

(b) Link masses lying off the joint-to-joint axes may be employed without restriction.

(c) Since the coefficients of all time-dependent terms are made zero permanently, any restrictions on mobility or other purely kinematic limitations on a given linkage do not invalidate the method.

(d) As the examples have shown, the resulting weight increases, as well as the physical dimensions of the counterweights, can easily conform to the demands of practical applications.

References

- 1 Artobolevskii, I. I., *Theory of Mechanisms and Machines* (Russian), Gosudarstvennoe Izdatel'stvo Tekhniko-Teoret, Literaturny, Moscow, 2nd ed., 1951.
- 2 Artobolevskii, I. I., Zinov'yev, V. A., and Edel'shtein, B. V., *Collected Problems on the Theory of Mechanisms and Machines* (Russian), Gosudarstvennoe Izdatel'stvo Tekhniko-Teoret, Literaturny, Moscow, 3rd ed., 1955.
- 3 Baranov, G. G., *A Course in the Theory of Mechanisms and Machines* (Russian), Mashgiz, Moscow, 2nd ed., 1958.
- 4 Crossley, F. R. E., *Dynamics in Machines*, Ronald Press, N. Y., 1954.
- 5 Crossley, F. R. E., "The Balancing of High-Speed Oscillating Feed Mechanisms," ASME Paper No. 64—Mech-28.
- 6 Davies, T. H., "On the Balancing of Mechanisms and Machines With Particular Reference to High-Speed Linkages," Manuscript (from author), 1965.
- 7 Diziloglu, B., "Getriebelehre," *Dynamik*, Vol. 3, F. Vieweg and Sohn, Braunschweig, 1966.
- 8 Dobrovol'skii, V. V., "On the Motion of the Center of Gravity of a Hinged Four-Bar Linkage," (Russian), *Izvestiya Akademii Nauk SSSR, Otdelenie Tekhnicheskikh Nauk*, No. 4, 1941, pp. 107–108.
- 9 Fischer, O., "Über die reduzierten Systeme und die Hauptpunkte der Glieder eines Gelenkmechanismus," *Zeit. für Math. und Phys.*, Vol. 47, 1902, pp. 429–466.
- 10 Hilpert, H., "Gewichtsausgleich an feinmechanischen Geräten," *Feingerätetechnik*, Vol. 14, No. 2, 1965, pp. 61–66.
- 11 Kamenskii, V. A., "Toward the Question of the Balancing of Plane Rod Mechanisms," (Russian), *Trudy Moskovskogo Instituta Inzhenerov Zhel.-dor. Transporta*, No. 150, 1962, pp. 29–49.
- 12 Kamenskii, V. A., "The Problem of the Number of Counterweights for the Balancing of Plane Rod Mechanisms," *Balancing of Machines and Instruments* (Russian), ed. Shchepetil'nikov, V. A., Mashinostroenie, Moscow, 1965, 571 pp. (pp. 435–445).
- 13 Kreutzinger, R., "Über die Bewegung des Schwerpunktes beim Kurbelgetriebe," *Getriebetechnik*, Vol. 10, No. 9, Sept. 1942, pp. 397–398.
- 14 Maxwell, R. L., *Kinematics and Dynamics of Machinery*, Prentice-Hall, Englewood Cliffs, N. J., 1960.
- 15 Reshetov, L. N., "Toward the Question of the Balancing of the Forces of Inertia of Plane Mechanisms" (Russian), *Izvestiya Vysshikh Uchebnykh Zavedenii, Mashinostroenie*, No. 11, 1964, pp. 5–13.
- 16 Shchepetil'nikov, V. A., "The Determination of the Mass

Centers of Mechanisms in Regard to the Problem of Their Balancing," (Russian), *Trudy Moskovskogo Instituta Inzhenerov Zhel.-dor. Transporta*, No. 92/11, 1957, pp. 211–233.

17 Talbourdet, G. J., and Shepler, P. R., "Mathematical Solution of 4-Bar Linkages, Part IV—Balancing of Linkages," *Machine Design*, Vol. 13, July 1941, pp. 73–77.

18 Wunderlich, W., "Über die Schwerpunktsbahn des Dreistab- und Schubkurbelgetriebes," *Buletinul Institutului Politehnic, Din Iasi, Serie Noua. Tomul X (XIV), Fasc. 1–2, 1964, pp. 285–291.*

DISCUSSION

Joseph Ku³

This paper presents a mathematical procedure whereby the total center of mass of a constrained four or six-bar planar linkage is made independent of the position of the input and hence time invariant. The presentation is clear, concise and in logical sequence.

However, several interesting observations could have been included in this paper as regarding the effects of using this method to balance a linkage. Firstly, although this method ensures that the vector sum of the forces acting on the mechanism frame vanish at all times, the individual force components in the horizontal and vertical directions are nevertheless finite and time varying. Hence, each of the linkage supports at the frame is individually still being subjected to a cyclic shaking force. The magnitude of these forces may actually be greater than the magnitude before balancing, due to the added counterweights. This may not be desirable in certain applications. Secondly, this method of balancing, in common with many other linkage balancing methods, does not eliminate the cyclic rocking moment acting on the frame due to the equal but opposite vertical force components acting at the linkage supports. Again, this shaking moment may actually be greater than that of the "unbalanced" case.

³ Research Assistant, Mechanical Engineering Department, University of California, Davis, Calif.

Author's Closure

The authors appreciate Mr. Ku's remarks and agree with them completely. The discussion of these questions has been purposely omitted in this paper because of the extended design considerations that have been found to be associated with them. We are pleased to report that a paper concerned with these problems will shortly be submitted to the American Society of Mechanical Engineers.