Simulation of a tunnel drilling sequence to determine loads on a rock drilling equipment

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Keywords: *Modeling, Simulation, System, Module, MBS*

ABSTRACT

Rock drilling for tunneling and mining is a task that is very tough for the drilling equipment which often has to operate during uncertain environmental conditions. The rock is always different, not homogenous and require careful geological investigations before a drilling operation can start.

Atlas Copco Rock Drills AB develops and manufactures equipment for rock drilling, tunneling and mining. A Robot Boomer is a rubber tyred rig with two booms mounted on it . This paper deals with the modeling and handling of one of the booms, see figure 1.

This paper deals with the development of methods for analysis of large interconnected, complex, systems where it is hard to get an holistic view of the products behavior. An approach based on treating the product as being a system that can be divided into smaller more manageable subsystems, has been used. This enables the use of a modular modeling of the different subsystems in the boom, where we want to model some of the parts as exchangeable subsystems.

The analysis tasks being covered here is to determine the work area for the boom and to traverse a drilling pattern for a tunnel face to examine angular deviation at the tool center point (TCP) of the boom and loads on the back plate where the boom is connected to the rig. For these tasks, a brief description is given, of the different ADAMS models that have been used as well as the different steps that have been taken to achieve the presented analysis results.

1. Introduction

Rock drilling for tunneling and mining is a task that is very tough for the drilling equipment which often has to operate during uncertain environmental conditions. The rock is always different, not homogenous and require careful geological investigations before a drilling operation can start.

Atlas Copco Rock Drills AB develops and manufactures equipment for rock drilling, tunneling and mining. A Robot Boomer is a rubber tyred rig with two booms mounted on it . This paper deals with the modeling and handling of one of the booms, see figure 1.

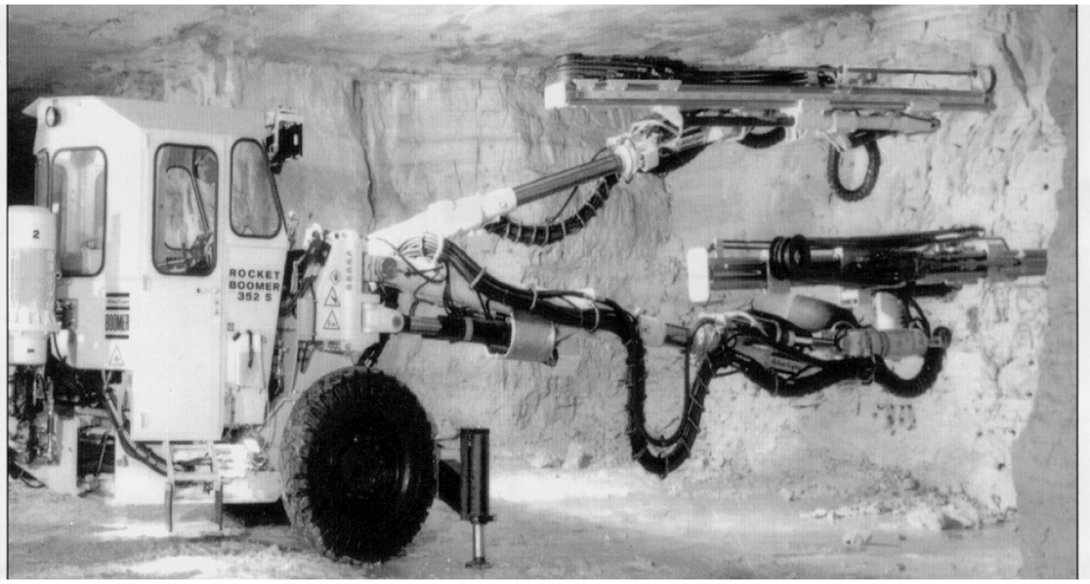

Figure 1. A Robot Boomer from Atlas Copco Rock Drills AB.

The boom can be seen as a good example of a product where it is hard to get overall view of the products behavior. To be able to predict the behavior of this boom a systematic approach can be of great use [1], [3], [8]. Modeling of this boom require an efficient way to handle different types of models because there are many different analysis that need to be performed, each with their specific demands. The modeling and analysis tasks being covered here is to determine the work area for the boom and to traverse a drilling pattern for a tunnel face to examine angular deviation at the tool center point (TCP) of the boom and loads on the back plate where the boom is connected to the rig.

2. Modeling of the boom

2.1 A systems approach

Treating the product as a system that can be divided into subsystems [4], [5], is a common way to treat large complex products today. This idea is based on the assumption that some kind of predefined interfaces exists on the products which enable subsystems to be exchangeable. This has been a frequently used method to handle product structures with open branches for customer preferences.

However, this paper is concerned with the activities of modeling and behavior prediction of product properties. For these activities we want to use a similar approach as for the case of handling product structures. This means that we want to define the interfaces that connects the subsystem models into a system model. These interfaces consist of mating entities from at least two parts, see e.g. [2], [6], [8].

Before we start any modeling of the boom it is useful to divide it into subsystems and to identify where and of what type the interfaces between these subsystems are. This can then be illustrated in a connection graph as shown in figure 2.

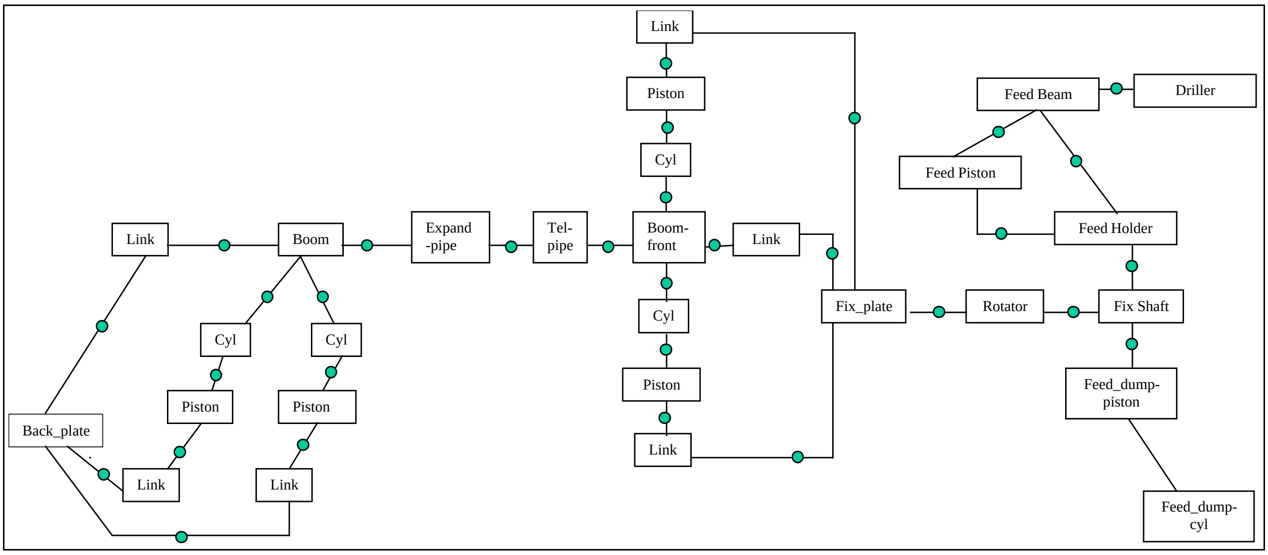

Figure 2. Connection graph for the boom.

2.2 Modeling of subsystems

The decision to make when modeling the different subsystems is to decide where to place and how to model the interfaces that previously were identified and drawn in the connection graph. Next we have to decide which parts that we need to make exchangeable for the initial analysis and what type of models they are to be replaced by.

For this application, we have two major analysis that we will discuss in this paper. First we want to calculate the outer boundaries of the work area which actually restricts the size of the tunnel that can this boom can be used for. Second we want to examine the effects of applying a force of about 20 kN at the TCP of the boom and to repeat this for a drilling sequence. This force represents the action of pre loading the TCP against the rock before the drilling of each hole starts.

As a starting point for the analysis we decide to make a mechanism model in ADAMS with solely rigid parts. This model consists of 28 different parts and 32 joints connecting the parts and reducing the degrees of freedom of the total system, see figure 3.

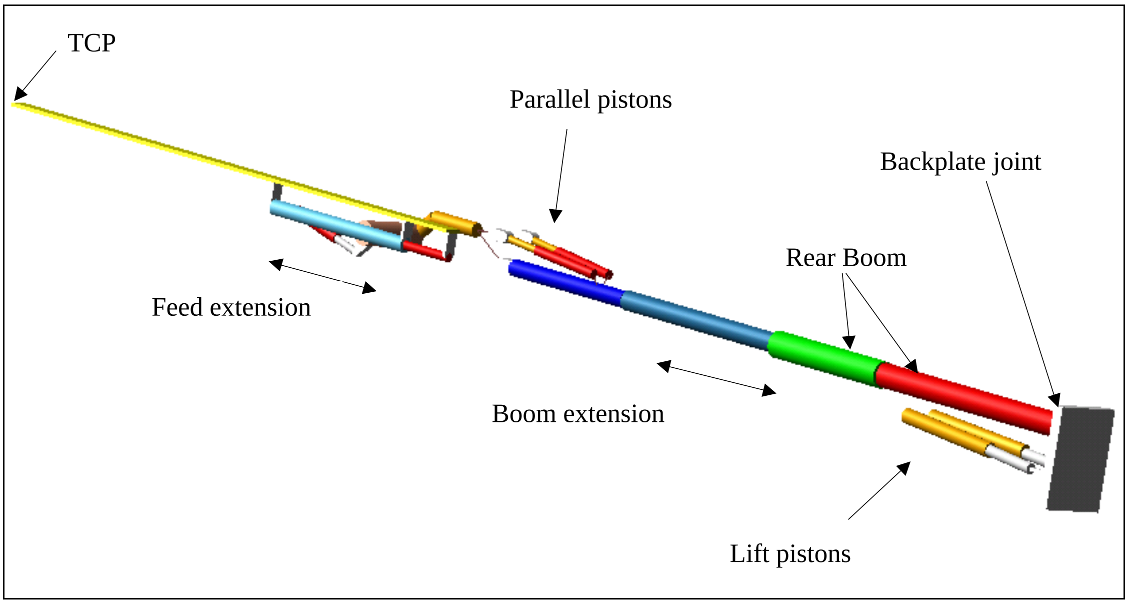

Figure 3. ADAMS model of one of the booms in figure 1.

3. Analysis

3.1 Analysis of work area

The calculation of work area for this type of mechanism is a task that is difficult and time consuming if it would be made manually. However, with modern Computer Aided Engineering, CAE tools, such as ADAMS, this task is very well supported. For the analysis of work area, the ideal kinematic movements with respect to angular restrictions and restrictions of piston length, is wanted. The model suitable for this analysis is based on the rigid model shown in figure 3. This is then completed with restrictions on angular movements and piston strokes.

In order to restrict both the lateral and vertical angular movements we have defined two moments in terms of "single component forces" where a step function is activated at both max and min limits of the allowed angles, see figure 4. These moments have been applied on the two joints at the back of the boom allowing these movements, see figure 4. In a similar way, actuator lengths are restricted by "single component forces" at both ends of the pistons. The parallel positioning is achieved by a coupler joint between lift pistons and parallel pistons.

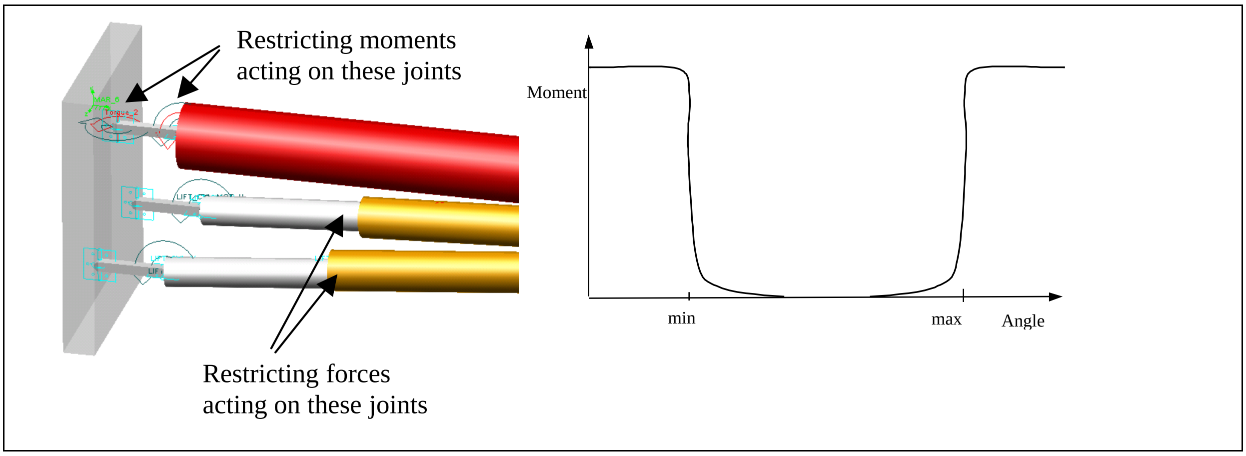

Figure 4. Restriction of lateral and vertical angular movements and of piston lengths by using force elements.

The actuators are then relaxed before we apply an external load, e.g. a tension force from a spring, at the TCP. This forces the TCP to follow an extreme path that is limiting the work space. The definition of this tensioning force that have been used is the one suggested by Makkonen [7], see eq. (1). This force rotates around the outer limit of the work space and thus forces the TCP of the boom to follow the outer path of the work space. The work area can then be obtained by performing a quasistatic analysis, see figure 5.

$$\begin{bmatrix} F_x \\ F_y \\ F_z \end{bmatrix} = \begin{bmatrix} k_x r\cos(\omega \cdot t) - c_x \dot{x} \\ k_y r\cos(\omega \cdot t) - c_y \dot{y} \\ k_z (z_0 - \Delta z \,\mathrm{int}(\omega \cdot t / 2\pi) - c_z \dot{z} \end{bmatrix} \qquad (1)$$

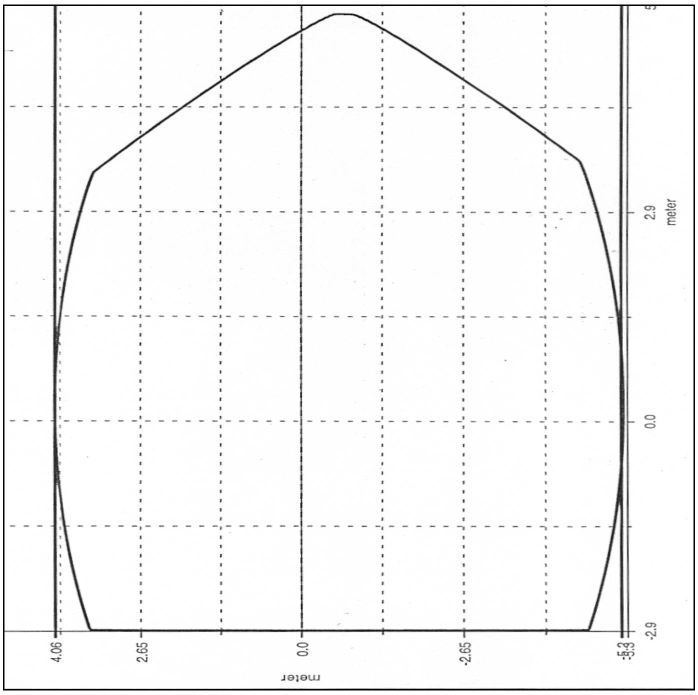

Figure 5. Work area envelop.

3.2 Analysis of loads during a drill sequence.

A drill pattern for a tunnel face consists of about 80 holes that should be drilled as fast and as parallel as possible. After drilling the holes, they are loaded with explosives which are scheduled and blown in a sequence giving the maximum effect. The quality of the blowing result, is much depending on the precision in positioning and how parallel the holes are. A low precision on positioning and parallel drilling of holes will result in a larger crack-zone.

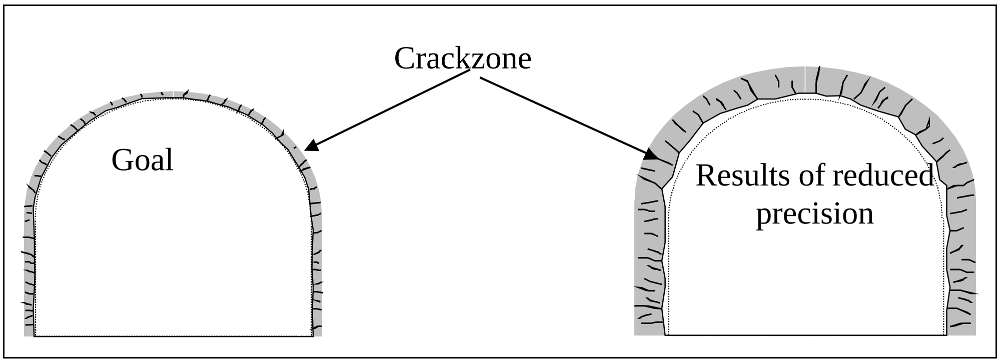

Figure 6. A low precision will result in a larger crack-zone [9].

The starting point of the drilling is a hole pattern that is drawn for the actual tunnel face (figure 7). Based on this, a drilling sequence is determined, which is based on having two operating booms on a rig (figure 7).

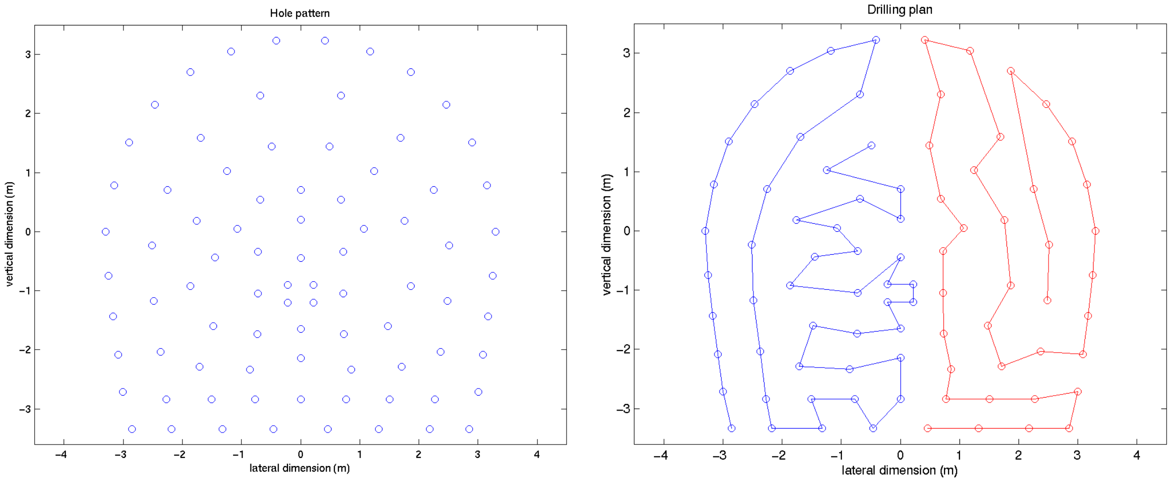

Figure 7. Drill pattern (left) and drilling sequence (right) for a rig with two booms.

Now we want to examine the effects of applying a force of about 20kN at the TCP of the boom and to repeat this for a drilling sequence. This force represents the action of pre loading the TCP against the rock before the drilling of each hole starts. The effects that we are interested to study are the deflection of the boom when it is pressed against the wall and the reaction forces in the back plate. The deflection angle is very important since the operator has to compensate the drilling orientation for this effect and a good estimate would then be very valuable. The other interest, the loads on the back plate, are interesting as a basis for dimensioning and optimizing the back plate.

The analysis will be performed in a two step sequence.

1. Determine piston length at every hole position in the drilling sequence.
2. Use the measured piston lengths to position the boom and then pre load TCP with a force of 20 kN at every hole position.

In order to determine the piston lengths at the specified hole positions we use the configuration consisting of rigid parts only, shown in figure 3, but without the restrictions for the work area analysis illustrated in figure 4. The reason for this is that these are not needed since the hole pattern is defined within the reachable work area. Furthermore, the feed extension (figure 3) is restricted at its maximum extension since this causes largest deflections as well as largest loads on the back plate.

The lift pistons constraints are relaxed and a measure is defined for the length of each lift piston. The positioning is then achieved by applying a "single component force" between the TCP and the hole position represented by a marker on ground. The simulation is then performed as a scripted quasistatic analysis where the ground marker is moved for each hole position. A sample of the simulation script is shown in figure 8 and the measured piston lengths are shown in figure 9.

Simulation script

```
MARKER/658, QP=12,-3.34,-2.85
SIMULATE/STATIC, END=10.0, STEPS=2
OUTPUT/NOSEPARATOR
MARKER/658, QP=12,-2.72,-3
SIMULATE/STATIC, END=30.0, STEPS=2
Etc.
.
.
.
```

Figure 8. Sample of the simulation script.

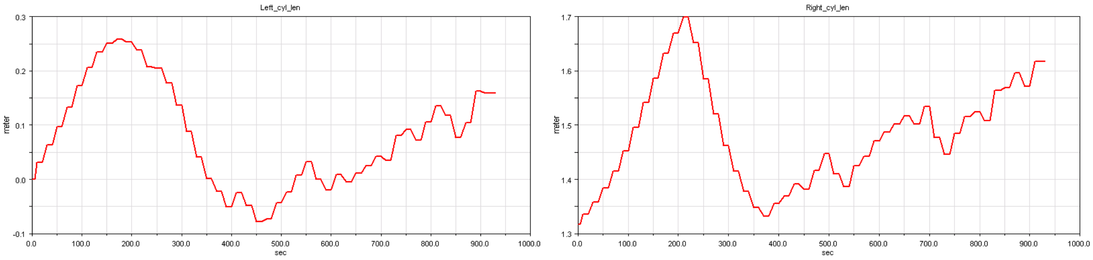

Figure 9. Lengths of lift pistons for the drill sequence.

In the next step of the simulation we have to introduce elasticity in some of the subsystems in order to study deflections and dynamic loads. The subsystems that we have selected to be elastic are those estimated to have the largest impact on the deflection of the boom. For this reason we have selected the rear part of the boom to be elastic. We have chosen to use the "discrete flexible link" command that divides the boom into a number of discrete masses with beam elements between them.

Next we are going to use the measures in figure 9 as splines in motion constraints that will position the pistons and then at every hole position we will apply a "vector force" representing the pre load of TCP against the rock.

For this simulation we have chosen to combine a quasistatic analysis for the positioning of the boom with dynamic analysis at each hole when applying the "vector force". For this purpose we have defined a simulation script and a sample of this script is given in figure 10.

Simulation script

```
SIMULATE/STATIC, END=10.0, STEPS=10
OUTPUT/NOSEPARATOR
VFORCE/2, I= 731, JFLOAT=625, RM = 730,
FX=(STEP(time,10,0,11,-20E3)+
STEP(time,19,0,20,20e3))\FY=0\FZ=0
SIMULATE/Transient, END=20.0, STEPS=100
OUTPUT/NOSEPARATOR
SIMULATE/STATIC, END=30.0, STEPS=10
Etc.
```

Figure 10. Sample of the simulation script mixing quasistatic and dynamic analysis.

The analysis that have been performed concerns the left drilling sequence in figure 7. This sequence consists of 47 holes and the load spectrum that have been applied on TCP is shown in figure 11. The results of this analysis concerning the angle deviation at TCP is shown in figure 12 . The back plate with an illustration of where the analyzed reaction forces and moments will occur is shown in figure 13 and the X-component of the reaction force and the Z-component of reaction moment is shown in figure 14 and 15.

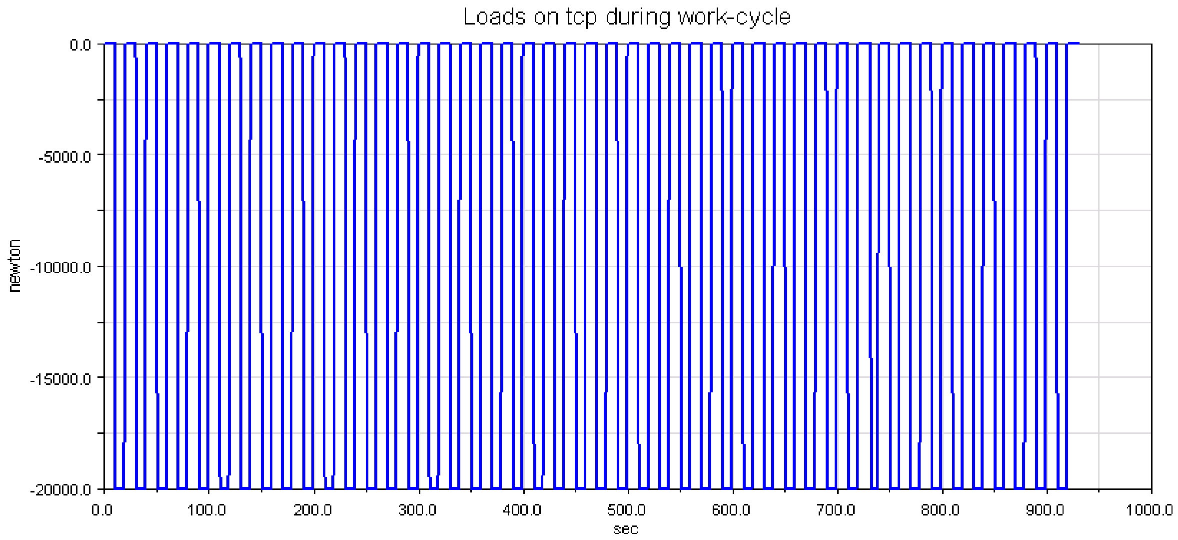

Figure 11. Loads on TCP during the drill sequence

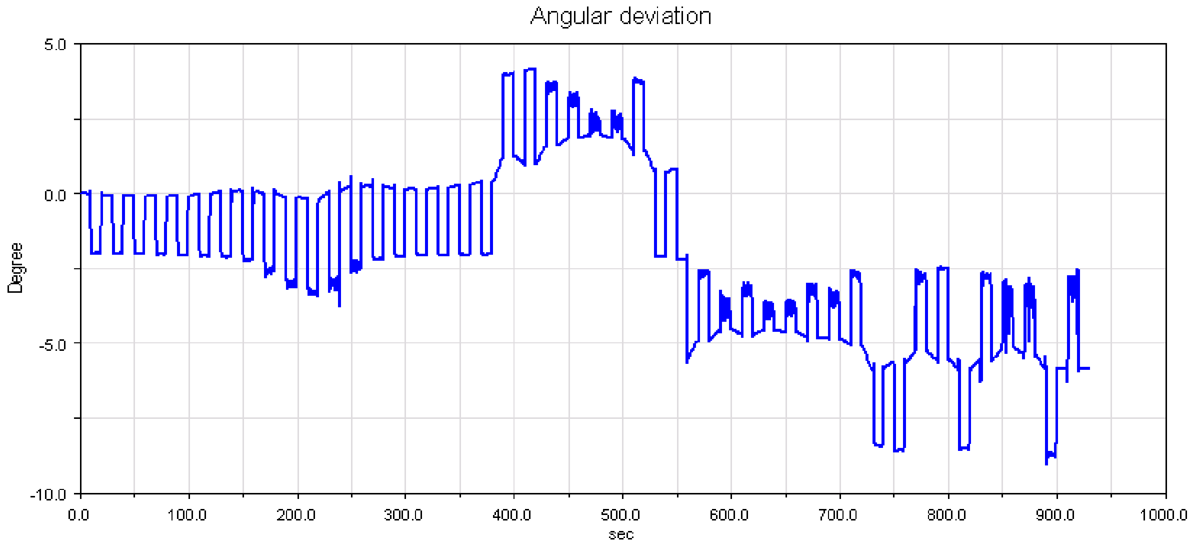

Figure 12. Angular deviation at TCP.

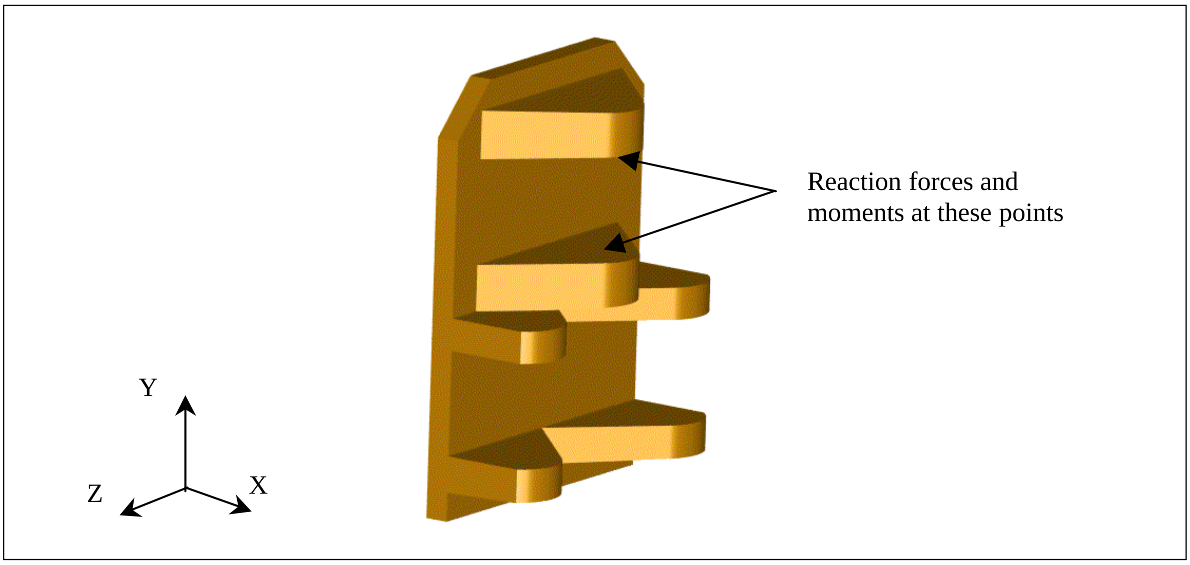

Figure 13. Position of analyzed reaction forces and moments on back plate.

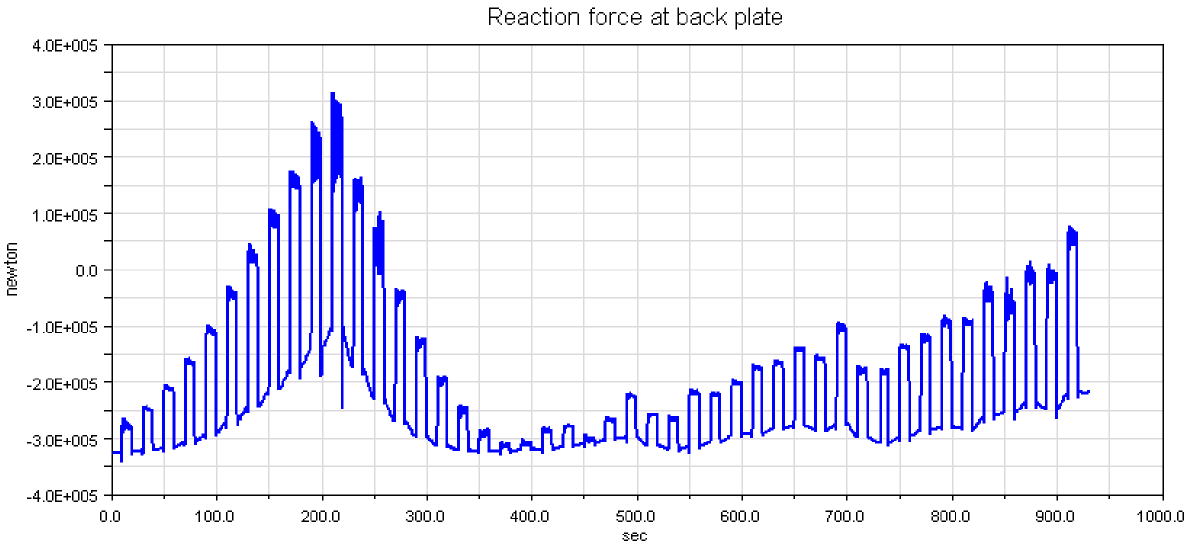

Figure 14. The X-component of the reaction force at back plate.

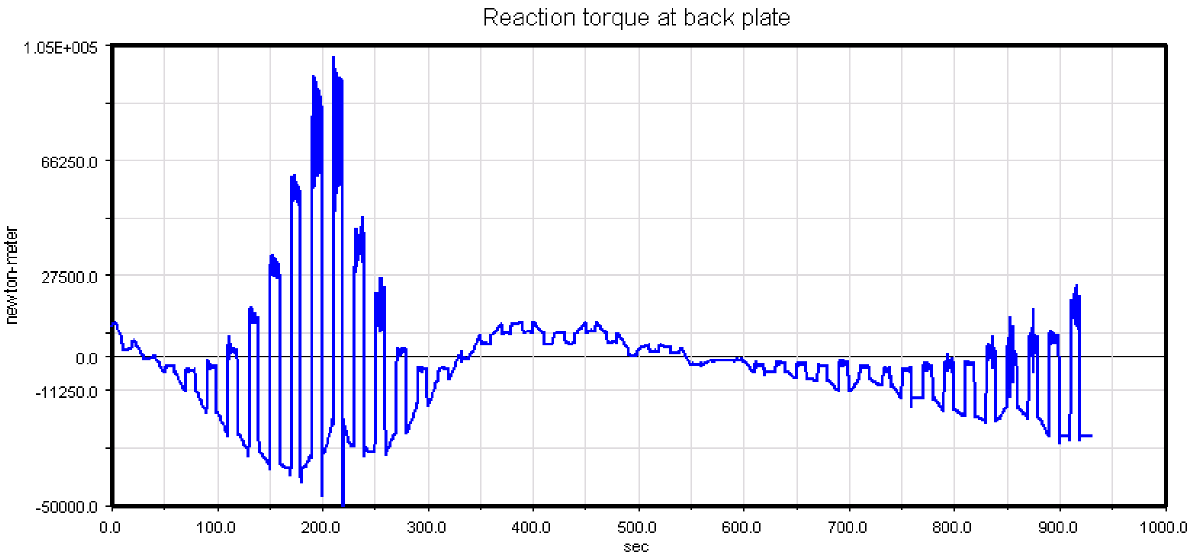

Figure 15. The Z-component of the reaction torque at back plate.

4. Summary

This paper deals with the development of methods for analysis of large interconnected, complex, systems where it is hard to get an holistic view of the products behavior. As an example part of a rock drilling equipment from AtlasCopco Rock Drills AB, i.e. one of the booms of a Robot Boomer, has been used. An approach based on a treating the product as being a system that can be divided into smaller more manageable subsystems, has been used in this example. This approach enables the use of a modular modeling of the different subsystems in the boom, where we want some of the parts to modeled as exchangeable subsystems.

The analysis tasks being covered here is to determine the work area for the boom and to traverse a drilling pattern for a tunnel face to examine angular deviation at the TCP of the boom and to examine loads in the structure. In this paper we have picked out one force and one torque component, as illustrations, on the back plate where the boom is connected to the rig. For strength calculation and dimension of the boom reaction forces at many points on the boom are needed. However, the described simulation approach can be used for achieving this data as well. For the selected analysis tasks we have given a brief description of the different ADAMS models that have been used as well as the different steps that have been taken to achieve the presented analysis results.

Acknowledgments

This work was financially supported by the Swedish National Board for Industrial and Technical Development (NUTEK). The support from Dr. Kenneth Weddfelt, Atlas Copco Rock Drills AB, is also acknowledged.

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