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Research paper

Pulse drive: A new power-transmission principle for a compact, high-efficiency, infinitely variable transmission

Eiji Tsuchiya[a,*], Eiji Shamoto[b]

[a] Toyota Central R&D Labs., Inc., 41-1 Yokomichi, Nagakute-shi Aichi 480-1192, Japan
[b] Nagoya University, Japan

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ABSTRACT

In this paper, a new transmission principle, named "pulse drive," is proposed for potentially realizing a highly compact, high-efficiency, infinitely variable transmission, such as that used in switching electrical power supply systems, by transmitting the driving power intermittently through periodic vibration control. In addition, the experimental results of a prototype pulse-drive transmission are discussed. Conventionally, rotational speed and torque are converted using radius ratios (e.g., gears) or slips (e.g., friction clutches). By contrast, in the proposed principle, this conversion is achieved by controlling the engagement time of compact slipless clutches (e.g., dog clutches). This principle is similar to duty control in electronic voltage converters, which utilize the ratio of engagement time rather than that of turns of coils. The experiments confirmed that the pulse drive can transmit rotational power and that torque can be converted by controlling the engagement time.

1. Introduction

Highly efficient and compact power transmissions are crucial for realizing high energy economy and have thus been studied in various fields such as automobiles and robotics [1–3]. Rotational energy can be transmitted between two objects rotating at different speeds through two principles: the radius ratio and slip principles. Gear systems utilize the radius ratio principle to ensure that the circumferential speeds of two rotating objects are the same. Many studies have investigated methods to improve the contact strength and bending strength of gears [4]. Because only a limited circumferential section of the gears are engaged in power transmission, gear systems tend to be larger than systems wherein the power transmission is through the entire circumference, such as in spline couplings [5]. This trend should be noted especially when a flexible component is used to vary the rotational speed continuously, such as in a continuously variable transmission (CVT) belt [6,7]. In the slip principle, a friction clutch allows slip between two axes and transmits torque through friction. Such a system is particularly useful in starting the rotation, but it tends to lose energy even when a liquid is used to transmit torque, such as in a fluid torque converter [8]. This energy loss decreases the transmission efficiency and thus necessitates large systems.

This paper presents a new principle, named "pulse drive," for transmitting rotational energy that overcomes the aforementioned problems, wherein torque is transmitted between two axes moving at different speeds through interlocking engagement. Theoretically, this system has high torque density because the entire circumference is engaged in torque trans-

* Corresponding author.
E-mail address: t-eiji@mosk.tytlabs.co.jp (E. Tsuchiya).

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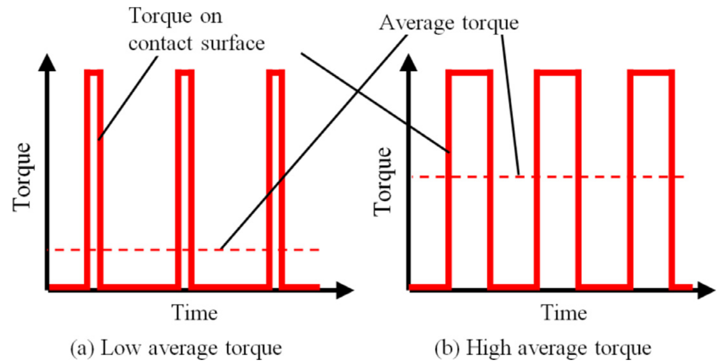

Fig. 1. Principle of intermittent drive.

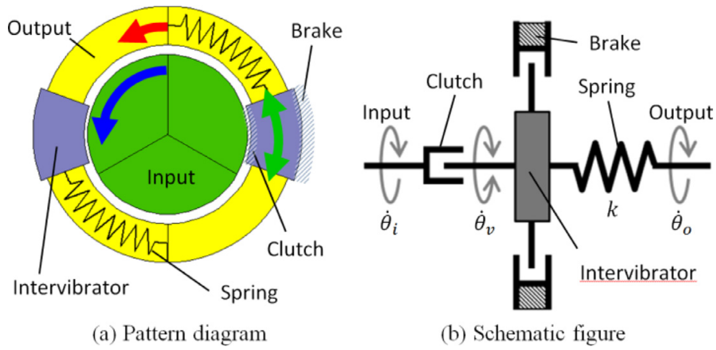

Fig. 2. Realizing interlocking engagement between two axes moving at different speeds.

mission. Interlocking engagement between two axes moving at different speeds is impossible. Nevertheless, in the proposed principle, the engagement can be switched on and off if the speed difference can be made zero at the moment of engagement (Fig. 1). Accordingly, this intermittent engagement–based principle has the following characteristics: the average torque can be continuously controlled using the duty ratio, and the high drive frequency smoothens the rotational speed of the output, which typically has relatively large inertia and thus low frequency response. These characteristics are well-known in electrical engineering and are generally used to convert voltages through pulse-width modulation (PWM) control [9]. The major advantage of PWM control and related switching devices is that they can be used to realize highly compact, efficient, and practicable electrical power supply systems [10]. The proposed principle and the intermittent mechanical drive bring this advantage to mechanical power transmissions.

2. Realizing the proposed principle

The frictional engagement of two axes rotating at different speeds results in energy loss, and interlocking engagement between such axes is impossible. To achieve interlocking engagement, a flexible intermediate component that can shrink and expand to support the speed difference is essential between the input and output axes. To this end, this paper proposes a new engagement method wherein a vibrator is used as the intermediate component, using which the proposed pulse drive can be realized.

2.1. Working principle of the intervibrator

Fig. 2 illustrates the proposed method of engaging two axes using the intervibrator. The intervibrator is connected to the output axis via a spring and can freely vibrate on the output axis. A clutch is present between the input and the intervibrator, and a brake is present between the intervibrator and the nonrotational component (e.g., the casing).

Fig. 3(a) shows the absolute rotational speeds of the input (input speed), the output (output speed), and the intervibrator (intervibrator speed), and Fig. 3(b) shows the relative rotational displacement of the intervibrator to the output axis (spring displacement), to which the spring torque is proportional. Because the intervibrator is connected to the output, if the rotational speed of the vibrator relative to the output (vibration speed) is higher than the difference between the input and output speeds, the input speed becomes equal to the intervibrator speed at moment (A). For ease of discussion and as the first stage of this research work, this paper only discusses speed reduction when the input speed is higher than the output speed and the vibration speed is higher than the difference between the input and output speeds.