Design of constant velocity joint puller for passenger vehicles and light trucks

Projekt ściągacza przegubów o stałej prędkości do samochodów osobowych i dostawczych

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Abstract
Replacing components on an already assembled inertia shaft of a car transmission system can be tedious and detrimental to some components, so using a puller instead of a tool like a hammer can help you get the job done safely and faster. The aim of the study was to evaluate the performance of the designed fixed-speed puller, allowing easier access to the shaft. Based on the geometry of the existing puller, its model was made using the finite element method, and the resulting stress distribution during dynamic loading was investigated. Based on the determined stresses, the components of the puller have been redesigned so that they can safely transmit the stresses that arise while providing sufficient pressure to disconnect the selected elements of the inertia shaft.

Abstrakt
Wymiana elementów na już zmontowanym wale bezwładności samochodowego układu przeniesienia napędu może być żmudna i szkodliwa dla niektórych elementów, dlatego użycie ściągacza zamiast narzędzia takiego, jak młotek może pomóc w bezpiecznym i szybszym wykonaniu pracy. Celem badań była ocena działania zaprojektowanego ściągacza o stałej prędkości, umożliwiającego łatwiejszy dostęp do wału. Na podstawie geometrii istniejącego ściągacza wykonano jego model metodą elementów skończonych i zbadano wynikowy rozkład naprężeń podczas obciążenia dynamicznego. W oparciu o wyznaczone naprężenia elementy ściągacza zostały zaprojektowane tak, aby mogły bezpiecznie przenosić powstające naprężenia przy jednoczesnym zapewnieniu docisku wystarczającego do rozłączenia wybranych elementów wałka bezwładnościowego.

Keywords: inertia hammer, constant velocity joint, driveshaft, puller, stress analysis.
Słowa kluczowe: młot bezwładnościowy, przegub homokinetyczny, wał napędowy, ściągacz, analiza naprężeń

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1. Introduction

Getting rid of bearings and other mechanical parts already secured on a shaft can be a tricky task, even when you know how to do it. For example, the driveshaft subassemblies such as Constant-velocity joints (so-called homokinetic or CV joints) are mechanisms tightly packed that are not easy to peer into it whenever it is necessary. Such joints allow a drive shaft to transmit power under a variable angle, at constant rotational speed, without a significant enhancement in friction or play. They are often applied in front-wheel drive vehicles and all-wheel drive vehicles [1,2]. Also, many rear-wheel drive cars, as well as trucks, comprise CV joints on both ends of the drive shafts (half shafts). Inner CV joints link the drive shafts to the transmission, while the outer CV joints link the drive shafts to the wheels [3]. Most vehicles use a combination of the two joint types including ball ones and tripod ones. The outer joints linking the driveshaft to the wheel, use ball joints. The inner joints linking the driveshaft to the transmission, usually use tripod ones [2]. They are pretty important joints containing multiple rolling elements arranged like a bearing as seen in Fig. 1.

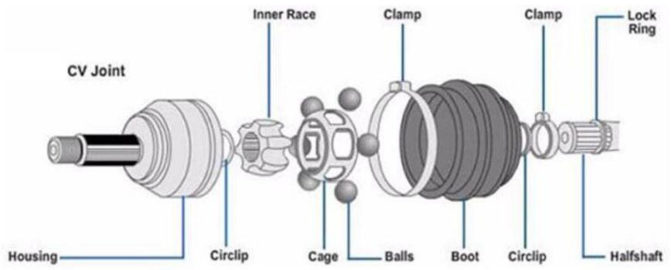

Fig. 1. Exploded view of a CV joint [4].

The smooth operation of CV joints needs lubricating with grease in them. CV joints need to be protected against hazards such as dirt, oil, water, grime, and also against eventual grease leaks. Such protection is provided by the rubber boots keeping debris out. The CV or axle boots made of rubber or plastic usually last a long time without failure. But sometimes due to being hit by debris or age the deterioration of rubber or plastic occur. That can initiate the grease to leak out of the joint and the moisture to get in [5]. Therefore, vehicle's CV boots should be checked periodically for tears or cracks. The failed boots should be replaced and the joints should be simultaneously re-packed with grease. But sometimes despite the lack of boot failure the CV joint can wear out causing an audible grindinga grinding, humming, or clicking noise and feel the vibrations [5].

To get rid of the CV joint from the shaft, it needs a firm hit to free all the components of the joint. A simple way to get it off is just using a hammer to dislocate it, but it is not the best way to do it since it may damage some other parts in the process. That is why it is important to have a specially sized puller for that kind of joint. In that manner, it is already possible to find several systems that were invented in an attempt to have a simple and safe system to pull out different kinds of objects instead of hammering them down. For example, it is fairly easy to find patents, some posted decades ago, showing different puller systems imagined for various purposes such as pulling out bearings [6], or other more general joint systems [7, 8]. In the case of the CV joint puller which is a subject of this paper, after analyzing different systems like a U tool shape [9] that uses a screwing principle to get the joint off or another one, pipe-like [10], that uses a pump principle to apply the force, it has been decided to base our design of the object on a system quite similar to the last one quoted but to better fit it for CV joints. Thus, the object designed is a system based on the pump principle. In order to use such a puller, it is first needed to place the head of the puller on the joint end and make sure it is locked in place. Then, it should be hit repeatedly the end part of the puller where you have a handle with the sliding mass that is free on the beam, to apply the force necessary to dissociate the joint from the shaft.

As the integrity of the puller plays also an important role, it is needed to be sure that the puller resists the shock of the repeated impact of the mass in initial period of utilization, when not all operational conditions are sufficiently recognized. Moreover, it must survive through an acceptable number of cycles without breaking or deteriorating itself too much in the process. While the object might survive the first few cycles it might become unusable or even break completely over the time, it is often said that “fatigue accounts for at least 90% of all service failure” since most systems are used for millions of cycles during their life. As the object is designed for the utilizing in the private services, its durability is predicted rather for the relatively small number of cycles, and the occurrence of a fatigue failure is rather hardly possible.

2. Calculation of force need to remove the cv joint

Any hand tools, especially pullers have to be designed in accordance with the strength of materials rules concerning dynamic loading. To perform any strength calculations, the load that would be applied to the puller has to be determined. It can be assumed that the force, which would act on the puller, is equal to the force needed to disconnect the CV joint. It can be assumed that the force needed to dismantle a joint is equal to the force needed to break out the retaining ring which is locking the joint. Based on the dimensions of an exemplary driveshaft shown in Fig. 2, the model of the retaining ring groove was done.

Fig. 2. The designed CV joint puller in its working position.

Having those data, it was possible to determine the thrust load capacity of the ring, according to the retaining rings catalog [11], which states that '[…] the load-bearing capacity of the assembly depends only on the strength of the shaft and housing materials and is independent of the ring itself.' Coming from that statement the groove's load-bearing capacity was calculated from equation (1).

$$F_{Nr} = \frac{\sigma_y \cdot A_N}{1{,}2 \cdot f_s} \tag{1}$$

where:

σ_y - Yield Strength,

A_N – groove area,

f_s – safety factor.

Groove area A_N can be calculated from equation (2):

$$A_N = 0.25 \cdot \pi \cdot \left({d_1}^2 - {d_2}^2\right) \tag{2}$$

where:

d_1- external diameter of the groove,

d_2 - internal diameter of the groove.

From equation (2) it was obtained that A_N=104.8 [mm^2]. According to the properties of the material for the puller chosen (chrome-plated steel) σ_y equals to 250 MPa. The required safety factor f_s was assumed to be equal to 1.5. The force needed to dismantle a joint was calculated from equation (1) and reached value of F_{Nr}=17466.7 [N]. Except for circular section retaining rings, some of the car manufacturers implement Seeger rings for the purpose of locking the cv joint. Driveshaft puller has to be a universal tool for most of the car models maintenance, therefore it is necessary to check if the puller will be able to dismantle the kind of cv joint with Seeger ring. To do that, equation (3) from the Seeger ring catalog [12] was used.

$$R_s = \frac{A \cdot D \cdot T \cdot S_S \cdot \pi}{S} \quad (3)$$

where:

A - shape factor of retaining rings,

D - shaft diameter,

T - ring thickness,

S_S - strength in shear of ring,

S - safety factor.

After substitution of all the factors in equation (3) based on the catalog [12] the force R_s reached a value R_s=12047.2 [N]. Having the force that puller should exert on the joint for two variants of the rings, the force that the real puller is able to generate has to be determined. The kinematic diagram of the puller work is presented in the Fig. 3, where:

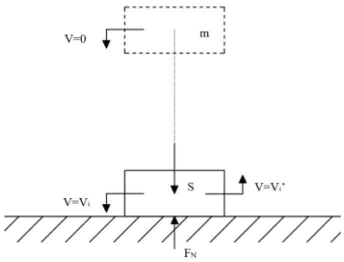

Fig. 3. Mass m impact diagram. v_i – velocity before impact, v_i' – velocity after impact, m – mass of the hammer, S – impact force, F_N – thrust force.

The thrust load has to be considered as an impact force. Coefficient of restitution denoted ask was determined from equation (4).

$$k = \frac{V_{i'}}{V_i} \quad (4)$$

The impact of the force S can be obtained from equation (5).

$$S = \int_{t_1}^{t_2} F_N \, dt \tag{5}$$

Assuming that force F_N remains constant during the impact, equation (6) holds.

$$S = F_N \cdot (t_2 - t_1) \tag{6}$$

Assuming that impact time T can be expressed by equation (7):

$$T = (t_2 - t_1) \tag{7}$$

Equation (6) can be rearranged to the form (8).

$$S = F_N \cdot T \tag{8}$$

An increment of mass m momentum ΔQ (due to the impact) is denoted as in equation (9):

$$\Delta Q = m \cdot (V_i - V_i') \tag{9}$$

Therefore, equation (10) holds.

$$S = m \cdot (V_i - V_i') \tag{10}$$

From equations (8) and (10), equation (11) is given:

$$F_N \cdot T = m \cdot (V_i - V_i') \tag{11}$$

Thus the force F_N is obtained from Equation (12).

$$F_N = \frac{m \cdot V_i \cdot (k+1)}{T} \tag{12}$$

For the reference puller for this research mass m of the hammer equals to 5 kilograms. Due to that hammer is driven by the human arm the impact velocity v_i can be assumed to be equal to 20 m/s. Value of the restitution coefficient k (steel to steel) equals to 5/9. For the impact time T=0.01s, thrust force F_N equals to F_N=15555.6 [N]. Then $F_{Nr} > F_N > R_s$. The forces needed to disconnect a joint are different for different kinds of rings – one being greater than the force exerted by the puller and the second one weaker. However, the determination of the force F_N was based on a few assumptions and approximations. For example, the velocity of impact could be increased easily, due to that, the chosen value is not a maximal value for a human to move his arm. From that can be concluded that the force that puller of such a design will be enough to disassemble drive shaft.

3. CAD 3D project of the puller

The 3D geometrical model of the puller was created using commercial software Autodesk Inventor, as seen in Fig. 4.

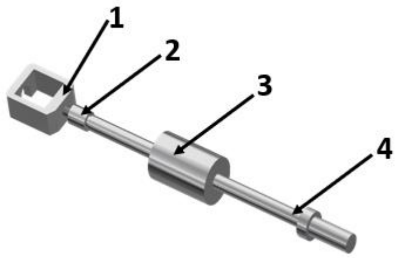

Fig. 4. The geometrical model of the designed puller.

This model comprises 4 distinctive parts including 1 - Adaptor, 2 - Reducer, 3 - Mass, 4 – Beam & Handle. To allow the performing of the analysis on stress distribution in such a model, the material has been first chosen. It was decided to take into account chrome-plated steel, due to such a steel provided necessary durability and hardness, a corrosive resistant surface, and a smooth surface easier to clean.

4. Stress analysis

The set of the mentioned four parts was fixed on the surface chosen belonging to the adaptor 1 (Fig. 4). The mass 3 was displaced to its bottom extreme position, where bottom front plane came into contact with the front plane of the fandle 4 (Fig. 5). In such position the opposite front plane of the mass 3 was loaded by the force F_N equal to that calculated from Equation (12).

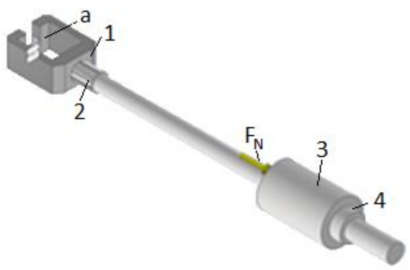

Fig. 5. The boundary conditions for the model of the designed puller.

The finite element grid generated (Fig. 6) included tetrahedral ones with four nodes. Each node possessed three degrees of freedom in the form of displacements u_X, u_Y, u_Z along the corresponding axes X, Y, and Z of the Global Coordinate System chosen. The average size of the finite element corresponding to the 0.01 of the overall dimensions of the considered volumes along the X, Y, and Z axes.

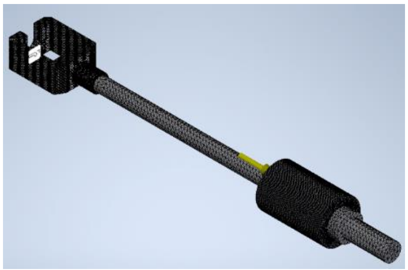

Fig. 6. Grid of the finite elements.

From this, the von Mises stress distribution was obtained. Then the Safety Factor, related to the Von Mises Stresses σ_{VM} and materials' Yield Strength σ_Y was calculated from Equation (13). Based on the values of such a factor, it could be coarsely determined, if the part analyzed might be subjected to failure or not during its lifetime.

$$Safety\ factor = \frac{\sigma_Y}{\sigma_{VM}} \tag{13}$$

Assuming that Yield strength reaches value σ_Y=250 MPa, it was obtained simultaneously the von Mises stresses and safety factors distributions for each object studied. Thanks to that, it was easy to check which part was subjected to the highest stress and needed to be redesigned. The von Mises stresses were presented in figure 7 for the Adaptor and in Figure 8 for the Reducer before their redesigning. The corresponding values of safety factor were presented in figure 9 for the adaptor, and in figure 10 for the reducer.

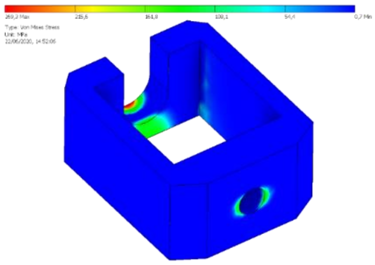

Fig. 7. Von Mises stresses for the Adaptor before redesigning.

Before redesigning of the adaptor the von Mises stresses obtained reached value of up to 270 MPa.

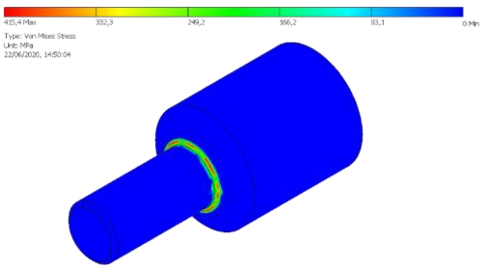

Fig. 8. Von Mises stresses for the reducer before redesigning.

Before redesigning of the reducer the von Mises stresses obtained reached value of up to 416 MPa.

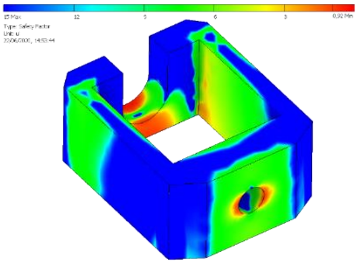

Fig. 9. Safety factor for the adaptor before redesigning.

The min. value of the safety factor for the adaptor before its redesigning was 0.92.

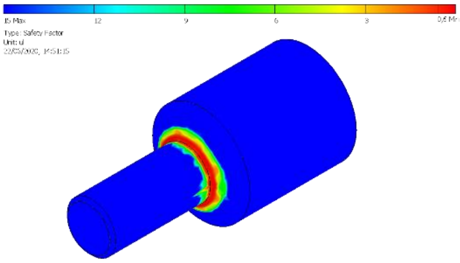

Fig. 10. Safety factor for the reducer before redesigning.

The minimum value of the safety factor for the reducer before its redesigning was equal to 0.6. It was obtained that, 2 parts are in need of redesign since they have a safety factor under 1 in some places. After redesigning of the adaptor and the reducer involving the introduction of additional chamfers the values of safety factor were shown in figure 11 for the adaptor and in figure 12 for the Reducer.

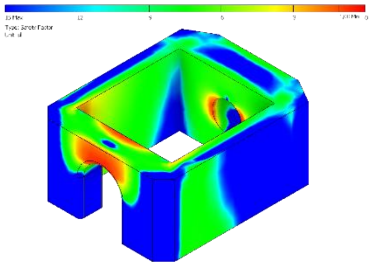

Fig. 11. Safety factor for the adaptor after redesigning.

The minimum value of the safety factor for the adaptor after its redesigning increased 1.08.

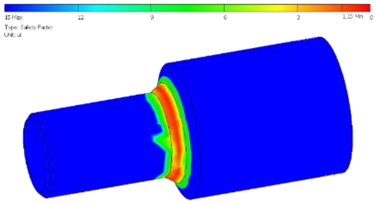

Fig. 10. Safety factor for the reducer after redesigning.

The minimum value of the safety factor for the reducer after its redesigning enhanced to 1.15. After redesigning the Safety factor values for both the adaptor and the reducer and thus the whole system have become acceptable.

5. Summary

The newly designed puller could be a very attractive alternative to some other existing products that aren't made especially for CV joints. In addition to the improved durability from the redesign and general ease of use of the object, the puller is a cost effective device possible to be produced in large quantities. Although it could be more durable than usual, and already available systems if one or more of its components are damaged it can be easy to replace them separately avoiding throwing away the whole system since it can be dismantled and assembled together again.

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