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Self-Locking Gears: Design and Potential Applications

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Self-Locking Gears: Design and Potential Applications

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[The statements and opinions contained herein are those of the author and should not be construed as an official action or opinion of the American Gear Manufacturers Association.]

Abstract

In most of the gear drives, when the driving torque is suddenly reduced as a result of power off, torsional vibration, power outage or any mechanical failure at the transmission input side, then gears will be rotating either in the same direction driven by the system inertia, or in the opposite direction driven by the resistant output load due to gravity, spring load, etc. The latter condition is known as backdriving. During inertial motion or backdriving, the driven output shaft (load) becomes the driving one and the driving input shaft (load) becomes the driven one. There are many gear drive applications where the output shaft driving is less desirable. In order to prevent it, different types of brake or clutch devices are used. However, there are also solutions in gear transmission that prevent inertial motion or backdriving using self-locking gears without any additional devices. The most common one is a worm gear with a low lead angle. In self-locking worm gears, torque applied from the load side (worm gear) is blocked, i.e. cannot drive the worm. However, their application comes with some limitations: the crossed axis shafts' arrangement, relatively high gear ratio, low speed, low gear mesh efficiency, increased heat generation, etc.

The paper describes the design approach as well as potential applications of the parallel axis self-locking gears. These gears, unlike the worm gears don't have such application limitations. They can utilize any gear ratio from 1:1 and higher. They can be external, internal, or incorporated into the planetary gear stage or multistage gear system. Their gear mesh efficiency is significantly higher than the worm gears and closer to conventional gears. As a result they generate less heat. The self-locking can be designed to prevent either the inertia driving, or backdriving, or both. The paper explains the principle of the self-locking process for gears with symmetric and asymmetric teeth profile, and shows their suitability for different applications. It defines the main parameters of gear geometry and operating conditions. It also describes potential self-locking gear applications and references to related publications.

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Introduction

In most gear drives, when driving torque is suddenly reduced as a result of power off, torsional vibration, power outage, or any mechanical failure at the transmission input side, then gears will be rotating either in the same direction driven by the system inertia, or in the opposite direction driven by the resistant output load due to gravity, spring load, etc. The latter condition is known as backdriving. During inertial motion or backdriving, the driven output shaft (load) becomes the driving one and the driving input shaft (load) becomes the driven one. There are many gear drive applications where output shaft driving is undesirable. In order to prevent it, different types of brake or clutch devices are used. However, there are also solutions in the gear transmission that prevent inertial motion or backdriving using self-locking gears without any additional devices. The most common one is a worm gear with a low lead angle. In self-locking worm gears, torque applied from the load side (worm gear) is blocked, i.e. cannot drive the worm. However, their application comes with some limitations: the crossed axis shafts' arrangement, relatively high gear ratio, low speed, low gear mesh efficiency, increased heat generation, etc.

Also there are parallel axis self-locking gears [1, 2]. These gears, unlike the worm gears can utilize any gear ratio from 1:1 and higher. They have the driving mode and self-locking mode, when the inertial or backdriving torque is applied to the output gear. Initially these gears had very low (< 50%) driving efficiency that limited their application. Then it was proved [3] that high driving efficiency of such gears is possible. Criteria of the self-locking was analyzed in this article [4].

This paper explains the principle of the self-locking process for the parallel axis gears with symmetric and asymmetric teeth profile, and shows their suitability for different applications.

Self-locking condition

Figure 1 presents conventional gears (a) and self-locking gears (b), in case of backdriving. Figure 2 presents conventional gears (a) and self-locking gears (b), in case of inertial driving. Practically all conventional gear drives have the pitch point P located in the active portion the contact line B₁-B₂ (Figure 1a and Figure 2a). This pitch point location provides low specific sliding velocities and friction, and, as a result, high driving efficiency. In case when such gears are driven by output load or inertia, they are rotating freely, because the friction moment (or torque) is not sufficient to stop rotation.

In order to make gears self-locking, the pitch point P should be located off the active portion the contact line B₁-B₂. There are two options. Option 1: when the point P is placed between a center of the pinion O₁ and the point B₂, where the outer diameter of the gear intersects the line contact. This makes the self-locking possible, but the driving efficiency will be low under 50% [3]. Option 2 (Figure 1b and Figure 2b): when the point P is placed between the point B₁, where the outer diameter of the pinion intersects the line contact and a center of the gear O₂. This type of gears can be self-locking with relatively high driving efficiency > 50%.

Another condition of self-locking is to have a sufficient friction angle, γ , to deflect the force F' beyond the center of the pinion O₁. It creates the resisting self-locking moment (torque) $T'_1 = F' L'_1$, L'_1 is a lever of the force F'_1 . This condition can be presented as $L'_{1min} > 0$ or

$$\gamma > \arctan \left[\frac{1}{(1+u) \tan \alpha_w - u \tan \alpha_{a2}} \right] \quad (1)$$

or

$$f > \frac{1}{(1+u) \tan \alpha_w - u \tan \alpha_{a2}} \quad (2)$$

where

$$u \text{ is gear ratio,} \\ = \frac{n_2}{n_1}$$