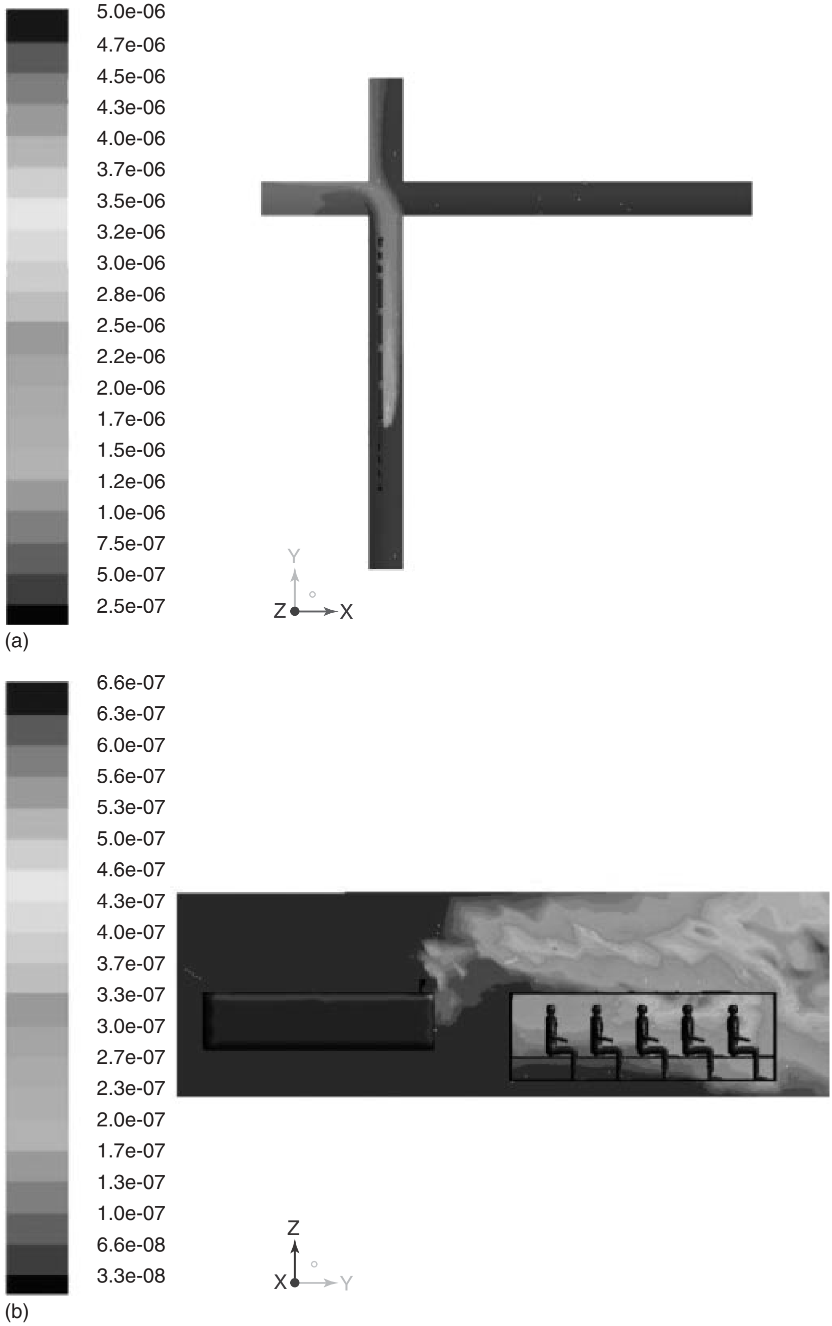

Figure 19.9 Scalar fields of distribution of volume content of carbon monoxide: (a) total top view; (b) side view for the bench just behind the locomotive (MINTOS, 2010).

Figure 19.9 shows scalar fields of distribution of volume content of carbon monoxide: (a) in a top view and also (b) for the bench, which is just behind the drive unit.

Simulation with use of the CFD method first permits the quantitative assessment of the efficiency of ventilation in roadways where transportation with diesel locomotives is carried out; second, the results obtained are useful tips for designers of transportation systems to improve further design solutions for locomotives. Hence the traditional method of verification of material prototypes, which is has to be applied at the stage of implementation of new technical means, can be eliminated.

19.7 Conclusion

In hard coal mines, the majority of fatal and serious accidents are associated with the use of machines during assembly, transportation, and mining operations in longwall and roadway faces.

Mining machines are large in size and very heavy, so their manufacture, testing, and transportation are difficult. The machines often operate within integrated mechanization systems. Sometimes different machines in one system are manufactured by different producers located far apart from each other, so they have no chance of verifying that the machines work correctly together under conditions close to the real ones. As a result, the machinery systems are often verified only underground when the systems are started up.

As the requirements of users of mining machines become more differentiated, the machines are manufactured in short series or even as single items, hence the cost of material prototyping cannot be distributed over a larger number of manufactured machines. Therefore, it is justified to carry out VP of the machine of the developed design. Simulation tests, carried out on computer models of the machines, are economically reasonable, as they can eliminate the costs of eventual changes required to be applied to the material prototype.

VP used in the development of new generation machines enables tests to be carried out at an early stage in the design of the machine to achieve an optimal solution. The correct structure of the calculation model enables high conformity of the simulation tests with the operational test results of those machines to be achieved.

Owing to the increasing importance of computer design methods and computational methods, they have become part of the curricula in technical universities.

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