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Control of the optimum synthesis process of a four-bar linkage whose point on the working member generates the given path

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ABSTRACT

This paper presents the optimum synthesis of a four-bar linkage in which the coupler point performs a path composed of rectilinear segments and a circular arc. The Grashof four-bar linkage whose geometry provides minimum deviations from the given problem for certain parts of the crank cycle is chosen. The motion of the coupler point of the four-bar linkage is controlled within the given values of allowed deviations so that it is always in the prescribed environment of the given point on the observed segment. The synthesis process tends to bring only those path segments that are beyond the boundaries within the prescribed boundary deviations. During the synthesis, allowed deviations change from the initial maximum values to the given minimum ones. Groups of mechanisms realising satisfactory approximation to the desired motion can be obtained by the method of controlled decrease of allowed deviations with the application of the Differential Evolution (DE) algorithm.

1. Introduction

Numerous working processes in machines and devices will be successfully performed even when the paths of working bodies do not realise ideal shapes. It is enough that they come closer to the desired paths, i.e. that they are within the allowed deviations around the given paths. Since the increase in the number of members of the mechanism and the accompanying imprecision in manufacturing increase the imprecision of the path, it is necessary to be oriented towards the mechanisms with a smaller number of members. Certainly, possibilities of a mechanism with a smaller number of members are decreased with respect to the variety of the path shape, and hence it is very important to achieve a quality synthesis so that the real motion could approach the ideal one as much as possible.

The field of research in this paper is oriented toward the motion of a point of a mechanism along the path which is a combination of a rectilinear segment and a circular arc. The motion of executive bodies of machines and devices is, in practice, most frequently reduced to these two mentioned segments of the path.

This paper presents the methods which, with considerable certainty, lead to the success of dimensional synthesis of the mechanisms realising the mentioned shapes of motion. Only simple shapes of allowed deviations of generated paths are used. The model is a four-member lever planar mechanism with rotating kinematic pairs (four-bar linkage) as the simplest mechanism most used in practice.

The shapes of functions of allowed deviations, during the motion of a point of the executive body of a mechanism, can be varied. Practically, every technological process can be assigned a corresponding shape. In paper [1], Đorđević examined, in a

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detailed manner, influences of shapes of allowed deviations on the success of optimal synthesis, i.e. approximation to technological requirements of motion of mechanisms.

Bulatović and Đorđević in [2] considered synthesis of a four-bar linkage whose coupler point realises motion along a rectilinear segment the length of which is 980 mm. The method of constant allowed deviations of the shape function and the positional function was applied. The Hooke–Jeeves optimisation method was used in the optimisation and the minimum allowed deviation in the rectilinear segment of 2 mm was achieved. The total number of desired points is 16 and they are uniformly distributed on that segment.

Papers [3,4] present the Genetic Algorithm (GA) as the main technique in the synthesis of mechanisms. The procedure of GA described in the paper Kunjur and Krishanamurthy [4] is not directly applied to the synthesis of mechanisms because there are highly non-linear constraints of the optimisation problem. Certain modifications in the main GA in relation to the constraints and avoidance of early convergence in the solution were made. The paper presents a formulation of GA which, with constraints, leads the mechanism synthesis procedure into the global minimum region.

Cabrera et al. [3] also applied the GA method for the synthesis of the path of planar mechanisms. The objective function has two parts. The first part is calculation of the position error between the given points and the points within the reach of the resulting mechanism. The second part of the objective function refers to deduced constraints which are prescribed by the mechanism. Three cases of synthesis of a four-bar linkage with very fast convergence of the objective function in the vicinity of the optimal solution were considered; the error is very small and reaches the approximate value zero in the first 100 generations.

Price and Storn [5] successfully applied the DE algorithm during optimisation of certain well-known non-linear, non-differentiable and non-convex functions. Papers (cf. [6–11]) and Ref. [12] give a detailed description of the DE algorithm as well as its application to various optimisation problems.

Shiakolas et al. [13] performed synthesis of a six-bar linkage with dwell, combining DE and the geometric centroid of precision positions technique, where dwell is defined by timing relative to the motion of the input member (crank). The coupler curve contains 18 precision points with two circular arcs. Dependence at precision points on circular arcs in relation to the input crank angle is given.

2. Analysis of a four-bar linkage

A four-bar linkage, as one of typical representatives of planar lever mechanisms, is considered. The relevant parameters defining the geometry of the mechanism are presented in Fig. 1. In addition to these parameters, the following parameters are also used in further analysis:

x_p – the initial position of the point M of the coupler on the path (which corresponds to the initial angle φ_0),
x_k – the final position of the point M of the coupler on the path (which corresponds to the initial angle φ_k),
$\varphi = \varphi_k - \varphi_0$ – the working angle of the crank which corresponds to the given path.

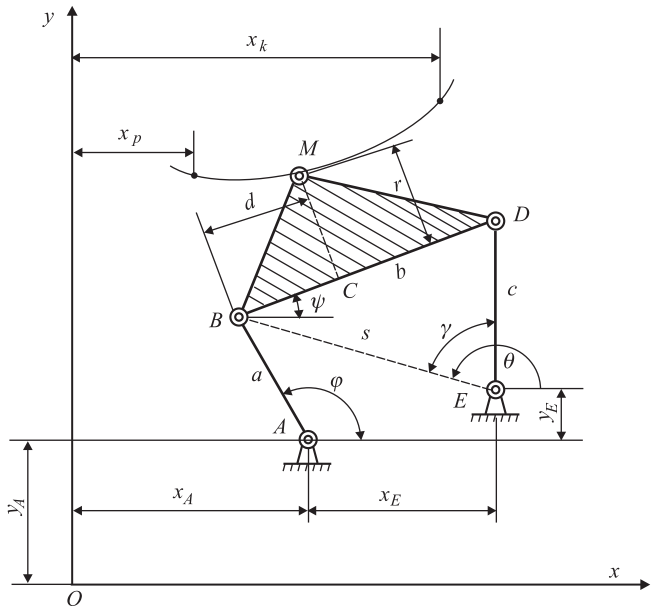

Fig. 1. Geometry of the four-bar linkage.