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SELECTED ASPECTS OF CONSTRUCTING A FINAL DRIVE FOR A TRACKED VEHICLE

Abstract. The paper describes selected elements of the process of designing a final drive of a tracked vehicle by a design engineer. The problems of designing are described with account taken of the search for a compromise between the often conflicting requirements. The most important structural units of the final drive are discussed, including: gears, bearings and the acting forces. Consideration is also given to the construction technology of the body and to the effect of gear accuracy grade on the structure and operating properties of the drive.

Particular attention was drawn in the summary to the key elements of the design process that determine the correctness of the final structural form of the final drive.

Keywords: tracked vehicle, final drive, gear, bearing arrangement.

1. INTRODUCTION

The concept of the design of the final drive of a tracked vehicle was discussed in article [1]. Concept development commenced from the design of the main structural units that have an effect on the form of the entire drive assembly. The need for a three-part drive body and its impact on the complexity of the structure were further justified. Factors that often are decisive when choosing between a ready commercial solution and the design and creation of a new, optimised solution for the drive were identified.

Further the paper discusses the key issues encountered when designing a new optimised drive structure.

Then it becomes necessary to make a compromise between the sometimes opposite requirements, namely:

- need to minimise the weight of the drive;
- attaining high strength, durability and reliability of the drive;
- low manufacturing cost;
- ease of assembly.

Modern mobile working machines desirably have the lowest possible weight while maintaining the assumed durability. Weight minimisation is particularly important when the vehicle is designed to negotiate water obstacles. In such case the vehicle must demonstrate flotability and necessary displacement. Strict criteria, resulting from the requirement to reduce weight, make it impossible to apply traditional design solutions. Optimising the drive design requires verification, under field test conditions, of the safety coefficients specified in the design. This also imposes a number of complex calculations and simulations to determine if the design meets specific requirements. Maintaining high durability limits the extent of weight minimisation and of the drive design optimisation.

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2. CRITICAL STRUCTURAL UNITS OF THE FINAL DRIVE

Particularly important design elements that have a substantial effect on failure-free and long-lasting drive operation include: a floating internal gear (ring gear) and bearing arrangement designed for the operating load.

2.1. Floating ring gear

Usually in a planetary gear system the sun gear or planet gears are the floating gears, and in a few cases the central gear [6], [7]. The floating gears are not supported on bearings and can therefore change their position in relation to meshing gears. This relieves the load distribution in the meshing of the planetary gear system. When the driven wheel is set on the same shaft as the sun gear, the latter cannot be a floating gear. In view of the above an additional ring with external splines on the internal ring gear (Fig. 1) was used in the drive under design. This enabled the use of different construction materials for the body and for the ring gear, while the weight of the complete final drive was only slightly increased. Introduction of large play, form-fitting connection and crowning of the splines enable elimination of fabrication inaccuracies.

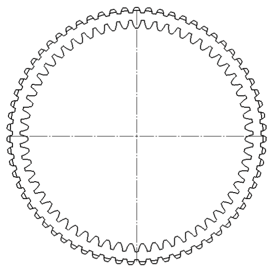

Fig. 1. Illustration of the proposed design of the ring gear of planetary gear system

Figure 2 presents the conceptual design of the planetary gear system.

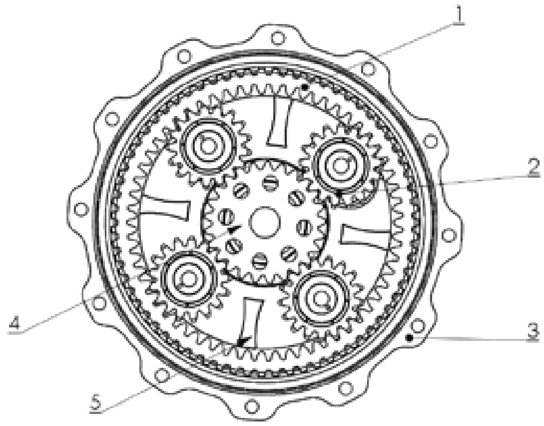

Fig. 2. Conceptual design of the planetary gear system

1 - ring gear, 2 – planet gears, 3 – drive body, 4 - sun gear, 5 – carrier

2.2. Bearing arrangement for gears and carrier in the planetary gear system

The bearing system of gear shafts in a mechanical transmission is of key importance for its proper operation, operating life and reliability. Bearings are responsible for transmitting forces that act on shafts. As a result of these forces, resistance to motion appears, which is largely responsible for heat generation and increased noise during gear operation. Properly sized bearings warrant stable and long-lasting failure-free gear operation. The bearing system applied arised directly from the adopted kinematic chain and the internal and external load, as well as from the initially developed structural form. For this reason the design of the bearing system has to be taken into account at the concept design stage, as the adopted criteria may rule out attaining an optimum design of the structural form of the drive.

2.3. Significant factors in sizing bearings

An important issue to consider when selecting bearings is, among others, the adopted bearing arrangement, i.e. proper bearing types and appropriate positioning thereof. The factors affecting the performance of a gear system and its durability include the accuracy grade of the components, in particular of the gear teeth, the values of adopted clearances compensating axial load of bearings, including bearing preload. Cross section of the final drive, which illustrates the adopted bearing arrangement, is shown in Fig. 3.

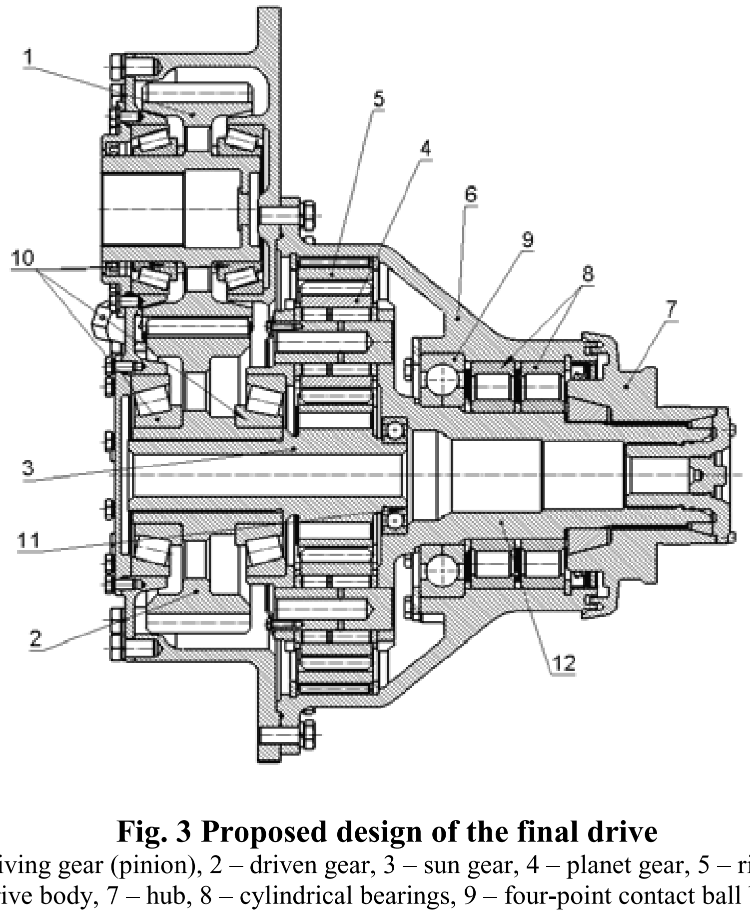

Fig. 3 Proposed design of the final drive
1 – driving gear (pinion), 2 – driven gear, 3 – sun gear, 4 – planet gear, 5 – ring gear, 6 – drive body, 7 – hub, 8 – cylindrical bearings, 9 – four-point contact ball bearing, 10 – cone bearings, 11 – ball bearing, 12 – carrier

Forces arising from the applied driving torque and from the external load (resistance) are generated in the kinematic pairs of the drive. Transmission of the loads and heat generation in meshings and bearings cause thermal expansion and strain in drive components.

This results in changes in mating conditions of the components, which directly affects the load conditions on bearings. Depending on the bearing arrangement, preload or initial clearance is introduced to compensate for the deformation of components and for the inaccuracy of their fabrication and to avoid unfavourable operating conditions of the bearings. Compensation for the deformation of drive components (shafts, body) is particularly important when the gears operate under heavy load when large drive component deformations can occur. Properly sized clearances prevent generation of additional forces in the kinematic pairs. Preload enables attaining proper clearance when drive operating conditions become stable and eliminates the risk of gear seizure.

Friction forces in bearings cause significant temperature and noise increase. Excessive load on the drive and generated vibration may lead to damage or shorten the operating life of the drive. These may also cause high tribological wear and seizure of bearings. Excessive temperature affects the physicochemical properties of lubricant. Prolonged operation at increased temperature has a strong impact on the tightness and life of seals.

2.4. Load conditions of bearings of gear shafts of the drive

Due to the complex load conditions of the power transmission of a tracked vehicle, the bearing arrangement of the shafts of the drive is a big challenge for the design engineer The drive is subjected to internal and external loads. The loads that occur inside the final drive are caused by the driving torque. These loads have the form of torsional and bending moments that act on gears and shafts, as well as reactive forces generated in bearings that act on the drive body. The external loads include the forces of resistance to motion derived from the caterpillar tracks. These are a combination of forces arising from the tension of the caterpillar tracks, forces arising from the motion of the vehicle, and additional forces generated during driving manoeuvres. Forces derived from the caterpillar tracks are transmitted onto the output shaft of the final drive by the drive wheels. The output shaft bearings transmit the loads onto the body of the drive. As a result of the external forces and the driving torque, reaction forces occur at the points of attachment of the final drive to the vehicle body. These forces can be considered to be composed of component forces: forces perpendicular (vertical and horizontal) to the drive wheel axis and axial forces acting along the wheel axis. Axial forces occur when the vehicle is turning, for instance when one track is stopped and the other moves, or when the vehicle is turning in place.

The action of the force of initial tension becomes important in the case of a caterpillar track made of polymer material, as the adverse effects are then greater than in the case of steel tracks (track manufacturer states that the force of tension may be as high as 30% of the driving force).

Forces have been determined for various driving conditions of the vehicle using the final drive of the developed concept, particularly for forward travel (Fig. 4a) and backward travel (Fig. 4b). Based on the knowledge of the loads occurring in the structural units of the drive, requirements have been defined to enable proper mounting of the bearings accordant with recommendations specified in the literature [5], [6], [8], [9], [10].

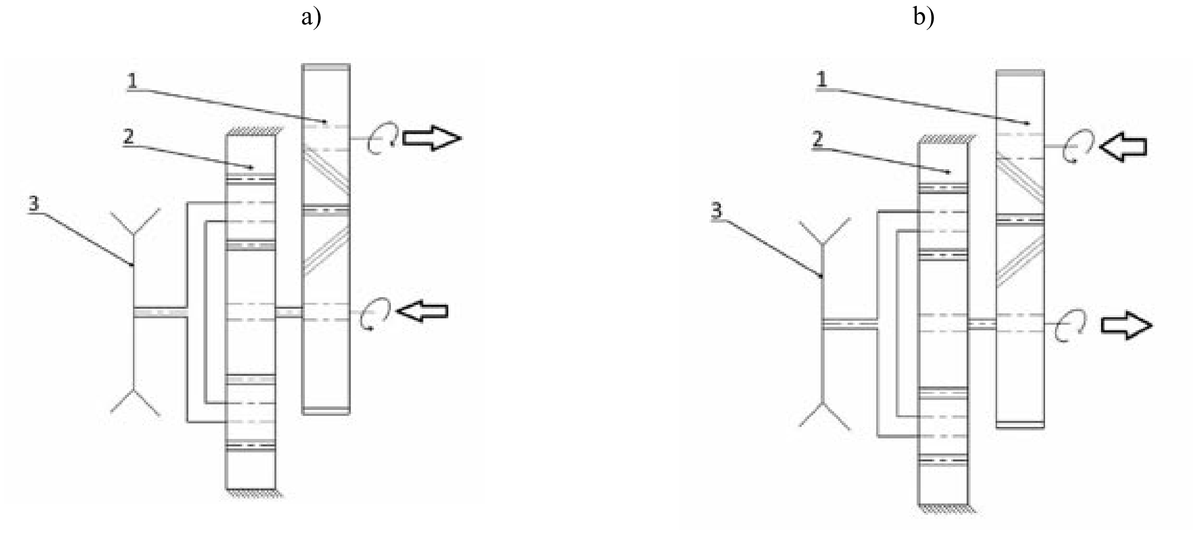

Fig. 4. Directions of axial force action in the final drive
1 – cylindrical stage, 2 – planet stage, 3 – track drive wheel

2.5. Bearing arrangement of shafts in the final drive

In view of the problems mentioned above, method of mounting shafts of the drive under design in bearings, sizing and arrangement of bearings, and because of the high impact (pulsed) load, decision was made to use cylindrical helical gears in stage I of the drive. Such design contributes to higher volumetric and tribological durability of gear teeth. Such gear teeth also make teeth engagement smoother due to increased tooth contact ratio. The load on a single tooth is therefore reduced and the safety factor is thereby increased. In addition the meshing rigidity is increased.

In stage II of the planetary gear system traditional straight-cut gears were used.

Despite the many advantages of helical gears, as compared to straight-cut gears, application of such design generates adverse axial forces that act on the bearings. Large helix angle of 20 degrees makes the use of the simplest bearing solution with ball bearings impossible due to high axial forces. For this reason cone bearings, which transmit axial forces much better than ball bearings, were used in stage I of the final drive. These bearing are arranged in the structural scheme designated "O". [9]

The use of helical teeth in a cylindrical gear complicates the system of bearings in the planetary gear train. The axial force generated in the driven gear of cylindrical gear transmission is transmitted onto the carrier in the planetary gear train because one of the bearings of the cylindrical gear transmission is seated in the carrier. During forward travel (clockwise rotation of the final drive - when viewed from the drive wheel of the right side final drive), the component of the reaction force occurring in the bearing acts on the carrier.

In addition, the carrier in the planetary gear train is also subject to the action of axial forces from the caterpillar track. These forces occur when vehicle manoeuvres are made and they can act in both directions.

When the drive operates in both directions, and the axial forces that act on bearings also change their direction of action, a tandem arrangement of bearings is required (scheme "O" or "X"). Each of the arrangements has its pros and cons, and the choice depends on technical and tactical objectives.

The X arrangement of bearings necessitates application of preload, which is effected, for instance, by using additional lock nuts. In the "O" arrangement, clearance adjustment system is required. This complicates the design and requires more space. For this reason a four-point contact ball bearing was introduced to fix the position and transmit axial loads in both directions.

When choosing between "X" and "O" bearing arrangements, their mounting flexibility also has to be taken into account.

In view of the high radial and axial forces acting in the gear train, reliability of the structural unit of the output shaft and disadvantages of using cone bearings, decision was made to use two roller bearings and one four-point contact ball bearing.

In order to reduce the load on the bearing and to avoid making the structure over-rigid, the bearing was mounted with radial clearance on the outer race, as a result of which the bearing did not transfer radial forces. Application of a more expensive solution, the four-point contact bearing (QJ226N2), contributed to space saving, lower weight, reduced complexity of the structural unit and improved conditions of assembly. Radial loads from the caterpillar track are transmitted by two cylindrical bearings (N224) shown in Fig. 5 and located on the carrier in the planetary gear train. These bearings have to be precisely matched with regard to dimensional tolerance in order to ensure uniform load transfer [5].

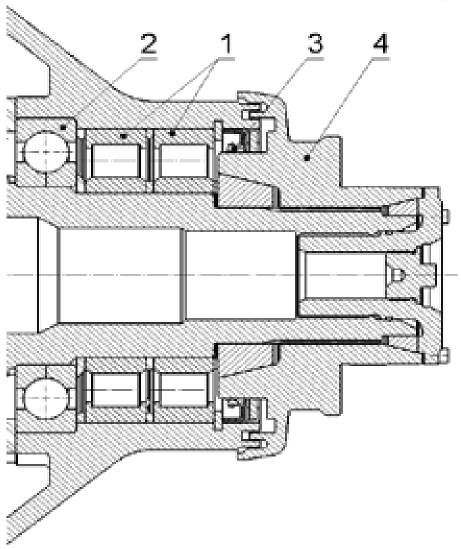

Fig. 5. Carrier bearing on final drive output

1 – cylindrical bearing N224, 2 – four-point contact ball bearing QJ226N2, 3 – lip sealing ring of shaft B2USL 180-215-15, 4 – drive wheel hub

2.6. Form-fitting connection on drive output

The use of outer conical rings (Figs. 6.1 and 6.2) when connecting the drive wheel hub to the carrier shaft generates a number of problems, including "knocking out of teeth", when using a form-fitting connection such as an involute spline, due to high load variability and amplitude. In order to solve these problems, a pair of conical sleeves was used to ensure good alignment when connecting the hub (Fig. 6 - item 3) with the drive shaft. In addition, this helps avoid seizure of gear teeth and the spline.

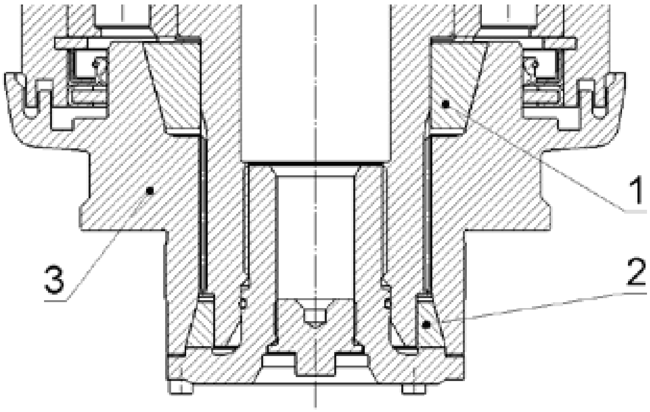

Fig. 6. Arrangement of conical sleeves on final drive output
1 – cone, 2 – cone, 3- hub

When designing the final drive, the type of spline to be used was also analysed. A requirement was adopted to transfer maximum pressures for stationary connection and for working conditions under variable load. The analysis included a spline with an involute outline for the shaft diameter of 100 mm taken as example, the highest force transmitted by the spline was adopted in calculations. Comparison of calculation results is presented in Table 1.

Table 1. Bearing pressures in a shaft 100 mm in diameter

Analysis number	Designation	Pressures (N/mm^2)
1	N100x1,5x8f	321.96
2	N100x2x8f	320.29
3	N100x2,5x8f	365.52
4	N100x3x8f	325.29
5	N100x4x8f	328.63
6	N100x5x8f	289.88
7	N100x8x8f	374.15
8	12/24 - 46;30°	263.88
9	12/24 - 46;45°	279.68
10	5/10 - 19;30°	325.88
11	10/20 - 36;30°	278.40

Table 1 illustrates that the inch spline with the same overall dimensions is characterised by lower bearing pressure values. Therefore, in the case of significant limitations of maximum dimensions, as well as of permissible weight of the drive, the optimum solution is to make an inch splined shaft which, due to its structure, i.e. a higher tooth and increased number of teeth on the perimeter, transmits slightly greater forces resulting from the bearing pressures of the form-fitting connection.

3. ASSEMBLY OF THE FINAL DRIVE

The impact of the assembly method on the design of the final drive is of great importance when designing the body of the drive. Bodies of standard drives consist of two parts. In order to reduce the weight, the dimensions were minimised, which required the use of a casing made of three separate parts (Fig. 3, item 6). The advantage of such design is that assembly is facilitated and that initial inspection of drive operation can be made after removing the cover. The drive should run smoothly with low resistance to motion - in such case the drive can be finally assembled and clearances can be set on the cone bearings. The initial clearance is set to 0.2 mm. There is often a need to readjust the initial clearance after operating the drive for the first time. This is due to various factors, most often the fabrication tolerance of the individual parts. If clearance is not adjusted, there is a risk of the outer ring of the bearing being cramped.

Inappropriate dimensional tolerance of the individual parts, particularly of the mating rotating parts, may cause misalignment leading to unsteady operation of the drive. Bad tolerance may also cause problems in the mounting of bearings. Fabrication inaccuracies are often the cause of bearing failures, radial bearing run-out, which may lead to overheating and even to drive damage.

4. TECHNICAL CAPABILITIES OF MANUFACTURE

Another topic of discussion and analysis is the possibility of using various types (in terms of construction material) of bodies and manufacturing capabilities. Three construction materials were taken into consideration: ADI cast iron, special cast steel and 18H2N4A steel, and methods of fabrication were assigned to these materials (Table 2).

Table 2. Comparison between body construction materials.

Material type	Fabrication method	Body weight (kg)
ADI cast iron	Casting	105
Special cast steel	Casting	117
18H2N4A Steel	Machining	117
ARMOX 150T	Welding	-

The problem that has been tackled for a long time is to make a proper body in the case of unit production, large-scale production, and in the case of introducing new gear transmissions where one unit only is made initially, followed by the next stage when two units are made and finally a series production is launched. In the first case the body is usually made by welding in order to minimise cost, which is then lower than in the case of casting. In a series production the casings are made by casting, the main reasons being lower cost and repeatability of the process. Therefore, for the final drive discussed here, a decision was made to fabricate the casing completely by machining, which lowered the cost of fabrication but required redesign of the drive at the stage of series production.

5. SUMMARY

As the lubrication system applied was simple, this problem was not discussed here. Splash lubrication with no forced lubricant circulation was applied, as such system was considered sufficient. No oil cooler was used, as most of the final drive is located outside of the vehicle and the heat is dissipated through the body [11].

Conceptual design work, calculations and analyses have shown that there are many factors on which proper design and fabrication of gear transmissions for tracked vehicles depend. These factors have an impact on design objectives, structural form, method of assembly and fabrication process of the transmission components.

The major factors include:
- proper bearing arrangement,
- fabrication accuracy,
- proper fabrication tolerance of mating parts,
- proper lubrication.

One of the biggest challenges for the design engineer is proper bearing arrangement for the transmission. Correct choice of bearings, method of their mounting and fabrication accuracy of the mating subassemblies, as well as the tolerances of the mating parts, allow to construct a transmission that will operate for a long time without the risk of failure.

In addition, the structural elements used in the design, such as conical sleeves and the floating ring gear, protect the transmission against damage resulting from high loads and impacts caused by the nature of the ground driven over and of obstacles negotiated. The tracked vehicle is subjected to mechanical stresses during travel, exiting a ramp, driving through rough terrain, when such stresses are transmitted through caterpillar tracks and the traction system onto the drive wheel and the output shaft of the final drive.

All these issues form a chain of relationships that are closely interrelated. If any of the links of such chain fails, it may shorten the operating life or cause failure of the drive. For this reason it is important that the design engineers be aware of the complexity of the task they are facing.

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