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FINITE ELEMENT ANALYSIS OF A LONGITUDINAL TRANSMISSION SYSTEM

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ABSTRACT

This paper addresses how a longitudinal transmission system of a car could be analyzed using Autodesk Inventor software. The longitudinal transmission, also known as a driveshaft or cardan shaft, is a system used in rear-wheel-drive or all-wheel-drive vehicles where power is transmitted from the engine to the rear axle or to both axles. During the operation of the longitudinal transmission, various loads can lead to the wear and tear of the universal joints, resulting in failures or even the destruction of the system. To prevent these issues, we considered it necessary to analyze the modelled driveshaft using Inventor based on von Mises stresses and the safety factor. The material used in this study is a cast steel with the following properties: Mass Density 7.85 g/cm³, Yield Strength 250 MPa, Ultimate Tensile Strength 300 MPa, Young's Modulus 210 GPa. The results obtained for different angles of inclination of the universal joint axes lead to the conclusion that the positioning of the driveshaft significantly influences the durability of the longitudinal transmission system.

KEYWORDS: cardan transmission, solid modeling, von Mises stresses.

1. INTRODUCTION

Universal joints are mechanisms used to transmit rotary motion between two intersecting shafts, typically with varying angles between their axes, and their transmission ratio is usually equal to one. Universal joints used in longitudinal transmissions can be either rigid or elastic in their construction. Rigid universal joints facilitate the transmission of rotary motion between intersecting shafts through the articulation of component elements, while elastic ones rely on the elastic deformation of certain elements. Rigid asynchronous universal joints can be equipped with sliding bearings or ball bearings [1].

In the case of automobiles, longitudinal transmissions are equipped with open-type rigid asynchronous universal joints, fitted with needle roller bearings. These joints are characterized by high durability, compact dimensions, and the ability to transmit heavy loads at high speeds. The longitudinal shafts, numbers 3 and 4 in Figure 1, are composed of a central part represented by the shaft itself, which has a circular cross-section, and connecting components with the universal joints or the transmission assembly [1].

The central part can be made in the form of a tube or can be solid. Tubular shafts are most commonly used because, in comparison to solid-section ones, they offer higher rigidity for the same weight, allowing for an increase in working speed. The structural shape of the shaft depends on the distance between the universal joints, the load regime, and the transmission layout. The fork is mounted on the shaft through grooves, allowing for the adjustment of the distance between the axes of the universal joints based on the suspension deflection (axial compensation coupling), as shown in Figure 1. To reduce friction between the grooves and, consequently, their wear, a lubricant is applied in the fork hub, and a sealing gasket is provided for this purpose. After manufacturing the longitudinal shaft along with the universal joints, they undergo dynamic balancing operations. This operation is carried out by adding material through spot welding or using plates. For proper balancing, it is recommended to perform balancing at low speeds, approximately 600-1000 rotations per minute. The maximum allowable imbalance is from 5 mN·m to 7.5 mN·m, depending on the vehicle's size. In some cases, when the longitudinal shafts do not require axial compensation, their length remains constant, and the forks of the universal joints are welded directly to the shaft itself. The shaft can have the same diameter along its entire length or can have an increased diameter in the central part.

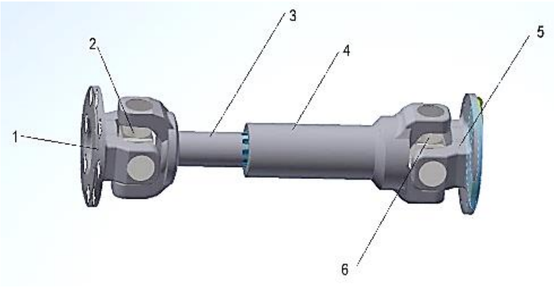

Fig. 1. *Structural Components of the Cardan Transmission*

1,5 – flanges; 2,6 - universal joints; 3, 4 - driveshaft

Excessive wear of the cardan components or its imbalance can lead to the emergence of axial stresses. Additionally, bending stresses may arise in the cardan transmission in the case of a long driveshaft or when the cardan shafts are not perfectly aligned. These bending stresses can impact the performance and durability of the system. Here are some aspects related to bending stresses in the cardan transmission:

Inclined driveshaft: When a vehicle is equipped with a cardan transmission, the driveshaft between the gearbox and the differential can be inclined to compensate for height or distance differences between the two axes. This inclination can generate bending stresses in the cardan shaft as it needs to compensate for a misaligned angle between the axes [1], [2].

Changes in height or distance between axes: If the height or distance between the transmission axes changes during vehicle operation, for example, when the suspension is compressed or extended, bending stresses can occur in the cardan shaft [2]. These stresses result from the efforts to maintain the continuous transfer of rotational torque between the misaligned axes.

In this paper, we aim to analyze the behavior of the propeller shaft using the finite element method as the inclination angle of the universal joint varies. Consequently, the structure of a propeller shaft and potential malfunctions that may arise during its operation are presented in this chapter. In the following chapter, we will explain the modeling approach for a double-cardan transmission using an Autodesk application. Chapter 3 will then present the simulation results for different universal joint inclination angles, focusing particularly on von Mises stresses. The final chapter is dedicated to drawing conclusions based on the simulation results, identifying the most favorable scenarios among those analyzed.

2. MODELING THE CARDAN TRANSMISSION IN AUTODESK INVENTOR

Finite Element Analysis (FEA) in Autodesk Inventor is a technique used to assess the structural behavior of 3D models. The process begins with modeling the geometry of the part or assembly in Inventor, where components, relationships, and necessary geometric constraints are defined [3], [4]. This step ensures an accurate representation of the shape and structure of the analyzed component. Following modeling, the next step is to create the finite element mesh. Inventor provides advanced tools to automatically generate finite element meshes that approximate the behavior of the structure. These meshes consist of many small elements, each with specific properties, such as shape, rigidity, and connectivity. Optimizing and refining the finite element mesh ensures a more precise approximation of the behavior of the analyzed structure [5], [6], [7], [8]. Figure 2 shows the discretization of the assembly. This numerical method involves breaking down the assembly into simple elements to highlight the stresses to which the assembly is subjected and the resulting deformations at the element level.

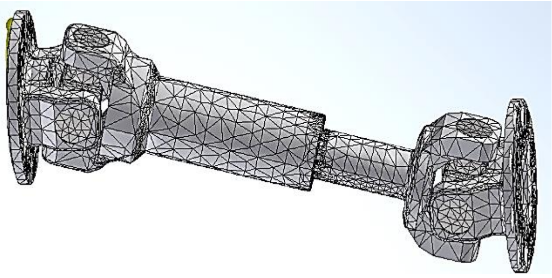

Fig. 2. *Discretization of the cardan transmission*

The assembly was constrained by fixing it to the attachment holes on one of the flanges, as shown in Figure 3.

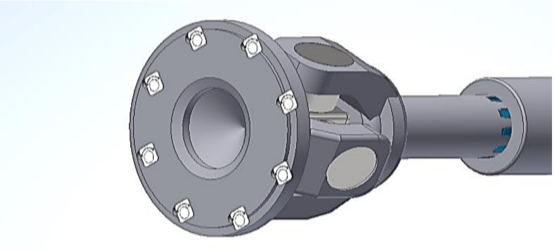

Fig. 3. *Assembly Fixation Constraint*

On the other flange, a force moment was introduced with a value that allows testing without damaging the materials when the cardan operates on a horizontal plane, as shown in Figure 4.

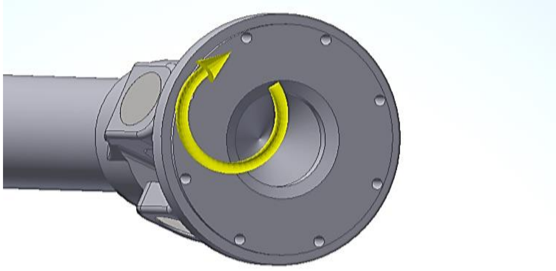

Fig. 4. *Flange Moment Loading*

Defining the material and its properties is another important aspect of finite element analysis in Inventor. The user can assign appropriate materials to the components and specify their properties, such as the elastic modulus, coefficient of thermal expansion, density, and others. The material proposed for this cardan transmission is cast steel, and its properties are presented in Table 1.

Table 1. *Properties of the analyzed steel*

Name	Cast Steel	
General	Mass Density	7.5 g/cm^3
	Yield Strength	250 MPa
	Ultimate Tensile Strength	300 MPa
Stress	Young's Modulus	210 GPa
	Poisson's Ratio	0.3 ul
	Shear Modulus	80.7692 GPa

3. SIMULATION RESULTS OF CARDAN TRANSMISSION

The simulation was carried out with the help of Autodesk Inventor software, considering four distinct situations found in longitudinal transmissions:

1. Tilting the axes of the cardan transmission to 0°;
2. Tilting the axles of the cardan transmission at 5°;
3. Tilting the axles of the cardan transmission at 10°;
4. Tilting the axles of the cardan transmission at 15°;

The discretization of the assembly was carried out with the default value of the program, figure 5, after which 102856 nodes and 59048 elements were obtained.

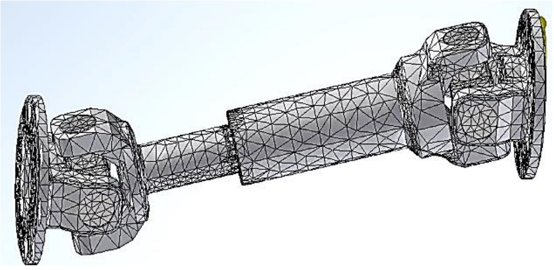

Fig. 5. *Discretization of the longitudinal transmission system*

In the case of angles of inclination of the cardan axes of 0°, a position in which the two axes of the joint are perfectly aligned, the minimum safety factor is found in the grooved area of the movable part of the longitudinal shaft (2.05), figure 6.

This area describes the resistance value of the analyzed structure in relation to the applied loads. The joint angle having the value of 0 degrees, the gimbal is arranged in a horizontal position, which results in the fact that the minimum safety factor is found approximately in the middle of the longitudinal shaft.

The von Mises stresses are noted in figure 7, thus illustrating the stress distribution over the assembly. These tensions are distinguished by different shades. When the angles of inclination of the cardan transmission are equal to 0˚, the maximum value of the von Mises stresses (122 MPa) is found in the grooved part, more precisely in the central area of the mobile shaft. This fact denotes a portion where external forces are present, such as applied loads, loads or an uneven distribution of material.

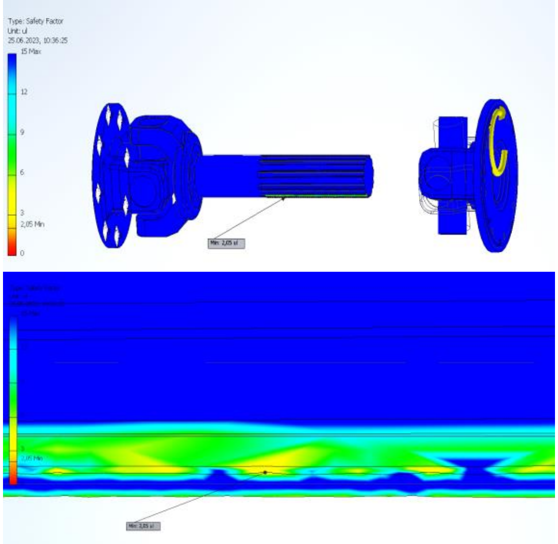

Fig. 6. *The value of the minimum safety factor for gimbal tilt of 0°*

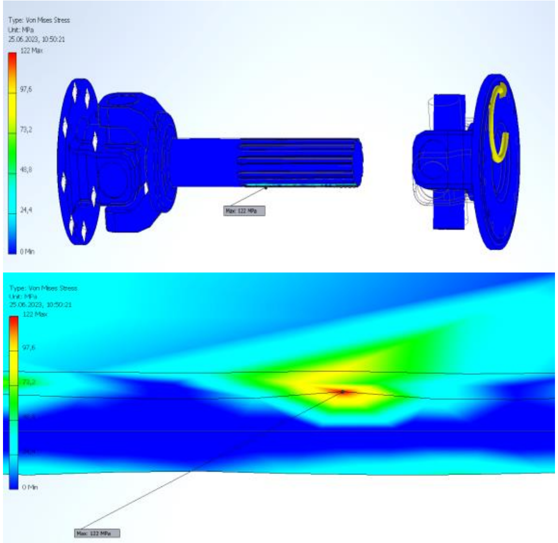

Fig. 7. *The value of the von Mises stresses for the tilt of the axes of 0°*

In the case of tilting the axes by 5°, the minimum safety factor is found in the peripheral grooved area of the movable part of the longitudinal shaft, having in this case the value of 1.55. This value reflects the strength of the analyzed structure in relation to the applied loads. We can see from figures 8 a reduced resistance of the groove structure, which may mean a high degree of breakage or the occurrence of plastic deformation.

In the situation where the angles of inclination of the cardan transmission are 5°, the maximum value of the von Mises stresses (161.6 MPa) is in the grooved area, especially in the extremity of the mobile shaft, figure 9. This observation indicates the existence of a portion where forces act external factors such as applied loads, loads or the possibility of uneven material distribution.

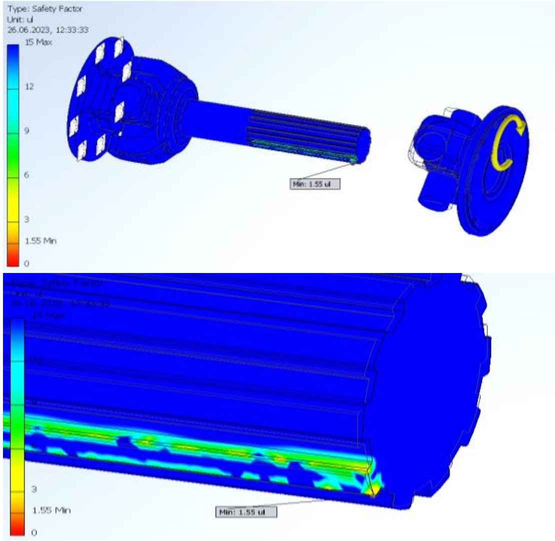

Fig. 8. *The value of the minimum safety factor for tilting the gimbal axes of 5°*

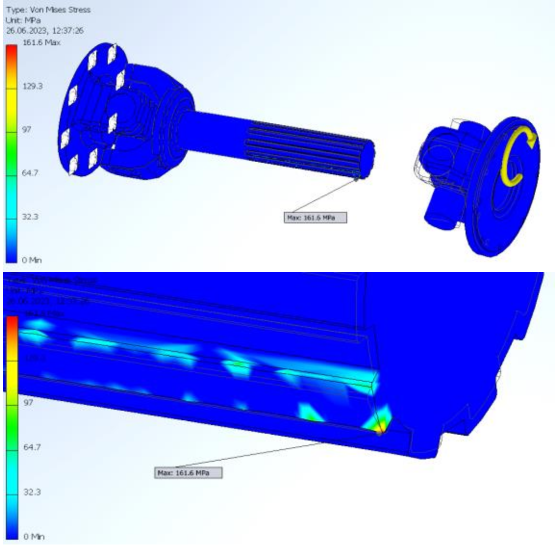

Fig. 9. *The value of the von Mises stresses for the axis tilt of 5°*

The ratio of the minimum factor of safety for the angles of inclination of the joints of 10 degrees is specified in figure 10. When the angles of the joints have the value of 10 degrees, in the splined area of the movable part of the longitudinal shaft, a minimum factor of safety of 1.89 is found. This value reflects the strength of the analyzed structure in relation to the applied loads.

When the joint angles have a value of 10 degrees, in the grooved area of the mobile part of the longitudinal shaft, a minimum safety factor of 1.89 is found, figure 11. This value reflects the strength of the analyzed structure in relation to the applied loads.

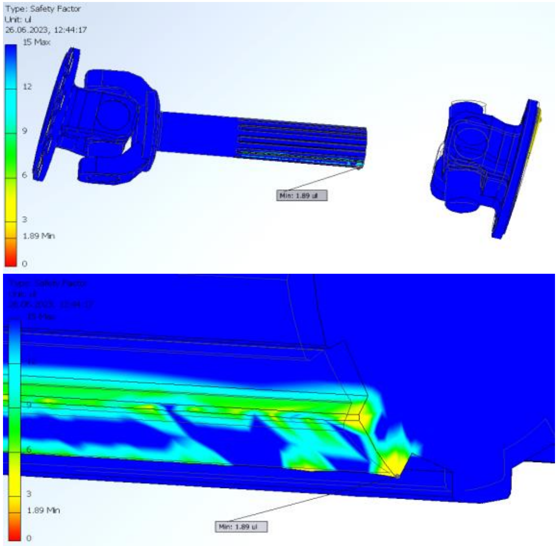

Fig. 10. *The value of the minimum safety factor for gimbal tilt of 10°*

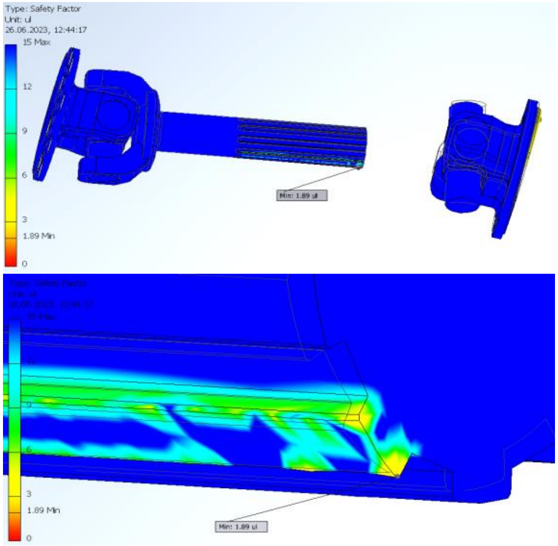

Fig. 11. *The value of the minimum safety factor for gimbal tilt of 10°*

In the situation when the angles of inclination of the cardan transmission is 10°, the maximum value of the von Mises stresses (132.3 MPa) is found at the extremity of the grooved area of the mobile shaft, figure 12. These values are lower compared to the von Mises stresses found in the situation of the 5° angles of the joints (161.6 MPa).

The representation of the ratio of the minimum factor of safety for the angles of inclination of the joints of 15 degrees are illustrated in figure 13. In this last phase of the analysis of the minimum factor of safety of the longitudinal transmission, when the angles have the value of 15 degrees, the factor of safety is found, as in most cases, in the extreme part of the grooved area of the movable part of the longitudinal shaft (1.85).

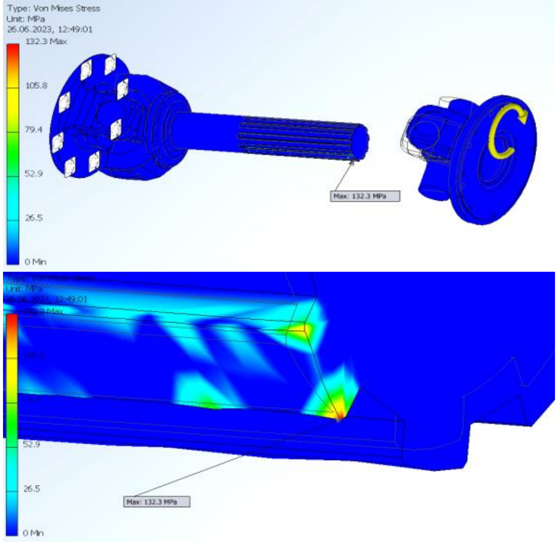

Fig. 12. *The value of von Mises stresses for 10° axis inclination*

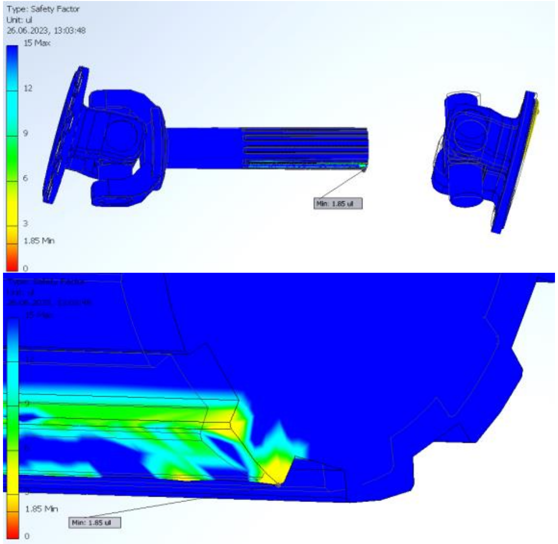

Fig. 13. *The value of the minimum safety factor for tilting the gimbal axes of 15°*

The analysis of von Mises stresses is represented in the situation when the angles of inclination of the cardan transmission are 15 degrees reaching the maximum value of these stresses of 135.2 MPa. Similar to the previous analyses, these stresses are illustrated and located in the area of the edge of the grooves, at the end of the longitudinal shaft, figure 14.

It can be concluded that the study of drive shaft using finite element analysis in Autodesk Inventor is a complex process that involves using Inventor software to model the geometry of the drive shaft and then perform finite element analysis to evaluate its behavior under various loads and conditions operating.

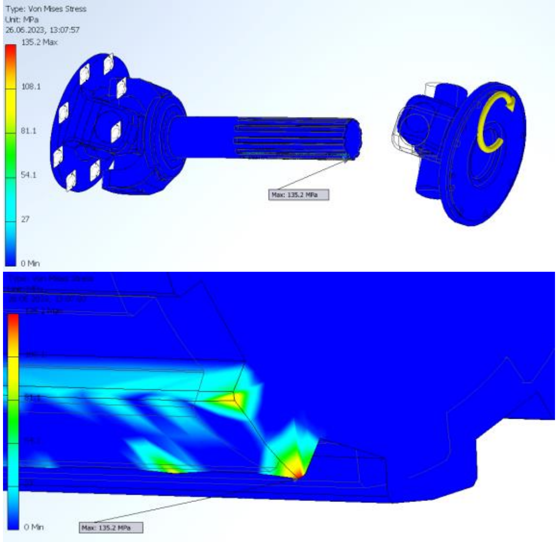

Fig. 14. *Value of von Mises stresses for 15° axis inclination*

In Table 2, the values obtained by finite element analysis for different gimbal angles are systematically represented.

Table 2. *The values obtained from the finite element analysis of the universal joint transmission*

	0°	**5°**	**10°**	**15°**
Safety Factor	2.05	1.55	1.89	1.85
Von Mises Stress [MPa]	122	161.6	132.3	135.2

4. THE CONCLUSIONS OF THE FINITE ELEMENT ANALYSIS OF THE LONGITUDINAL TRANSMISSION

Analysis (FEA) of a universal joint involves using the finite element analysis method to assess the behavior of the universal joint structure under various loads and operating conditions. It is necessary to follow the general steps to perform such an analysis: modeling the geometry, creating the finite element mesh, defining materials and properties, applying boundary conditions, applying loads, configuring the analysis, running the analysis, and evaluating the results.

By analyzing the results obtained for the von Mises stresses of the joint angles, we can highlight that at a 5-degree angle inclination of the axes, compared to other angular inclinations, there are some higher values. Consequently, there is a significant predisposition to wear and, at the same time, lower transmission strength.

When the angles have a value of 0 degrees, the joint axes' conditions are the most favorable in terms of mechanical strength because they provide a higher degree of stability in the operation of the longitudinal transmission system.

The inclination angles can vary depending on the geometry and positioning of the components and can affect the operating characteristics of the transmission.

By adjusting these angles, a transfer of force torque and smoother system operation can be achieved.

Phase angles represent the angles between the rotation planes of different universal joints in an assembly. These phase angles can influence motion synchronization and affect the overall behavior of the universal joint transmission. It is important to ensure the correct alignment of these angles to avoid issues such as unbalanced torques or the occurrence of unwanted vibrations.

Thus, it is observed that when universal joints are arranged at certain angles, the minimum safety factor and von Mises stresses have different values, which affect the degree of assembly strength. Joint angles of 0 degrees are the most favorable in terms of strength, offering a higher degree of stability in the operation of the longitudinal transmission system. These considerations also consider the material from which the universal joint is made.

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