

Implementation of VDI Guidelines in Parametric 3D CAD Systems and Their Functional Extension to Dynamically Associative Optimization Tools

Christian Ahl and Rainer Lohe

Abstract Design guidelines, such as the VDI guidelines, help the designer in the synthesis of gears and mechanisms for standard recurring tasks. The guidelines provide graphical and computational methods, leading the designer systematically to solve the task. In addition to the actual synthesis process, they often contain diagrams and formulas to support identification of a “good” mechanism. This paper shows how the synthesis method derived from such guidelines can be integrated into modern 3D parametric CAD systems. In addition, design criteria can be used in the search for “good” mechanisms which are specifically tailored to the particular application and thus cannot be covered in general guidelines. In order to take into account such criteria in the individual optimization, the editor should work dynamically, interactively and associatively. Simultaneously with the modification of the mechanism via the graphical input device of his or her CAD system, the editor has to identify and manage the new mechanism dimensions, space requirement and the quality of its criteria. The paper clearly shows also that by using design guidelines in conjunction with parametric CAD systems, synergies are realized. The design engineer is offered a good guide to the solution of the task in his or her usual working environment. The use of features and parameters in CAD systems is explained and solutions are shown to design the mechanism according to requirements. Typical applications are shown using the 3D CAD systems CATIA V5 and Pro/Engineer Wildfire 5.0.

Keywords VDI guidelines · CAD systems · Mechanism synthesis · Graphical methods · Design criteria

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1 Introduction

During conferences in the past, several models to appropriately synthesize mechanisms using modern CAD systems have been presented, covering the design requirements of VDI guidelines [1]. In this paper, a general procedure is presented and complemented by the specific application of two VDI guidelines. Two recently released official VDI guidelines are presented in this paper, the new CAD-based dynamic associative component is also discussed. In the VDI Guideline 2125 [2], new design and calculation instructions for 4-bar linkage to convert rocker motion into slider motion are described. In the VDI Guideline 2728 Part 2 [3], a guide for the synthesis of a mechanism is presented for approximating linear guiding.

2 VDI Guidelines

VDI guidelines are approved standards that represent the state of the art. They serve the community as manuals, working papers and decision-making support [4]. For the selection, design and calculation of 4-bar linkages, numerous guidelines are available to accompany the product development of type and dimension synthesis up to analysis and simulation.

2.1 Approximating Linear Path-Generating Mechanisms of High Quality, VDI Guideline 2728

Using the VDI Guideline 2728, 4-bar linkages, such as for example those shown in Fig. 1 can be realized by utilizing a symmetrical coupler curve in regions with an approximated linear guiding of high quality.

In the area of linear guiding, a coupler curve has a maximum of six points of intersection with a line. The extremes that the coupler curve, k_k , passes in the area of the approximated linear guiding determine the dimensions of a rectangular tolerance band. The largest deviation from the straight line determines the height h of the tolerance range and the distance of the entry points G_R , G_L determines the length L . The dimensions of the deviations can be unified using the Chebyshev approximation and thus be minimized to h_{opt} . In general, there is exactly one point at the coupler link which corresponds to the coupler curve of the Chebyshev approximation. This coupler curve is also referred to as a balanced straight guide [3].

As a basis for an starting linkage, an isosceles crank rocker or the ROBERTS'sche equivalent, the symmetric double rocker can be used.

For the selection of such four bar mechanisms monograms are available in the VDI Guideline 2728 from which the achievable linear guide quality and the required dimensions can be read off or calculated. The guideline allows an overview

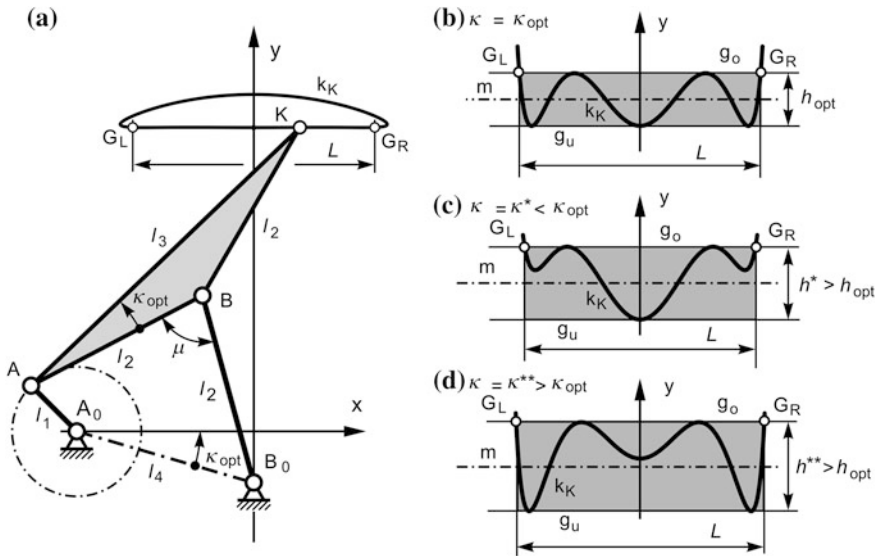


Fig. 1 Curve in the linear guided section of the isosceles crank rocker [3]

and evidence feasibility for one’s own task. This is required for the 4-bar mechanism synthesis and is helpful to create a parametric CAD model which allows interactive variation of task and solution.

A four bar mechanism with isosceles bars, ($AB = BB_0 = BK = l_2$), which is drawn in the Sketcher in 4 different positions, serves as a starting point. These four positions correspond to those positions of the coupler point on one half of the symmetrical coupler curve in which the maximum deviations occur (Fig. 2).

In order to allow variation only within Chebyshev solutions, some restrictions must be imposed on the model:

- In isosceles basic four bar, the length, $l_2 = AB = BB_0 = BK$, occurs three times.
- In the coupler triangle and in the inclination of the frame, the same angle, κ , occurs.
- The vertical positions of the coupler point, K, have to alternate between the upper limit, g_o , and the lower limit, g_u , of the tolerance band.
- In position 1, the coupler point is located straight above B_0 (${}_1K_x = B_{0x}$).
- In the positions 2 and 3, the coupler path has a horizontal tangent. For this purpose, the orbit normal, n_K , of the coupler point is determined via the instantaneous center and constrained vertical.
- In the position 4, the horizontal position of the coupler point is half the length of the straight guide.

The vertical positions of the coupler points 2 and 3 are automatically arranged according to the Chebyshev restrictions pointed above. Figure 3 shows a corresponding coupler curve from the linkages shown in Fig. 2. The display of the

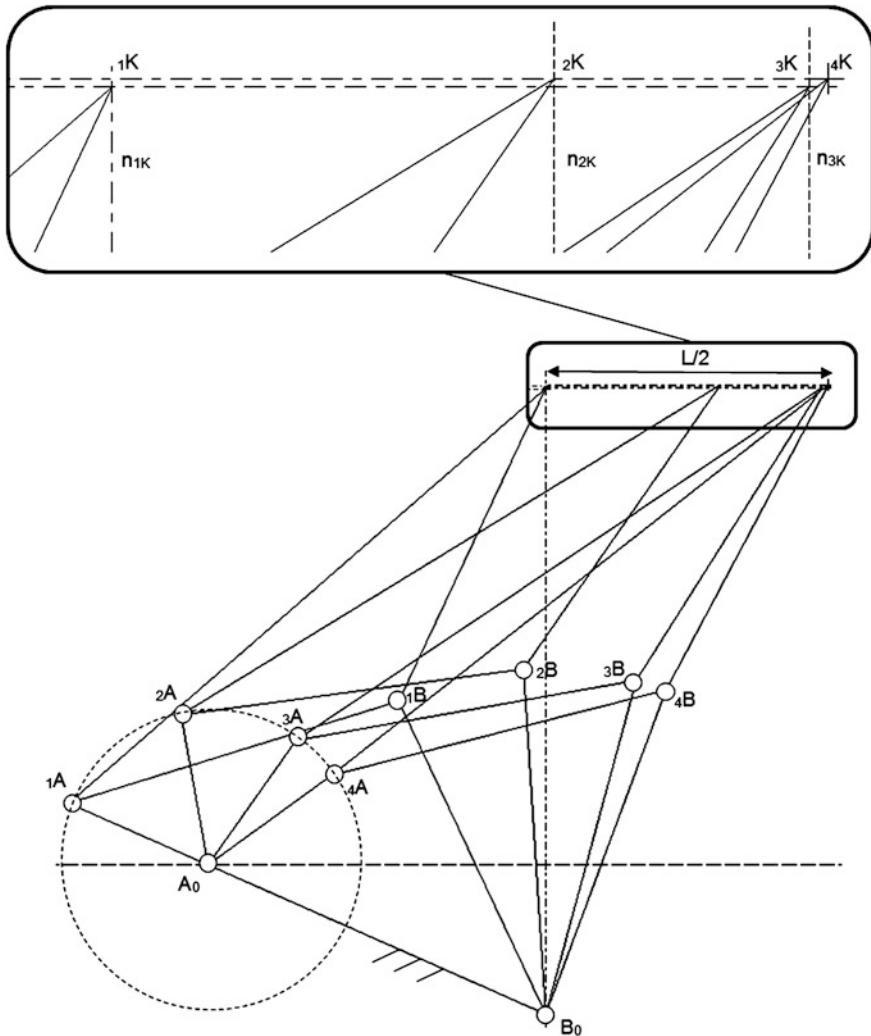


Fig. 2 Isosceles crank rocker in 4 positions as a ProE screenshot

coupler curve in Fig. 3 is required to retain control when varying the linear guide in the CAD system. To clearly define a solution, three parameters can now be varied. For example, moving point $4K$ with the mouse varies two parameters that describe the actual task, i.e. length and width of the tolerance band. Since there is an infinite number of possible four bar mechanisms (∞^1) at any tolerance rectangle, it is possible to choose any bar dimensions and thus the size of the linkage with the third parameter.

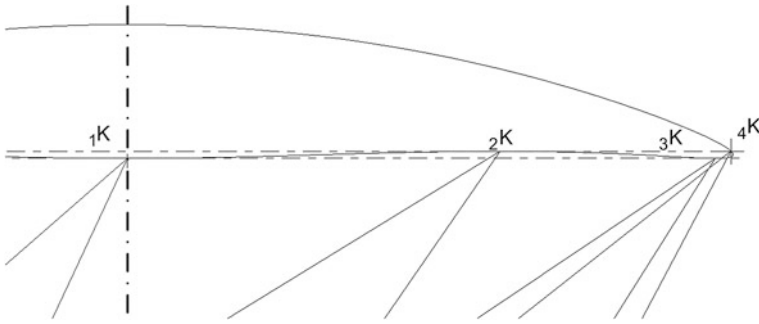


Fig. 3 Coupler curve of the requirements corresponding linkage

The engineering designer is able to realize a mechanism with the help of his or her CAD system which has a predetermined linear guide length and—deviation. As expected, this approach only provides results if the required linear guide qualities and allowable linkage sizes are harmonized. The admissible ranges are clearly laid out in the VDI Guideline 2728 sheet 2 [3].

2.2 Slider Motion into Rocker Motion, VDI Guideline 2125

The VDI Guideline 2125 describes methods for a favourable conversion of slider into rocker motion and provides charts for the selection of a high transmission quality. In the 2014 guideline, the focus is no longer only on the absolute best transmission. The charts now also contain minor deteriorations of the transmission angle in the range of the absolute optimum and thus allow the consideration of additional criteria e.g. the space requirement of the mechanism or the characteristic of the transfer function. The mechanism structure and the equivalent structure of the parametric CAD model are shown in Fig. 4.

This guideline distinguishes between procedures I and II according to the required angular output ψ_H .

If the transmission angle is good enough, other criteria might be improved. For this, Procedure III has been added. It helps to manipulate the transfer function and to monitor the transmission angle in order to find a compromise.

Important equations of the guideline are stored in the knowledge base of CATIA as parameters to be regulated [5]. In **Procedure I**, i.e. for angular output $\psi_H < 76.3^\circ$, the best value achievable for the transmission angle is first determined. For this purpose, the necessary coupler length, b , is either read off from the chart of the guideline, or determined by a parameter study using the Product Engineering Optimizer in CATIA [5]. For the remaining three linkage dimensions, c , e and t , there are simple explicit equations available in the guideline which are easy to use in the CAD system. The linkage lengths, b and c , and the best achievable value of

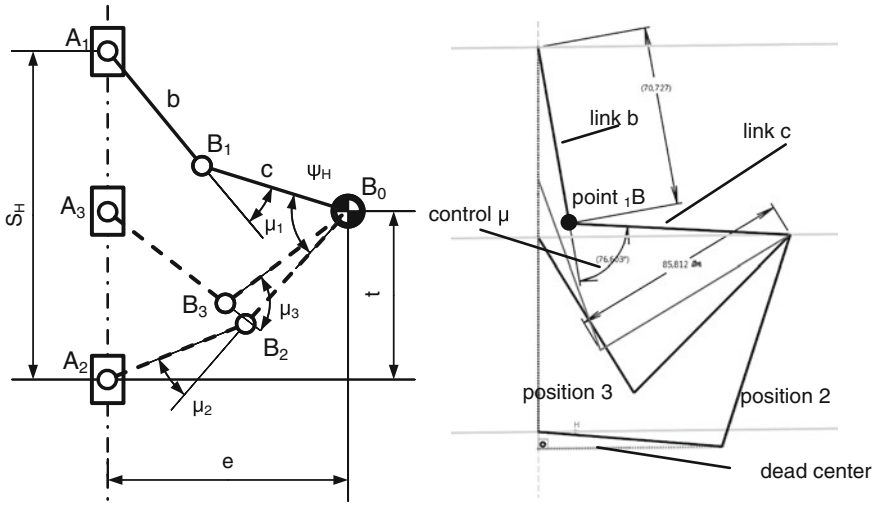


Fig. 4 Left Names on the thrust rocker [2]. Right sketch of the procedure I

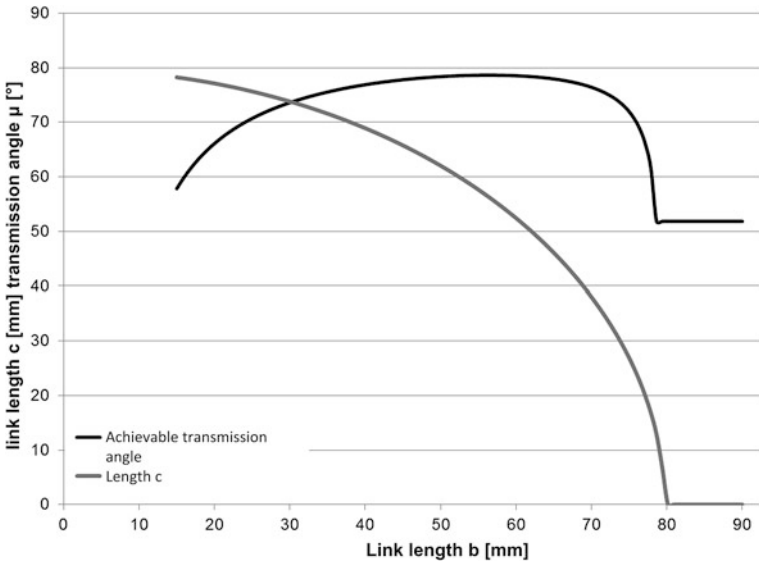


Fig. 5 Transmission angle, μ , and link length, c , for $s_H = 100$ mm and $\psi_H = 75^\circ$

the transmission angle μ_{\min} are displayed and illustrated in a diagram (Figs. 4 and 5).

If the angular output of $\psi_H = 75^\circ$ for an input of $s_H = 100$ mm is required, the result of the study is the optimal transmission angle $\max \mu_{\min} = 76.854^\circ$ with the link length $b = c = 52.42$ mm.

The design engineer can now adopt this absolute best transmission linkage or, by an initial slight deterioration of the transmission angle, vary the dimensions and take into account his or her own criteria. Therefore he or she must “grab” the coupler length b and modify it dynamically and interactively by dragging point B . Since the three remaining linkage dimensions, e , t and c , are adjusted automatically (see VDI 2125), the transmission angle only deteriorates recognizably as a result of large manipulations, see Fig. 5. In a range of $b = 24 \text{ mm}$ to $b = 75 \text{ mm}$, the maximum achievable transmission angle μ_{\min} is always above 70° .

The basis for procedure I applies theoretically for angular output up to $\psi_H \leq 90^\circ$. However for an output $\psi_H > 76.3^\circ$ (while $b = c$) there would be a reversal movement after passing the dead point (cf. [2, 6]).

The requirement of no reverse movement in the range of motion is fulfilled with the help of illustrating the dead point. The transmission is free of return motion if the dead-center as shown in Fig. 6 is on the edge of or outside the range of motion.

In **Procedure II**, i.e. for stroke angle $\psi_H > 76.3^\circ$, the absolute best transmission-friendly linkage has to be determined iteratively. The results are shown in the selection charts of the guideline, in addition to a guide for the numerical calculation. However, because in these linkages the coupler length is always about $b = 0.5 \times s_H$, it gives a very good starting value for an iteration [7, 8]. In general, the iteration is not necessary. Diagram 1 in the VDI Guideline 2125 shows only small improvements for the transmission angle in the case that iteration is applied.

In CATIA, it is advisable to determine the remaining three dimensions in the same manner as given in diagram 2 in VDI Guideline 2125. Varying the base point coordinate, e (eccentricity), the parameter study calculates all linkages that meet the conditions for an optimal transmission angle. From these mechanisms, shown in Fig. 7 the one with the required angular output, ψ_H , is chosen. In our example, an output of $\psi_H = 160^\circ$ at a stroke $s_H = 100 \text{ mm}$ is required. So we have to select the highlighted mechanisms shown in Fig. 7 to find the absolute best transmission.

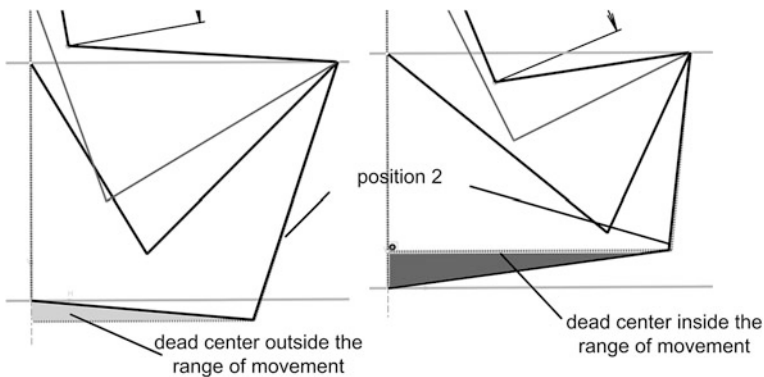


Fig. 6 Parameter variation according to Procedure I and return motion control

| e (mm) | c (mm) | t (mm) | psiH (deg) | Mue_I (deg) |
|--------|--------|--------|------------|-------------|
| 26,36 | 33,39 | 23,58 | 188,57 | 29,02 |
| 27,12 | 33,30 | 24,19 | 185,42 | 30,36 |
| 27,88 | 33,23 | 24,80 | 182,26 | 31,71 |
| 28,64 | 33,20 | 25,41 | 179,09 | 33,07 |
| 29,39 | 33,18 | 26,01 | 175,92 | 34,43 |
| 30,15 | 33,20 | 26,61 | 172,76 | 35,79 |
| 30,91 | 33,24 | 27,21 | 169,61 | 37,15 |
| 31,67 | 33,30 | 27,80 | 166,47 | 38,50 |
| 32,42 | 33,39 | 28,39 | 163,34 | 39,85 |
| 33,18 | 33,51 | 28,98 | 160,25 | 41,19 |
| 33,94 | 33,65 | 29,57 | 157,18 | 42,51 |
| 34,70 | 33,81 | 30,15 | 154,14 | 43,83 |

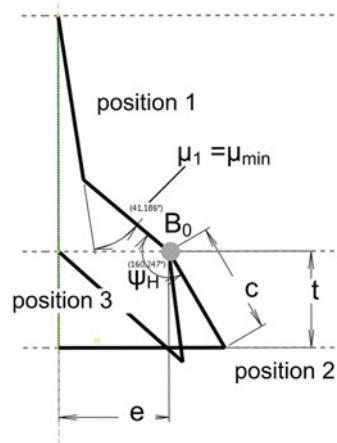


Fig. 7 Left VDI 2125 Procedure II—Parameter study for $b = 0.5$. Right Sketch Procedure II

Based on this linkage, Procedure II also gives the possibility to influence positively the angular output ψ_H , the transmission angle μ_{min} , the space requirements or the transfer function (cf. Fig. 7) by dynamically and interactively pulling at point B_0 , thus modifying the eccentricity e .

3 Conclusion

By implementing design rules in 3D CAD systems, the designer can crucially simplify the design process for mechanisms.

The dynamic behaviour of CAD systems is ideal for the mechanisms' synthesis. Classical graphical methods gain a new and greater importance because nowadays these graphs can be dynamically, interactively and associatedly varied in CAD systems. Many alternatives are assessed very quickly. Sufficient accuracy is available. Space analysis and collision checks can be simulated.

This dynamic and interactive approach becomes perfect by the associative component, that indicates the search direction in which a better mechanism can be expected to be found. Another positive experience is the required expertise of the user. The CAD models can be applied with standard CAD knowledge and no special programming is required.

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