Krzysztof **SKOWRON**
Krzysztof **BASIURA**

DESIGNING A FINAL DRIVE FOR A TRACKED VEHICLE

Abstract. The paper presents concepts of solutions developed for a final drive for light tracked vehicles weighing from $2 \cdot 10^4$ to $3 \cdot 10^4$ kg. A short theoretical discussion of design methodology is given. A general review of problems associated with final drives is made, highlighting those that occur in the process of designing transmission for tracked vehicles. Design requirements are defined. Three concepts of the final drive are discussed and subjected to multi-criteria analysis. Finally one concept is selected based on the carried out multi-criteria analysis.

Keywords: tracked vehicles, final drive, design concepts.

1. INTRODUCTION

Power transmission systems of tracked vehicles consist of an engine connected by means of a coupling with a gearbox, usually arranged in a transverse position at the front of the vehicle in its central part. Such arrangement of the main transmission has an impact on both the shape, as well as the structural form of the final drive (because of the axles translation). There are a number of drive train installation arrangements and ways of transmitting driving power in tracked vehicles, which has been described in "Modular drive systems" [2]. The gearbox distributes power to the left and right track via the final drive. The output of the final drive is the drive wheel. The available space in the vehicle hull, design and overall dimensions of the drive wheel determine the structural form of the final drive.

Individual vehicle design and precisely defined requirements as well as severe dimensional restrictions demand the use of drive trains characterized by ever higher performance characteristics while minimizing the dimensions and weight.

Final drives available on the market are of highly versatile design. They may therefore be used in tracked vehicles of new design. However, when the requirements are strictly defined and possible deviations highly reduced, commercial transmissions are not an optimum solution, and using them proves unreasonable.

The analyzes performed indicate that while there are ready solutions that provide the required performance characteristics in terms of strength and durability, the dimensions and weight go far beyond the acceptable limits. Note that in this case, precise specification of the final drive ratio is necessary to attain the required traction parameters. One must also be aware of the fact that the basic parameter in the off the shelf solutions may not be met because the transmission ratio is determined at the start by the manufacturer.

Therefore, designers of tracked vehicles are faced with the dilemma of choosing between using an existing commercial product or developing a completely new design.

When ready commercial solutions are used, a trade-off should also be taken into account between using a proven solution, with a relatively short delivery time and often a relatively low cost, and the optimum matching of the transmission gear with other components

Krzysztof **SKOWRON**, Krzysztof **BASIURA -** Ośrodek Badawczo-Rozwojowy Urządzeń Mechanicznych „OBRUM" sp. z o.o., Gliwice

of the drive system. Taking the challenge and developing a concept of a new transmission entails costs of design and research. When only unit production is considered, it is more advantageous to use catalogue products, but when design parameters are decisive, and production volume increases, the innovative solution gains definite advantage.

This solution has one more important advantage in relation to a catalogue product: it may be modified and optimized.

The following are the factors that are conclusive when deciding on designing a new solution:

- time between maintenance;
- weight criterion resulting from the use of gears in vehicles characterized by the so-called floatability;
- required overall dimensions.

Demanding requirements are the main reasons to undertake the design of an optimal structural form of the final drive and provide a justification to begin design work.

2. THE DESIGN PROCESS

The design process consists of several stages. These include: specifying the requirements, developing a concept of the final drive, specifying the number of teeth and module pitches of the gears, supported by detailed strength calculations, selection of the bearing points, comprehensive design of the entire transmission, design documentation. Here we will deal with only the first three stages.

The basic parameters include: transmitted power and the required life and reliability. In this article life means the period of use expressed in kilometres after which an inspection of the unit is carried out and worn parts and assemblies of the vehicle are repaired or replaced.

As a result of discussions and analyzes based on the state of the art, design requirements outlined in Section 2.1 were specified. Performance characteristics important in the process of developing the concept of the transmission were identified.

2.1. Principal design requirements

Designing a transmission should commence with specifying input data required to develop a concept. In the case under consideration the adopted main objective was the design of the final drive for tracked reconnaissance, engineering, transport and combat vehicles weighing from 20 to 30 tonnes. Bearing in mind that the vehicles will operate under different conditions, the final drive should meet the conditions of minimized weight and optimum durability.

The following are the necessary parameters required for developing the final drive:

- Required transmission ratios

The required transmission ratio is necessary to ensure proper traction characteristics and the desired maximum speed of the tracked vehicle. The transmission ratio was selected to match other components of the drive system on the basis of the defined specifications of the engine and of the main transmission.

– Durability and operating endurance

Durability is expressed in kilometres; it defines period of operation between subsequent planned maintenance. To determine endurance of the final drive components, the anticipated maximum load occurring in the system was adopted. However, in order to determine the durability of the transmission it is necessary to know the manner of use of the vehicle, land configuration (model), time of operation running on the individual gears of the main transmission. These parameters are crucial for attaining high accuracy in estimating the durability of the transmission without unnecessarily increasing its weight by oversizing it.

– Maximum torque

Maximum torque to which the transmission will be subjected, being the result of traction characteristics of the drive train (engine and gearbox). As the final drive is the ultimate component of the kinematic chain of the drive train, the torque transmitted by this transmission is the highest. Maximum torque in the gearbox is attained when driving in the gear in which the transmission ratio is the highest, in this case the reverse gear.

– Weight

Unlike in stationary transmissions, for the transmissions of special vehicles it is extremely important to minimize weight. Mechanical components of the drive train represent a large share of the total weight of the vehicle, therefore determining the best possible parameters in the design of the transmission is so important. Weight becomes even more important when floatability of the vehicle is to be ensured.

– Axis offset

This parameter indicates whether a transmission with axle offset must be used or not. This is due to the design of the gearbox used, and its location in the hull of the vehicle.

In order to improve the capability of negotiating terrain obstacles, the track drive wheel is shifted as far as possible to the front of the vehicle. However, excessive shifting of the wheel to the front and relative position of the engine and the gearbox often result in an offset of the gearbox output shaft in relation to the axis of the drive wheel. The offset may be in the horizontal and/or vertical direction. In order to maintain continuity of the kinematic chain, an intermediate component is introduced to cater for the axis offset. To avoid introduction of additional elements into the drive system, there must be an optimum offset of the axes of the input and output shafts of the final drive. The required axis offset is effected by means of a cylindrical transmission gear where axes of the gears are offset by the required distance.

2.2. Developing assumptions/requirements for the concept design

The general requirements presented above (section 2.1) form basis for initiating the process of final drive design. Table 1 shows examples of the parameter values determined on the basis of literature and an analysis of the configuration of other power units. Because of its great importance, particular emphasis in the development of the concept and the design has been placed on reducing the weight of the transmission structure, while maintaining enhanced durability.

Table 1. Assumptions/requirements for the concept design of the final drive

Symbol	Name	Value	Unit
u	Required transmission ratio	~ 4	
L	Durability	12,000	km
a_w	Axis offset	250	mm
Mk	Torque on input shaft	18,000	Nm

At first the materials for fabricating the individual components of the final drive are selected. In view of the weight criterion, materials of higher volumetric strength and contact strength are adopted. The table shows characteristics of the material adopted (carburizing and hardening steel17CrNiMo6) for the final drive components that carry the highest loads (Table 2).

Table 2. Principal characteristics of 17CrNiMo6 steel (17HMN upon chemical and thermal treatment) [9]

Name	Symbol	Value	Unit
Yield strength	$R_{0.2}$	1,180	MPa
Tensile strength	R_m	1,180	MPa
Compressive strength	σ_{FE}	1,060	MPa
Bending strength	σ_{Hlim}	1,595	MPa
Hardness	core	34...42	HRC
	surface	60...63	HRC

2.3. Description of concept design I

The first solution (Fig. 1) comprises a cylindrical gear and a planetary gear. The cylindrical gear provides the required axis offset a_w of the input and output shafts. The gear input is on the single reduction cylindrical gear end. The cylindrical gear wheel transmits torque to the sun wheel of the planetary gear, the central wheel is fixed, and the driving torque is transmitted through a carrier to the drive wheel of the tracked vehicle.

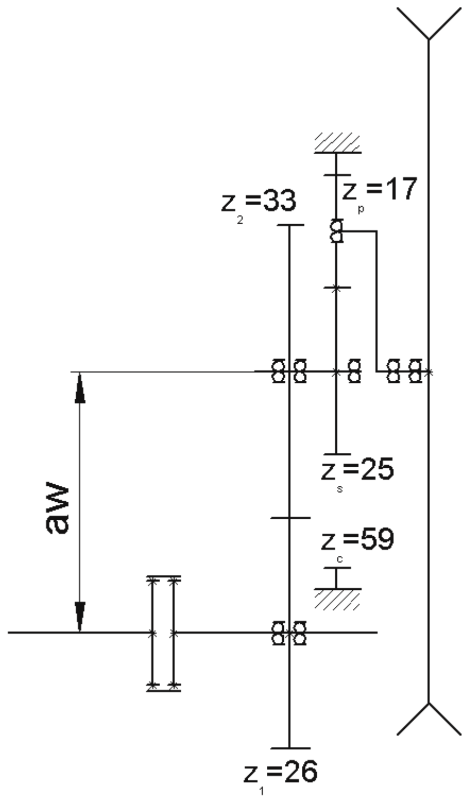

Fig. 1. Kinematic diagram of final drive concept I

Table 3 lists the principal parameters of final drive concept I.

Table 3. Basic specifications of final drive concept I

Symbol		**Name**	**Value**	**Unit**
z1	Cylindrical gear	Number of teeth of wheel 1	26	-
z2		Number of teeth of wheel 2	33	-
iw		Diameter ratio	1.27	-
m_{nw}		Normal module	8	mm
Zs	Planetary gear	Number of teeth of the sun wheel	25	-
zp		Number of teeth of the planet wheel	17	-
zc		Number of teeth of the central wheel	59	-
ip		Diameter ratio	2.36	-
m_{np}		Normal module	6	mm
Q		Estimated weight	290	kg

2.4. Description of concept design II

The second concept is based exclusively on a cylindrical gear. The gear ratio and parameters were adopted to meet the accepted traction criteria. In the case of cylindrical gear there is a certain difficulty involving the simultaneous fulfilment of the requirements of the specified offset of the axes of the input and output shafts, and of the specified ratio and optimum selection of the minimum module.

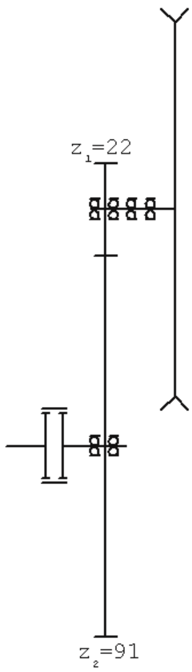

Fig. 2. Kinematic diagram of final drive concept II

Table 4 lists the principal parameters of final drive concept II.

Table 4. Basic specifications of final drive concept II

Symbol	Name	Value	Unit
z1	Number of teeth of wheel 1	22	-
z2	Number of teeth of wheel 2	91	-
u_w	Diameter ratio	4.13	-
m_{np}	Normal module	7	mm
Q	Estimated weight	420	kg

2.5. Description of concept design III

The third concept is that of a cylindrical double reduction gear (Fig. 3). There may be several embodiments of this solution. The axes of the gears are arranged in such manner as to ensure that such an important parameter as the offset of the axes of the input and output shafts is appropriate. The arrangement of the axes is shown in Fig. 3. The required offset of axes is attained despite the double reduction.

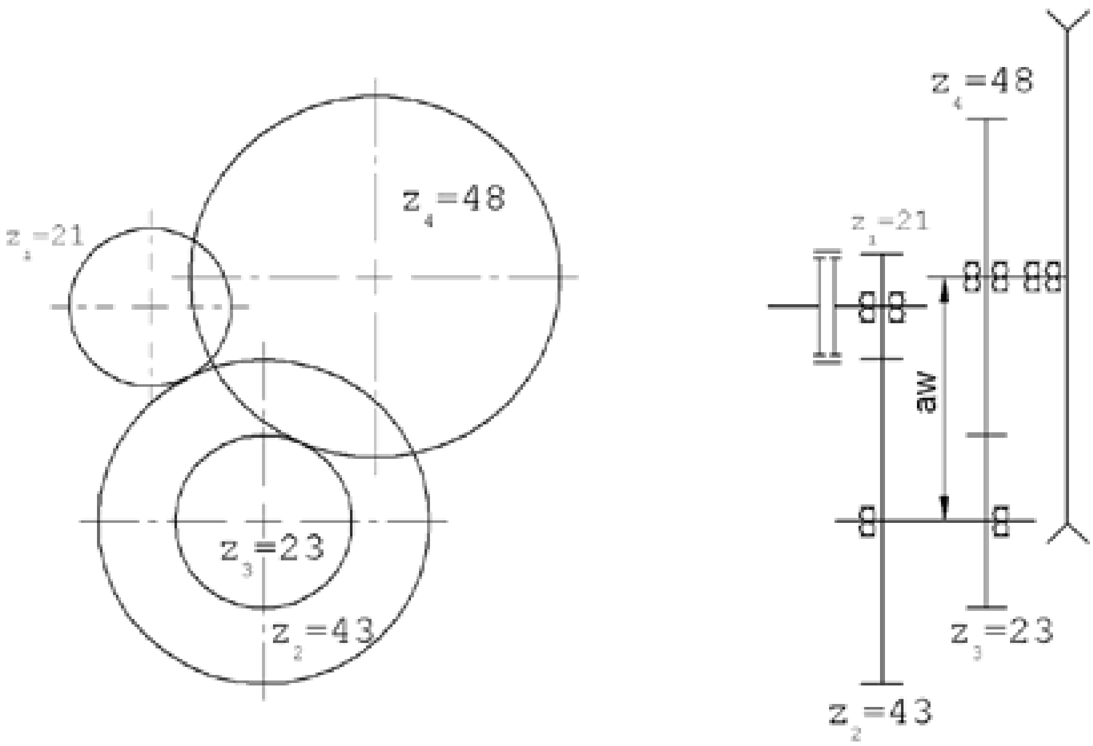

Fig. 3. Kinematic diagram of final drive concept III

Table 5 lists the principal parameters of final drive concept III.

Table 5. Basic specifications of final drive concept III

Symbol		Name	Value	Unit
z1	Stage I	Number of teeth of wheel 1	21	-
z2		Number of teeth of wheel 2	43	-
u_w		Diameter ratio	2.05	-
m_{nw}		Normal module of wheels	8	mm
Zs	Stage II	Number of teeth of wheel 3	23	-
zp		Number of teeth of wheel 4	48	-
u_p		Diameter ratio	2.09	-
m_{np}		Normal module	10	mm
Q		Estimated weight	350	kg

3. MULTI-CRITERIA ASSESSMENT OF DESIGN CONCEPTS

The following criteria were taken into account in assessing the design suitability of the developed concepts I, II and III:

K1 – cost of the drive train; cost as low as possible is desirable. The cost of the final gear is meant as the sum of the costs of an innovative product (research and development, development of manufacturing technology, production line, operation and maintenance).

K2 – weight of final drive; minimized weight is desirable. Minimum weight applies to each concept when the adopted performance requirements are met.

K3 – geometric features, maximum permissible overall dimensions, offset of axes, structure preferred on account of installation, required structural rigidity.

K4 – usage structure; design simplicity - degree of structure complexity, as low complexity as possible is desirable, which reduces the risk of failure and the number of components that can be damaged.

Table 6 lists all criteria and the importance assigned to them. The criteria were assessed by comparing all of them with each other. In that comparison the importance (value) of the criterion with respect to the other was checked, and points were awarded in the following manner - if the compared criteria were equally important, each of them received 0.5 point; if one of the criteria was more important than the other, the former received 1 point, the latter 0 points. The final assessment result is the sum of the positive decisions of the given criterion divided by the weight factor of that criterion taken from the table above.

In the next step each of the concepts was assessed. A five-point rating scale was adopted, where 1 means that the criterion in the concept is fulfilled in the least degree, and 5 means that the criterion is fulfilled to the greatest degree. Analyzing each criterion in turn we get an assessment value, which is then multiplied by the weight factor of the criterion, to provide the value of concept factors and the final result of the selection criterion.

This process indicates that concept I fulfils the adopted criteria to the greatest degree.

Table 6. Weight factors of the individual criteria [10]

	K1	K2	K3	K4	Total	Weight factor
K1	-	0	0	0.5	0.5	0.083
K2	1	-	1	1	3	0.5
K3	1	0	-	1	2	0.33
K4	0.5	0	0	-	0.5	0.083

Table 7. Multi-criteria assessment of the concepts

Name	K1	K2	K3	K4	TOTAL
Concept rating	4	5	5	3	
Criterion weight factor	0.083	0.5	0.33	0.083	
Concept weight factor (rating x weight factor)	0.332	2.5	1.65	0.249	**4.721**
Concept rating	5	4	1	5	
Criterion weight factor	0.083	0.5	0.33	0.083	
Concept weight factor (rating x weight factor)	0.415	2	0.33	0.415	**3.16**
Concept rating	4	3	5	4	
Criterion weight factor	0.083	0.5	0.33	0.083	
Concept weight factor (rating x weight factor)	0.322	1.5	1.65	0.322	**3.794**

4. SUMMARY

The result of the literature review and of the analyses carried out was a decision to work on the design of a new final drive. Design and research work comprised the following stages: from the formulation of guidelines to conceptual work, performing calculations, developing a geometric model and design documentation. The goal is to produce the final product. In addition, before the final drive is installed in the vehicle, it will undergo tests on a laboratory stand and then it will be tested on a model of the target vehicle.

This paper focuses on the concepts of designing the final drive and presents the results of multi-criteria analysis. Effort was made to identify reasons and factors that often are decisive when choosing between a ready commercial solution and the design and creation of a new, optimized solution. As a result of the multi-criteria analysis concept I was adopted, that concept comprising a single reduction cylindrical gear combined with a planetary gear.

A paper that will follow will discuss the issues of polishing the conceptual design to arrive at the final product. The work will focus on: performing calculations, analyses of the main structural units of the final drive, and the design engineers' dilemmas in the choice of the final solution.

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