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Brief Review of the Self-Tightening, Left-Handed Thread

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***Abstract*—**Loosening of bolted joints in rotating machines can adversely affect their performance, cause mechanical damage, and lead to injuries. In this paper, two potential loosening phenomena in rotating applications are discussed. First, 'precession,' is governed by thread/nut contact forces, while the second is based on inertial effects of the fastened assembly. These mechanisms are reviewed within the context of historical usage of left-handed fasteners in rotating machines which appears absent in the literature and common machine design texts. Historically, to prevent loosening of wheel nuts, vehicle manufacturers have used right-handed and left-handed threads on different sides of the vehicle, but most modern vehicles have abandoned this custom and only use right-handed, tapered lug nuts on all sides of the vehicle. Other classical machines such as the bicycle continue to use different handed threads on each side while other machines such as, bench grinders, circular saws and brush cutters still use left-handed threads to fasten rotating components. Despite the continued use of left-handed fasteners, the rationale and analysis of left-handed threads to mitigate self-loosening of fasteners in rotating applications is not commonly, if at all, discussed in the literature or design textbooks. Without scientific literature to support these design selections, these implementations may be the result of experimental findings or aged institutional knowledge. Based on a review of rotating applications, historical documents and mechanical design references, a formal study of the paradoxical nature of left-handed threads in various applications is merited.

***Keywords*—**Rotating machinery, self-loosening fasteners, wheel fastening, vibration loosening.

I. Introduction

THREADED fasteners are hardware devices that mechanically join two or more components together. Fasteners have been used in machinery for over two millennia [1]. Threaded, removable, fasteners are useful in many applications where the components fastened are expected to wear and need replacing or for ease of assembly or disassembly. Machines that use threaded fasteners range from cars and bicycles to computers and eyeglasses. Complications in fastening arise when the parts fastened together must move or rotate. Most screws, bolts, and nuts obey the right-handed convention for threading; however, for certain applications engineers have chosen to utilize the left-handed thread. Historically, left-handed threads have been used in rotating applications in which the direction of rotation of the nut or fastener is in the left-handed direction, under the rationale that the fastener may tighten with time (i.e. applicable pulleys, propellers, and control rods). The necessity of the left-handed thread in some other applications is not readily apparent. Modern passenger vehicles generally employ right-handed threads on all the wheel's lug nut fasteners. In recent history, many vehicles were manufactured with right-handed lugs on the right side of the vehicle and left-handed lugs on the left side of the vehicle. The modern bicycle remains a predominant example of this same application, whereby the left side of the bicycle attaches the pedals to the crank arms with left-handed threaded fasteners while the pedal for the right foot is affixed using a right-handed fastener. The necessity of these applications is seemingly paradoxical given how the direction of rotation would naturally be assumed to loosen the fastener rather than tighten it. The literature has been reviewed for design guidance in such applications, but an unforeseen lack of explanation resulted. In lieu of applicable literature on the matter, the original event of these design practices is most likely the result of experimental findings and pilot studies. Such design knowledge is therefore understood to be within the experience and practice of weathered engineers. The goal of this paper is to discuss self-loosening mechanisms and to revisit the utility of the left-handed fastener in practical applications.

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II. Background

Examining historical usage of the left-handed thread, common usage is found in several every-day rotary applications, namely left-side bicycle pedals, left grinding wheel in bench grinders, left-handed circular saws, brush cutters, and left-side automobile hubs. While bicycles, bench grinders, and automobiles use right-handed fasteners on the right side, it is standard for contemporary bicycle pedals to have left-handed threads on the left side, connecting the pedal to the crank of the bicycle. On a typical bench grinder, the nut is right-handed on the right side of the grinder viewed from the operator's standpoint, and left-handed on the other side. Contemporary automobiles do not generally utilize left-handed lug nuts primarily due to the locking design of modern lugs; however classic cars frequently do, especially those that use center hub spinners that are applied with a mallet. In these applications, the necessity of the left-handed thread is not readily apparent and can be perceived as counterintuitive or paradoxical. The left side of a bicycle crank turns counterclockwise during forward propulsion, when observing the bicycle from its left side. Since the pedal maintains its orientation with the foot of the cyclist, and therefore the ground, the pedal rotates clockwise relative to the crank. This relative rotation direction is the same as that of tightening for a right-handed thread, and, conversely, is the direction of loosening for a left-handed thread. The same concept applies to the left grinding wheel of a bench grinder, which rotates clockwise when observing the grinder from its left side. In case of the driver's side ("left side") wheels of automobiles, left-handed lug nuts have been used. The wheels on the left side of automobiles rotate counterclockwise during forward movement and likewise the lug nuts do as well. These rotating components are oftentimes critical components. If they come loose or disengage from the machine, they could cause damage to the machine or serious or even fatal injury to users.

III. Self-Loosening Mechanisms

Prior to the 1960's the mechanism of fastener self-loosening was primarily associated with axial vibration. With the advent of Junker's research in 1969 [2], transverse vibration was found to be a much larger factor in causing fasteners to self-loosen. Subsequent research has identified several finer points associated with transverse vibration that cause self-loosening behavior: localized slip on the thread surface [3], slip on the fastener head, fastener bending, angular deformation related to preload, elongation, etc. [4]-[7]. Analytical quantification of these factors is quite complicated, and for the purposes of this technical brief, qualitative descriptions are much more illustrative. When components are joined via threaded fastener, the fastener is turned on one side. As the fastener becomes tight, it not only stretches elastically along its axis, but it also elastically twists. Friction along the thread faces and the fastener head maintains the preloaded deformation (torsional and axial) of the fastener. Upon loading the fastener, several phenomena may occur. Once enough transverse load exists, the fastener can both bend and slide in the transverse direction, overcoming friction, due to differences in size between the threaded fastener and the tapped hole. As soon as slipping occurs in the transverse direction, friction is overcome, and portions of the threads relieve the preload through local slippage. Eventually, through this localized incremental process, the threads work themselves into a loose condition whereby there is little to no preload left.

Current research in threaded fastener self-loosening is examined from the perspective of transverse vibration, frequently via a Junker machine style experiment or through finite element analysis. However, we have not been able to locate scientific research examining the problem of self-loosening from the perspectives of the handed examples provided above. A survey of machine design/mechanism books commonly used in undergraduate courses [8], [9] or even machine design handbooks or fastener handbooks, has found no discussion of the topic of thread selection in terms of handedness and application. A literature search regarding handedness in rotating applications found little scientific data or research regarding the usage, testing, or analysis. Scientific articles discussing left-hand thread usage were found to be scarce, with the search locating four discussions [10]-[13], one of which is a more than 50-year-old automobile wheel study, and two of which are more than 100-year-old discussions of wagon wheel loosening. The only modern reference to the mechanism of paradoxical left-handed self-tightening/self-loosening, as found in wheel hubs and bicycle pedals is found in Wikipedia and lacks reference to scientific publications, providing sources primarily from blogs.

IV. Left-Handed Fasteners on Left-Side Bicycle Pedals

A bicycle's pedal typically has three mechanical components, or equivalent: 1) the foot support, 2) the bearing or bushing set in the foot support, and 3) the partially threaded spindle that mates with the crank. The pedal should rotate freely on the spindle. The force applied to the pedal by the foot is fairly complicated in nature, changing magnitude and direction throughout the pedaling cycle [14], [15].

As an illustrative simplification herein, the foot force of the rider will be considered to be directed downwards (not considering any sort of clips being used) and applied through a limited portion of one rotation of the crank. When considering the force applied to the left side pedal while crank rotates in the counterclockwise direction (CCW) relative to the bicycle, the motion required for forward propulsion in the usual bicycle, the foot force rotates in the clockwise direction (CW) relative to the crank, i.e. the relative direction of tightening for the right-handed fastener (see Fig. 1).

Blogs found on the internet rationalize that, because the rotation of the pedal relative to the spindle which seemingly is the loosening direction for a left-handed fastener, the precession hypothesis is true. The precession hypothesis, a simplified version of the "wabble" hypothesis presented in 1896 [10], indicates that microscopic clearances between the spindle and the crank exist and allow for a rolling motion between the two that generates an oppositely directed relative net rotation, akin to the hypocyclic movement of the planets in a planetary gear set or to the Spirograph toy (see Fig. 2).

The precession hypothesis describes relative motion inside the tapped hole of the crank: the pedal spindle is required to pivot off-axis about the center line of the tapped hole and the outer edge of the crank, so that the outer edge of the spindle is contacting the tapped hole on the downward side, while the inside portion of the spindle has contact on the upper side. Once the spindle has stopped the local slipping required to move, friction is again holding the threads in place, but, the force changes direction and the spindle threads continue to slip within the tapped crank. As the crank rotates, the downward side rotates with it. This causes the threaded spindle to roll within the crank. This relative rolling action is in the counterclockwise, i.e. the tightening direction of a left-handed thread. This phenomenon, identified by the internet as mechanical precession, or cited to the same internet sources as "fretting induced precession," is governed by thread/nut contact forces and does not depend on inertial effects. However, to date, no formal studies have been found in scientific literature to support this hypothesis.

In automobile wheel hubs and wagon wheel hubs, e.g. [10]-[12], there is not always an obvious force present that is analogous to the cantilevered foot force acting on a bicycle pedal's spindle that can be used to justify the wabble hypothesis in those applications. In studies of automobile wheels [12], tests of cars with all right-handed lug nuts were found to loosen on the left side only if the nuts were finger tightened, not tool tightened, and in these situations the hubs wore out and came around the nuts before the nuts fully loosened.

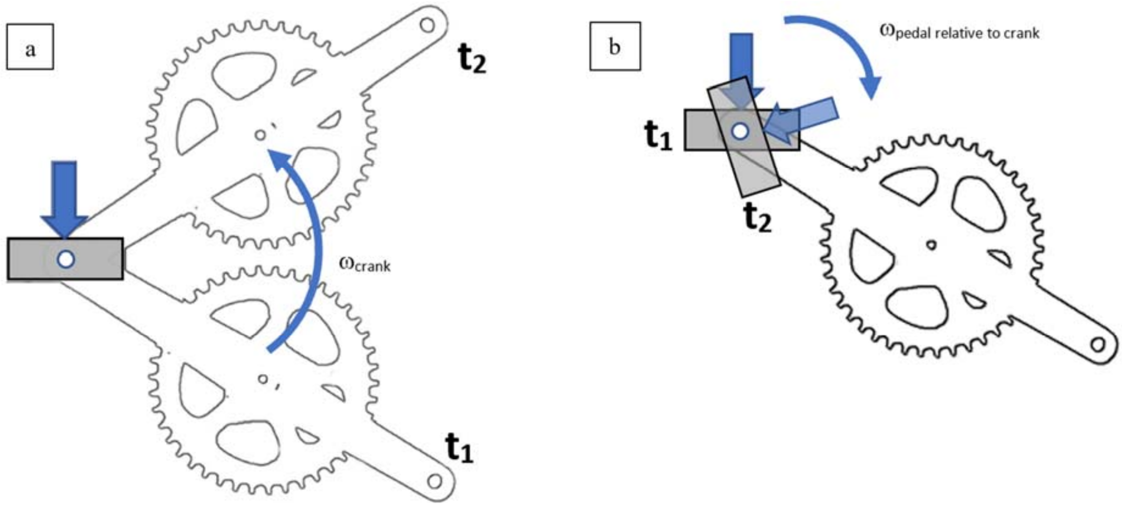

Fig. 1 (a) Bicycle crank shown from the left side of a bicycle from the perspective of the pedal in two successive instants in time, t_1 and t_2. (b): Bicycle pedal shown from the crank perspective at two instants in time, t_1 and t_2. Because the force and pedal maintain orientations within the bicycle reference frame and the crank rotates CCW relative to the bicycle, the pedal and force rotate clockwise relative to the crank, the apparent tightening direction of a right-handed fastener

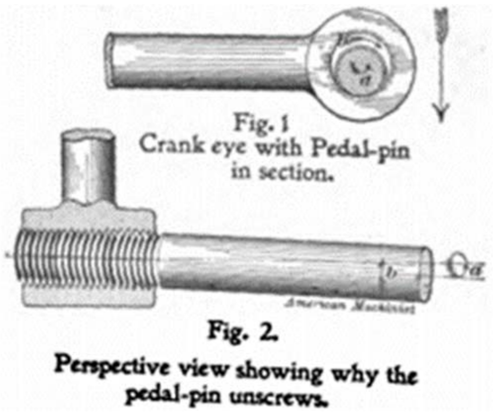

Fig. 2 Reproduction from [10] (1896) illustrating the wabble hypothesis

V. Left-Handed Fasteners on Bench Grinder, Circular Saw, and Brush Cutter

The mechanisms of vibration loosening that affect the mechanical integrity of several rotating machines used in manufacturing and agricultural applications are reviewed. In particular, the machines considered in this section are bench grinders, circular saws, and brush cutters. On a typical bench grinder, the grinding wheel on the left side of the grinder, as viewed from the operator's standpoint, is secured using left-handed threads. The left grinding wheel rotates towards the operator, i.e., clockwise, and the tightening direction of the nut is opposite. Similarly, in the case of circular saws and brush cutters the nut always tightens in the opposite direction of the saw blade's rotation. This tightening direction comports with the typical thought process when considering the relative angular accelerations of the grinder disc.

Another important self-loosening mechanism which affects the structural integrity of the fastened rotating machines discussed in this section is the inertial torque developed as a result of the spindle's angular acceleration. In these applications spindle acceleration occurs mainly during machine start-up. For the bench grinder left-sides' CW accelerating spindle, the inertial torque of the nut and the grinder disc on the spindle are in the CCW direction. Because the inertial torque is CCW, this is the tightening direction for a left-handed thread. Accordingly, a left-handed thread is also found on left-handed circular saws and brush cutters. This situation is not analogous to the bicycle pedal, however. In the bicycle pedal, the external foot force rotates the left pedal in the relative CW direction and imparts a CW torque on the pedal spindle by friction, whereas in bench grinder case, the inertia of the disc and the nut impart a CCW torque on the CW rotating spindle.

VI. Left-Handed Fasteners on Vehicle Lug Nuts

As recently as the 1950s/60s it was not fully understood by researchers why wheels had left-handed threads on the driver's side wheel lugs. White's work provides insight into this phenomenon by testing automobiles with left and right-handed threads to determine if left-handed threads on the driver's side improved the performance of the lugs [12]. White found that all lugs that were sufficiently tightened (tool fastened as opposed to finger tight) tended to remain on cars that were towed or driven for a mile. Right-handed lugs that were finger tightened, or less, were found to self-loosen on the driver's side after only a few miles. In some circumstances the whole wheel came off due to hub failure inspiring the researchers to switch to towed vehicles, as opposed to driven vehicles since complete loss of control occurred when the front wheel detached. The researchers also found that left-handed finger tightened lugs on the driver's side of cars self-tightened after being driven. A qualitative scheme of the rotating forces acting on the lug nuts on the driver's side is shown in Fig. 3. The same finding applied to right-handed finger tightened lugs on the passenger's sides of vehicles. In [12], once lug nuts were loosened, the wheel wore out and could come off, even with the nuts still in place. However, it is unclear if modern lug nuts' tapered portions alleviate this fast-acting wear that could develop after driving short distances with loose nuts, or if the "precession" hypothesis initiated the development of the modern tapered lug nut design. In [16], the loosening mechanism for a rotating disk connected to a shaft by lugs fastened with tapered nuts subjected to a rotating bending force was studied. It was found that the fastener loosening mechanism is affected by frictional torques developed on the thread and nut bearing surfaces as well as by the location of the high pressure contact area (Fig. 3) between thread and nut. Of interest in this review, [16] showed that depending on the location of the high pressure contact area relative to the vertical centerline through the lug (Fig. 3), the tapered bolt could both loosen *and* tighten such that after one full revolution of the disk no net relative unscrewing of the nut takes place.

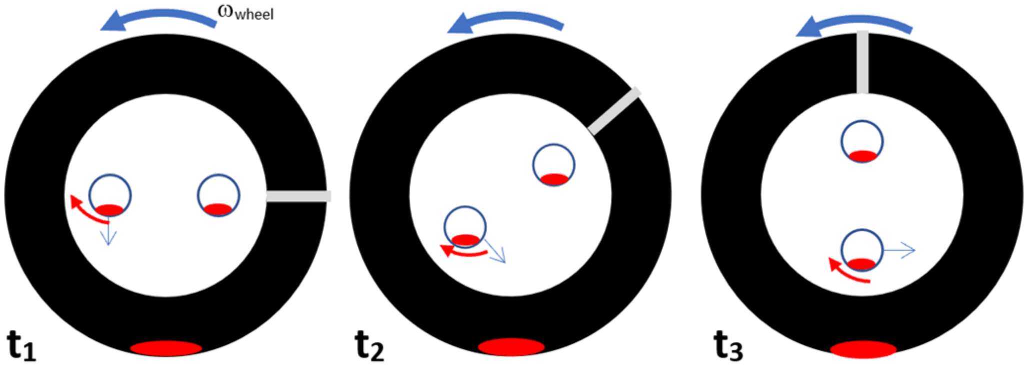

Fig. 3 As a left-side wheel with two lugs rolls forward the high pressure contact area resulting from the weight of the car (solid ovals) rests on different parts of the wheel if no lug nuts are present for simplification, as indicated in these three successive instants in time. The contact patch on the idealized tire is also shown as a solid oval at the bottom of each tire. One arrow and a fiducial mark on the tire are included in each instant to track wheel orientation. Therefore, the weight bearing on the wheel from the lugs rotates clockwise with respect to the wheel, while the wheel itself rotates counterclockwise. Lug nuts, as examined in [12] were simple nuts, unlike modern lug nuts that commonly include tapered portions

VII. Conclusion

The literature relevant to the application of left-handed and right-handed threads in several rotating machines has been reviewed. Scientific literature located in our search did not address the usage of left-handed threads in seemingly paradoxical applications, such as bicycle pedals while aged empirical reviews indicate commonly known advantages in wagon wheels over a century ago. It seems that the paradoxical use of left-handed threads in these historical applications was likely developed through trial and error due to field failures, originating with the attachment of wagon wheels or cart wheels via threaded fastener. Other uses of the left-handed thread are more straightforward and comport with expected behavior, such as in the bench grinder application. Although the precession hypothesis found on the internet appears to be a reasonable explanation, it is not fully supported by published scientific evidence that indicates loosening or tightening may occur depending on the loading conditions. Therefore this paradoxical usage merits a renewed scientific review.

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