An Upper Bound Energy Formulation of Free-Chip Machining with Flat Chips and an Alternative Method of Determination of Cutting Forces without using Merchant's Circle Diagram	
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Abstract: An upper bound analysis of free-chip machining has been carried out, where the tool cutting and friction forces were determined from the deformation energy dissipated during the chip separation process. The method employed was based on the classical upper bound theorem, as formulated by Prager and Hodge, and Drucker, Prager, and Greenberg, and its modification by Collins, to deal with the metal forming processes involving coulomb friction. A straight shear plane and coulomb friction at the chip/tool interface were assumed and the energy required for cutting was calculated from a strain rate/velocity field that was constructed using the method proposed by Collins. Cutting forces, thrust forces, tool/chip contact lengths, and chip thickness ratios were determined for different tool rake angles and friction conditions. The theoretical results were also compared with some experimental results that are available in the published literature. The comparison between the two was not found to be satisfactory. This may be due to the non-unique nature of the machining process, as stated by Hill and demonstrated by other authors. The results calculated from the present method of ”energy balance” were also found to be in agreement with those obtained by Merchant using the principle of ”force balance”.