Contribution to the ASME 2002 Design Engineering Technical Conferences (Special Session on Computer Aided Linkage Design), Canada, Montreal, September,2002.

SAM (Simulation and Analysis of Mechanisms)

A PC-program for the motion and force analysis of planar mechanisms based on the Finite Element Method

Dr.ir. Adrian M. Rankers

ARTAS - Engineering Software
rankers@artas.nl/www.artas.nl

Summary

SAM (Simulation and Analysis of Mechanisms) is an interactive PC-software package for the motion and force analysis of arbitrary planar mechanisms, which can be assembled from basic components including beams, sliders, gears, belts, springs, dampers and friction elements. SAM integrates pre-processing, numerical analysis and postprocessing, such as animation and xy-plots, in an easy to-use environment offering pull-down menus, mouse support and help facilities.

The mathematical foundation of the program is based on the well-known finite element approach. Open loop, closed loop, multiple loop and even complex planetary mechanisms can equally well be analysed due to the finite element formulation.

Over the past ten years since the first release, the program has proven its value and is appreciated by many users from industry and especially from educational institutes. Apart from the internal analysis engine its most apparent feature is its ease of use, which makes it an interesting tool for non-expert and occasional users.

1. Introduction

The process of designing mechanisms, basically can be divided into two distinct phases, as indicated in fig.1.

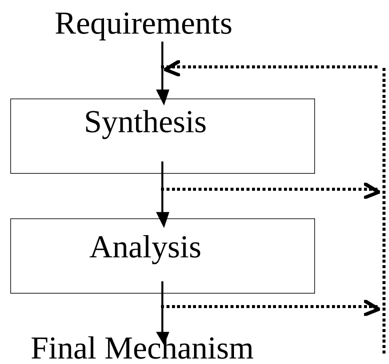


Fig. 1 Main Steps in the design of a mechanism

After a proper specification of the demands, the first step in the design cycle consists of the synthesis phase, in which the designer attempts to find the type of mechanism and its dimensions, such that the requirements are met (as good as possible). Experience, pervious designs, mechanism handbooks and a limited number of software tools for special cases (for example Burmester theory) can guide this creative process.

Once a mechanism has been chosen, its motion and force behaviour can be analysed. Typical questions, such as “how long is the usable stroke of an approximate linear guiding, given a certain acceptable deviation from the straight line” or “what are the bearing forces”, can be answered with little effort using computer simulation. Looking at the class of mechanism independent programs - there are also special programs for certain types of mechanisms (slider-crank, 4-bar mechanism ...) - one can observe various approaches, such as :

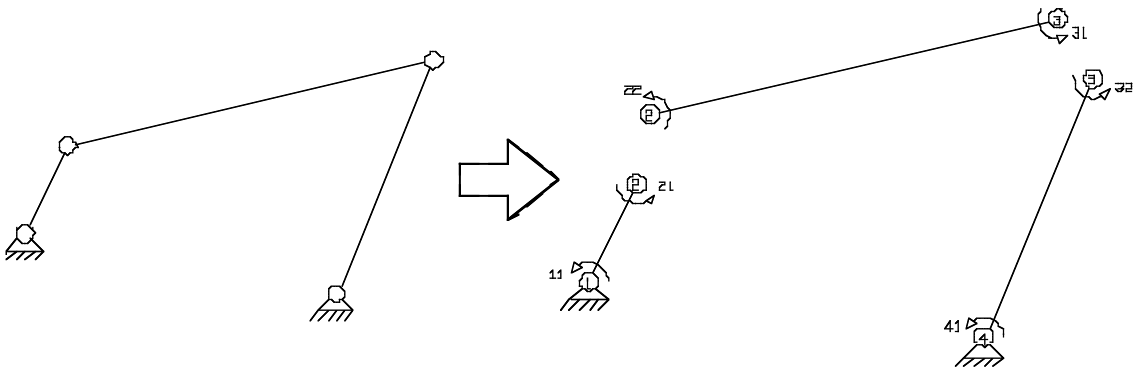
- modular kinematics [1], [2]
- vector analysis [3], [4], [5]
- finite element method [6], [7], [8],

The latter of these approaches and especially one implementation, namely the analysis program SAM, will be discussed in this paper. The software is currently available in English, German, Dutch, Portugese and will also become available in French and Spanish.

2. Basic Theory

Characteristic for the Finite Element Method, on which SAM is based, is the decomposition of the mechanism into finite elements with well defined mechanical properties (fig.2). Contact between the elements is obtained by letting them have nodal points in common, and in these nodal points they share some or all the co-ordinates of these points. In this section the basic ideas of the approach will be treated very briefly.

Fig. 2   Decomposition of a 4-bar mechanism into beam elements



The finite element approach of mechanism analysis is very similar to the "traditional" static and dynamic finite element simulations, since both are based on the concept of global system displacements and deformations of elements.

It is essential in the finite element approach that the momentary form or deformation of each element is entirely determined by its momentary position parameters (nodal co-ordinates and eventually angles). The difference lies in the fact that in static analyses the internal deformation of a structure is computed due to external forces, whereas in the kinematic analysis of a mechanism - in each position of the mechanism - the nodal co-ordinates and angles must be such that deformations are zero.

As mentioned before the kinematics problem is basically nothing more than - after each input step - finding those position parameters that result in zero deformation of all elements. There is one exception to the requirement of zero deformation, which is related to the way that relative displacements or rotations (hydraulic cylinder or elbow rotation of a robot arm) are modelled. The easiest way to model such a relative motion is by prescribing certain deformation parameters of an element, in which case the position parameters must not result in a zero deformation for these elements but must correspond to the prescribed values.

3. Capabilities of SAM

3.1 Modelling

SAM is equipped with a large library of basic elements, including :

- beam, slider
- belt, gear
- sensor
- spring, damper and friction element (both translational and rotational)

which allows the analysis of a huge variety of mechanisms. The unique mathematical foundation of the program offers a large number of features and overcomes many of the problems of traditional mechanism programs. Open loop, closed loop and even multiple loop mechanisms are treated in the same way and even the most complex mechanisms, including planetary gear trains, can be modeled within minutes.

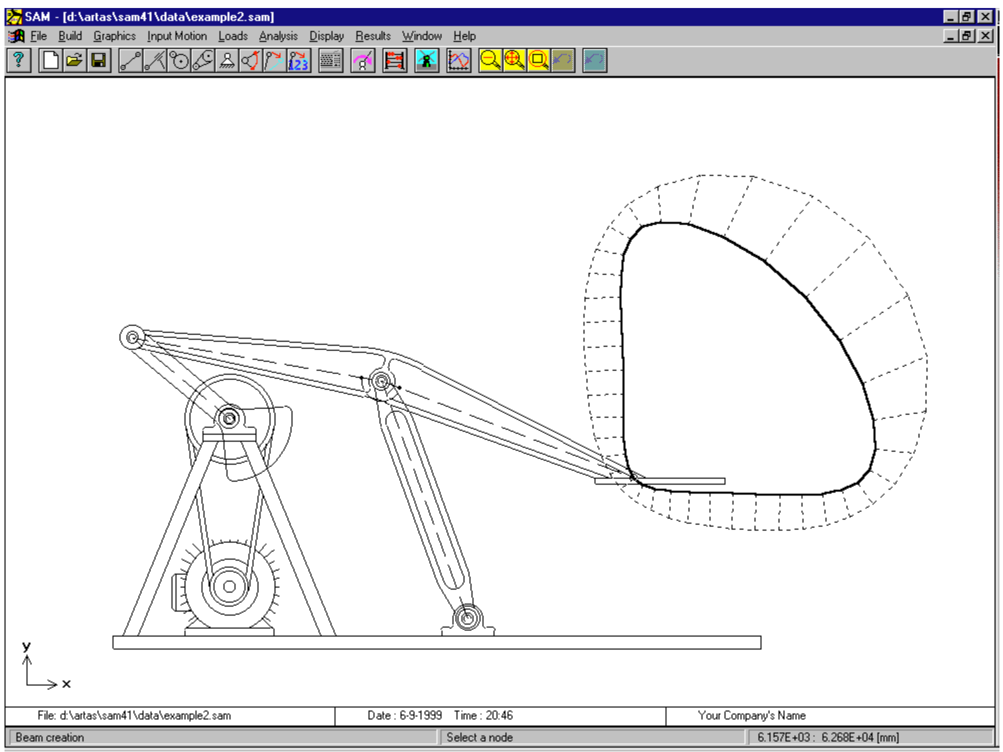


Fig. 3 Typical screenshot of SAM

Points, lines, circles, centrelines and intersections can be constructed directly in SAM. This enables the graphical mechanism synthesis, such as the well-known Burmester approach.

3.2 Input Motion

SAM allows the definition of multiple inputs, which can either be defined in terms of absolute displacements or in terms of elemental change of shape to model relative inputs (e.g. elongation of a hydraulic cylinder or relative rotation of a robot elbow). Each of the inputs can be defined independently. Various frequently used input motion laws, such as

- constant velocity
- polynomial
- cyclical motion

are available and can be combined to form any desired input diagram. Inputs can also be read from an external ASCII file to enable the definition of arbitrary motions. This latter feature is especially handy for the modeling of non-standard cam profiles.

3.3 CAD Interface

The DXF import/export facility lets you export your conceptual mechanism design to any CAD program to work out the details and it lets you import CAD data to easily set-up the mechanism in SAM or to perform animation of the final mechanism.

3.4 Analysis Results

Once the mechanism has been constructed and the inputs have been defined any of the following kinematic quantities can be calculated (all relative or absolute) :

- nodal position, displacement, velocity, acceleration
- angles, angular velocity and acceleration

Furthermore SAM can perform force-analysis (kinetostatics), thus enabling the calculation of :

- driving torque (force)
- reaction forces in bearings
- internal forces in elements
- required or transmitted power

3.5 Post-Processing

The analysis results can be displayed either in tabular or graphical form. The tabular listing can be viewed on the screen, send to a printer or stored in a readable formatted list file. The x/y plot option allows to plot any variable against time or any other variable. An unlimited number of functions can be combined into one x/y plot with optionally two different scalings to allow proper multiple display of variables with different amplitude ranges. It is possible to output selected data to an external file (ASCII format) for customized post-processing.

SAM can also animate the mechanism motion. As a further aid for the designer the path and velocity hodograph of any number of moving points can be plotted. Also, the fixed/moving centrode and evolute can be plotted.

Furthermore, a complete project documentation (ASCII-format) can be automatically generated.

4. Examples

In order to demonstrate the versatility of SAM a number of examples will be given, each consisting of a sketch of the mechanism plus a typical analysis result.

4.1. Quick-Return Mechanism

In push-up units, a quick return mechanism is often used. Important in these mechanisms is the velocity diagram of the translating node.

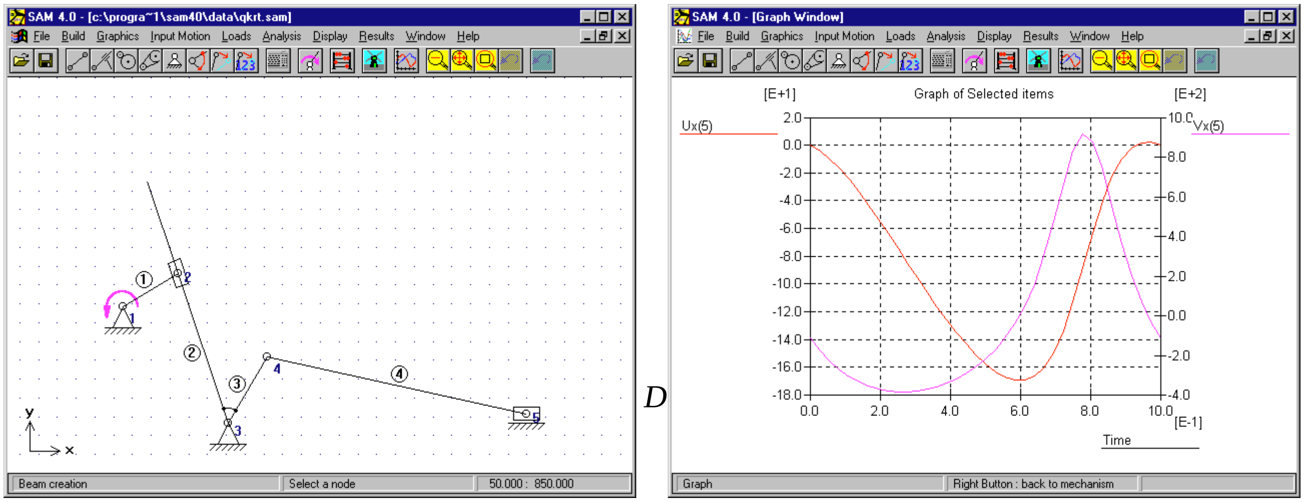


Fig.4 *a.* Quick-Return Mechanism b. Displacement & Velocity of Node 5

4.2. Hypo-Cyclic Mechanism

A hypo cyclic planetary mechanism can be used to generate an approximated dwell. This is achieved by attaching an output linkage to the gear in such a way that the length of that linkage equals the radius of curvature of the connection (gear) node.

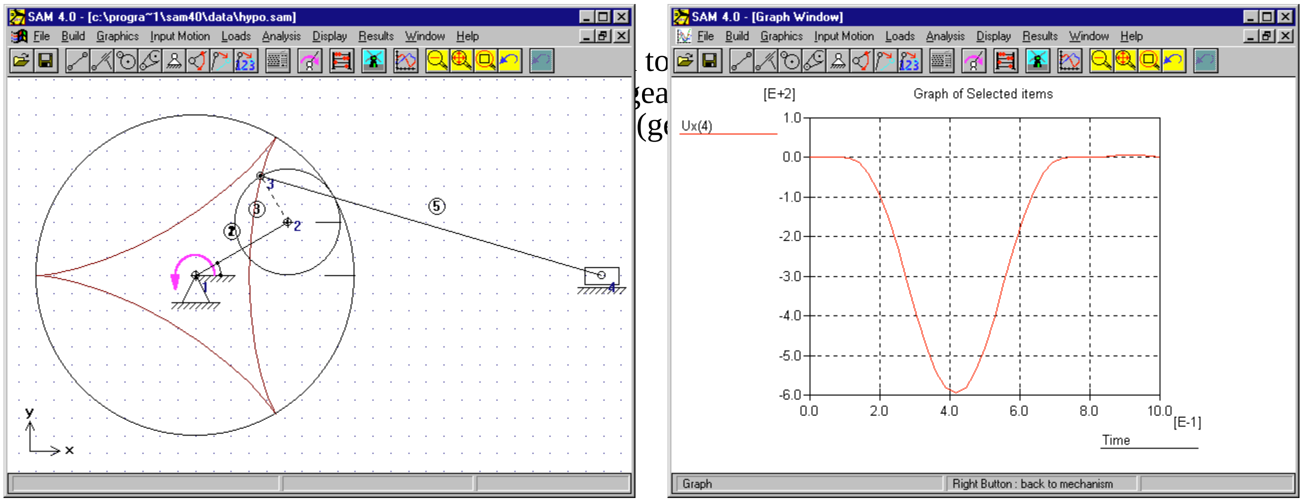


Fig.5 a. Hypo-Cyclic Mechanism b. Displacement of Output Slider

The transfer mechanism can be used to transfer products without introducing any rotation. Due to the mass of the transfer linkage, which is modeled as discrete masses at the end nodes of that linkage, a certain static driving torque is required.

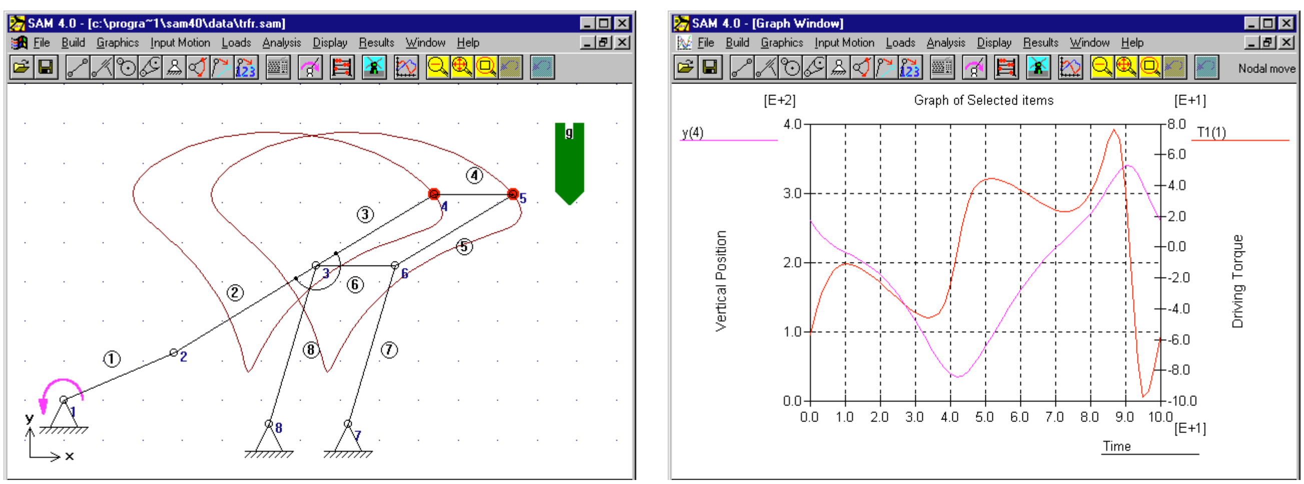
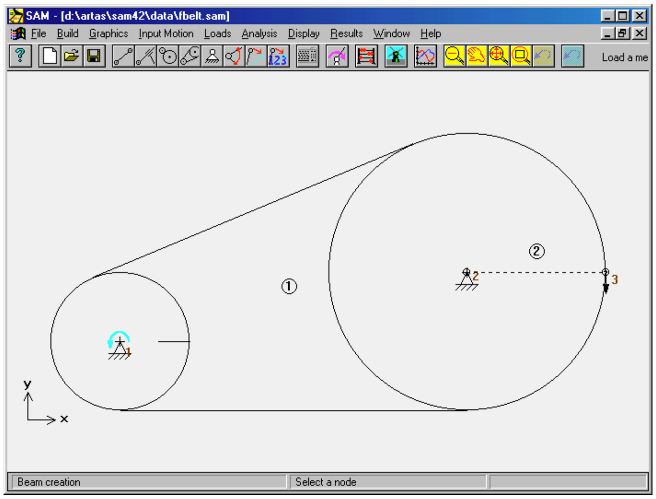


Fig.6 a.Transfer Mechanism b. Vertical Position & Driving Torque

4.4. Belt drive with external force

The following example illustrates the force analysis of a belt drive without pretension that is loaded by an external force. Depending on the rotation of the wheel the vertical force acting in node 3 leads to positive or a negative torque on the second wheel. This torque needs to be counteracted by either a positive force (tension) in the upper or a positive force in the lower part of the belt drive, since a non-loaded beltdrive can not transfer negative forces (pressure). In case of a tension force in the upper part the force in the lower part is equal to zero and vice versa.



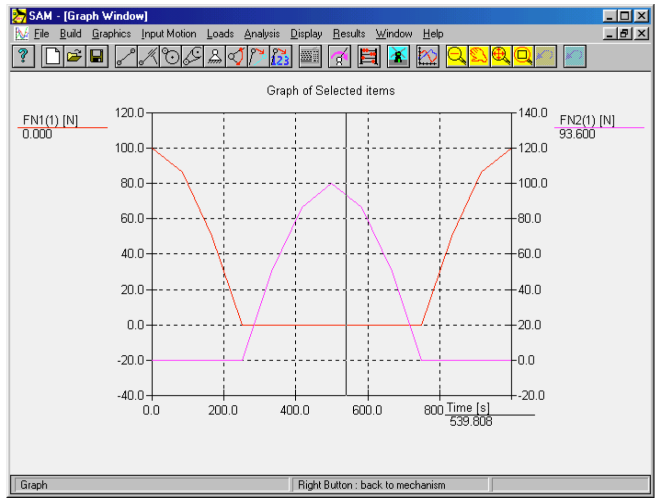


Fig.7 a. Belt-drive with external force b. Forces in upper and lower belt part

5. Conclusion

During the past two decades, the finite element based mechanism approach has proven to be a versatile tool for the motion and force analysis of arbitrary mechanisms, varying from simple slider-crank mechanisms to complex planetary gear mechanisms.

Based on this approach a PC-software program called SAM (Simulation and Analysis of Mechanisms) has been developed. The fact, that more than 60 educational institutes and a growing number of companies is using the program shows that there is a need for this type of easy-to-use mechanism software.

It is the firm believe of the author, that user-friendly software is a very suitable medium to achieve effective knowledge transfer from research and academic institutes to industrial users.

References

[1] VDI-Richtlinie 2729 (Entwurf), “Moduläre kinematische Analyse ebener Getriebe mit Dreh- und Schubgelenken, Nov.1990

[2] KAMOS - Kinematic Analysis Module System, Kurzbeschreibung, Universität Hannover, Institut für Getriebelehre

[3] Erdman, A.G. and G.N. Sandor, “Mechanism Design I”, Prentice-Hall, 1984

[4] VDI-Richtlinie 2723, Vektorielle Methode zur Berechnung der Kinematik räumlicher Getriebe”, Düsseldorf, 1982

[5] Volmer, J., [Hrsg.], “Getriebetechnik”, Verlag Technik, Berlin 1992

[6] Werff, K. van der, "Kinematic and dynamic analysis of mechanisms, a finite element approach", PhD-thesis, Delft University of Technology, 1977.

[7] Schwab, A.L., “The wheel and other special finite elements for kinematic and dynamic analyses of multi body systems”, Delft University of Technology, 1985

[8] Klein Breteler, A.J., “Kinematische Getriebeanalyse, eine iterative Methode mit Hilfe Finiter Elemente”, VDI-Forschungsbericht Nr. 211, VDI-Verlag, 1992