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Research Article

Teaching Planetary Gear Trains with the Aid of Nomographs

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Planetary gear trains (PGTs) are introduced to undergraduate mechanical engineering students in the course of Theory of Machines. The complexity of the traditional methods for analyzing PGTs has kept many from becoming familiar with the capability of PGTs in mechanisms and machine design. In this paper a unified general formulation for simultaneously visualizing velocities, torques, and power flow through a train is presented on a single nomograph. Therefore, the increasing complex mechanical systems, such as automotive transmissions, are much easier to understand. Nomographs of Fundamental Gear Entities (FGEs) are constructed based on the nomographs of their fundamental circuits, without specifying the exact gear dimensions. They are then unified in one system nomograph. Nomographs are promising to provide designers with an efficient tool for the design of geared mechanisms.

1. Introduction and Literature Review

Epicyclic gear trains (EGTs) are commonly used in automatic transmission mechanisms to achieve a set of desired velocity ratios [1]. Figure 1 shows an epicyclic gear mechanism employing the Ravigneaux gear set as the ratio change gear train where the rotating and band clutches are designed as C and B, respectively. The velocity ratios selected for a transmission are tailored for vehicle performance. Typically, they include a first gear for starting, a second or third gear for passing, an overdrive for fuel economy at road speeds, and a reverse [2]. Table 1 shows the clutching sequence for the transmission shown in Figure 1.

For the kinematic analysis of EGMs, various approaches such as the relative velocity method [3–5], energy method [6], bond graph method [7], vector-loop method [8, 9], and the nomograph method [10–12] have been proposed. Freudenstein and Yang [13] introduced the concept of fundamental circuit to analyze EGTs. The concept was further extended by other researchers [14, 15]. The concept of fundamental circuit is a powerful tool for automated analysis of EGTs. In addition, some other studies have concentrated on structural and dimensional syntheses [16–21].

A practical approach uses a lever analogy [22] that translates a planetary gear set to a lever of certain amount of nodes. For instance, a single plane of gears (single-planet or double-planet gear sets) can be represented by a lever with three nodes representing the sun gear, internal gear, and the carrier, whose linear velocities are analogous to the angular velocity of the respective component in the actual planetary gear train. Any one-degree-of-freedom planetary gear train can be reduced into a single lever to allow easy calculation of speeds, but the calculations must still be carried out manually. In addition, the planet rotational speeds, which are not included in level analogy, must still be determined using the conventional methods.

The studies on power flow analysis of EGMs are mostly done in the context of efficiency formulations [14, 23, 24]. Pennestri and Freudenstein [14, 24] use the same fundamental circuits proposed earlier [13] for a complete static force analysis [23]. They apply a similar formulation in conjunction with their earlier kinematic study [2] to determine the most efficient kinematic configuration. The work by [25] further generalizes the efficiency formulations of gear trains formed by single- or double-planet arrangements. A review of formulas for the mechanical efficiency analysis of two-degrees-of-freedom epicyclic gear trains is presented by Pennestri and Valentini [26].

Reference [10] used a practical approach to investigate both the angular velocities and the torques acting on the first and last gears and the carrier of a train depending on nomographs. The origins of nomographs date back to