SYNTHESIS OF PLANAR LINKAGES AND POSSIBILITIES OF INTEGRATION OF THE SYNTHESIS-MODULE INTO ADAMS

Prof. Dr. E. Peisach, Dr.-Ing. R. Vogel, Dipl.-Ing. J. Weiss

Technische Universität Chemnitz, Institut für Mechanik

1 Introduction

Linkages are widely used for the drive of operating members of different machines: textile-, knitting-, loom-, sewing-, shoe-, polygraphic-, food-, agricultural-, loading-, packing-machines, press-automats and many others.

Linkages differ by a huge variety of type diagrams. They can be planar or spatial. They can have from 3 to 20 and more links. The links of linkages can form with each other kinematic pairs of different kinds: revolute (R), prismatic (P), cylindrical (C) or spherical (S). The links of planar linkages form with each other revolute or prismatic pairs.

Linkages possess vast possibilities and favorable properties. They can reproduce the given planar or spatial motions of operating members of machines with the prescribed degree of accuracy.

There are linkages of three genus:
- *function generators* (when the output link forms P- or R-pair with a frame);
- *path generators* (when the operating point of the output link has to move along the given plane or spatial curve);
- *generators of the prescribed motion* of the output link (when the latter forms pairs only with mobile links).

The process of linkage design may be divided into three stages:
1) *the choice of type diagram* (type synthesis);
2) *kinematic synthesis*;
3) *working out the construction* (dynamic, strength and other calculations may be related to this stage).

As a result of realization of the first and second stage we obtain a kinematic diagram of a linkage, so that the kinematic diagram is presupposed known to the beginning of the third stage.

The large general-purpose CAD-systems of wide spectrum of application are oriented to perform only the third stage of linkage design.

There are different specialized programs intended for kinematic synthesis of linkages (the second stage of design). These programs, being created by individual specialists in different countries, didn't receive any wide acceptance and application in engineering practice. To give some reasons of this it should be noted the following:
- most often only comparatively simple synthesis problems for mechanisms with a small number of links can be solved with the help of the mentioned programs;
- the ineffective algorithms, not reflecting the contemporary level of development of linkage synthesis theory, are used not infrequently in them;
- the variety of conditions met in actual applied linkage design problems, as a rule, don't consider in the proper degree in itself formulation of synthesis problems built into a program;
- the majority of specialized programs don't correspond on their interface and accessibility for designers to up-to-date representations about applied software.

As for the choice of a type diagram (the first stage of linkage design), a designer usually produces this choice on a base of his own experience or by use of an arbitrary suitable prototype. Note that the choice of the type diagram must be done with due regard to substance of the concrete design problem. In this connection the problem of exposure of potential functional possibilities of different type diagram mechanisms arises. Meanwhile, we don't know any elaborations in the field of automation of this design stage.

Thus, *the problem of automation* of the two first stages of linkage design, the choice of type diagram and kinematic synthesis, is actual. When creating the corresponding automatized systems one has to use the most effective contemporary methods and algorithms of kinematic synthesis of linkages with possible more complete accounting of conditions met in applied design problems.

Two approaches of creation of an automatized linkage type and kinematic synthesis system are possible. *The first approach* is the elaboration of a specialized system operating autonomously. *The second approach* means the elaboration of *the special module* built in some kind of powerful existing CAD-systems.

In the presented paper we have made an attempt to justify the possibility and advisability of working out *the special module* of planar linkage type and kinematic synthesis for the software ADAMS.

This module will consist of two blocks: "*Database*" and "*Kinematic synthesis*".

Block "*Database*" includes: the catalogue of standard problems of linkage synthesis; the catalogue of type diagrams of plane linkages accompanied by information about functional possibilities of every diagram; recommendations to the choice of the type diagram depending on contents of the synthesis problem.

Block "*Kinematic synthesis*" is intended for the solution of different standard synthesis problems (see section 2) with due regard to additional synthesis conditions (limitations of different kinds). We also assume to develop the subblock "*Kinematic analysis*" in the framework of block "Kinematic synthesis" since it is necessary to repeatedly turn into mechanism analysis during the kinematic synthesis.

2 Problems of synthesis of plane linkages

As an example, kinematic diagrams of four linkages are shown in Fig. 1,a-d: four-link, two six-link and eight-link mechanisms. The fixed link (frame) has the number 1, the input link has the number 2, the output link has the number n, other moving links have numbers 3, 4, ..., n-1, where n is the number of links.

Let us introduce the notations: R is a set of constant parameters of the mechanism kinematic diagram (coordinates of fixed joints, lengths of links, invariable angles); φ is the angle of rotation of the input link; ψ is the angle of rotation of the output link.

Dependence $\psi = \psi(\varphi)$ is called *a position function* of the mechanism. The shape of function $\psi = \psi(\varphi)$ depends on values of constant parameters R as well as on branche variants of each relevant mechanism structural group (for example, two-link structural group, or dyad, can have two branche variants).

By synthesizing *the function generator* a certain function $\psi = \psi(\varphi)$, with $0 \leq \varphi \leq \Phi$, is given which must be approximately reproduced by the mechanism. If $\Phi = 2\pi$ the synthesized mechanism will be *cyclic* (input link is a crank). If $\Phi < 2\pi$ the synthesized mechanism will be *acyclic* (input link is a rocker). The cyclic linkages are mainly applied in engineering.

By synthesizing *the path generator,* a certain planar curve is given which must be approximately reproduced by any point of a floating link (coupler) of the mechanism.

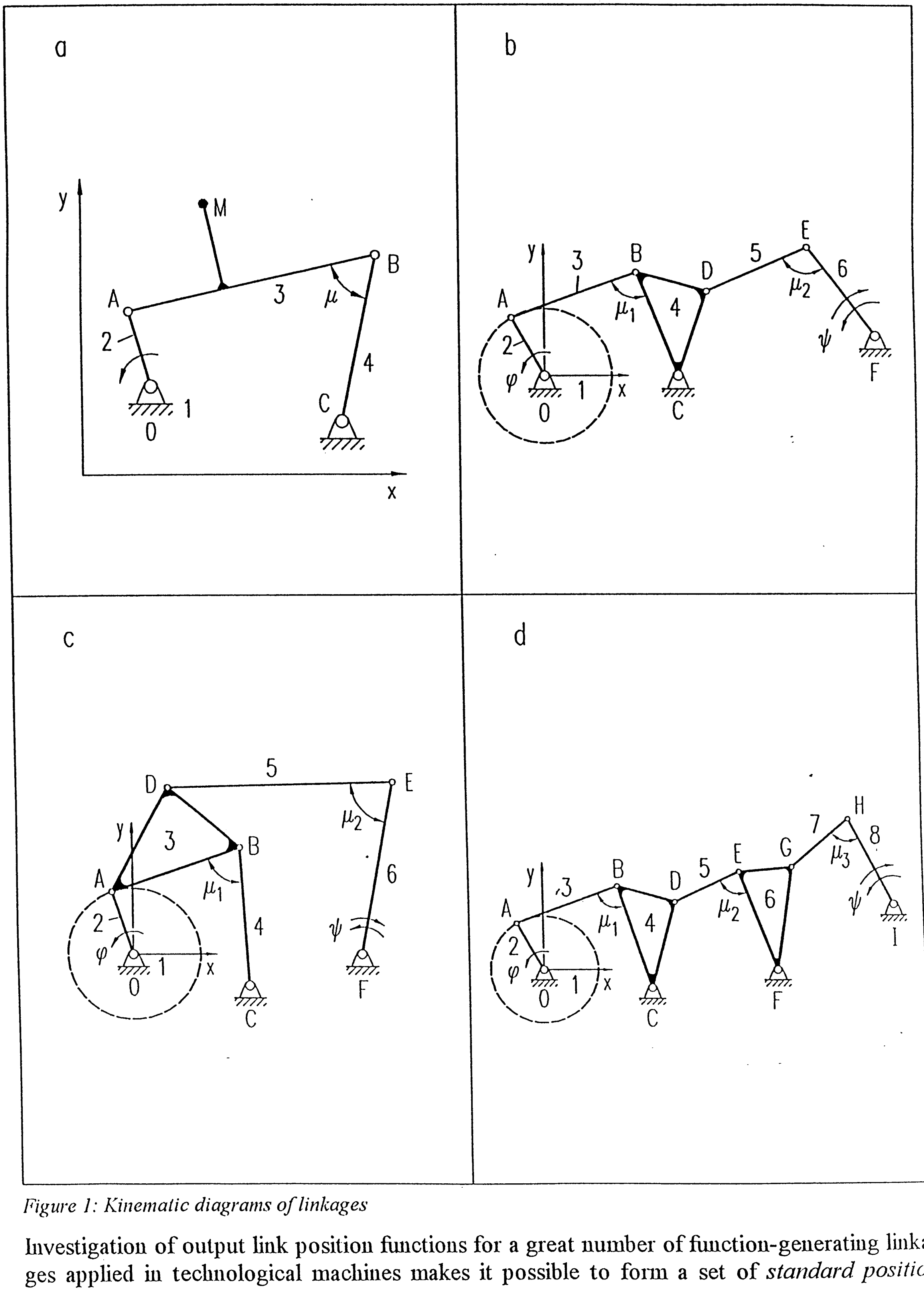

Figure 1: Kinematic diagrams of linkages

Investigation of output link position functions for a great number of function-generating linkages applied in technological machines makes it possible to form a set of *standard position functions* $\psi = \psi(\varphi)$ (Fig. 2). Represented in Fig. 2 plots of position functions include apparently no less than 90% of such functions met in practice.

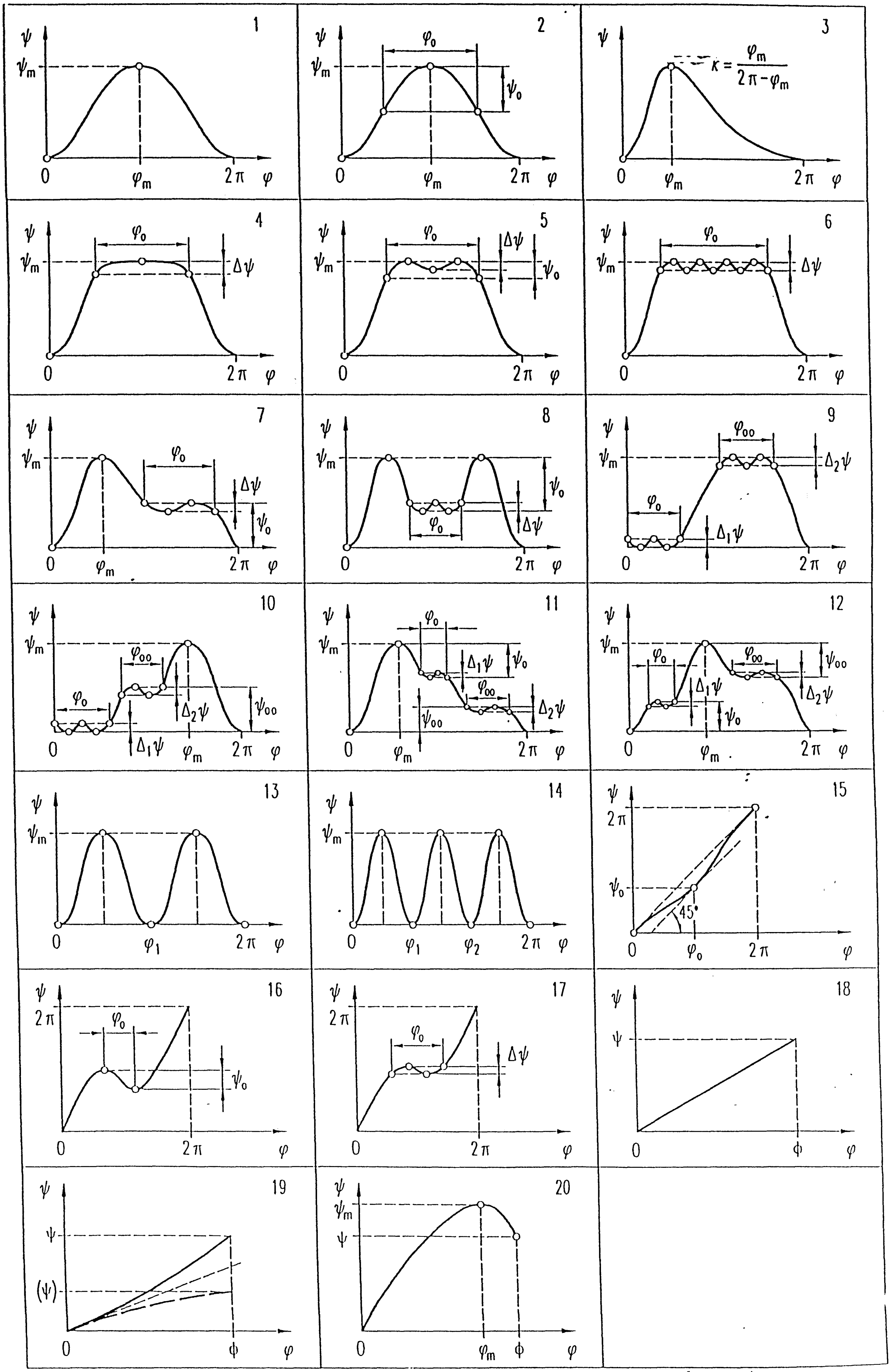

Figure 2: Standard position functions of the output link (for function-generating mechanisms)

Trajectories of working points of the path-generating mechanisms differ by a great variety. As an example, plots of two such trajectories are shown in Fig. 3: the first curve is closed (a cyclic mechanism), the second curve is nonclosed (an acyclic mechanism).

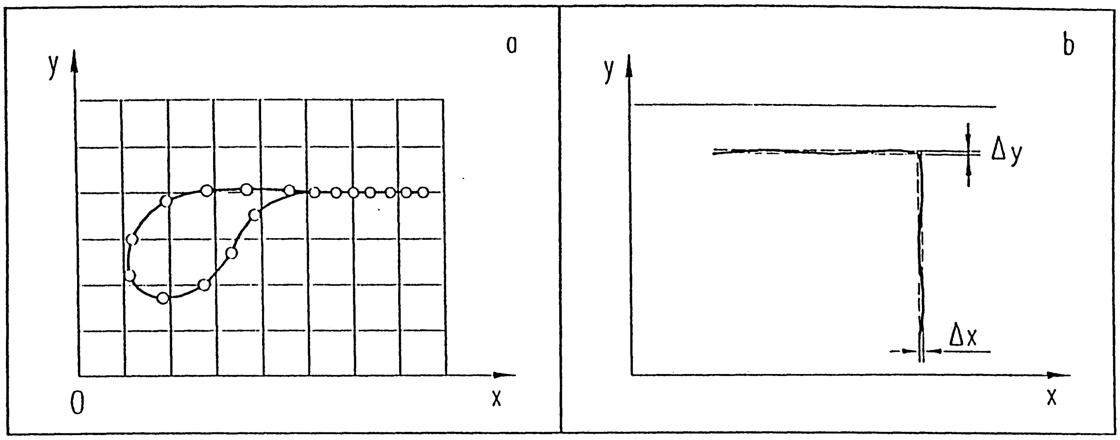

Figure 3: Two examples of working point trajectories (for the path-generating mechanisms)

3 Choice of the type diagram of linkages

By choosing a type diagram of a linkage it is necessary to take into account two competitive requirements. In the first place, it is desirable that number n of mechanism links should be as less as possible. In the second place, the mechanism of chosen structure should be able to reproduce in principle the prescribed function $\psi = f(\varphi)$ in the given interval $[0, \Phi]$ as well as to satisfy additional limitations.

With the goal of elaboration of justified recommendations on the choice of the type diagram, the investigation of *functional possibilities* of planar linkages with different numbers of links had been fulfilled [1]. In the framework of this investigation the criteria of estimation of functional possibilities were proposed, the methods and algorithms of research of functional possibilities were worked out, and the functional possibilities of the most-used planar linkages were discovered.

Comparing the functional possibilities of examined mechanisms with the plots of standard position functions represented in Fig. 2, one can come to the conclusion that any of this function may be reproduced by some kind of examined mechanisms. For example, the eight-link mechanism (Fig. 1,d) can be used to reproduce the standard functions 6, 8, 9, 13 and 14.

Obtained information about functional possibilities of linkages of different structure can be used for automation of the first stage of its design, that is the choice of type diagram.

4 Kinematic synthesis of linkages

Kinematic synthesis of a linkage consists of the determination of the constant parameter values of the mechanism kinematic diagram in the assumption that its type diagram is given as well as the motion laws of input link and output link are known. It is required to pick up the values of the constant parameters of the kinematic diagram of the mechanism, so that the motion of the output link is reproduced with the prescribed degree of precision. In addition, the limitations of different kinds (constructive, geometric, kinematic and other) are realized. At the stage of kinematic synthesis the dynamic conditions can be also taken into account to a limited degree (we keep in mind accounting such geometric criteria of quality of motion and force transmission from input link to other moving links as transmission angles or pressure angles).

In creation of the block "Kinematic synthesis" for the module automatized type and kinematic synthesis of planar linkages (see section 1), we presuppose to use the methods and algorithms developed by E. Peisach and J. Schönherr (in References only three works out of great numbers of their publications about this topics are adduced). Essentially all problems indicated in section 2 can be solved with the help of these methods. The most effective and reliable methods are analytical-optimizing methods where one group of the mechanism parameters is defined directly by analytical formulas and the other group of parameters is calculated by nonlinear optimization methods. A great number of specialized programs has been worked out on the basis of mentioned methods and algorithms.

In the following, some examples of linkage syntheses will be cited.

Example 1.
The function 5 (Fig. 2) can be reproduced by a six-link mechanism (Fig. 1,b). The given angles ψ_m, φ_0, ψ_0 and $\Delta\psi$ may be taken arbitrarily in wide limits. Let there be, for example, $\psi_m = 30°$, $\varphi_0 = 120°$, $\psi_0 = 1°$, $\Delta\psi = 1°$. In addition, we assign coordinates x and y of the fixed joint O, C, F and length of output link FE as well as the admissible boundaries for lengths of other links.

As a result of mechanism synthesis performed with the help of developed programs [2] the values of calculated parameters OA, AB, BC, $\angle BCD$, CD and DE were obtained. Therewith, 16 variants of the six-link mechanism differing from each other in a number of signs (the branch versions of dyads, disposition of dwell region of output link and other) are synthesized. Fig. 4 shows the obtained mechanisms in scale. All 16 mechanisms reproduce approximately identical position functions $\psi = \psi(\varphi)$ since the synthesis method ensures obtaining the given values of angles ψ_m, φ_0 and ψ_0 exactly while the value of angle $\Delta\psi$ is less than or equal to the given one (so, for eight of 16 found mechanisms turned out to be: $\Delta\psi = 0.2°$).

Optimization of transmission angles μ_1 and μ_2 in the first and second dyad of the mechanism is provided in the program. Therefore the transmission angles μ_1 and μ_2 came out very favorable for all 16 found mechanisms: the angle μ_* ranges from 54° to 70° for different ones, where: $\mu_* = \min(\mu_{1min}, \pi - \mu_{1max}, \mu_{2min}, \pi - \mu_{2max})$. The designer can select any one of 16 mechanisms.

Example 2.
The function 6 (Fig. 2) can be reproduced by an eight-link mechanism (Fig. 1,d). The given angles ψ_m, φ_0, $\Delta\psi$ may be taken arbitrarily over wide limits. Let there be, for example, $\psi_m = 40°$ $\varphi_0 = 140°$, $\Delta\psi = 0.002°$. It follows that in the present case the dwell duration of output link is large while dwell precision is very high. As a result of analytical synthesis of the eight-link mechanism with the help of developed programs 32 variants of mechanisms were obtained. Many of them have favorable values of transmission angles.

Example 3.
The working point path given by coordinates x and y of several positions (Fig. 3,a) may be reproduced by a four-bar linkage (Fig. 1,a). In line with the proposed technique [3] and by the use of the corresponding program the problem is solved in two stages. In the first stage the user should look into the catalogue containing nearly 100 000 variants of the problem solution for variously shaped paths. Nine kinematic diagrams of four-bar linkages with the least deviations of coupler curve from the given path are selected automatically from this catalogue. For the considered example the found nine kinematic diagrams are shown in Fig. 5. In the second stage the user can reduce deviations between mentioned curves by use of an optimization procedure.

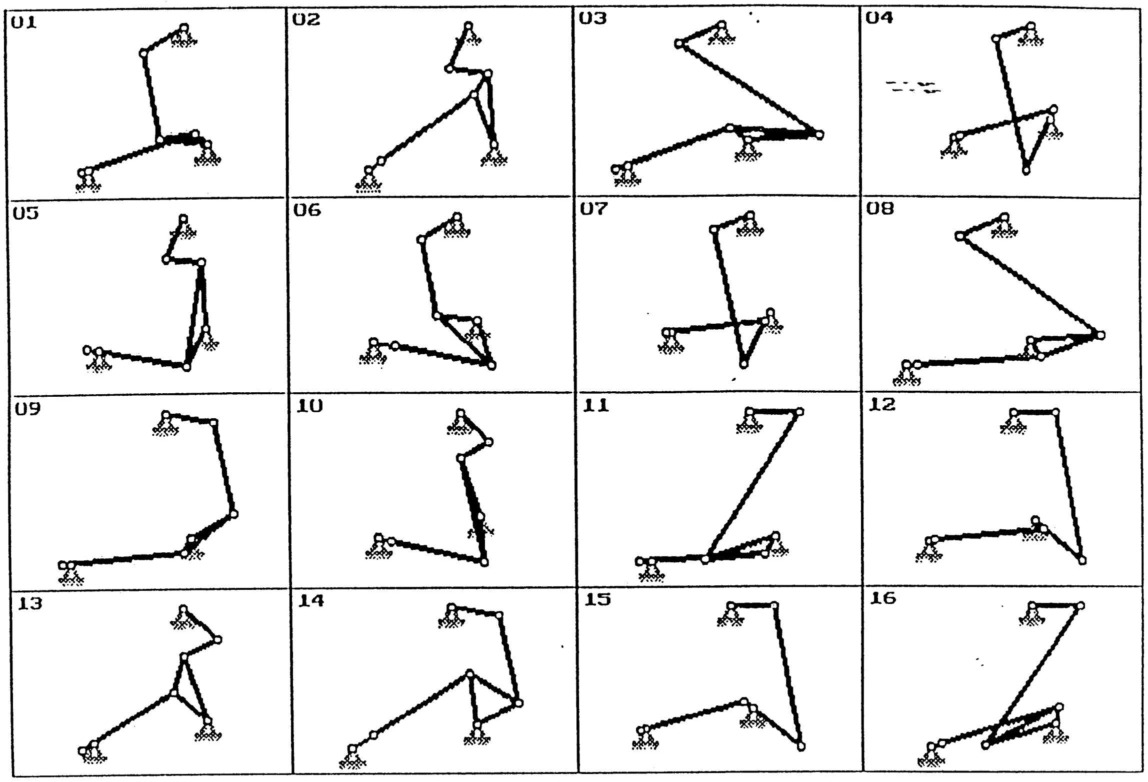

Figure 4: The result of synthesis of a six link mechanism: sixteen kinematic diagrams (to example 1)

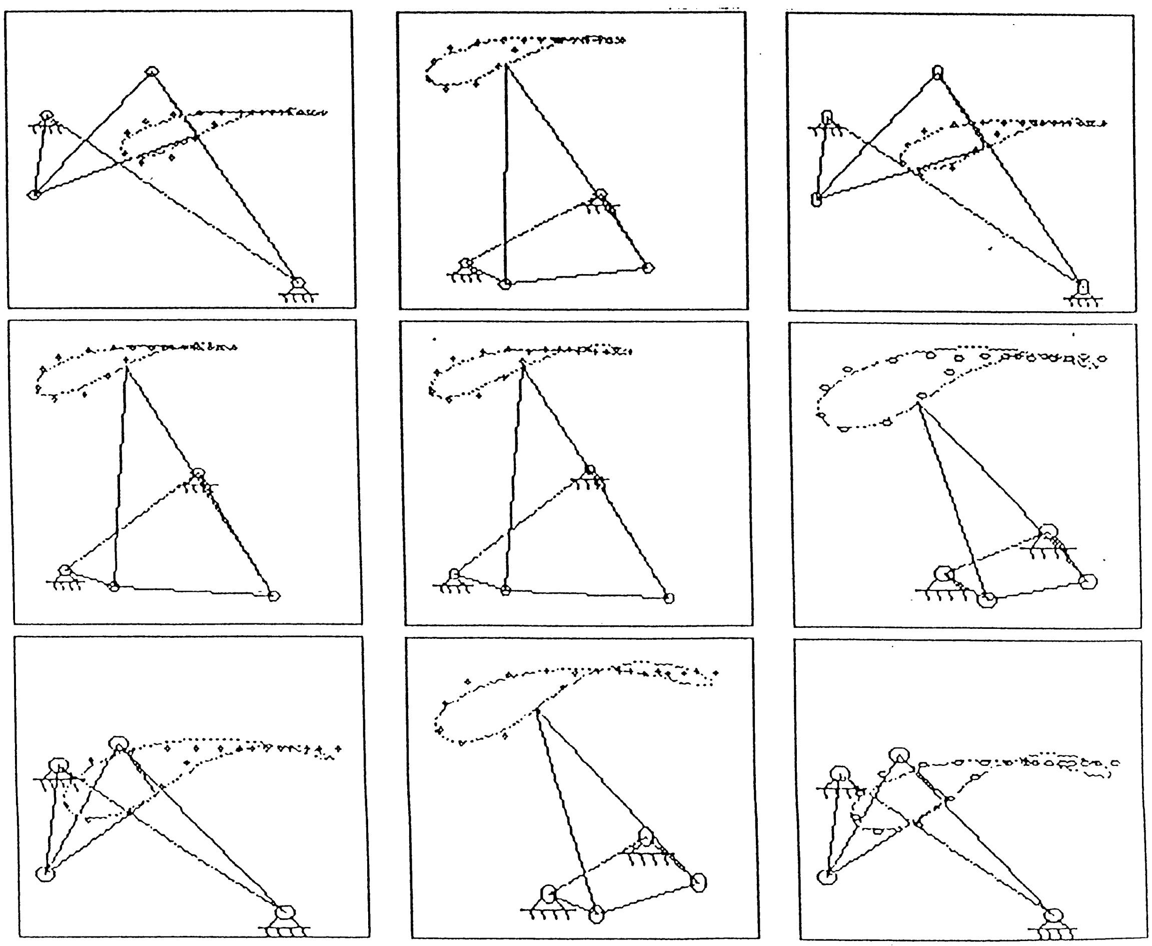

Figure 5: The result of synthesis of a four bar path-generating linkage: nine kinematic diagrams (to example 3)

5 About Integration of Synthesis Routines into ADAMS/MDI

Several points have to be noticed in connection with the integration of the new module of kinematic synthesis of planar linkages into the dynamical analysis system ADAMS. In our opinion, every external routine developed to increase the capacity of ADAMS has to satisfy the following conditions:

• The communication between user and external routine has to be realised within the ADAMS environment.

• The dialogue has to be clearly structured. Only the menues needed for the following working steps are displayed, all others are undisplayed or grayed out.

• All hardware platforms which are supported by MDI must be also supported by the external procedures .

The support of the module SYNTHESIS becomes available with the start of the ADAMS-VIEW environment. ADAMS-VIEW includes powerful tools to create an individual working environment. That means dialogboxes and multiple choice menues for problem description as well as grafical functions to visualize results [4]. We suggest to work out several parts of the new module SYNTHESIS with the help of these tools.

The main menu will be expanded with a new menu entry "SYNTHESIS". The choice of "SYNTHESIS" calls a corresponding toolkit, which will guide the user from problem formulation to an ADAMS-mechanism-model.

At first the user has to choose the most suitable standard position function and the proper type diagram of a linkage (the first stage of synthesis procedure). To support this stage of synthesis, the corresponding DATABASE will be created.

The kinematic synthesis (the second stage of problem solution) will be worked out as a set of external subroutines basing on effective algorithms.

As a result of the kinematic synthesis we will obtain a set of kinematic diagrams of mechanisms (of same structure) which satisfy all given conditions. For every kinematic diagram we will obtain a set of its constant parameters. These constant parameters of all found mechanisms will be returned to ADAMS.

The user has the possibility to choose the most suitable mechanism from the set of found solutions. Supporting this stage, a simulation procedure is also necessary to visualize the obtained linkages in any position or in a number of successive positions (that means in motion).

The synthesis process is finished with the choice of the best mechanism. In this way, a linkage model has been created . This model is available for further modelling and analyses with known ADAMS-tools.

6 References

1 Peisach E.E., Nesterov V.A.: System of designing of plane linkages. Publ. "Mashinostroenie", Moscow, 1988, 232 p.

2 Peisach E., Kikin A.: SYNMECH: the computer system on synthesis of plane linkages. Proceedings of the Seventh IFToMM International Symposium on Linkages and Computer Aided Design Methods, Bucharest, Romania, Vol. 1, 1997, pp. 227-234.

3 Schönherr J.: Digital mechanism catalogues for path generators based on Fourier's curve represantation. Proceedings of the Ninth World Congress of the Theory of Machines and Mechanisms, Milan, Italy, Vol. 2, 1995, pp. 817-821.

4 ADAMS Reference Manual, ADAMS Release 9.0