

Application Note: Driving Torque Optimization

Introduction

The optimization module of SAM offers single-function multi-parameter optimization based on a mix of evolutionary algorithms and Simplex techniques.

Taking the initial design/topology as a starting point one can for example further improve the quality in which the trajectory of a coupler point equals the target trajectory by changing the geometry of the mechanism within pre-defined ranges. Or one can minimize the peak or RMS value of the driving torque of a mechanism by adding a compensating mass and let SAM determine the optimal value of the mass and its position within the allowable range. Just as in the case of the trajectory optimization one can also specify a reference function and minimize the difference between the actual and the reference function. When designing for example fitness equipment one is generally seeking a predefined force as function of displacement.

The goal for optimization can be the minimization or maximization of a variety of properties (peak, RMS, average, ...) or the difference between the actual and the target behaviour of a mechanism, such as :

- trajectory of a node (with or without prescribed timing)
- any motion or force quantity (as function of time or another quantity)

SAM seeks the optimum by modifying the following properties within user-defined ranges :

- geometry of mechanism
- mass and mass moment of inertia elements
- spring properties

The optimization process in SAM is based on a two step approach, consisting of :

- Exploration of the design space
- Optimization of a specific solution

First, the entire parameter space is explored globally using a combination of a pure Monte-Carlo technique and a so-called *Evolutionary Algorithm*, which is a optimization technique derived from Genetic Optimization. The top list of such a global exploration are shown in the Explore list box, which displays the value of the optimization function and the corresponding parameters. The individual with the best property is listed at the top.

Next, the designer can select one of the results from the Explore window and start a local optimization. This local search can be either based on a Simplex technique or on a Evolutionary Algorithm with a smaller parameter range centered around the selected solution.

The combination of a global exploration strategy and a local optimization strategy - with the designer in the loop for selecting the mechanism that is further optimized - is believed to give the best trade-off between speed and coverage of the design space. However, options can also be set in such a way, that a fully automated optimization is performed.

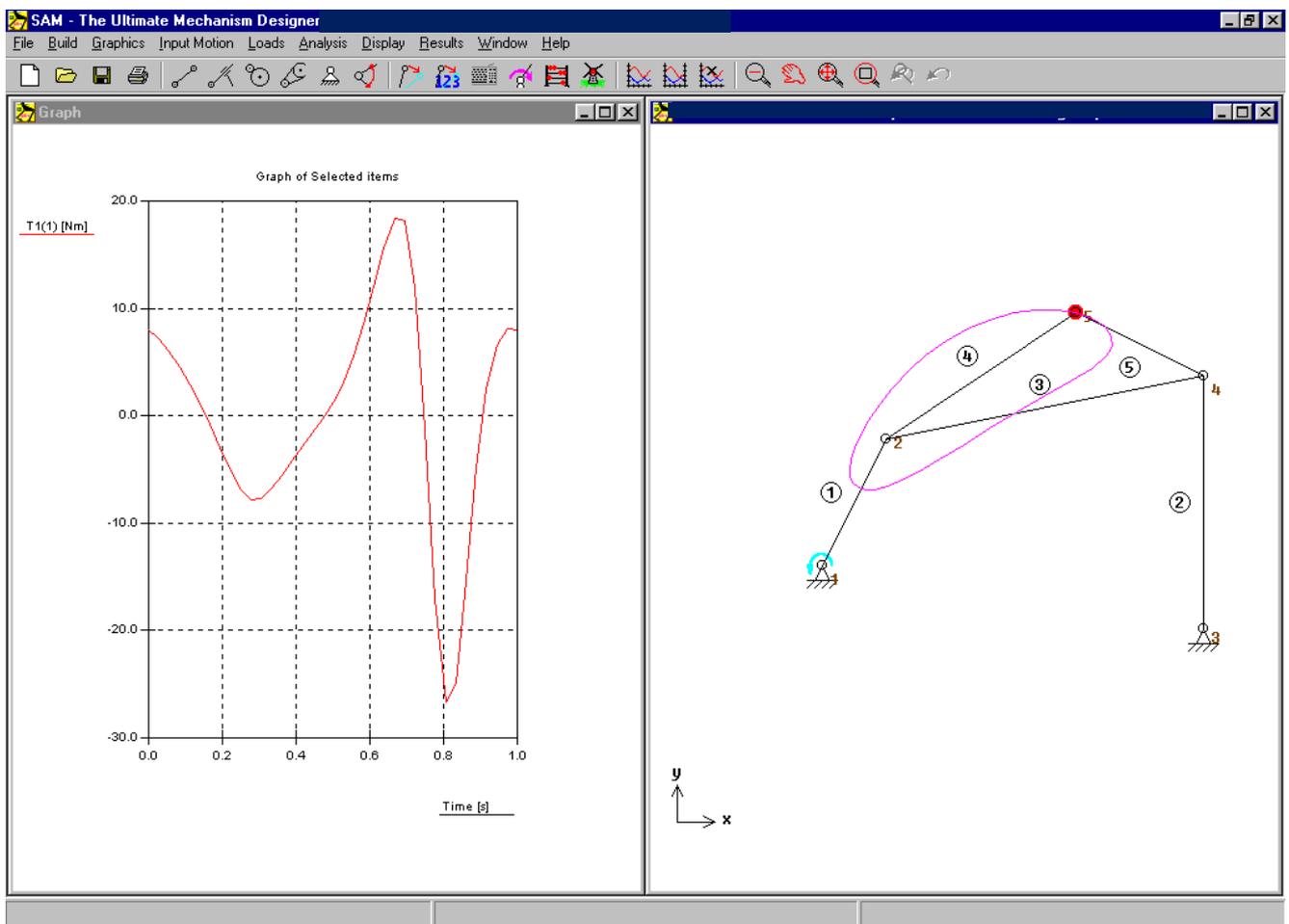
Example

As an example the reduction of the driving torque of a 4-bar mechanism with mass in the coupler point by addition of one single mass in the coupler plane is demonstrated. The mechanism is driven by a constant angular velocity at the crank and gravity effects are excluded from the study. The optimization algorithm must search for the optimal value and location of the compensating mass.

The example is based on the default 4-bar mechanism that is generated by the command sequence FILE / WIZARD / 4 BAR MECHANISM and by accepting the default values. In addition to that a mass of 10kg is added to point 5 of the mechanism. The input motion consists of a constant velocity that corresponds to a motion of 360 degree in 1 s. The analysis is divided into 36 intervals.

Reference Mechanism

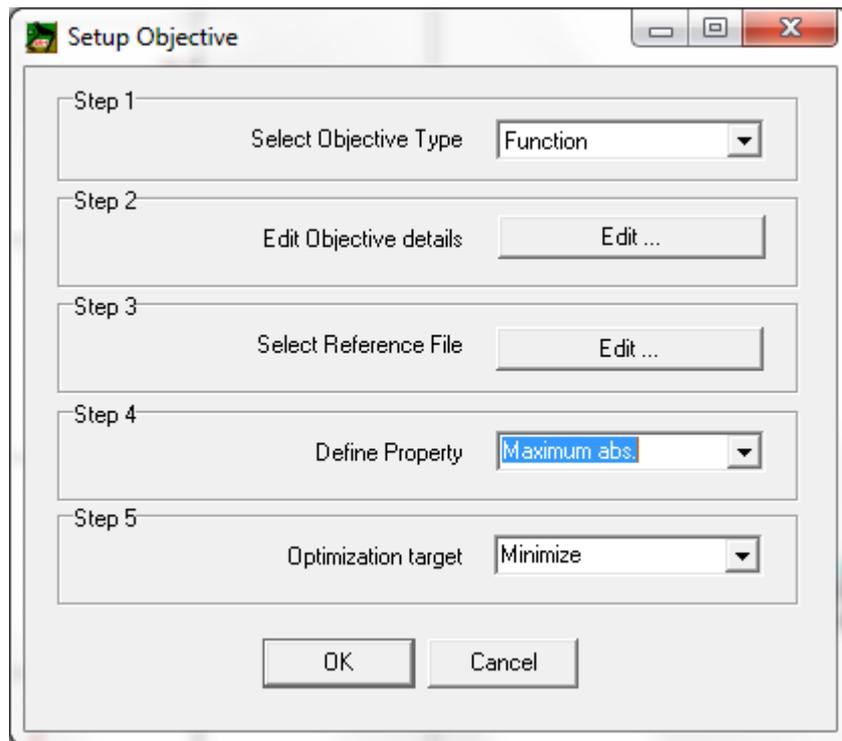
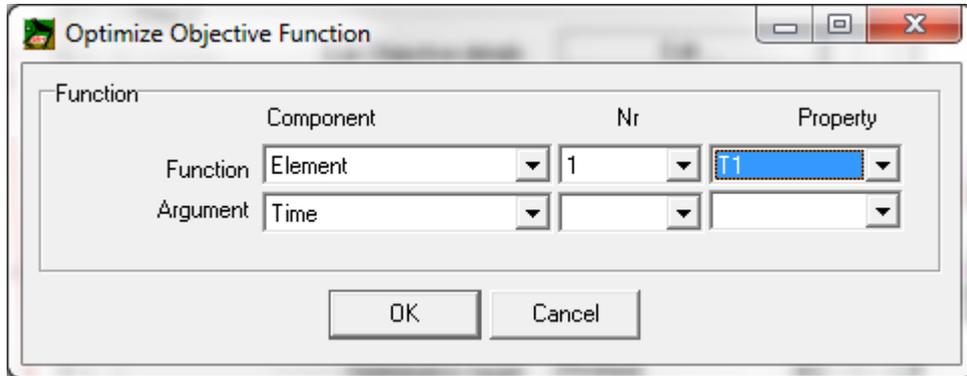
In the reference situation the driving torque as a function of time will look like depicted in the following picture. The absolute maximum of the driving torque equals 26.6 Nm.



In order to see how the optimization improves the results it's best to go to Results/Options and turn the AUTOSCALE option OFF. The vertical axes is then fixed to -30N to +20N.

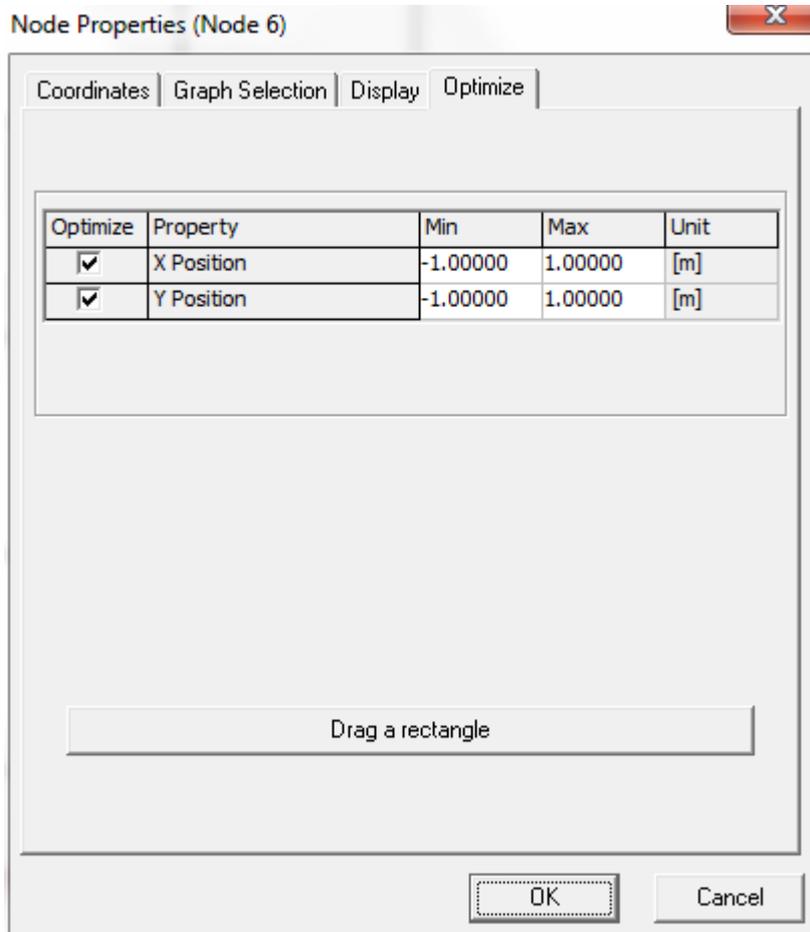
Optimization Objective

The settings of the optimization are shown in the following screenshot. The torque T1 of element 1 as a function of time is chosen as objective function and the maximum absolute value of that curve is to be minimized.

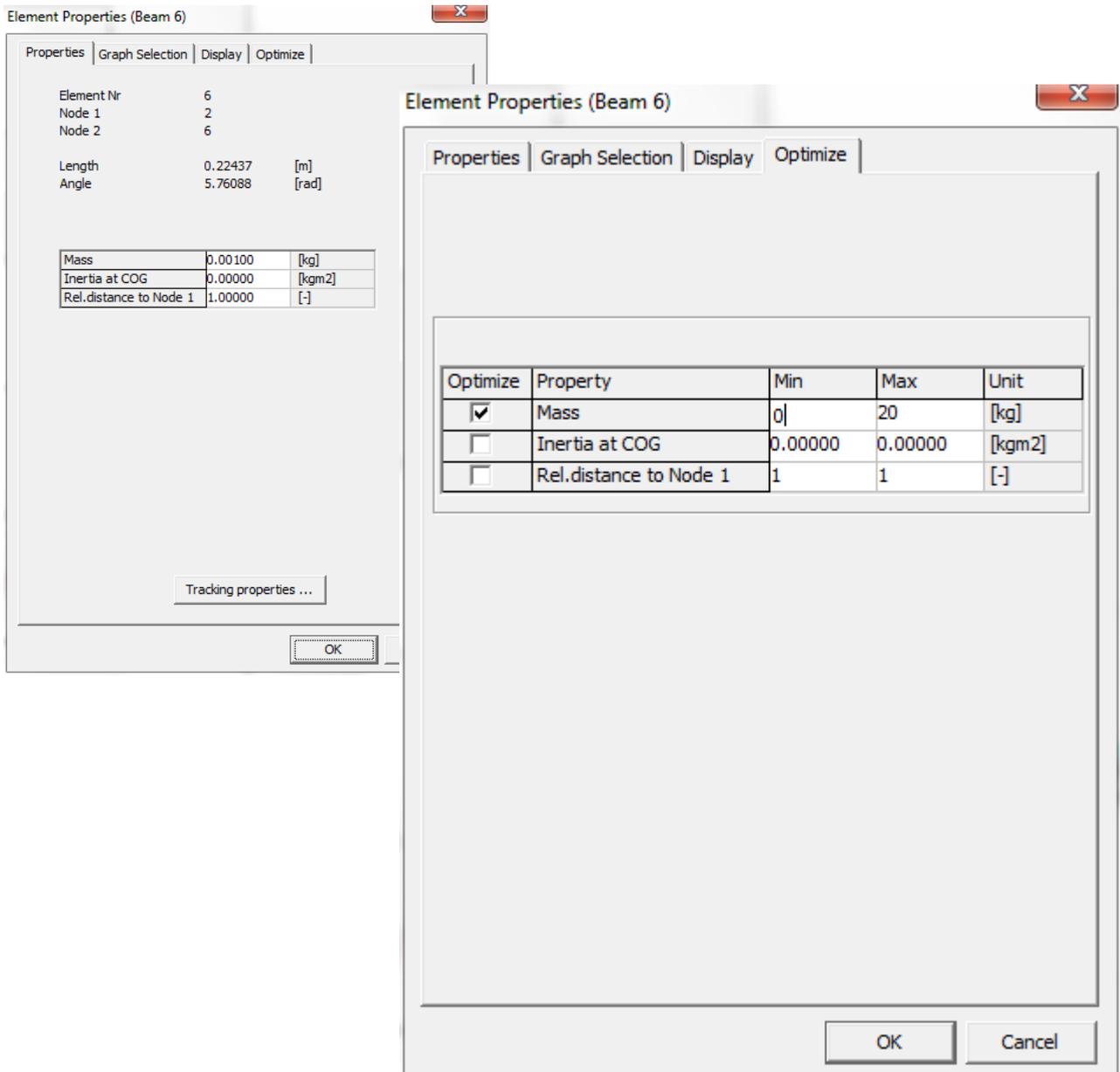


Optimization Parameter Range

The maximum absolute value of the driving torque is reduced by adding a single mass to the coupler linkage. The search region for the location was set at (-1.0,-1.0) up to (1.0,1.0).

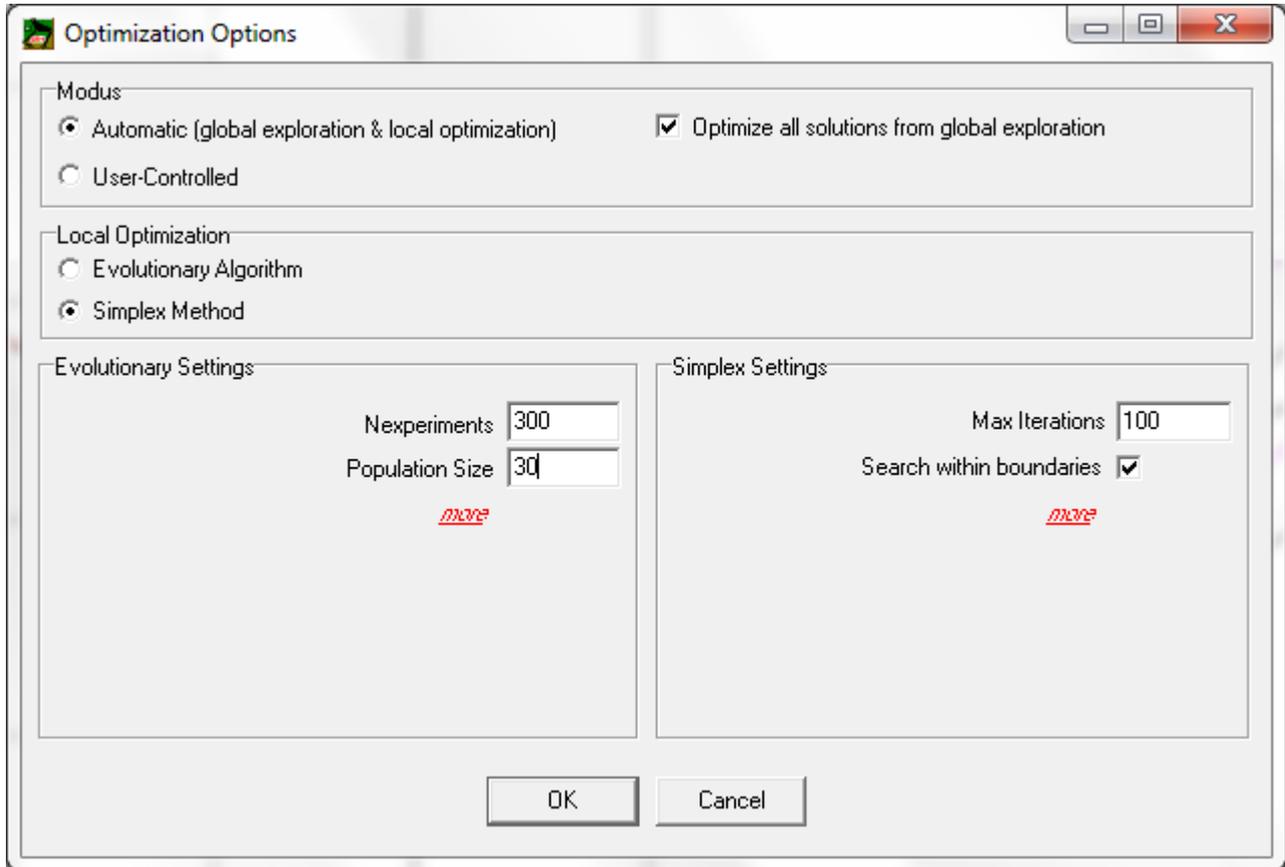


The search region for the mass of element 6 was set at 0-20kg (note: you need to set the location of the mass within the element such that it is located in node 6; which means that depending on the sequence in which element 6 was created – from node 2 to node 6 or the other way around – one needs to enter the value for relative distance to first node of either 0.0 or 1.0).



Optimization Options

For the sake of simplicity, the automatic modus was chosen. In this modus a global exploration is performed based on evolutionary algorithms using the settings as shown. The best results of that global approach are each then further optimized automatically - in this case using the Simplex method as indicated.



Modus

- Choosing AUTOMATIC is the easiest way to do an optimization.
- The checkbox “Optimize all solutions from global exploration” indicates that after the global exploration of the solution space (always done via evolutionary algorithm), ALL best results of the exploration are further improved via a local optimization. After the global exploration a pool of best results exists and the size of that pool of results is equal to the Population Size defined in the Evolutionary Settings. So in this case 300 evolutionary (or genetic) experiments are done based on a population size of 30 “members”. At the end a pool of 30 best members or solutions exist. If the checkbox is checked, all these 30 best results are further optimized via local optimization. If the checkbox is NOT checked, only the best solution found in the global exploration is further improved via local optimization.

Local Optimization

- In general using the Simplex Method for the local optimization yields good results.

Evolutionary Setting

- The evolutionary algorithm starts with filling a pool or population of results via a random process (Population Size indicates the size of the population). This population is then improved via a evolutionary (nature inspired genetic) process. The number of genetic experiments is indicated by Nexperiments.

Simplex Setting

The main setting for the Simplex Method is the max. number of iterations. The default value is generally OK but based on the progress that is monitored online one can decide that a smaller number is sufficient. On the other hand, if one observes significant progress just before reaching the max. number of iterations it is very likely that continuing the process yields better results and it makes sense to increase this number.

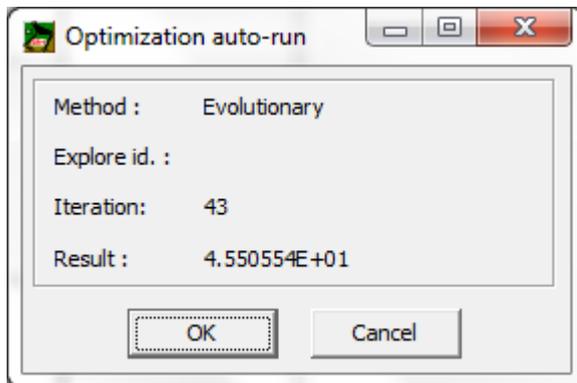
In principle the boundaries of the optimization space should always be respected. However, sometimes it is very interesting – and one may be triggered to find new solutions – to allow the algorithm to disrespect these boundaries. This is the reason why the user has a choice.

If the process takes too long one can decide to do less experiments, choose a smaller population size (though it should always be at least 20-30 to give the evolutionary algorithm a chance), do less iterations in the local optimization process or decide NOT to further optimize all results from the global search but to only post-process the best result of the global search.

Optimization Run

Global Exploration

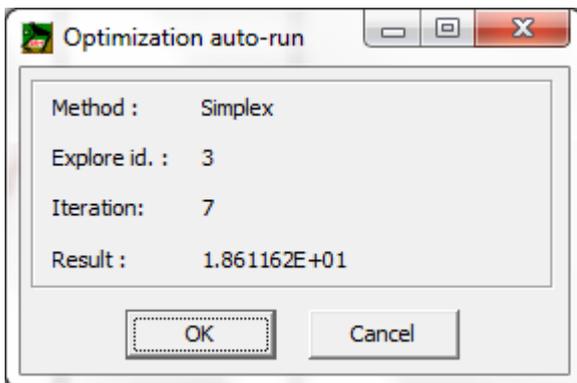
The status window shows the process of the global exploration.



Method: The method for global exploration is always the Evolutionary Algorithm.
Explore id: empty (has only meaning when doing the local optimization).
Iteration: Current iteration step in the evolutionary process
Result: Current value of the experiment.

Local Optimization

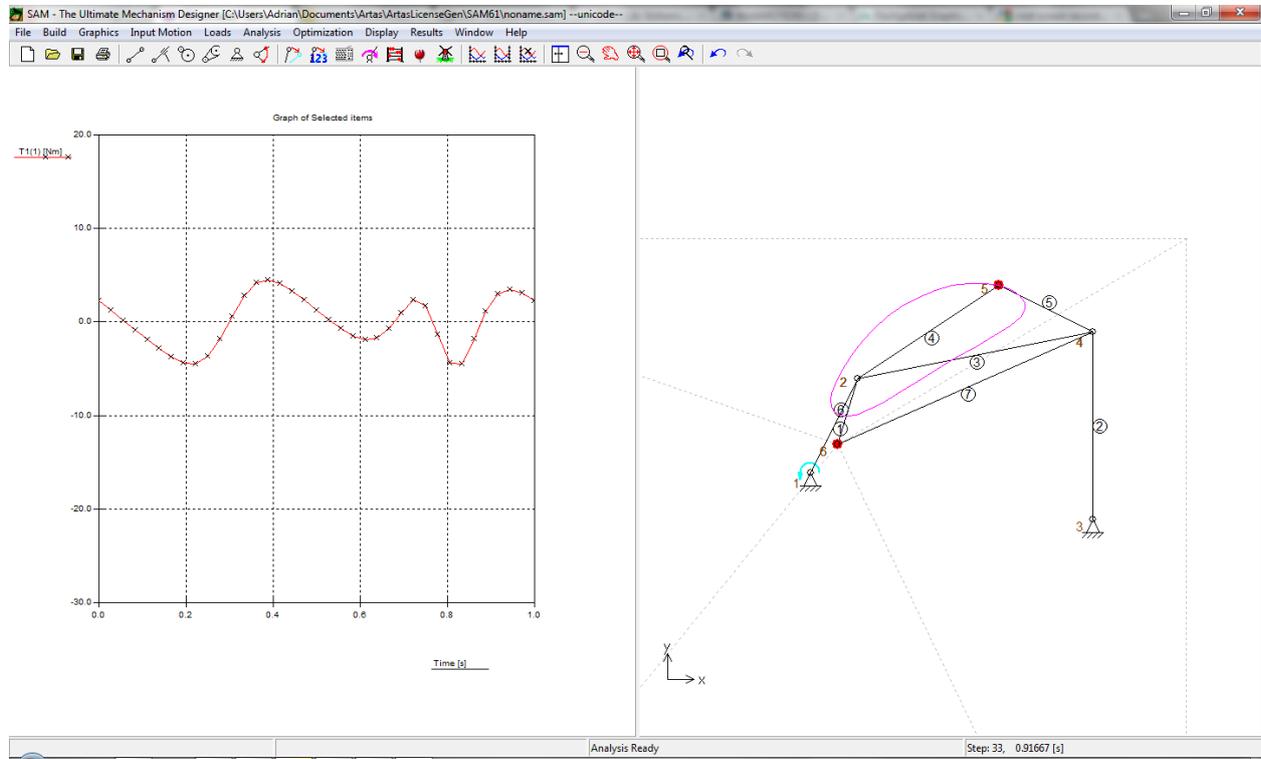
In this case all 30 results of the global exploration are improved via a local optimization proces. The status window shows:



Method: chosen method for local optimization
Explore id: ID of the solution of the global exploration that is currently locally optimized.
Iteration: Current iteration step in the local optimization process
Result: Current value of the optimization goal.

Optimized Mechanism

The value ($m=19.49$ kg) and location ($x=0.25813$ m and $y=0.56019$) is derived by the optimization module. The corresponding maximum absolute value of the driving force in the optimized situation equals 4.6 Nm.



Conclusion

A significant reduction of the driving torque was achieved by adding a compensating mass to the coupler plane. The value of the compensating mass and its location was automatically determined by an optimization procedure based on an evolutionary algorithm.

Further reduction of the driving torque can be achieved by also adding masses to the other linkages and/or applying compensating springs as well.