

A Comprehensive Review of Wear Characteristics in Chain Sprocket

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Abstract: Driving and timing chains are common machine components that are always being upgraded in terms of wear and energy efficiency. Reduced wear is especially important for timing chains consisting of sprockets, as the chain is crucial to the combustion engine's operation. The present article reviews the study conducted by the researcher over the wear characteristics of chain-sprocket. The classification of all the major elements that can possibly wear in chain sprocket mechanisms like roller, chain pin, sprocket, pin and bush, and linking plate is described in this article. In addition, wear consideration in the design of chain-sprocket consisting formulae and conditions is explained. The methodology to examine the wear in chain Sprocket are different from each other. The present article describes the process to measure the wear in the chain and sprocket. Moreover, the parameter such as preload, heat treatment, material consideration, lubrication, fabrication, wear measurement, and chain wear that influences the wear life is explained.

Keywords: Chain, Roller, Sprocket, Wear.

1 INTRODUCTION

In "power transmission and conveyor systems", chain sprockets engage chain drives. Though sprockets can make an engagement to every material that is perforated, roller chain is the most common application. If the drive is correctly maintained, chain drives can be extremely efficient and reliable in applications with low shock and torque loads. Chain drives can be used to increase or decrease the speed by using sprockets of various diameters to provide a mechanical advantage. Whereas sprockets are similar to gears, the key characteristics are that they never directly engage another sprocket and that their radial projections necessitate a sloping profile for smooth chain contact and disengagement [1, 2].

Sprockets are made up of a disc with radially projecting straight teeth. Sprockets would only operate with chains and other sprockets if the teeth are in the same plane and the shafts are parallel. A chain is a continuous group of links that convey

motion by riding on the sprockets. The teeth of the sprocket mesh with the teeth of a roller chain, delivering rotational energy across parallel axes over long distances. Sprockets contain multiple places of high friction contact with a roller chain, which is necessary for efficient rotation but also quickly wears out the sprocket and roller chain. Lubricated bushings surrounding the pins that the sprocket grasps, and between the plate that connects the chain connected, help to prevent this. A dry sprocket is one that is fixed to a shaft for the purpose of supplying or receiving motion. An idler sprocket is one that is placed in the chain drive for the purpose of stability, chain re-routing, or increased friction [3, 4].

In terms of wear efficiency, the chain joint of "driving and timing chains", consisting of a pin and a bush, is a significant component. Driving chains' lifetime is determined by joint wear. The chain is loaded with a driving torque in a running chain drive, which causes contact forces within the chain joints. The 2 components of the chain joints produce a relative motion whenever the chain travels onto and off the sprocket. When there are vibrations in the slack strands of the chain drive, the same thing happens. The pin and bush of the chain joints wear down at a specific point owing to the contact stress and sliding action. The clearance between the joints is enhanced, resulting in chain elongation. Low-viscosity engine lubricants, for example, have a negative impact on timing chain wear. As a result, better wear behavior is required in order to implement measures that maximize the overall engine's energy efficiency. Reducing friction losses within chain joint, which impact the energy efficiency of the entire chain to a considerable extent, is one of them [5-7]. In relation, certain studies have been conducted that are described in the present article.

According to Nichols (2003), a hybrid sprocket is excellent for replacing high-performance motorbike sprockets that can wear out rapidly when they are lightweight aluminum sprockets. It can be costly to replace the complete sprocket. Steel sprockets, on the

other hand, wear out less quickly, however, are too hefty for high-performance motorcycles [8]. The spacing in the exterior chain parts restricts the transmission's operational fitness, according to research into the wear of roller drive chains. Enhanced transmission performance standards in regard to chain coupling were suggested [9].

Binder and Covert proposed several analytical relationships that may aid in the development of a better understanding of roller-sprocket interaction mechanics. Different relative impact velocity was calculated. Those velocities can be utilized to determine sprocket speed limits based on roller breakage, heating, and sprocket wear using impact energy relations. Certain experimental results on roller breaking were supplied, and it was utilized to demonstrate a data-organization strategy. Impact strength at a specific velocity is related to roller breakage to some extent [10].

In 2015, Danial Sappok et al studied the chain-sprocket joint regarding the reduction of wear. To complete their objective, they measured the wear in the chain joint by measuring the chain's entire length. More extensive data about the wear inside the chain joints was obtained utilizing a supplementary measuring and evaluating technique using a standard roundness tool. Unworn chain joint elements are defined, and wear on worn components was assessed and compared for pins with various surface treatments using this innovative method. In addition, methods for using measurable data in simulation and calculation were discussed [11].

Kavit Shah et al in 2014, the influence of plasma nitriding over the chain-sprocket joint utilized in motorbike by the experimental evaluation technique. According to their claims, it was observed that among all the nitriding methods, the automotive industry mostly use plasma nitriding, since it is administered at a low temperature and hence the sprocket's inherent qualities are not affected. In comparison to typical chain-sprocket assemblies, the wear resistance of plasma nitrided chain-sprocket assemblies is extremely high. The friction created by the chain-sprocket meshing is a key source of concern, as it wastes several of the engine's power. Plasma Nitriding provides a high level of wear resistance, which reduces wear and extends the life of the chain and sprocket when compared to regular

chains and sprockets. Friction loss is reduced, which will increase motorbike transmission efficiency [12].

In the year 2007, P. Sadagopan et al studied the wear characteristics of chain transmission systems utilized in motorbikes along with fatigue influence consideration. Their article presented the technique to reduce the wear of chain-sprocket used in 100 cc motorbikes. The field result was compared with the evaluated elongation in the chain. In addition, the new design was given by them in which numerical evaluation was done for elongation considering the identical condition used in the existing system. Moreover, Using ANSYS and mathematical modeling, the fatigue characteristics were evaluated. They made the remark that a higher endurance limit than operating level stress was observed for all the components leading not to fail [13].

Ryoichi Saito conducted a study in 2018 over fatigue strength and damage for roller chains. The FEM was used to model components of the roller chain in 3 independent states: "press-fitting, static tensile, and sprocket-engaging". The stress magnitude and mean stress of every element were evaluated and plotted on the fatigue limit graph by correlating those states. Also mentioned is the impact of the plastic region on fatigue strength. The findings indicated that fatigue crack formation may occur around the bush's middle inner surface [14]. H. Peeken et al (1985), studied the impact of oil viscosity over the roller chain's wear. The primary intention of the study was to display the experimental results that show the impact of various lubrication conditions on roller chain wear. The different volumes of lubricant, applicator, the viscosity of oil, and anti-wear additives were evaluated. They concluded that the supply of the oil must be inside the drive where the slack span leaves the driving sprocket [15].

G. K. Ryabov and M. A. Seledzhieva (2013) gave constraints for the design of chain-sprocket drives formulation. The mathematical expression of criteria for ensuring a chain's wear resistance, provision for fatigue resistance of chain leaves, roller, and bushing, removal of seizing and progressing wear in links, assurance of the necessary sprocket angle of engagement, and structural constraints were given [16]. S. A. Metil'kov and V. V. Yunin (2008) studied the impact of wear of roller chains over the fitness of transmission. The spacing in the exterior chain parts limits the transmission's operational fitness, according to research into the wear of roller drive

chains. Enhanced transmission performance standards in regard to chain coupling was suggested [17].

2 CLASSIFICATION OF WEAR IN CHAIN-SPROCKET ELEMENTS

Chain elements wear out over time, and the extent of wear can be utilized to determine when a chain should be replaced. There are different small to large elements in which the wear can be aroused. The wear in major elements is discussed in the present section.

2.1 Wear in Linking Plate

Interaction with the load and casing wears down the undersides of link plates. Communication between the inner and outer link plates, as well as the inner face of the inner links and the sidewalls of the rollers, causes wear. Figure 1 represents the wear in linking plates. When a lateral type of load acts over the chain, equation (1) is used as a guideline for replacement, whereas the guide rail is in contact with the link, equation (2) is used as a guideline for replacement [18, 19].

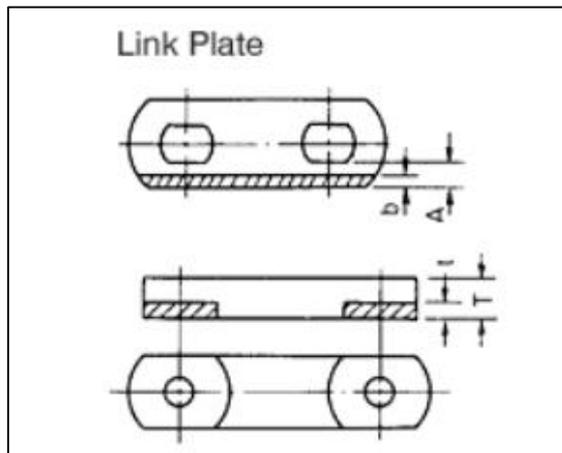


Figure 1: Linking Plate

$$t = \frac{T}{3} \quad (1)$$

$$b = \frac{A}{2} \quad (2)$$

2.2 Wear in Bush and Pin

Chains flex at the point wherein they meet sprockets, creating slide wear among pin and bushing (Figure 2) leading to extension in pitch. When the cross-section area of a pin is reduced to half, it is at fracture risk. Under such circumstances, equation (3) is used as a guideline for a replacement for the materials that are carburized along with inner diameter's wear is reached to 0.025b. Whereas for tempered/hardened materials, equations (4) and (5) are used [20-22].

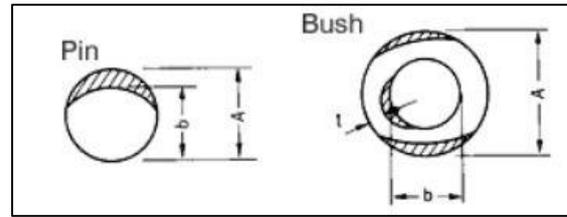


Figure 2: Bush and Pin

$$\frac{b}{A} = 0.975 \quad (3)$$

$$\frac{b}{A} = 0.85 \quad (4)$$

$$t = (A - b) \times 0.5 \times 0.4 \quad (5)$$

2.3 Wear in Roller

As the wear on the "R-type and F-type rollers" (Figure 3) rises, the frictional resistance against the link plates and rails rises, generating chain tension. That scenario will be used as a benchmark for replacements. The limitation of usage for S-type rollers is achieved whenever the roller gets pitted or cracked [23].

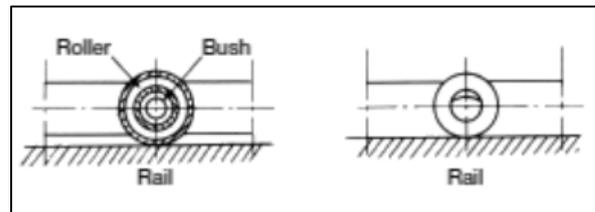


Figure 3: Roller

2.4 Extension in Chain Pin

The wear to "chain bushes and pins" over time leads the chain to extend, causing it to run poorly on the sprockets. As a result, when pitch extension exceeds 23 percent of the standard dimension, it's necessary to replace them. As illustrated in figure 4, take measurements of the chain across 4 or even more links [24, 25].

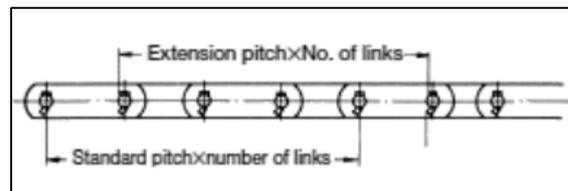


Figure 4: Chain bushes and pins

2.5 Wear in Sprocket

As the wear in sprocket (Figure 5) progresses, it approaches the state depicted in the figure, causing the chain roller to snag in "area (A)", causing it to wrap all-around rollers. Wear at the base of the tooth varies depending on the chain's speed and size, however when wear exceeds 3-10 mm, the sprocket must be replaced or fixed [26].

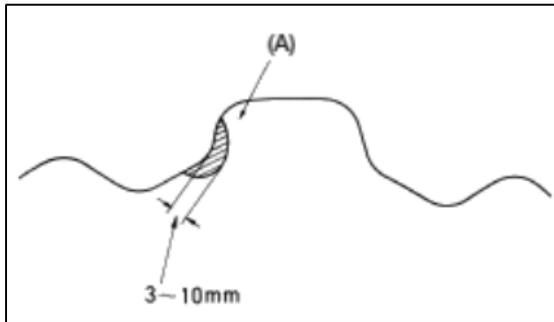


Figure 5: Sprocket

3 WEAR CONSIDERATION IN DESIGN OF CHAIN-SPROCKET

When present methods for choosing the number of sprocket teeth (ST) and chain pitch are utilized, the best driving indicators are not always guaranteed [27, 28]. Many critical factors of a "chain-and-sprocket drive (CSD)" are allocated using approximation formulas and conditionally adopted coefficients, that determine the drive's reliability and overall cost [29, 30]. Furthermore, the required chain service life, clearance constraints, and other critical considerations are ignored, leading to a decrease in CSD quality and unnecessary chain usage. Methods for predicting the probable service life of CSDs are available [31, 32], and the use of "nonlinear programming" of the drives (NPD) ensures the ability to choose appropriate parameters while taking into account individual drive needs. In this context, optimization of CSD parameters utilizing NPD approaches becomes necessary [33]. The parameters that ensure the drive's serviceability in terms of the basic factors that affect the majority of CSD are the chain's wear resistance, the leaves' fatigue resistance. This section covers the wear resistance criteria. The annotations used in the equations are described in table 1.

Table 1: Annotations

Annotation	Description
t	Chain pitch (mm)
a	Number of rows
z_1	Number of teeth of driving sprocket
n_1	Rotational speed of driving sprocket (rpm)
u	Gear ratio
A	Interaxial distance (mm)
δ	Angle of Incline
P	Power transmitted (kW)
L_h	Service life of chain

The degradation curve, which is derived with an account of the pressure p (Pa) and slip velocity V_{sl} (m/sec) in the chain links, will determine the wear resistance of the chain I_N (mm/cycle) [33]. The expression obtained is

$$I_N = \frac{3.05 \times 10^{-2} P^2}{z_1^2 t^4 K_a^2 (1 + \frac{1}{u^2})^{-1}} \quad (6)$$

Here, K_a is an assignable factor as a function of "a". Furthermore, $N = [\Delta t_c] / I_N$ is the total number of chains and $n_t / (60 z_1 n_1)$ is single run time, the determination of chain's longevity in h can be given as:

$$L_h = \frac{[\Delta t_c] n_t}{60 z_1 n_1 I_N} \quad (7)$$

Here, $[\Delta t_c]$ refers to permissible limit wear (in mm) and $n_t = \frac{2A}{t} + 0.5(1 + u)z_1 + 2.5 \times 10^{-2}(u - 1)^2 z_1^2 t / A$ represents the links in the circuit of the chain.

Substituting equations (6) and (7), the expression obtained is [34, 35]

$$L_h = \frac{0.55 [\Delta t_c] n_1 z_1 t^4 (u^2 + 1)^{-1} K_a^2}{n_1 P^2 u^{-2}} \quad (8)$$

The equation for the permissible limiting wear can be expressed as:

$$[\Delta t_c] = \frac{K_0 t}{z_2} = \frac{K_0 t}{u z_1} = K_1 t \quad (9)$$

Here K_0 is a coefficient based on sprocket fabrication accuracy.

Based on the study of (reference), $K_0 = 0.8, 0.8,$ and 0.18 for precision groups "A, B, and C sprockets", respectively. The bushing's strength condition $[\Delta t_c] \leq (0.03 - 0.05)t$ limits the $[\Delta t_c]$, therefore the following assumptions can be made:

$$K_1 = \min\left\{\frac{K_0}{u z_1}; (0.03 \dots 0.05)\right\} \quad (10)$$

Taking into account the drive's lubrication and dust load.

$$L_h = \frac{0.55 K_1 n_t (u^2 + 1)^{-1} K_a^2 z_1 t^5}{K_2 n_1 P^2 u^{-2}} \quad (11)$$

Here, K_2 is the coefficient for dust in the air (g/m³) [36],

"In order to ensure the chain wear resistance, the inequality $L_h - L_{hT} \geq 0$ must be satisfied, where L_{hT} is the required service life of the chain in h."

4 MEASUREMENT OF WEAR

The methodology to examine the wear in chain Sprocket are different from each other. The present section describes the process to measure the wear in a chain as well as a sprocket.

4.1 Chain Wear

As shown in figure 6, the procedure commences with measuring length M in mm. The equation (7) can be

used to compute the % extension. The number of measured pitches is represented by X and Pitch is represented by P. When the percentage extension exceeds 2%, the chain's usable life is typically finished, and the chain is substituted (1 percent for extended pitch chains). The rejection limit is lesser for drives without a provision for adjustment, depending on speed and configuration [37].

$$\% \text{ extension} = \frac{M - (X \times P)}{X \times P} \times 100 \quad (12)$$

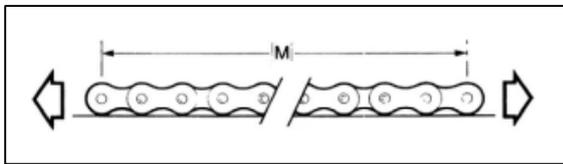


Figure 6: Chain wear measurement

4.2 Sprocket Wear

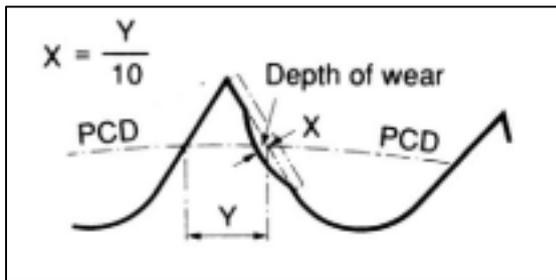


Figure 7: Wheel wear measurement

The extent of wear (Figure 7) that has developed can be determined by looking at the tooth flanks. This will show up as a polished worn stripe around the pitch circle diameter of the sprocket tooth in typical circumstances. If indeed the depth of the wear has reached 10% of the 'Y' dimension (as shown in the figure), the sprocket should be replaced. Placing a new chain on sprockets with this much tooth wear will lead the chain to wear out quickly. It should be remembered that the extent of wear at 'X' would not manifest until numerous chains are used in normal operating conditions with proper lubrication [38].

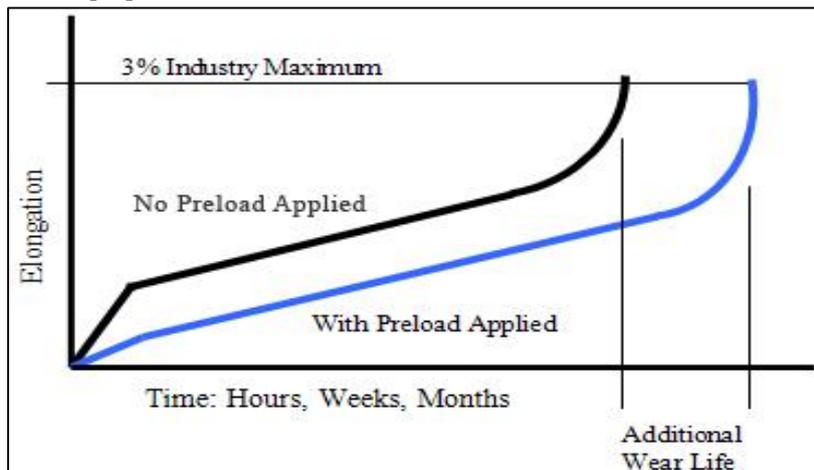


Figure 8: Preload Curve

5 WEAR LIFE

Chain sprocket drives are among the most common power transmission and product conveyance methods in the industry. Because chain sprocket drives are so frequently utilized, their performance has a big impact on productivity. A Roller chain that is subjected to premature elongation because of excessive wear and must be changed on a regular basis will reduce productivity and raise operating costs. This section would provide information in a manner beyond the basic aspects that lengthen chain sprocket wear life, such as lubrication and routine maintenance, to certain other factors including roller chain component part production, preparations, and assembling. Factors that must be considered in order to get optimal wear life [39].

5.1 Preload

After the chains have been assembled, a preload is applied to them. This preloading is close to the maximum load that should be used in service. Preloading can be accomplished in two ways: "statically and dynamically". The different chain elements, such as pin, bushing, and link plate, are preloaded as a final alignment. Preloading aims to minimize premature elongation, which is common in lower-quality chains. The removal of this early elongation can extend the useful service life. The Preload curve (Figure 8) depicts the advantages of preloading in terms of increased wear life. During the start point of the drive, the chain without any or little preload will experience substantial elongation before levelling off. The chain would then extend at a constant rate till the worn components' case hardness is lost and the chain undergoes fast elongation [40].

5.2 Chain Wear

A chain is made up of a set of linked journal bearings that rotate as they approach and exit sprockets. The "pins and bushings" wear out as a consequence of this articulation. The chain will progressively lengthen (Figure 9) as the material on these surfaces wears away. During drive operation, elongation owing to wear is a common occurrence. Various factors influence the wear rate, including "lubrication, load, and the frequency and degree of articulation between pins and bushings". The pins and bushings, which are crucial wear components, must be manufactured with extreme precision. Beginning with correct material selection, part manufacture, and part preparation before to and including assembly. These are all important factors in obtaining peak performance. Regardless of other considerations, the roller chain's wear life will be shortened if the wear components are of poor quality [41].

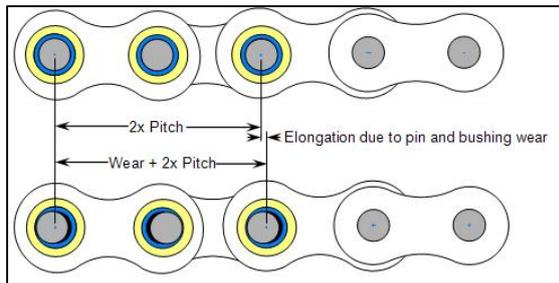


Figure 9: Chain Wear

5.3 Heat Treatment

The heat treatment of the wear elements is an essential characteristic of achieving maximum wear life. Heat treatment can change the mechanical and physical properties of worn elements that much if done incorrectly, can cause more harm. To achieve the best outcomes, heat treatment must be completely comprehended and meticulously regulated. This process turns the parts' outsides into a hard, wear-resistant surface while keeping the internal structure strong and ductile enough to sustain normal impact load. "Case hardness and case depth" are the two most important factors to consider when heat treating has worn components. The case hardness and depth must be within a certain limit to ensure maximum wear resistance and longevity. The part becomes fragile and can shatter during operations if the case hardness is too deep. The case hardness will wear away early if the case hardness' depth is too deep, accompanied by quick elongation [42].

5.4 Lubrication

The significance of adequate chain sprocket lubrication and maintenance during operations

cannot be emphasized. Strict compliance to the drive's specifications for lubrication type and procedure will not only prevent wear but also will also provide additional benefits including cushioning impact loads and thermal dissipation. However, lubrication is still only one stage in the process of extending the life of the drive. It will be equally crucial to choose a high-quality chain. There are certain types of lubrication that are represented in Table 2 [43].

Table 2: Classification of Lubrication

Type	First	Second	Third	Fourth
Method	Manual	Drip	Bath	Pump
			Slinger Disc	
Quality	Minimum	Good	Better	Best

5.5 Material

The material's "chemical composition and mechanical characteristics" must meet the chain-sprocket drive's standard standards. In the manufacturing and heat treatment of the components, a high level of attention to detail is critical [44].

5.6 Fabrication

Fabrication of the wear components must be done according to standard standards in order to achieve the correct assembly and performance. Pins are "cold-drawn" via a die, resulting in diameter with extremely tight tolerance limits. The pins are next subjected to a "centerless" grinding process, which eliminates any surface flaws and leaves a "mirror-like" gloss on the surface. This finishing creates a homogeneous bearing area on the face, distributing the load, or bearing stress, uniformly down the pin's length. Furthermore, the pin is uniformly dispersed along its whole length, extending chain life. A grinding operation is also performed on the bushings to guarantee a homogeneous bearing surface. To ensure roundness, stringent tolerances on the bushing's inside and exterior diameters are stipulated. The bushing's roundness is crucial because it provides the most area of contact between the pin as well as the bushing. Any uneven surface in the area of contact would cause the chains to wear faster and last less time [45].

5.7 Wear Measurement

Wear measures can be taken to see if the chain has extended to the point where it needs to be replaced. Roller chain length measurements should be taken while the chain is in strain or tension to achieve reliable results. The equipment must always be

switched off and all safety measures must be followed if the chain is measured while still on the sprockets. The part of the chain with the tightest span should be measured. If the chain has been withdrawn out from sprockets, the ANSI-recommended measurement load should be given to the chain to eliminate any slack [46].

Measure as nearly as conceivable from one pin's center to another's center. The higher the number of pitches (pins) in measurements, the more accurate it is. The chain should be replaced if the measured value exceeds the nominal value by more than the permitted percent. Depending on sprocket design, the maximum permissible wear elongation for most commercial applications is around three percent. The relation $200/N$, where N represents a number of teeth in the large sprocket, can be used to compute the permissible chain wear in percentage for large sprockets with 68 teeth or more. Because of standard maximum permissible chain wear elongation of 3% is only applicable up to sixty-seven teeth in the larger sprocket, this relation is frequently useful [47].

6 CONCLUSION

In the present article, a comprehensive review of the chain-sprocket considering the wear influence is provided. Regular use will cause the roller chain to extend over time, necessitating replacement. Based on its characteristics and usage conditions, each roller chain has an estimated lifespan. Friction is created on the bushings and pins as the chain moves. These pieces will gradually wear down as a result of the friction. The space among the rollers interconnected by a pin link rises as the components wear. Hence, the paper contributes to predicting the conditions of wear exceeding its permissible limit. Moreover, the article tells how to measure the wear in chains and sprockets. The design procedure considering the wear consideration in mind is explained in the detail. All the major aspects that affect the wear or increase and decrease the wear in chain and sprocket are discussed in the present study. Moreover, how to increase the lifespan of the chain-sprocket system considering all major components is explained.

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