Mechanism and Machine Theory 74 (2014) 31–41

Contents lists available at ScienceDirect

Mechanism and Machine Theory

journal homepage: www.elsevier.com/locate/mechmt

A variant double-spherical linkage and its reciprocal screw

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ARTICLE INFO

Article history:
Received 30 May 2013
Received in revised form 11 November 2013
Accepted 13 November 2013
Available online 18 December 2013

Keywords:
Overconstrained linkages
Spatial linkages
Linkage mobility
Displacement-closure equations
Screw-motion algebra

ABSTRACT

Five- and six-bar linkages are formidable subjects for mobility analysis. Apart from those loops that arise through inspiration or hybridisation, success in isolating a new solution is generally only possible now under imposed and significantly simplifying geometrical constraints. Presented here is a modest example of such an approach, suggested by linkages already discovered. The establishment of mobility criteria is assisted by an examination of the single screw reciprocal to the screw system defined by the loop's articulations. Although the resulting kinematic chain is a minor extension of a known six-bar, knowledge of its existence is a worthwhile achievement, along with the elimination of ineligible sets of constraints.
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1. Introduction

In an article [1] devoted to the double-Hooke's-joint linkage and its progenitor, the double-spherical loop, the model selected for kinematic analysis, based upon industrial practice in the manufacture of two common forms of the six-bar, is shown to be successful in determining input–output relationships for the unspecialised double-Hooke's-joint loop (Fig. 1). When the kinematic chain is generalised to double-spherical form by permitting offsets on axes 1 and 2 (Fig. 2), there can still be mounted a set of independent closure equations, but their solution is no longer readily achievable in explicit form. The author takes a further step there in postulating the existence of an even less constrained six-bar (Fig. 3) which includes the abovementioned as particular cases, as well as the curious Schatz linkage.

We wish here to improve the credibility of the so-called R-X-X-R- linkage represented in Fig. 3 by, first, observing a subset of the double-spherical solution in a non-standard fashion. Specifically, denoting the vector direction of joint axis l by $\boldsymbol{n}_l$, in Fig. 2 we set $\boldsymbol{n}_2//\boldsymbol{n}_3$ and $\boldsymbol{n}_5//\boldsymbol{n}_6$; the resulting simplification of the governing relationships is clear from Ref. [1]. By virtue of the spherical joints we are free to define $\boldsymbol{n}_1//\boldsymbol{n}_6 \times \boldsymbol{n}_2$ and $\boldsymbol{n}_4//\boldsymbol{n}_3 \times \boldsymbol{n}_5$, so that $\boldsymbol{n}_4//\boldsymbol{n}_1$. We can apply these restrictions to the R-X-X-R- form in the knowledge that, at least, there is a solution of the double-spherical type.

In fact, we might approach the task in a more general fashion by seeking solutions to an initially non-specific 6-R linkage subject to similar, but less restrictive, requirements. The known 6-H linkages displaying parallel adjacent articulations have been listed in Ref. [2], where also named are those loops that have not yet been fully analysed. Parallelism between adjacent joint axes often leads to satisfactory treatment, because of consequent simplification of closure equations, but the H−H = H−H−H = H− (where the = symbol indicates parallelism) chain does not readily succumb to analysis. It is clear, however, that there will be solutions, even if only degenerate, because the two parallel pairs of articulations can be reduced to cylindric joints, and the C−H−C−H− linkage has solutions [3]. Hence, we can be confident that there will be solutions for the 6-R loop to be considered in this place.

The additional leading imposition here that a pair of opposite axes be permanently parallel is non-standard and expected to be highly restrictive, demanding strong constraints on the locations and orientations of neighbouring articulations. Nevertheless, if

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http://dx.doi.org/10.1016/j.mechmachtheory.2013.11.006

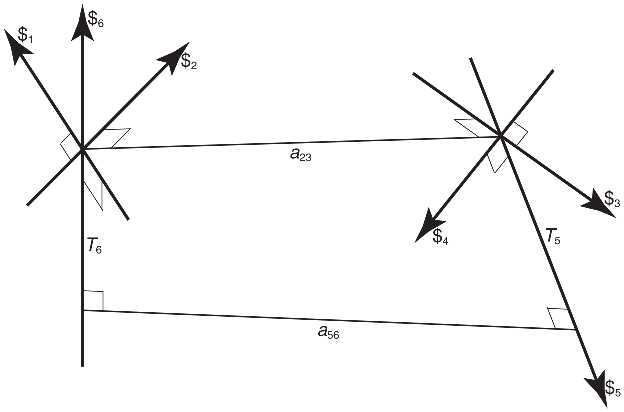

Fig. 1. The unspecialised double-Hooke's-joint linkage.

we are led thereby to a previously unknown result, the search will be of value. Certainly, as is clear from Ref. [2], it seems unlikely that closed-form solutions will be found for most of the remaining six-bars without a prior consideration of special cases.

2. The analysis

The primary analytical techniques applied here have been used many times in the literature and so a brief recapitulation should suffice. The form of linkage to be examined, consisting of six revolutes, is definable by its joint variables θ_l and fixed parameters T_l, $a_{l\,l+1}$, $\alpha_{l\,l+1}$, which are readily comprehended by recourse to Fig. 4. Relationships among these quantities in the closed loop are expressible in various ways, and a versatile avenue for the purpose is the universal set of displacement-closure Eqs. (A1)–(A12). A full explanation of their origin may be found, for example, in Ref. [4]. Trigonometric functions cosine, sine and tangent are denoted by c, s and t, respectively, and it will be convenient to signify ± 1 by each of the symbols ρ, σ, τ, υ. Of the twelve relationships given, the first nine are concerned with orientation and no more than three of them can be truly independent. Eqs. (A10)–(A12), the positional ones, are all nominally independent. Although a surfeit of relationships has its disadvantages, it can allow a greater range of choices in selecting more convenient forms of equations. There is also the latitude to cyclically advance subscripts and to reverse the sequence of reference axes, so that much flexibility is available when applying the equations.

A linkage with six joint freedoms and of gross mobility unity is governed by five mutually independent closure equations. Often, however, the nominated five relationships must be supplemented by others from the generic set to ascertain possible restrictions on domains of some of the linkage variables. In general, a linkage defined by certain dimensional conditions is capable of more closure modes than one. In principle, they are determined by the various solutions to the relevant closure equations. These many-termed, non-linear relationships are formidable objects for manipulation unless major simplifying constraints are applicable, as they are in the present instance. A judicious positioning of the reference frame sometimes eases the central task of

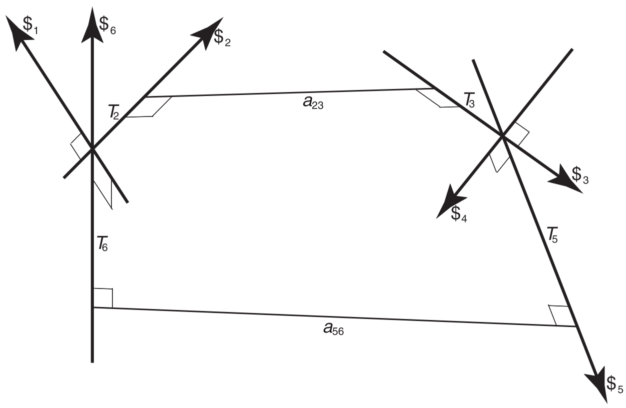

Fig. 2. The general double-spherical chain.

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