THE METHODOLOGY FOR DYNAMIC BELT SIMULATION – ENABLING DYNAMICALLY INTERACTING BELT MODELS IN DEM SIMULATIONS USING A BONDED-PARTICLE APPROACH

Eric Fimbinger
University of Leoben (Montanuniversität Leoben), Austria

ABSTRACT

The methodology discussed in this paper is based on using a bonded-particle belt (BP belt) model to represent conveyor belts in DEM simulations. Such BP belts are capable of depicting complex belt-related effects resulting from interactions – on the one hand with the conveyed bulk material and on the other hand with the belt-guiding idlers and pulleys. Further, using BP belts also enable the consideration of effects related to a belt acting as a non-rigid, dynamic object, such as by respecting deviating local belt tensions or belt mass-related effects. As a concluding consequence, this methodology for dynamic belt simulation allows complex belt/system behaviour in DEM simulations to be considered, e.g. concerning the depiction of belt sag or situation-specific formation of troughs.

Especially for the simulation of belt systems in which complex-behaving belts significantly influence those systems, this kind of dynamic belt consideration is necessary. This regards, e.g., sandwich, pipe, or pouched belt conveyors.

In contrast to this introduced approach of using a BP belt, the conventional conveyor belt modelling approach in DEM simulation uses a simple motion-inducing contact model applied to a rigid-surface belt model. This conventional approach does not support the effects mentioned above to be included; it is thus insufficient to simulate said cases properly.

The content of this paper starts with an introduction into the topic of (dynamic) belt consideration in DEM simulations, followed by the main section, where the fundamentals of the methodology for dynamic belt simulation are explained, comprising its two major parts: the bonded-particle belt setup and its initialisation with a specific geometry into a given DEM simulation setup. During this section, the workflow for applying the methodology is also illustrated. This workflow explains the use of a developed CAD-to-DEM conversion tool, BeltConverter, which was programmed in the course of this methodology’s development to allow a user-friendly creation of BP belts from given 3D CAD model files containing any specific belt geometry. The belt geometries in this context each show a single belt in a particular deformed shape, commonly to approximate its assembled state, as the converted BP belt would be placed later on in this shape via import into the corresponding belt conveyor system. In this context, essential aspects regarding this CAD-to-DEM conversion process are outlined. Ultimately, to highlight potential capabilities, some exemplary applications are illustratively outlined for which the presented methodology provides excellent applicability.

1. INTRODUCTION

Conveyor belts form the central components in belt conveyor systems, in which they are guided on idlers and driven via pulleys to transport material, often bulk solids, from a feeding to a discharge point. They are relatively flat with a constant width, and for operation in conveyor systems, they are connected to form an endless belt. This endless form allows a circulating operation mode (with one belt strand carrying the conveyed material and the other for returning, usually empty), for which a conveyor belt needs to be flexible (as to be bent around the pulleys) whilst also being stiff in the longitudinal direction (in order to transmit tensile forces). This behaviour is enabled by the belt being made as a multi-material/multi-layer structure, either with textile/fabric reinforcements or embedded steel cords. Further details on belt conveyors and their central components, particularly the belts, can also be found in the literature, such as by ContiTech [1], CEMA [2], and similar.

During the operation of a belt conveyor, the driven belt is not only moved through the system but also dynamically deformed due to various loads acting on the belt. These loads further relate to belt interactions which can be attributed to two main groups: interactions between a belt and the conveyed (bulk) material and interactions between a belt and (belt-guiding) system components (idlers and pulleys). Due to these deformability aspects, it is necessary to consider the belt as a dynamically interacting component, such as when analysing those systems, e.g. for the purpose of mechanical designing and dimensioning.

For conventional belt conveyor systems, analytical approaches have been established that allow specific considerations to be made in this regard (forming the base state-of-the-art; see also above-referenced literature). More extensive analysations or complex system situations, however, typically lead to numerical simulation/analysis to be used as a supporting tool in engineering.

In the scope of this work, the focus is set on belt conveyors for handling bulk solids, which is also the common application for those systems (in contrast to single-object (general cargo) conveying, e.g. baggage handling). This scope further sets a particle-based method, the Discrete Element Method (DEM), as the numerical simulation principle to be used further on. (Sidenote: Other principles, such as FEM/FEA (Finite Element Method/Analysis) or block diagram modelling, are also addressed in the corresponding dissertation by Fimbinger [3].)

The conventional approach for representing conveyor belts in DEM simulation setups is based on using a simple motion-inducing contact model on a rigid-surfaced belt geometry (see Moving Plane model [4]; or also virtual movement [5]). This simple approach is sufficient in specific cases, but correspondingly, such a rigid belt model does not support further belt-related effects (due to the interactions outlined above) to be included in a DEM simulation. In order to enable this consideration of a belt as a dynamically interacting object in a DEM simulation, a methodology was developed by Fimbinger [3]. The following content, showing selected insights into this methodology specifically to provide a concise understandability of essential aspects and its application, is generally based on this corresponding dissertation, which, respectively, covers the methodology in full detail. This methodology's base approach uses specifically arranged and connected particles to set up a bonded-particle belt (BP belt). Details in this regard are covered in the next chapter, followed by an illustration of a typical workflow for applying the methodology and some exemplary applications.

Source credit for the discussed contents:
Dissertation "A Methodology for Dynamic Belt Simulation", Fimbinger (2021) [3], and related publications [7,8,9]

2. THE METHODOLOGY'S FUNDAMENTALS

The fundamentals of the methodology for dynamic belt simulation relate, on the one hand, to the general setup of a belt as a bonded-particle structure and also to the initialisation of such a BP belt in a particular form (both directly related to the belt model), and on the other hand, to using smooth-surfaced cylinders for belt-contacting objects (idlers/pulleys) in the DEM setup of the conveyor system (indirectly related to the belt model, as regarding components in contact with it).

A BP belt, initialised in a specific (pre-deformed and pre-tensioned) state within a DEM simulation setup of a simple belt conveyor, is shown in Figure 1. The marked section on the top-right is further shown as a detailed view in Figure 2, where the particles forming the BP belt (left) and the particle-connecting bonding network (right) are illustrated. Furthermore, the idler, with which the BP belt is guided in this section of the conveyor system, is shown as modelled as a smooth-surfaced (non-triangulated) cylindrical part.

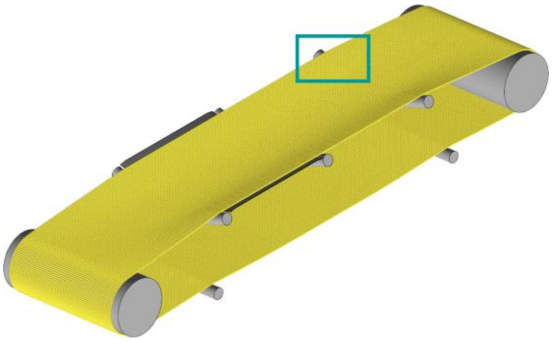


Figure 1. Simple belt conveyor setup modelled in a DEM simulation environment ([3])

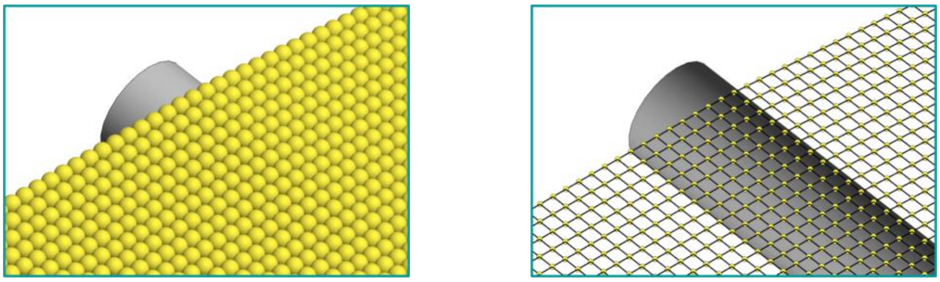


Figure 2. Detailed view on the BP belt, modelled with particles (left) and bondings (right) (after [3])

2.1. BP BELT SETUP

As shown in Figure 2, a BP belt is set up as a single layer of rectangularly arranged and correspondingly rectangularly bonded particles – with the particles forming the surface of a belt.

To reduce the effects of gaps between adjacent particles (which increase when the belt gets lengthened), overlapping of adjacent particles without resulting contact forces is enabled. This principle of enabling contactless particle overlapping is shown in Figure 3 (non-overlapping particles on the left; overlapping particles on the right).

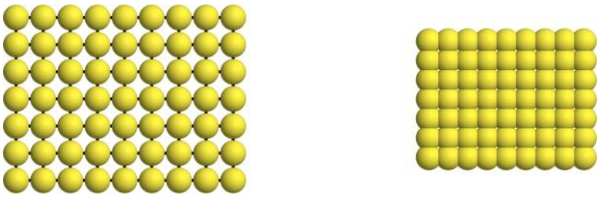


Figure 3. Rectangular bonded-particle setup without (left) / with overlapping particles (right) ([3])

Effects due to this enabled overlapping in combination with simple spherical particles are already obvious: The required amount of particles and, therefore, bondings per (belt) area get increased, which further relates to a higher computational effort required.

In contrast to belts for which setting all particles to globally non-contacting is possible, some applicational cases rely on belt-self-contact. This regards, e.g., pipe conveyors, specifically the area where the two edges of the belt are brought together to form a pipe-shaped conveyor line out of an initially flat belt. Applying contact groups to certain areas of the belt (particularly to certain groups of particles) allows such a belt contact to happen. Those contact groups can be defined as non-contacting or contacting, which is further illustrated on the example of a pipe conveyor shown in its cross-section in Figure 4 (with only the in green and the in blue indicated contact group set as contacting; all others, also inner-contacts (e.g. green-to-green) set with non-contacting).

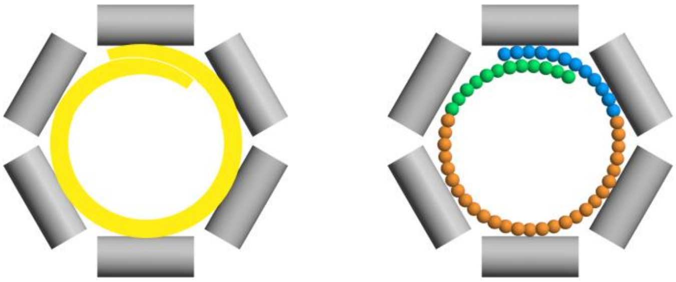


Figure 4. Using contact groups for belt-self-contact in a pipe conveyor: initial belt cross-section (left) and defined contact groups for belt contacting at the edges of the corresponding BP belt (right) (after [3])

The belt-forming particles shown so far were illustrated as spherically shaped, as spheres are the standard geometry for DEM particles. However, BP belt modelling using complex-shaped particles has proven effective, specifically with cuboidal particles (with rounded edges). This results not only in a smoothening of the resulting belt-representing surface but furthermore in a significant decrease of the required elements per belt area to be computed (particles and bondings), which also compensates for the higher computational effort required for complex-shaped particles. These aspects are further illustrated in Figure 5, showing the same belt section made with spherical (left) and cuboidal (right) particles.

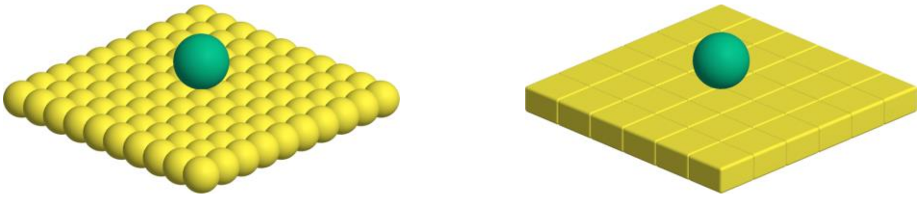


Figure 5. Comparison of spherical (left) and cuboidal (right) particles for BP belt modelling (after [3])

Besides these particle-related properties as described, the bondings (that connect those particles) significantly influence the dynamic behaviour of the resulting BP belt. In this context, the methodology introduces two major points: enabling a belt-typical bending-to-tension behaviour, i.e. a BP belt that is stiff in its tensional whilst soft in its bending behaviour – and enabling anisotropic behaviour, i.e. a BP belt with varying behaviour in the longitudinal and the transverse direction.

Figure 6 explains the use/effects of a bonding reduction factor, which is added to the bonding model by Obermayr, et al [6]. This bonding reduction factor ($f_{b,red}$) allows the bending behaviour of bondings to be adjusted (reduced), as illustrated: Under tensile load ($F_{tensile}$), both models with the same base setup but different factors (with $f_{b,red} = 1$ and $f_{b,red} = 0.1$) react the same. Under bending load ($F_{bending}$), however, the reduced factor ($f_{b,red} = 0.1$) results in a softening, as shown (bottom right).

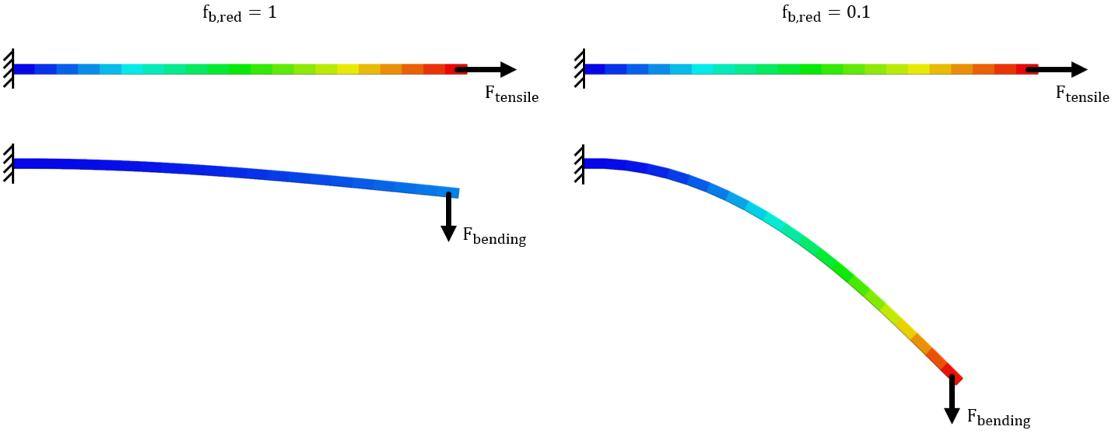


Figure 6. BP belt seen from the side, with varying reduction factor of 1 and 0.1 (left and right) under tensile and bending load (top and bottom) ([3])

To allow a deviating belt behaviour in the two main belt directions (longitudinal/transverse), the possibility of using a fibred belt setup is introduced, which is further explained with Figure 7 (corresponding to an additional detailed view of the system from Figure 2, right). In this detailed view, longitudinal-oriented rows of particles are indicated, forming fibres (e.g. light blue). Those particles are defined separately (typically via deviating names but identical properties) to allow different bondings to result within each fibre (e.g. blue-to-blue; i.e. in the longitudinal direction) and from fibre to fibre (e.g. blue-to-green; i.e. in the transverse direction).

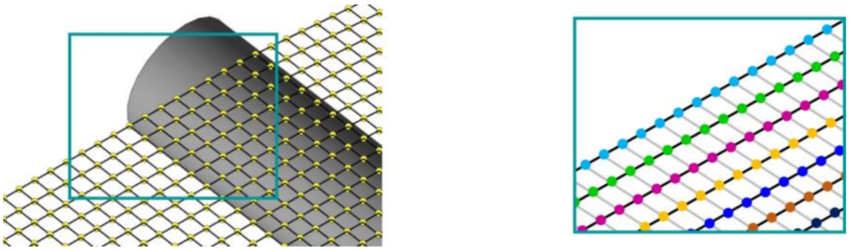


Figure 7. Fibred BP belt – bonded-particle structure (left) and detailed view with colours indicating the fibres as rows of particles and their respective bondings (right) (after [3,7,8,9])

In summary, the main parameters of a BP belt to depict a particular belt behaviour are: (with more details covered in the respective section "Structural belt setup" of the associated dissertation [3]), also including aspects for the determination of those parameters, as well as further belt structure-related extensions, e.g. heterogenous belt structuring, belt breakage capabilities, etc.)

- The belt particles'
  - Dimensions (cuboids with rounded edges; defining a belt model's surface), which further relates to the arrangement dimensions of the rectangular pattern formed by those particles as a bonded-particle structure (i.e. the particle numbers/distances in longitudinal/transverse belt direction)
  - Friction properties (defining the interactional behaviour for belt-bulk, belt-components (idlers/drums), and, if applicable, belt-belt contacts)
  - Mass properties (defining belt mass-related characteristics, e.g. regarding sag due to belt mass or mass inertia effects)
- The bondings'
  - Area (commonly defined via the bonding's radius)
  - Young's modulus (respectively: shear modulus/Poisson's ratio)
  - Reduction factor (with these three bonding parameters defining the deformability/flexibility behaviour of the belt)
  - Damping factor (defining the decay of belt oscillations)
  - (Breakage criteria, if applied; see also Figure 18)

2.2. BP BELT INITIALISATION

The principle for initialising a BP belt according to the presented methodology is based on using a given geometry of a belt via a CAD (Computer Aided Design) file and converting this data into a corresponding BP belt to result in a bonded-particle structure as introduced in the previous section. This mentioned conversion is one of the core elements of the methodology, with several aspects outlined but mathematical details not covered further in the following.

Figure 8 shows a representative workflow for initialising a BP belt in the DEM setup based on given a CAD model of a conveyor system, starting with the typical CAD belt model (top), over its preparation (second from top), and the meshing (third from top), to the final resulting DEM model with the corresponding BP belt (bottom).

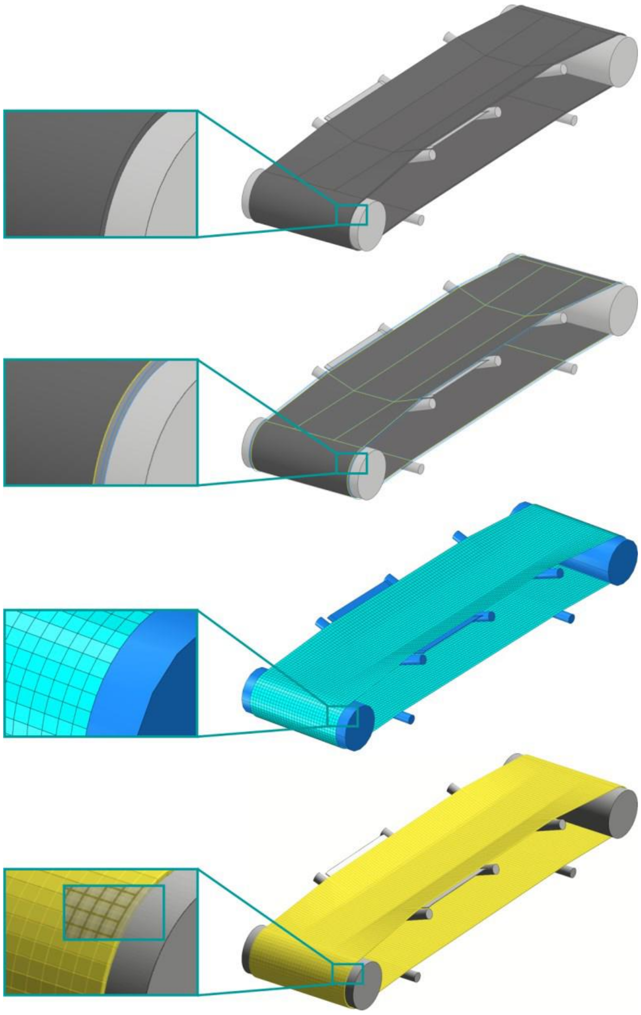


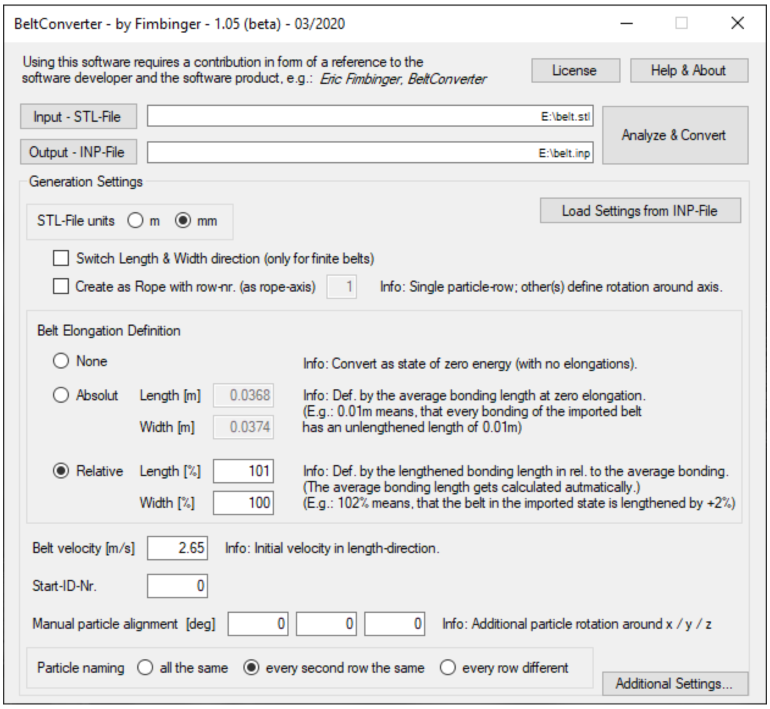
Figure 8. Workflow for creating a DEM model with a BP belt (bottom) based on a corresponding CAD model (top) via its preparation and meshing (second and third from top) (corr. to the model from Figure 1) ([3])

Prior to the actual CAD-to-DEM conversion (the step between the bottom two states in Figure 8), the belt geometry containing the CAD data file needs to be prepared for subsequent meshing. The resulting mesh then represents the grid structure of the bonding network (similar to the grid apparent in Figure 2, right). This preparation reduces the voluminous belt to a surface model, resulting in the middle surface lying between the outer and the inner surface of the initial voluminous belt model. Additionally, the edges need to be given an offset so that the edge distance from the bonding joint (mid-point of the particles) to the actual edge of the belt is considered (see details in Figure 8, second from top and bottom). In the subsequent meshing procedure, the surface model gets structured into a rectangular grid, whereby the applied meshing parameters must fulfil the requirements intended to be used in the BP belt (such as the particle dimensions, further relating to the number of particles along the transverse belt direction, etc.). Various software can be used for these addressed purposes of preparation (CAD software, e.g. Inventor [10], as illustrated in Figure 8, first and second from top) and meshing (mesher/mesh modules, e.g. Abaqus [11], as illustrated in Figure 88, third from top). For the last step, the conversion of the mesh, a CAD-to-DEM conversion algorithm was developed. This algorithm was also implemented into a software tool, BeltConverter [12] (licensed as free to use).

As a step towards supporting a universal input format, this developed software tool requires an (ASCII encoded) STL [13] file containing the rectangular grid data. STL is a widely used data format and, thus, convenient for this purpose (however, as it contains triangulated surface data, a triangle-to-quadrilateral merging is a required step, performed as one of the first computational steps within the developed software tool). As output, the DEM file format for ThreeParticle/CAE [14], INP file format, is used, with the BP belt data resulting as human-readable. This file is structured in:

- General information
    - Conversion settings
    - Information about the result (number of particles, etc.)
- Particle specifications, each with
    - Type (particle name)
    - Unique ID
    - Position (vector) & alignment (quaternion)
- Bonding specifications
    - Particle IDs of the two bonded particles
    - Initial state of those two particles, each with
        - Position (vector) & alignment (quaternion)

The GUI of the developed software tool, BeltConverter, is shown in Figure 9, with the input and output file button (STL/INP) as well as several conversion options visible.



Using this software requires a contribution in form of a reference to the software developer and the software product, e.g.: *Eric Fimbinger, BeltConverter*

Input - STL-File: E:\belt.stl

Output - INP-File: E:\belt.inp

STL-File units ○ m ● mm

☐ Switch Length & Width direction (only for finite belts)

☐ Create as Rope with row-nr. (as rope-axis) 1 Info: Single particle-row; other(s) define rotation around axis.

Belt Elongation Definition

○ None Info: Convert as state of zero energy (with no elongations).

○ Absolut Length [m] 0.0368 Width [m] 0.0374 Info: Def. by the average bonding length at zero elongation. (E.g.: 0.01m means, that every bonding of the imported belt has an unlengthened length of 0.01m)

● Relative Length [%] 101 Width [%] 100 Info: Def. by the lengthened bonding length in rel. to the average bonding. (The average bonding length gets calculated autmatically.) (E.g.: 102% means, that the belt in the imported state is lengthened by +2%)

Belt velocity [m/s] 2.65 Info: Initial velocity in length-direction.

Start-ID-Nr. 0

Manual particle alignment [deg] 0 0 0 Info: Additional particle rotation around x / y / z

Particle naming ○ all the same ● every second row the same ○ every row different

Figure 9. BeltConverter GUI ([3,12])

Notable options for the conversion process that can be seen/set in the GUI are

- the definition of pre-existing belt elongation in the longitudinal direction (when the CAD model corresponds to a pre-tensioned belt model, which is typical, and may go up to about 2%; and as also indicated in the shown GUI in the section for belt elongation definition of 101% relative in length direction),
- the option to apply an initial belt velocity during conversion (to initialise not only a pre-deformed and pre-tensioned but furthermore an already running belt model; which reduces simulation time as would be required to run up a conveyor system by accelerating a BP belt), and
- the option to apply varying particle naming as rows (which corresponds to a fibred belt setup (relating to anisotropic belt behaviour) as described in the previous section regarding the BP belt setup in general).

After conversion from CAD to DEM, the computed BP belt is ready to be imported into the simulation environment of ThreeParticle/CAE via the input command. When a simulation containing such an imported BP belt is started, the BP belt typically oscillates into its final state, as the geometry provided with the CAD file is most likely an approximation/estimation close but most likely not fully coinciding with the actual final state that a belt will form. Thus, this related conversion of approximated belt geometries is also referred to as almost-final state conversion.

The effects of the transient oscillation of a converted BP belt are visualised in Figure 10, which shows the workflow for initialising a BP belt based on CAD data and further starting the simulation, thus forming this computed BP belt from its almost-final into its final state, as it occurs during operation of the conveyor system. This workflow starts with the voluminous CAD model (top left) and its preparation/meshing (top right), and follows with the initialised BP belt (bottom left) and its steady (final) state resulting after transient oscillation (bottom right). (The belt is additionally applied a conveying velocity, which is not explicitly shown.)

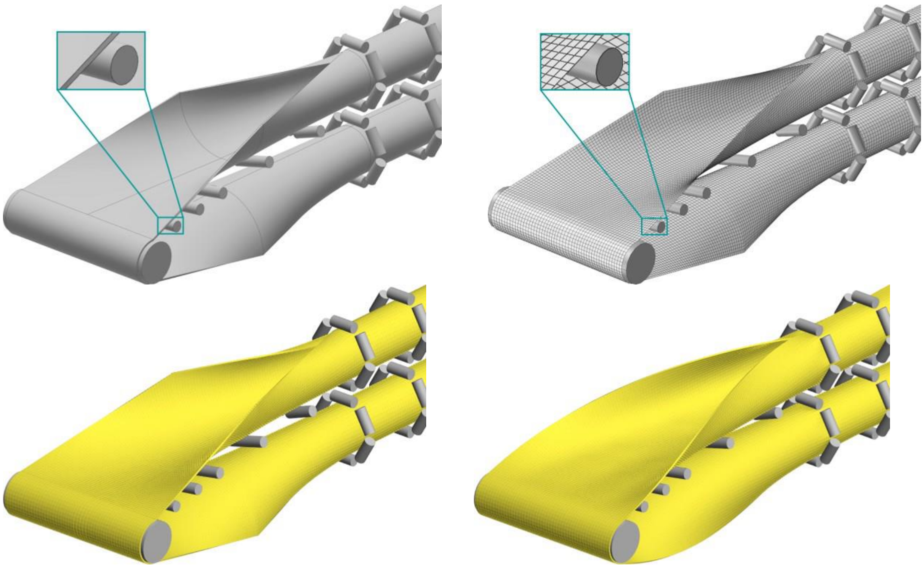


Figure 10. Workflow for CAD-to-DEM conversion (top left to top right to bottom left) on a pipe conveyor, extended with the transient oscillation when starting the simulation (bottom left to right) (after [3])

The transient oscillation of this BP belt, deforming from the almost-final/converted into its steady/final state, is further visualised in Figure 11 (from top left to bottom right), in which the first few timesteps of the simulation are shown in colour representing local belt (particle) velocities. It is to be noted that this transient oscillation typically happens within a very small time frame, as in the range of fractions of a second, when set in relation to the actual simulation of the conveyor system following this pre-simulation; thus, this remaining pre-simulation effort incurs insignificantly small.

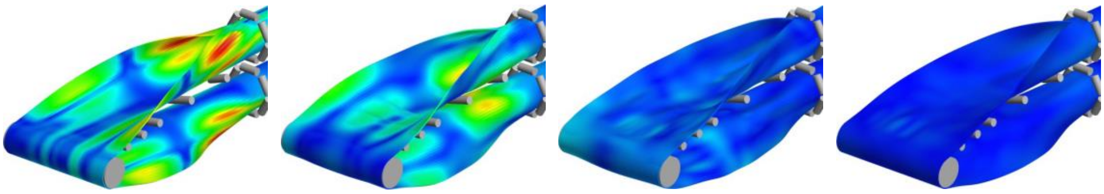


Figure 11. Transient oscillation visualised with colours indicating local belt velocities (rainbow scheme) (corr. to the model from Figure 10) (after [3])

2.3. SMOOTH-SURFACED CYLINDERS

As an extension to the parts of the methodology that directly relate to the belt (explained in the two previous sections: BP belt setup and BP belt initialisation), the methodology also introduces using numerically smooth-surfaced cylindrical objects to model belt-contacting system components. More specifically, this regards the modelling of idlers and pulleys in the DEM environment in which a BP belt is intended to be used; thus, this extension is indirectly related to simulation with BP belts.

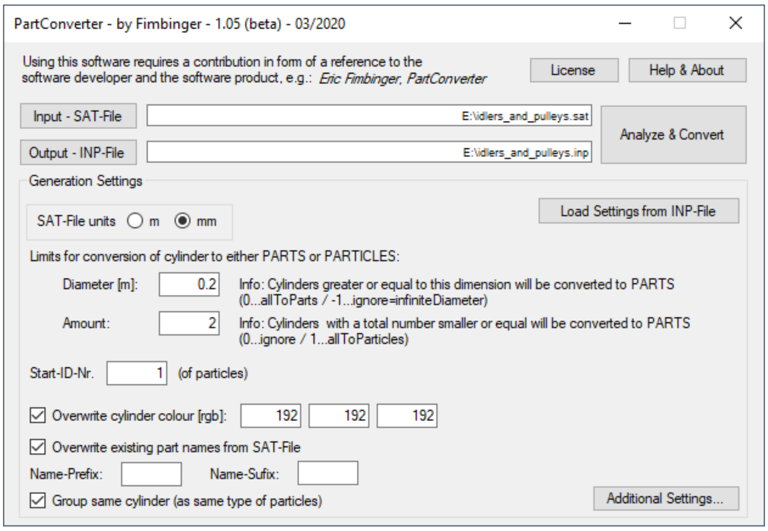
Conventionally, the system components in DEM simulation setups are modelled with triangulated surfaces. Particularly regarding idlers and pulleys, and specifically in combination with BP belts, the resulting approximation of those components' cylindrical surfaces as multiple triangles shows several disadvantages (in terms of computational efforts, simulation stability, and accuracy) when compared to using numerically smooth cylinders. Modelling numerically smooth cylinders is supported in several modern DEM environments, including ThreeParticle/CAE, in which selected mathematical primitives (including cylindrical objects) can be used correspondingly.

The challenge when using smooth cylinders lies in the efforts required to define their individual properties – in particular: each cylinder's position and alignment – especially as belt conveyor systems contain a relatively large number of such cylindrical components, and each cylinder needs to be defined manually. To overcome this challenge, a supporting tool, PartConverter [15], was created in the course of the methodology's development. Similar to the previously described tool, PartConverter, this tool converts the contents of a given CAD data file to a DEM data file – here focusing on the cylindrical system parts instead of the belt geometry.

The CAD file format used for conversion is Standard ACIS Text (SAT) [16], which is, above all, able to contain cylindrical part data (other than STL, which does not, due to only containing triangle data). Furthermore, this file format is widely used/supported, and also human-readable (which was beneficial for the tool's development).

The conceptual procedure behind the tool PartConverter is relatively simple: read the given CAD data file (SAT), typically containing a (large) number of cylindrical geometries – gather each their properties (diameter, length, position, alignment) – structure this data corresponding to some options set for the conversion process (e.g. detecting identical geometries) – compute and export each cylinder with its properties into the syntax of the ThreeParticle/CAE input file format.

There are several options implemented as available to be set by the user in the GUI of the tool PartConverter, shown in Figure 12, e.g. regarding part naming or colouring.



PartConverter - by Fimbinger - 1.05 (beta) - 03/2020

Using this software requires a contribution in form of a reference to the software developer and the software product, e.g.: *Eric Fimbinger, PartConverter*

Input - SAT-File: E:\idlers_and_pulleys.sat

Output - INP-File: E:\idlers_and_pulleys.inp

SAT-File units ○ m ● mm

Limits for conversion of cylinder to either PARTS or PARTICLES:

Diameter [m]: 0.2 Info: Cylinders greater or equal to this dimension will be converted to PARTS (0...allToParts / -1...ignore=infiniteDiameter)

Amount: 2 Info: Cylinders with a total number smaller or equal will be converted to PARTS (0...ignore / 1...allToParticles)

Start-ID-Nr. 1 (of particles)

☑ Overwrite cylinder colour [rgb]: 192 192 192

☑ Overwrite existing part names from SAT-File

Name-Prefix: Name-Sufix:

☑ Group same cylinder (as same type of particles)

Figure 12. PartConverter GUI ([3,15])

An essential option handles whether cylinders are exported to form part objects or particle objects when the resulting input file is loaded into the simulation environment. Principally, both types are justified, since cylindrical parts support certain part-related features, such as multibody dynamics (MBD), whereas cylindrical particles offer to be used in larger quantities, as well as supporting edge radii (which adds to the stability of the simulation, similar to using rounded cuboids for belt particles; cf. BP belt setup). Concluding from these aspects, the developed tool optionally allows differentiating of cylinders as potential pulleys or potential idlers. This differentiation is set via a diameter limit (above: pulley / below: idler) and also a quantity limit (below: pulley / above: idler).

3. EXEMPLARY APPLICATIONS

This chapter shows application examples of the presented methodology in which the details explained in the previous sections are correspondingly applied, resulting in the DEM simulations as shown in the following figures. Specific highlights, such as various enabled capabilities, are thereby illustrated. (General note: this chapter primarily uses illustrative insights into simulation results with colour indicators based on a rainbow scheme from blue to red, corresponding to visualising low to high values for various parameters respectively stated.)

At first, the application of a simple conventional belt conveyor (corresponding to the system already shown in Figures 1 and 8) is shown in Figure 13. This system is shown in a typical operational state (left), with the resulting belt deformations made visible (via indicating the z-position of the belt particles with the applied bulk material particles hidden; right).

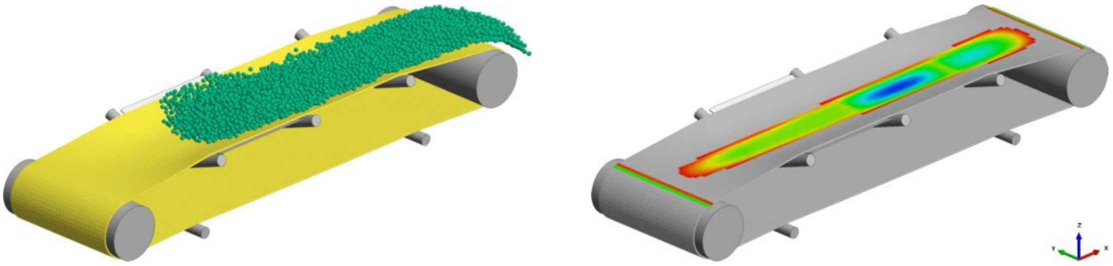


Figure 13. Conventional belt conveyor model (left) with resulting local belt deformations made visible (colour indicating z-position; right) (after [3])

A consequential effect, further made visible in Figure 14, is the formation of inner-bulk movements due to the material being moved on a deformable belt. This figure shows a sectional view from the side with the material being moved over an idler (from left to right) with the z-velocity indicated (left) and the same section with the particle movements visualised with vectors (right).

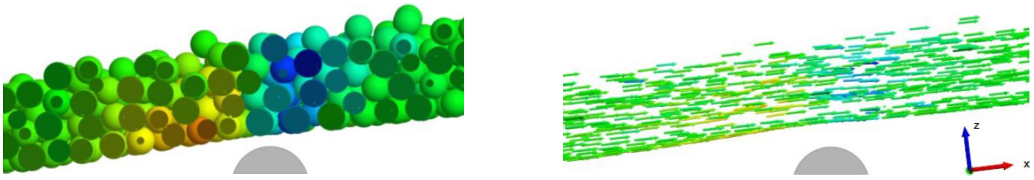


Figure 14. Inner bulk material movements made visible when transported on the deformable belt (sectional view from the side; colour indicating z-velocity) (after [3])

Ultimately, the BP belt allows analyses regarding local belt states (elongational/bending deformations/stresses) to be made, such as visualised in Figure 15. This figure shows local elongational deformations in the longitudinal direction (left) as well as local bending deformations in the transverse direction (right) of the belt during operation.

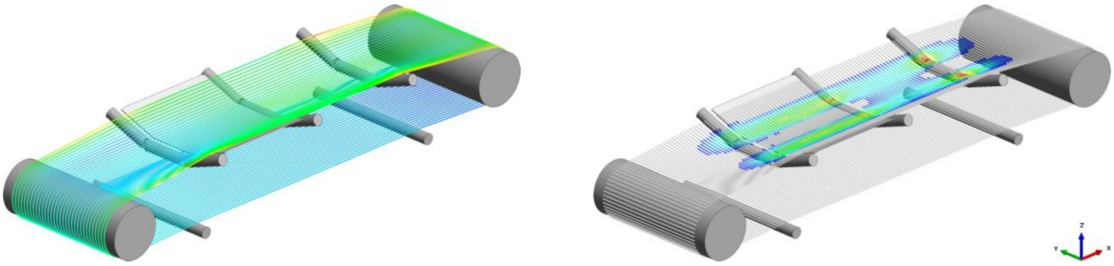


Figure 15. Bonding analyses of the BP belt regarding local deformation; longitudinal elongation (left) and transverse bending (right) (colour indicating the degree of respective bond deformation) (after [3])

Figure 16 shows a more complex application of the dynamic belt simulation methodology: a sandwich conveyor. This application comprises two BP belts, indicated in yellow (lower belt) and orange (upper belt). Besides the total conveyor system (right), the base principle of this conveyor type, a vertical material transport, is revealed with the upper belt hidden (middle). A material flow analysis is further shown, with both belts hidden and the bulk material particles' velocities indicated in colour, revealing sections with irregular material movements (blue areas, indicating a form of back-flowing particles).

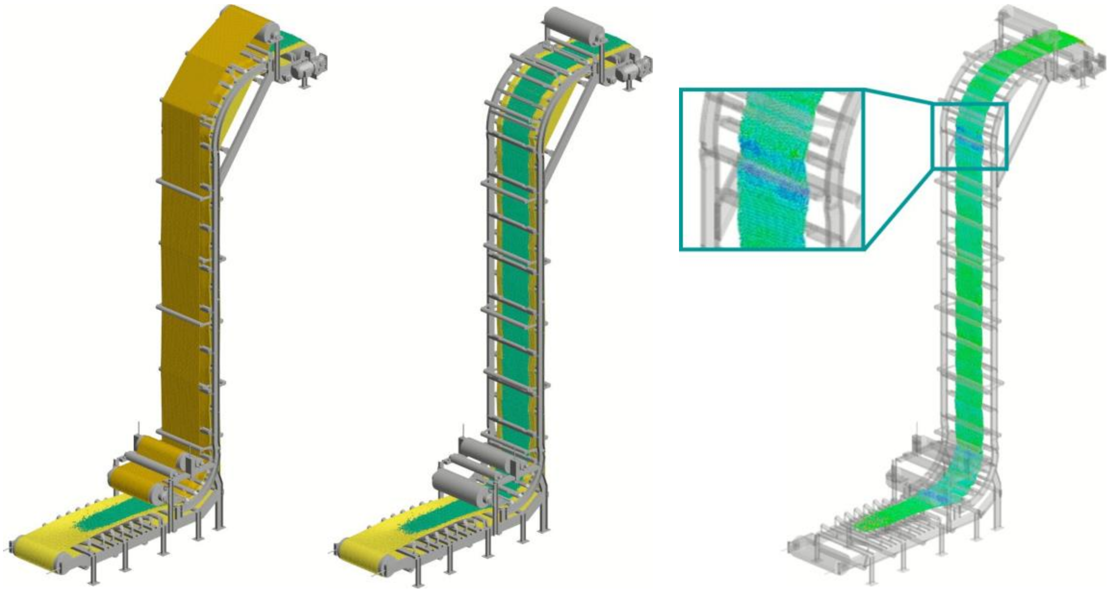


Figure 16. Sandwich conveyor model (left), with the upper belt hidden (middle) and an analysis of the bulk material flow (colour indicating bulk particle velocity; right) (after [3,8,9])

Another example of the methodology's application is shown in Figure 17, providing insights into the simulation of a pipe conveyor (corresponding to the model already shown in Figures 4, 10 and 11). The system is shown as consisting of the elements relevant to perform the BP belt simulation (left), comprising the BP belt itself and the belt-guiding idlers and pulleys (which are modelled as smooth-surfaced cylinders). Similar to the effects highlighted in Figure 14, this system also reveals inner-bulk movements due to the deformational abilities of the BP belt – but in a more distinctive form, as variations of local bulk particle velocities within the closed belt (not only in the vertical direction) are clearly present (right and detailed view).

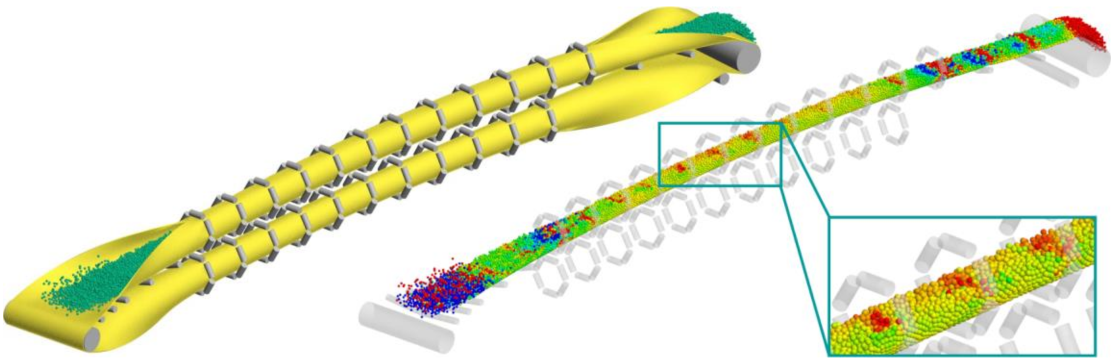


Figure 17. Pipe conveyor model (left) with the belt hidden (right) revealing bulk movement characteristics at idler stations (colour indicating bulk particle velocity; right) (after [3])

At last, an extension to the BP belt model, particularly to the bondings connecting the belt particles, is illustrated in Figure 18. This figure shows the resulting effects shortly after the breakage of a BP belt due to reaching a defined load limit at as-breakable-defined bondings.

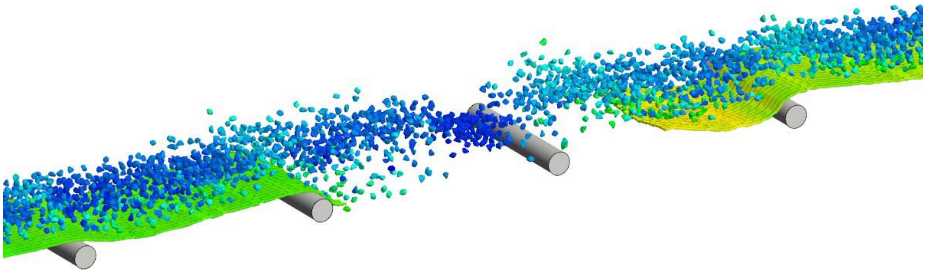


Figure 18. Breakage of a BP belt whilst conveying bulk material (colour indicating velocities) (after [3])

4. CONCLUDING REMARKS

The presented paper provided insights into the methodology for dynamic belt simulation, comprising the fundamentals to set up and initialise a bonded-particle belt model (BP belt) in a DEM simulation environment in order to enable dynamic belt interactions to be considered. Additionally, the use of smooth-surfaced cylinders for pulleys and idlers in such simulation setups is described, followed by a final chapter that shows the methodology's applicability on exemplary, industry-related applications, ultimately illustrating selected capabilities enabled by this methodology.

In a concise conclusion, the discussed methodology can be stated as suitable for the use as intended and, therefore, as successful, relating specifically to three major aspects:

- Enabling the modelling, simulation, and analysis of belt-like objects as dynamically deformable/interacting models in DEM simulations,
- Enabling simulation of application-oriented belt (conveyor) systems, and
- Significantly reducing related efforts/costs, as associated with the use of:
    - BP belts, thus staying within the DEM simulation environment,
    - Belt initialisation in almost-final state, thus reducing required pre-simulation efforts,
    - Smooth-surfaced cylinders, and
    - Developed software tools (BeltConverter and PartConverter; that particularly add to significantly reducing modelling efforts whilst also enhancing the methodology's usability).

An outlook on potential follow-up work, including areas that potentially benefit from the presented methodology, is organised into five sections (with these sections covered in more detail in the corresponding thesis [3]):

- Development of advancements and further extending methods (e.g. for initialising bulk material in motion on already running BP belts)

- Determination/calibration of parameters to depict specific, given belts (e.g. by analysing the deformation behaviour of one-side-fixed belts)
- Application of the methodology for its purpose of belt system engineering (e.g. for virtual prototyping on systems relying on complex belt behaviour)
- Application/adaptation of the methodology for further innovative purposes (e.g. for simulating ropes, nets, membranes, shell-like structures, etc.)
- Implementation of developed algorithms by third-party software developers (which would allow an even more convenient use of the methodology's functionalities, especially regarding CAD-to-DEM-based belt initialisation)

REFERENCES

1 CONTITECH TRANSPORTBANDSYSTEME GMBH (PART OF CONTINENTAL AG) (ContiTech). *Fördergurte Berechnungen:* 5. Auflage. Hannover, Germany: Continental AG, 2013.

2 CONVEYOR EQUIPMENT MANUFACTURERS ASSOCIATION (CEMA). *Belt Conveyors for Bulk Materials. The Voice of the Conveyor Industry of the Americas:* Seventh edition. Naples, Florida, USA: Conveyor Equipment Manufacturers Association, 2014. ISBN 978-1-891171-44-4.

3 FIMBINGER, E. *A Methodology for Dynamic Belt Simulation*. Dissertation. Leoben, Austria, 2021. Available from: doi:10.34901/mul.pub.2021.3

4 DEM SOLUTIONS LTD. *Theory Reference Guide (EDEM)*. 2014.

5 BECKER, A. *User Guide (ThreeParticle Simulation)*. ThreeParticle 2019 R4.0. 2019.

6 OBERMAYR, M., DRESSLER, K., VRETTOS, C., and EBERHARD P., *A bonded-particle model for cemented sand*. Computers and Geotechnics. 2013:49, 299-313. Available from: doi:10.1016/j.compgeo.2012.09.001

7 FIMBINGER, E. *Fördergurtsimulation - Entwicklungen und Anwendung der Methodik zur Simulation von Fördergurten mittels der DEM*. In: Fottner, J. et al., eds. 23. Fachtagung Schüttgutfördertechnik 2018: Tagungsbericht. Garching: Technische Universität München, Germany, 2018. ISBN 978-3-941702-95-0, pp. 19-42.

8 FIMBINGER, E. *Methodology for the Simulation of Conveyor Belts Using the Discrete Element Method.* NAFEMS World Congress 2019: Summary of Proceedings. Québec City, Canada, 2019. ISBN 978-1-910643-52-5, 94-95 (enclosed pdf NWC19-235).

9 FIMBINGER, E. *Dynamic Conveyor Belt Simulation using the Discrete Element Method*. In: Jones, M., ed. 13th Inter-national Conference on Bulk Materials Storage, Handling and Transportation ICBMH 2019: Conference Proceedings 2019. Barton, ACT, Australia, 2019. ISBN 978-1-925627-29-9, (enclosed pdf).

10 AUTODESK. Inventor [software]. Version 2020. Available from: https://www.autodesk.de/products/inventor

11 DASSAULT SYSTEMES, SIMULIA, ABAQUS INC. Abaqus [software]. Version 2020. Available from: https://www.3ds.com/products-services/simulia/products/abaqus/

12 FIMBINGER, E. BeltConverter [software]. Version v1.03 beta. 2019. Available from: https://github.com/Fimbinger/BeltConverter

13 3D SYSTEMS, INC. *StereoLithography Interface Specification*. 1988 and 1989

14 BECKER 3D GMBH. ThreeParticle/CAE [software]. Version 2019 R4.1.0 (RC). 2020. Available from: http://becker3d.com/

15 FIMBINGER, E. PartConverter [software]. Version v1.03 beta. 2019. Available from: https://github.com/Fimbinger/PartConverter

16 SPATIAL CORP. (PART OF DASSAULT SYSTEMES). *SAT File Format*. Available from: https://www.spatial.com/resources/glossary/sat-file-type

ABOUT THE AUTHOR

ERIC FIMBINGER

Dr Eric Fimbinger is Senior Scientist at the Chair of Mineral Processing at the University of Leoben, Austria. In 2016 he graduated in heavy/special mechanical engineering and received his doctorate in 2021, focused in the field of mining engineering – conveying technology and design methods, with the topic discussed in this paper. His area of expertise is mechanical engineering and multiphysics simulation, particularly with a focus on particle-based systems.

Dr Eric Fimbinger

Chair of Mineral Processing

University of Leoben (Montanuniversität Leoben)

Franz Josef Strasse 18, A-8700 Leoben, Austria

Telephone: (+43) 664 80898 1814

E-mail: eric.fimbinger@unileoben.ac.at