Letter to the editor

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Letter to the Editor

AS A READER of the Journal of Mechanisms, I studied the paper "Path Generating Five-Bar Mechanisms" published in Spring 1969 and written by the authors J. A. Brewer, Marvin Dixon and G. D. Whitehouse.

At first sight I was rather impressed by the authors' method of dealing with the five-bar mechanism, especially where they found a method to divide the problem in two similar parts. However, in thinking this over, I believe that the authors did overlook a vital point in doing this. Therefore, I will try to explain this by attacking the use the authors are making of equation (7) of their paper and by giving a graphical solution which is in contradiction with their six-point-precision method:

For each value of the number k , equation (7) contains the expression $(r_2^2 + p_1^2 - 2r_2p_{1x})$ which expression may be replaced by *one* variable representing the square of the constant distance $|\mathbf{R}_2 + \mathbf{P}_1|$. This means that four values of k (and not six) are enough to find the unknowns u , v , r_1 and $|\mathbf{R}_2 + \mathbf{P}_1|$. The remaining two equations, generally, are not in accordance with the mentioned four equations. It means that the whole set of equations (7) can not be used in order to find the tip of the extension vector $\mathbf{R}_2$.

If one substitutes the constant vector $(\mathbf{R}_2 + \mathbf{P}_1)$ by two vectors $(\mathbf{R}_2$ and $\mathbf{P}_1$ as done by the authors) or even more vectors of the same moving plane, one does not add design degrees of freedom in order to prescribe more than 5 precision-points.

In order to prove such a statement I take the special case by which the value of $K_1 = 1$ in the linearly co-ordinated input relationship (equation (2)) $\theta_3 = K_1\theta_1 + K_2$ of the five-bar, used in the paper.

In this case the input-rods $\mathbf{r}_1$ and $\mathbf{r}_3$ are moving with the same angular velocity. (See Fig. 3 of the paper) The pin-point of $\mathbf{R}_2$ then describes a coupler-curve produced by the four-bar represented by $(\mathbf{R}_2, \mathbf{r}_1 - \mathbf{r}_3, -(\mathbf{P}_2 + \mathbf{R}_4), \mathbf{C}_1 - \mathbf{C}_2)$ of which $\mathbf{C}_1 - \mathbf{C}_2$ is the fixed link and the vector-sum of these four vectors becomes the zero-vector. This can be seen by interchanging the sequence of the vectors $\mathbf{r}_1$ with $\mathbf{R}_2$ and simultaneously $\mathbf{r}_3$ with $(\mathbf{P}_2 + \mathbf{R}_4)$. The now shifted vectors $\mathbf{r}_1$ and $\mathbf{r}_3$ are not moving against each other, and are so defining one and the same moving plane, which then becomes a coupler-plane of which the coupler is represented by the vector $\mathbf{r}_1 - \mathbf{r}_3$. The coinciding pin-point of the shifted vectors $\mathbf{r}_1$ and $\mathbf{r}_3$ is also a coupler-point, which shall describe a coupler-curve of degree six and genus one. The next thing I will show, is that in this case also the pin-point of $\mathbf{P}_1$ will describe a coupler-curve of degree six, which curve can be produced by a four-bar linkage.

Sylvester's plagiograph.

As is shown by J. J. Sylvester in 1875 the points K and K' of the so-called "Plagiograph" describe similar curves. This plagiograph is a linkage of two degrees of freedom consisting of a parallelogram with two similar triangles attached to two connecting sides of this parallelogram.

In the mechanism of Fig. 3 a triangle similar to the one defined by the vectors $\mathbf{R}_2$ and $\mathbf{P}_1$ may be attached to the shifted vector $\mathbf{r}'_1 (= \mathbf{r}_1)$ in the same way as in the plagiograph of Sylvester. The point K' now becomes a fixed point in the coupler-plane of which $(\mathbf{r}'_1 - \mathbf{r}'_3)$ was the coupler. And so K' describes a coupler-curve of the sixth degree. Since K describes a similar curve, the pin-point K of $\mathbf{P}_1$ also shall describe a coupler-curve to generate by a four-bar linkage. Thus the proposition is valid.

As is shown by Freudenstein and Sandor in their paper, called "Synthesis of Path Generating Mechanisms by Means of a Programmed Digital Computer" in 1959, and by myself in a paper called "Coordination of Coupler-point positions and crank rotations in connection with Roberts' Configuration",* at most 5 *precision-points* which are coordinated to given crankrotations, can be prescribed on a coupler-curve. Thus in the special case by which $K_1 = 1$, I have now proved that the authors must be wrong in assuming that 6 precision-points are prescribable. Even $\theta_{1(\text{initial})}$ may not be given but will be found as a result.

I will now prove, that if $K_1 \neq 1$ the same statement holds. That is to say that also in general at most 5 precision-points can be prescribed. The two "additional" design degrees of freedom the authors invented by introducing a triangle instead of a simple rod ($\mathbf{R}_2$) can be used only to be in accordance with a chosen $\theta_{3(\text{initial})}$ and with the possibility to get the pin-point of $\mathbf{C}_2$ on an arbitrarily chosen locus. But it is not possible to accumulate the number of given precision-points in this way. In order to prove these statements I shall describe a graphical method to find the dimensions of the linkage in case only 5 precision-points are given in coordination with the four given increments of the angle θ_1 and the four given increments of the angle θ_3 . Hereby, the two remaining degrees of freedom in design may be used for a given location of the pin-point of vector $\mathbf{C}_2$.

In the solution of the stated problem the dyad $(\mathbf{r}_1, \mathbf{R}_2 + \mathbf{P}_1)$ which is a pair of connecting rods, has to be found. This dyad connects the so-called "pointer" of Fig. 3 with the fixed pin-point of $\mathbf{C}_1$. Interchanging the two elements of this dyad introduces another dyad, which together with the first one forms a parallelogram.

The shifted vector $\mathbf{r}''_1 (= \mathbf{r}_1)$ with pin-point at the pointer rotates about the given angle-increments of θ_1 , say $\theta_{15} - \theta_{10}$, $\theta_{14} - \theta_{10}$, $\theta_{13} - \theta_{10}$ and $\theta_{12} - \theta_{10}$ (with $\theta_{10} \equiv \theta_{1(\text{initial})}$).

Of $\mathbf{r}''_1$ the angle-rotations are given and also the 5 positions of the pointer. So in general a Burmester center (the pin-point of $\mathbf{C}_1$) may be found about which a circle can be drawn through the five positions of the starting-point of $\mathbf{r}''_1$. (In general 0, 2 or 4 of such Burmester centers can be found: one chooses the most suitable one, or like the authors did the most "workable" one. Methods to find such Burmester-centers are many: one of them has been shown by me at the Mechanism Conference at Atlanta (1968) and is presented in the paper: "Calculation and Construction of the Burmester-points for five positions of a moving plane".)

Since two rods of the above mentioned parallelogram are rotating about the same fixed center, it may be clear that the chosen Burmester-center (out of the possible four) is also a Burmester-center about which a circle can be drawn through the five positions of the starting-point of the moving vector $\mathbf{R}_2 + \mathbf{P}_1$.

Having found the pin-point of $\mathbf{C}_1$ it becomes easy to find the corresponding moving

*Presented at the Conference on Mechanisms at Atlanta in 1968.

point of Burmester which is the starting point of r_1'' and so all points of the mentioned parallelogram become known. The first dyad is now found and from now on we have to deal with the second "half" of the problem that is to say, with the other requirements regarding the increments of the angle θ_3 and the position of the pin-point of C_2 .

In the moving plane of the vector $(R_2 + P_1)$ we choose the lengths of the vectors R_2 and P_1 arbitrarily. (Simultaneously one consumes the already mentioned two remaining degrees of freedom.) In doing so we define the pin-point of R_2 .

By moving the pointer of the already found first dyad along the 5 given precision-points, five new precision-points of the end-point of R_2 can be located. Together with the help of the given increments of the angle θ_3 we find, in the same way as before, one (out of the possible four) Burmester-centers to be chosen as pin-points of C_2 .

Also as before, we find the whole dyad represented by its vectors $(r_3, R_4 + P_2)$. (It must be noted here that the vectors R_4 and P_2 alone are of no importance to the problem: it is sufficient to deal with their sum-vector.)

It may now be clear that by way of trial and error or by any other method, using the computer for instance, the arbitrarily chosen position of the end-point of R_2 can be varied in order to meet the last two requirements for instance the position of C_2 or any other two requirements which has to do with the second half of our mechanism.

Thus a given initial value of θ_3 may be met in this way, (but not a given initial value of θ_1 , which has to do with the first half of the mechanism). If one prescribes the angle $\theta_{16} - \theta_{10}$ as the increment of the angle rotation of r_1 , a sixth precision-point could not be met by the pointer of the mechanism, since the distance of the sixth precision-point to the end-point of r_1 in the sixth position, generally, is not the same as the already found length of $R_2 + P_1$.

By changing the lengths of R_2 and P_1 it is only possible to make the distance between a supposed sixth precision-point and the pointer as short as possible, but never shorter than a certain minimum value. This minimum value is the (shortest) distance between the sixth precision-point and the circle—about the pin-point of r_1 in position six—with the radius of the already found length of $R_2 + P_1$.

And by interchanging the numbers of the six precision-points one can get other solutions with other minimum values for the distance between the pointer in the sixth position and a supposed sixth precision-point. It is then possible to find a minimum of the minimum values, in this way getting what may be a "workable" solution. But generally speaking the sixth precision-point cannot be met by the pointer in any exact way but may be found in the neighbourhood especially if the authors locate the sixth precision-point in the neighbourhood of the curve described by the pointer of the already found mechanism! Knowing all this, however, it should now be possible to produce a computer-program based on the graphical design here presented while accepting a defined error in one of the given precision-points.

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29 August 1969

Author's Reply

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