

## A KBE tool for solving the mechanisms kinematics

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**Abstract.** Knowledge-Based-Engineering (KBE) is a research field in which the methodologies and technologies for capturing and re-using the engineering knowledge are studied. Nowadays, the mechanisms design is accomplished by using various CAD software. Since, every CAD system includes KBE tools, those can be used to reduce time and simplify the mechanism's design process. One step in the design of the mechanisms with more than one degree of freedom is the direct and inverse kinematic analysis. This step can be difficult, because many calculations are involved and usually more than one solution exists. The geometrical constraints defined in the CAD system for the mechanism linkage's assembling, offer a simple solution for the kinematics analysis. This paper presents a KBE tool useful for kinematics analysis. The automation of repetitive tasks is implemented in an external application written in C# that it is also presented.

### 1. Introduction

Knowledge-Based Engineering (KBE) is a technology based on the use of software tools called KBE systems, which are able to capture and systematically re-use product and process engineering knowledge. The final objective is to reduce time and cost of product development by means of the following [3]:

- Automation of repetitive and non-creative design tasks,
- Support of multidisciplinary design optimization in all the phases of the design process.

KBE technology has become accepted in many industries, especially in the cases of design with a high degree of repetition. KBE was used by several companies in the aerospace and automotive industries and has not yet been involved in academic research.

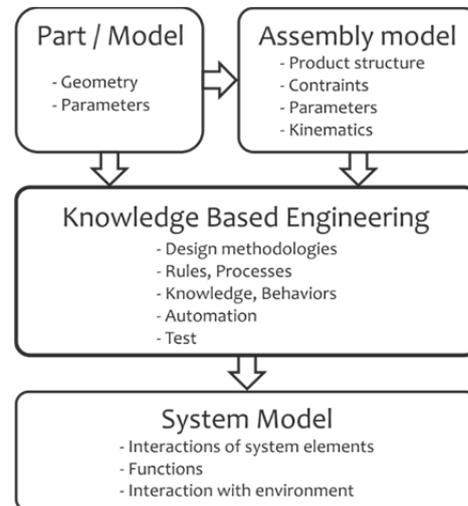
The CAD has always been an adopter of software engineering and knowledge-based systems such as object-oriented approaches and rules. Knowledge-based techniques integrate these technologies with traditional CAD and other software engineering tools. Benefits include better collaboration between design teams using knowledge management, improvement of re-design methods and automation of major components of the product life cycle [5].

Generally speaking, KBE is a multi-purpose programming and geometric modelling concept [1]. Thereby CAD data become a storage for product and method knowledge, which can be recalled by need [4]. By using a KBE template routine, tasks are transformed into an automated process with a minimum of user assistance/knowledge. An example of a general KBE routine is presented in figure 1.

The KBE is based on models that represents a mathematical/graphical virtual system capable to reproduce study and analyse a mechanical system from all points of interest. The basic structure of a KBE Model is composed by a collection of processes. The model is responsible for the coordination of



all the processes, keeping all the common information needed for the general functioning of all processes. The processes are independent each other, but can use results obtained from the previous [5].



**Figure 1.** A KBE template [4].

It is well known that the mechanism's design is rather complex and the workload is huge. Nowadays, the mechanisms design is accomplished by using various CAD software. The repetitive tasks involved in mechanism design can be automated with the help of KBE.

In this paper we propose a method, based on KBE, useful for kinematic analysis of mechanisms.

## 2. Using constraints to define CAD assemblies

In CAD every assembly model is created by specifying the relative location and orientation of component parts. By default, an assembly model is static, which means that all parts are completely constrained. But in many applications, the desired motion is required in product design in order to meet specific design requirements or to verify functionalities. In these situations the assembly is under constrained, so the component parts are allowed to move relative to each other, in order to verify the kinematic characteristics of the assembly [2].

In all high level CAD the location and orientation of individual parts relative to one another is specified through mating constraints. The positioning of parts causes some of the geometric entities such as faces, edges and vertices of the parts to be in contact [2].

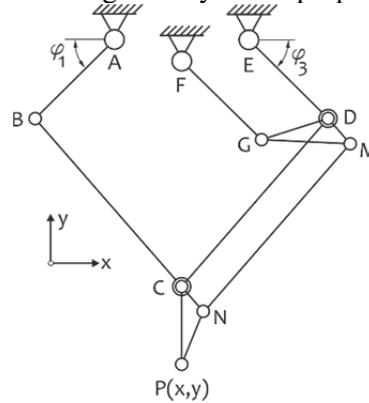
Using the appropriate geometric constraints it is possible to define kinematic joints between two adjacent parts. By definition, a kinematic joint is a connection between two parts that imposes constraints on their relative movements. As in mechanisms theory, in CAD we have two types of kinematic joints: lower pair and higher pair. Physically, a lower pair joint is used to describe the connection between two rigid parts, when the relative movement is defined by the contact between two adjacent surfaces sliding over one another [2].

A linkage, or kinematic chain, is an assembly of links and joints that provide a desired output motion in response to a specified input motion. So, a mechanism can be described in CAD as a collection of parts constrained with kinematic joints.

## 3. Kinematic analysis

In kinematic analysis of mechanisms the input motion is assumed to be known and the objective is to find the motion laws of driving elements. An example of a planar mechanism with 2 DOF is presented in figure 2. The actuated joint variables are  $\varphi_1$  and  $\varphi_3$  while the  $(x, y)$  coordinates of the point P represents the Cartesian variables. The constant orientation of the link PC is ensured with an external kinematic chain. The joint F is located midway between the joints A and E. We denote  $AB = DE =$

$FG = l, BC = DC = MN = L, AF = FE = l_0, AE = h$  and  $PC = e$ . The lengths  $l = 60\text{mm}, L = 120\text{mm}, h = 60\text{mm}, l_0 = 35\text{mm}$  and  $e = 20\text{mm}$  define the geometry of the proposed mechanism.



**Figure 2.** The proposed mechanism.

The relationship between the displacements of the end point of the mechanism and the angular position of the driving elements can be expressed as follows:

$$\phi_1 = 2 \tan^{-1} \frac{-b - \sqrt{b^2 - c^2 + a^2}}{c - a}; \tag{1}$$

$$\phi_3 = 2 \tan^{-1} \frac{-b + \sqrt{b^2 - e^2 + d^2}}{e - d}; \tag{2}$$

where:  $a = -2(x - h/2)l;$

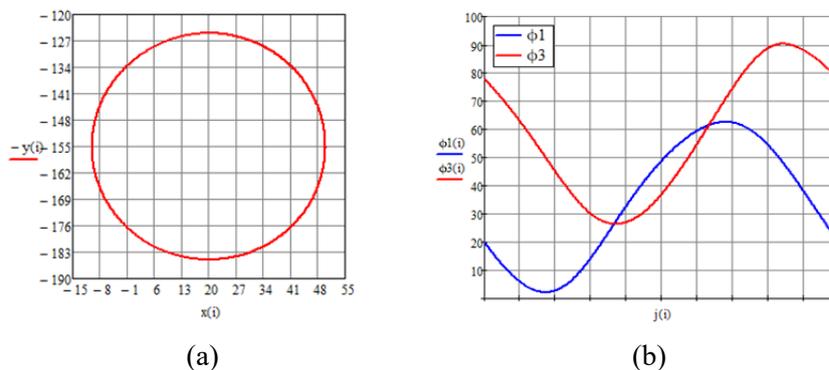
$b = -2(y - e)l;$

$c = (x - h/2)^2 + (y - e)^2 + l^2 - L^2;$ (3)

$d = -2(x + h/2)l;$

$e = (x + h/2)^2 + (y - e)^2 + l^2 - L^2.$

The imposed trajectory of point P, presented in figure 3a, is a circle with radius  $r = 30\text{mm}$  and center coordinates at  $x = 20\text{mm}$  and  $y = -155\text{mm}$



**Figure 3.** Imposed trajectory and angular position of driving elements.

The angular position of driving elements is presented in figure 3b. With relations (1) and (2) we can calculate the angular positions for any trajectory imposed for the end point of mechanism.

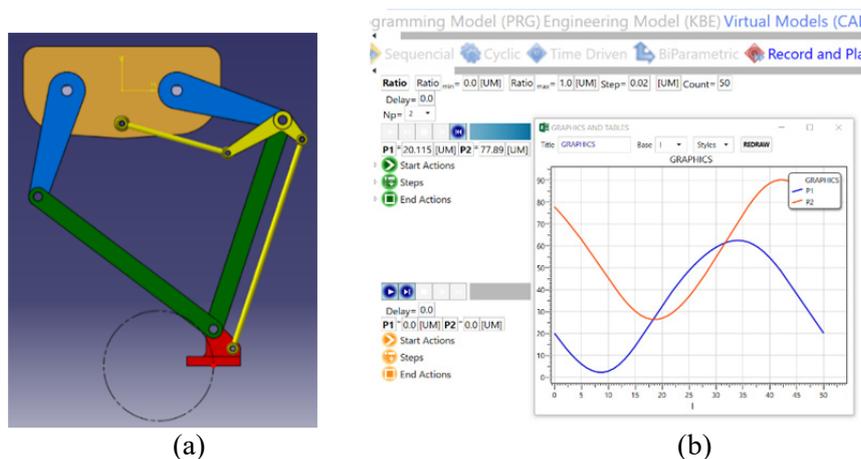
#### 4. The KBE approach

Nowadays, the mechanisms design is accomplished by using various CAD software. The three dimensional model of proposed mechanism was designed using CATIA V5 software and is presented in figure 4 a. The kinematic joint of the mechanisms were created through appropriate geometrical constraints.

It is well known that the kinematic analysis can be done using various math software. Since the model of the mechanism is already done, why not use CATIA for kinematic analysis?

In CAD having a mechanism and imposing the position of the end element, we can read the values of the angles in all the joints. All the joints defined in a CAD software are characterized by parameters. The interaction with a CAD system involves setting a parameter for the position of the end point of the mechanism and reading the values of the joint parameters. To do this, a unified method for accessing parameters is mandatory.

To interact with the CAD software we develop an application written in C#, with the Microsoft Visual Studio 2015 Environment. The application is capable to read and represent graphically the values for the joint parameters already defined in CAD. The user interface is presented in figure 4 b.



**Figure 4.** The CAD model and application interface.

By constraining the end point of the mechanisms along the desired trajectory we can obtain the joint angles for driving elements. The link between the position of end point and driving elements is provided by the geometrical constraints defined in CATIA. The values for joint angles are read by the external application. The application is able to read and plot up to six joint parameters regardless the CAD model.

#### 5. Conclusions

The modern CAD software can express knowledge in many forms, such as parameters, formulas, rules, check, reports, design table, reactions, and generative scripts and so on. The power of these can be incremented by the use of external high level programming language. In the paper we present an alternative approach to kinematic analysis using KBE tools. The values for joint angles can be obtained without calculations, based only on the geometrical constraints defined in CAD software. To facilitate reading and graphical representation of the parameters, an external application was developed. The application is useful for any planar or spatial mechanism up to 6 DOF.

#### 6. References

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