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SOLUTIONS TO OPTIMIZE TRANSMISSION CHAINS CHARACTERISTICS

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Abstract: The paper presents a comparative study of design solutions proposed to increase chain reliability, noise reduction while functioning and load, transmitted by some type of chain transmissions. There are analyzed comparatively technical solutions which involve pins construction and their interaction to the connected elements. The possibility to reduce wear and increase the chain load is analyzed also as connected materials type interaction. Main patents characteristics are summarized in a cumulative descriptive table.

1. INTRODUCTION

Chains are reliable machine components, which transmit power by means of tensile forces (Figure 1), and they are used primarily for power transmission and conveyance systems [6].

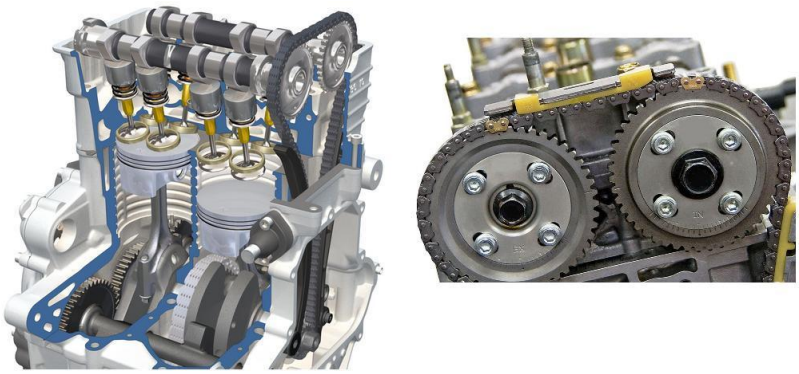

Figure 1. Timing chain gearing in an engine; view and detail [9]

Chain transmission is composed of two or more sprockets (Figure 2), in which one is the driver sprocket, and the other ones are the driven sprockets, and a chain that gears with them. Due to chain gearing on the sprocket, there is no slip present as in belt drives. This leads to a constant transmission ratio.

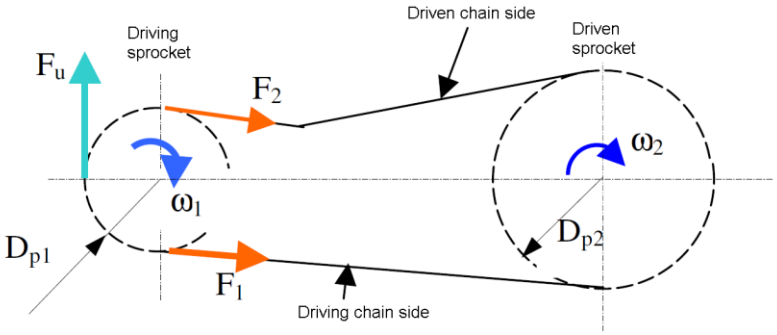

Figure 2. Kinematics of chain drive system

Chain transmission is proper to be used when high torques and constant transmission ratio are demanded. Large center distances can be dealt with more easily, with fewer elements and in less space than with gears. Chain drives have high efficiency. No initial tension is necessary and shaft loads are therefore smaller [7]. The only maintenance required, after a careful alignment of elements, is lubrication.

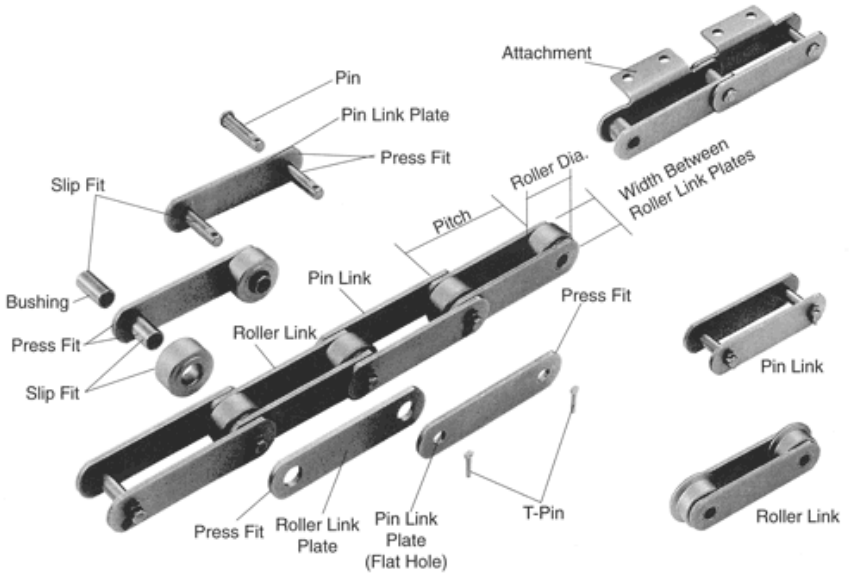

Figure 3. Basic structure of large pitch conveyor chain [6]

Chains are flexible kinematic elements consisting of articulated links (Figure 3). The operation of the chain transmission is based on the engagement of the chain with sprockets provided with special teeth. Chains are used for pulley hoists, in gearboxes for passenger cars and for agricultural machinery. They are used to rise loads (suspend, lift and descend), in traction (move weights in horizontally plane for transport machines) or drive mechanisms (transmit mechanical energy from a shaft to another).

The paper presents a comparative study of different design solutions proposed to increase chain reliability, noise reduction while functioning and load, transmitted by some type of chain transmissions. There are analyzed comparatively technical solutions which involve pins construction and their interaction to the connected elements. The possibility to reduce wear and increase the chain load is analyzed also as connected materials type interaction.

2. COMPARATIVE ANALYSIS OF CHAIN SOLUTIONS

Dynamic automotive components work is based on relative linear or spinning movements in order to transmit torque and power. In this case, the movement is accompanied by friction and wear, producing collateral increase of fuel consumption and noxious gas emission. It was reported that frictional loss was responsible for about 25% of the overall fuel consumption in engines. [1]

Frictional power loss and additional noise are produced by piston assembly movement, by gearbox components, but also by chain power or distribution transmission. The chain is important in automotive industry, providing ignition accuracy and reliability.

The chain design must ensure higher performance in order to transmit power as a silent and reliable product. If comparing the old design of a chain to the modern chain

solutions, we can admit that the basic and classic chain construction is not much modified. The continuous developing of technical knowledge referring to materials, combined with technological processes, lead to higher performances of chains due to modern design knowledge, material sophistication and technological processes. One of the most important technological processes, due to Hans Renold innovative technology, was the centerless grinding of a cold drawn bar to size close tolerances, on round parts, before processing. This early age technology did not reach the best reliability of the chain, comparing to modern chain, causing low strength to weight ratios, non uniform pitch of the links, tendency toward point loading and high bearing pressures, wear and large amount of premature failures. [8] These were the main targets to be solved by modern solution applied to the chain design and modern chain materials or method of construction. [6]

During time, different technical solutions were designed to increase chain load. A very interesting one is described in Maria van Rooij patent (2011) [3], which is proposing a transmission chain with links, coupled by rocker assemblies with each two longitudinal pins which roll over each other, and of which one cooperates in a force transmitting way with the opposite pulleys of a pair of cone shaped pulley sheaves (Figure 4).

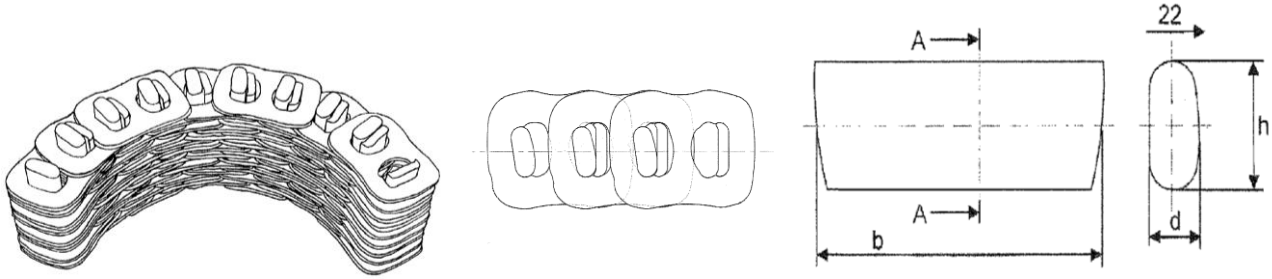

Figure 4. Basic structure of a rocker assembly chain; configuration and details [3]

These pins have a first dimension (b) in the longitudinal direction, a second dimension (h) perpendicular to the first one and to the running direction of the chain, and a third dimension (d) in the running direction (22). For each value of the first dimension (b) both other dimension (h) and (d), respectively are such that the ratio between this dimension (b) and each of the other dimension is taking into account the expected loading of the chain, as small as possible.

More simplified, can be accepted that it is used an alternate reciprocating rolling movement of a curved surface on a planar support. In this case, was excluded the rotating slide, which includes also a contact pressure point which slides. [3] The main application of this solution is to transmit torque, modifying continuously the transmission ratio between two cone pulleys (Figure 5).

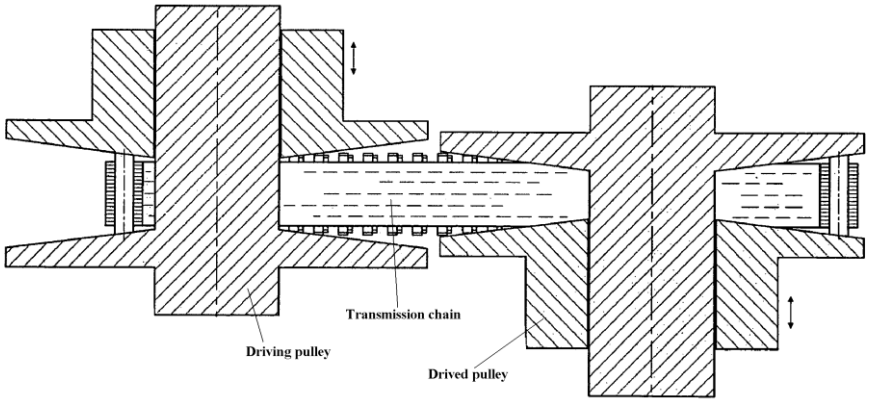

Figure 5. Continuously modifying ratio transmission between cone pulleys [3]

A very old patent (Frank L. Morse, *Drive chain*, 1927) [2] referring to chain design is using the combination of friction joints and antifriction joints, alternatively arranged along the drive chain (Figure 6). The combination of joints provides a grater friction inside of some joints (10 and 13) than the friction of the remainder joints (9 and 12), in order to minimize vibration of the chain and increase chain reliability. In the drive chain, the combination of rocker joints and bush joints, said bush joints being arranged at intervals along the chain, provide practically frictionless contact, alternate to appreciable friction joint. [2] This joint is made by two pin parts which are rolling one (9) against the other (12), providing the minimum friction, and high friction force between the parts (10) and (13) of the second pin assembly. Also, this solution is increasing the load of the drive chain due to rolling contact and zeroed contact friction of the rotating pin to the plate. The load direction will press on a large inner surface of half cylinder pin (13), which is blocked into the plate.

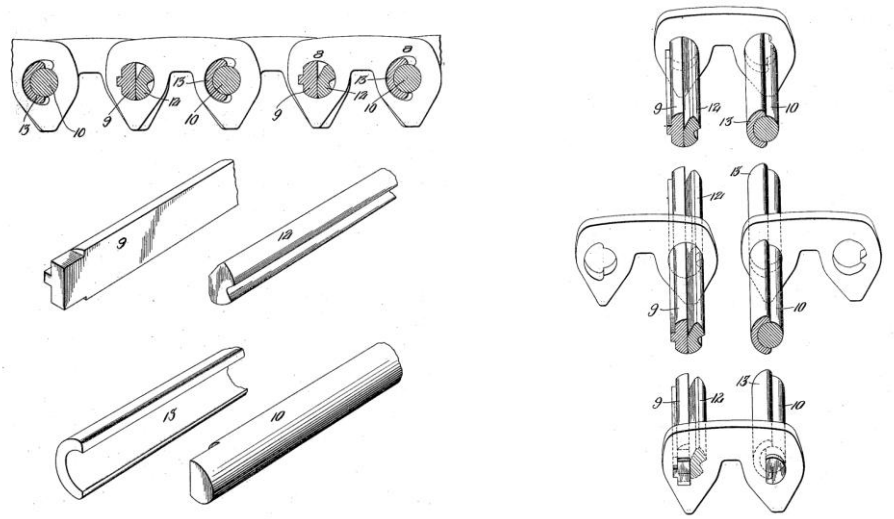

Figure 6. Alternatively arrangement of friction and antifriction joints [2]

So, in this case, there were solved both the load increase and the chain vibration reduction. This solution is very well elaborated, but the technological difficulties restricted the applicability area. [2]

Relatively new solution is minimizing the wear rate and the noise during function. Roger P. Butterfield has patented in 2008 a high performance silent chain solution [5].

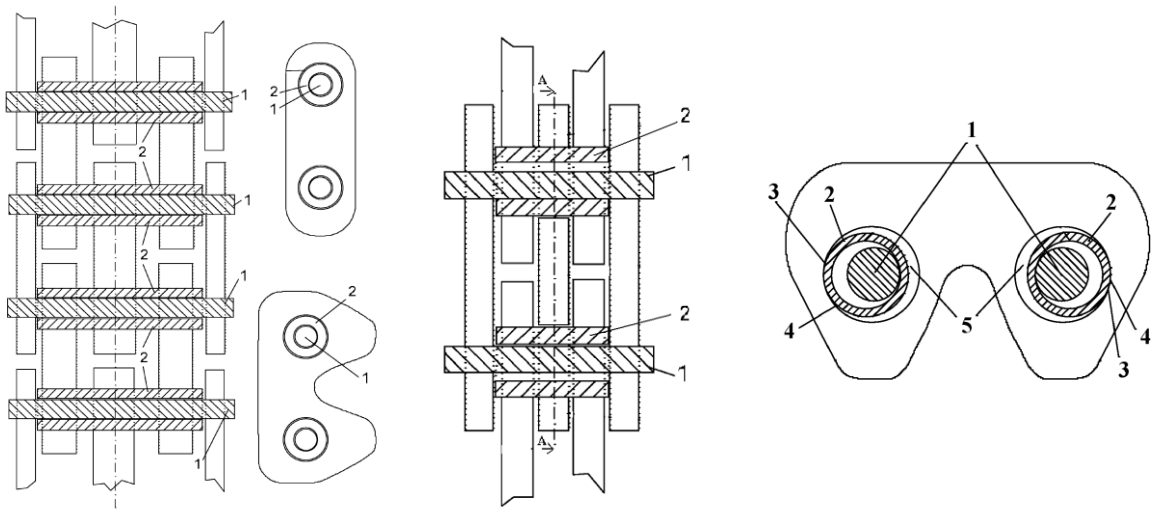

Figure 7. Hybrid roller / silent chain; configuration and detail [5]

He proposed to use a hybrid roller/silent chain, which provides wear resistance, using transverse load bearing elements that allow increased bearing area for the articulating members of the chain, accepting load to be transmitted through both the inside and outside diameter of the element in the same plane (Figure 7).

The transverse load-bearing elements are equipped with bush sleeves (2) and pins (1). These elements are blocked on the extension to the links.

According to this solution, the contact point (3) is rolling together with the connected sleeve (2), around the circular support surface (4). This movement is allowed by the extended clearance (5) between elements.

Philip J. Mott (*Power Transmission Chain with Ceramic Joint Components*, 2006) [4] has patented power transmission chains which are suitable for automotive uses as well as other uses, and which have a reduced susceptibility to wear and corrosion. Such chains are constructed to include a plurality of sets of links joined at overlapped ends thereof by a pivot (15, 16) including at least one ceramic joint component, such as a pivot means (Figure 8) [4]. These chains also include means to drivingly engage sprocket teeth of a sprocket drive in order to increase silent function.

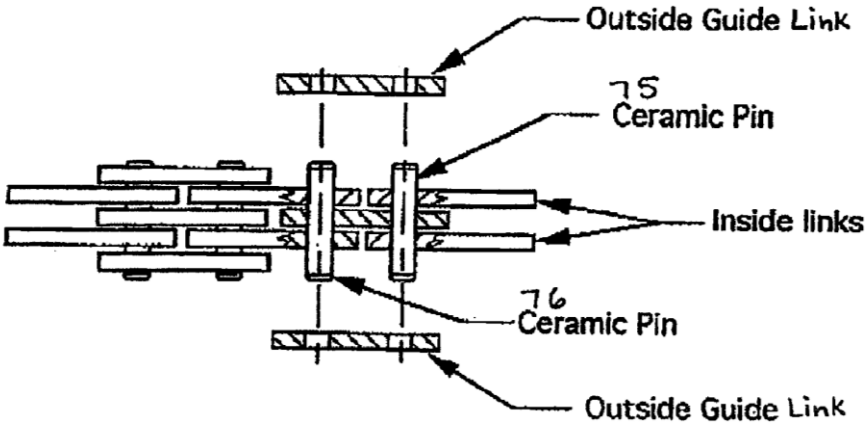

Figure 8. Drive chain equipped with ceramic joint component [4]

The inclusion of the ceramic joint component in the chain in place of steel parts reduce the chain elongation at least about 10% that otherwise would occur if steel parts are used. Using this type of ceramic pin connection, the chain service life can be comparable or even grater than full metallic chains. [4]

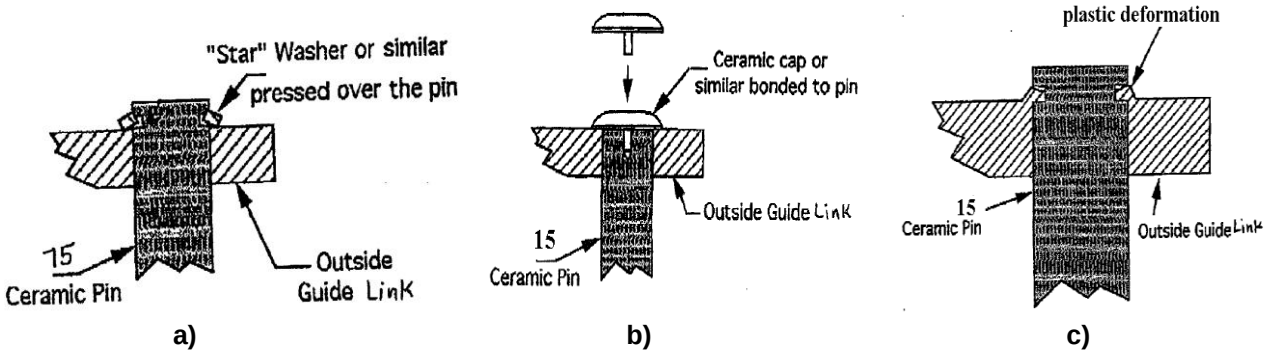

Figure 9 a) Ceramic joint pin-plate-washer assembly;
b) Ceramic joint pin-plate-cap assembly;
c) Ceramic joint pin-plate assembly blocked by plastic deformation[4]

Ceramic pin, used as chain pivot, accept great local critical stress point in an articulated timing chain, exactly in the area where severe radial, axial and longitudinal forces are all focused. Silent chains used in automotive timing application are often subjected to fluctuating loads during operation.

The axial movement of the ceramic pin in the joint can be blocked using either star washer system (Fig. 9a), or ceramic cap bonded to pin butt (Fig. 9b). The ceramic pins can be firmly blocked into the plate if this plate can be cold plastic formed, as shown in Fig. 9c.

The ceramic parts are usually considered as relatively brittle materials as compared to many common metals, but ceramic pins pivot are not functionally compromised due to any embrittlement or cracking when used in automotive timing chains despite the high load environment. [4]

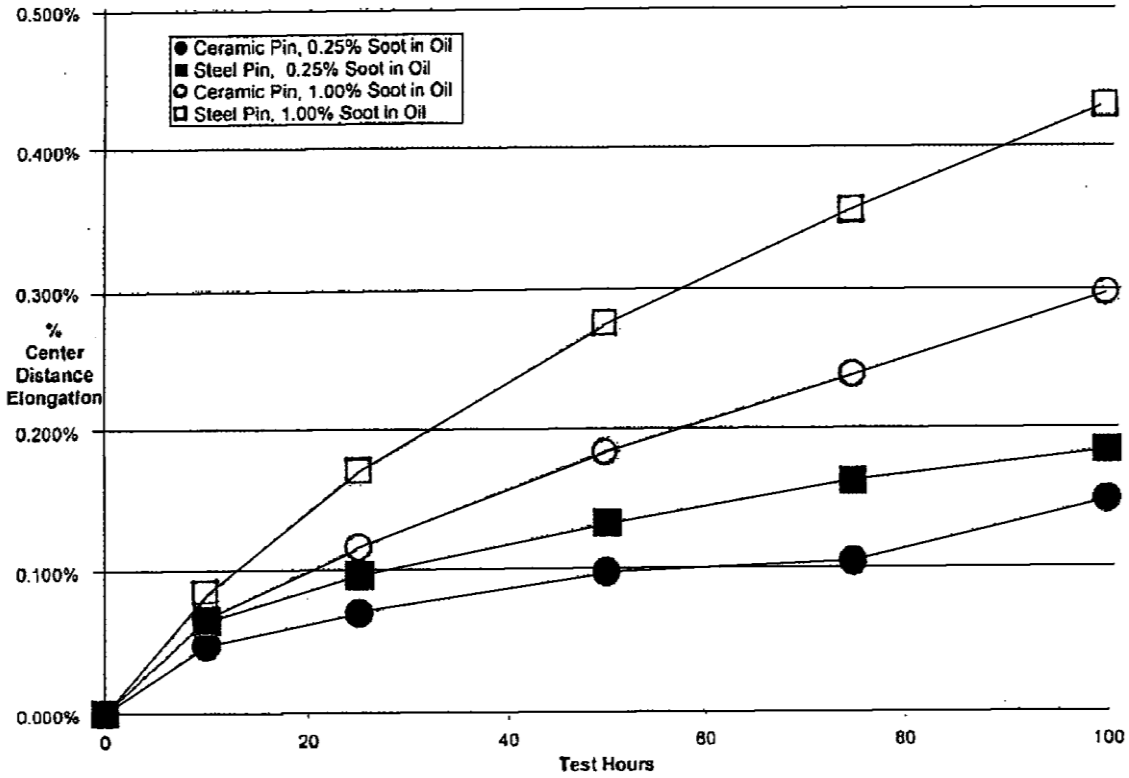

Figure 10. Chain elongation during function – comparison between ceramic and steel pins [4]

The use of ceramic joint reduces the chains susceptibility to wear, corrosion, chain elongation and overload, obtaining a silent system.

The tests were realized accepting that the oil is damaged during function and includes more impurities during time and increase also the acidity, which provides both supplementary wear, added to the local joint area friction. According to the comparative test presented in the patents graph (Figure 10), the percent (%) center distance elongation values measures over a period of test hours for silent chains tested at two different oil soot impurity level, can be observed that the ceramic pin type was more reliable than the steel pin type. Also, it can be observed that if the soot percentage is increasing from 0.25% to 1.00 %, the wear is damaging quicker the contact surface, producing higher wear inside of the pin contact assembly. The data represented in Figure 10, shows that the percentage center distance elongation for 1.00% soot in oil, increases two times compared to 0.25% soot in oil. This instability of chain length requires a system to tension the chain, in order to keep a untivibrating constant load on the driven chain side. In any case, the plates center

distance elongation must be reduced to reach a synchronized movement between driving and driven sprockets at the start and during function.

Table 1 synthesizes the main characteristics of the analyzed patents, including brief description of the solution, the targets that can be reached and some restrictions which limit their applicability.

Table 1. Patent comparison synthesis

Patents	Description	Targets	Restrictions
Maria van Rooij, *Transmission chain*, 2011, US8029398	-rocker assemblies; -roller contact faces; -designed to change the transmission ratio between two cone pulleys; -the pins can slide on the pulley.	-increase chain load; -increase reliability; -designed to be used as transmission chain in speed variators.	-not usable for sprocket drives; -not recommended for timing transmission.
Frank L. Morse, *Drive chain*, 1925, US1651832	-friction alternating to antifriction metallic joints; -rolling contact line inside the combined metallic pin; -expand sliding contact of the low friction pin assembly.	-minimize vibration of the chain; -increase chain reliability; -increase load transmission; -designed to be used as drive chain.	-request of oil lubrication; -technological restriction when manufacturing.
Roger P. Butterfield, *High performance silent chain*, 2008, US7404778B2	-rolling surface, not sliding friction due to clearance inside of combined pin-bush assembly.	-minimize vibration of the chain; -reduce noise; -superior wear performance; -designed to be used as timing chain.	-if unbalanced load, appears tendency to increase wear until a balance is naturally achieved; -technological difficulties to obtain repetitive dimensional clearance.
P.J. Mott et al., *Power transmission chain with ceramic joint components*, 2006, US20060276286A1	-ceramic pins combined with silent chain plates.	-reduce susceptibility to wear and corrosion; -reduce the chain elongation; -stabilize length of chain; -silent function; -designed to be used as timing chain.	-brittleness of ceramic pin joints; -susceptible to crack if shocks appear.

3. CONCLUSIONS

Different technical solutions which involve pins construction and their interaction to the connected elements are analyzed in the paper highlighting their limitations and field of application, in order to find better solutions for strong chain with reduced susceptibility to wear, silent function and stabilized length during function.

Analyzing the patents solutions, it can be observed that if using rolling movement in spite of sliding movement on the contact faces of pins, bushes and plates, the reliability is improved, and wear inside the chain joints decreases. If joint assembly is made from high hardness materials, the system provides a better wear resistance.

Generally solutions accepted to reduce noise are basically the same, using side tooth plates which cover the contact area as a closed chamber. The nature of connected materials is not so important to reach a silent transmission chain. The lubrication is an essential method to decrease wear and noise, and is necessary to find a lubricant providing chemical stability.

The instability of chain length requires a system to tension the chain, in order to keep a untivibrating constant load on the driven chain side. The plates center distance elongation must be reduced to reach a synchronized movement between driving and driven sprockets at the start and during function.

We can conclude that if combining high surface hardness material with rolling movement inside of the pin assembly, the wear will reduce more and the chain reliability will increase.

This analysis is used to develop a reliable new design of drive chain construction. The tests made to get necessary data will be analyzed in order to prove which characteristic is improved and if the solution can be applied on automotive timing chains.

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