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[1.]Daniel LATES, [2.]Claudiu OPREA

ANALYSIS OF THE CYLINDRICAL GEAR WHEELS IN THE GEAR OF THE CENTRAL DRUM OF THE CABLEWAY

[1.]SC IRUM SA, ROMANIA
[2.]Technical University of Cluj-Napoca, 400114, Cluj-Napoca, ROMANIA

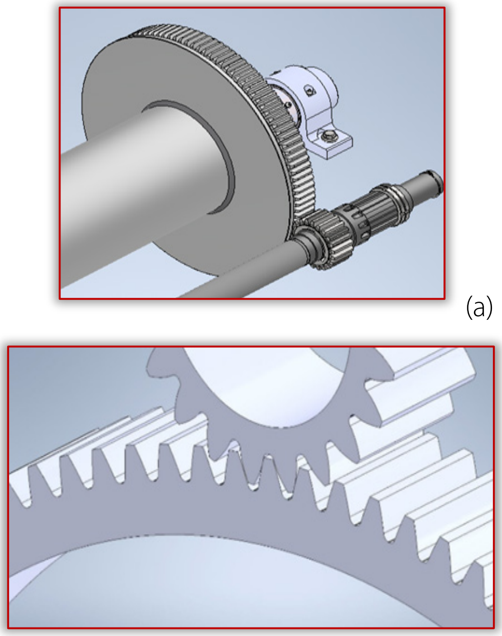
Abstract: The present paper presents aspects related to the analysis of the cylindrical gears of the central drum gear of the sled-type forestry cableway. This analysis helps to choose and correctly size the gear in the cableway winch drum. Based on the analysis performed on the gears teeth shapes, the analysis of the gear lubrication, and the analysis of the backlash of the teeth the final shape of the gear drive system will be presented. At the end of the work, the analysis with finite elements of the cylindrical gear is presented in order to obtain the optimal structure.
Keywords: cableway, gear drive, FEM analysis, backlash, gear lubrication

INTRODUCTION

In the logging industry, the construction of access roads has a negative impact on the entire forest ecosystem, especially in the case of high-slope hills or mountains. The national and international legislation recommends the use of alternative log transportation systems when the slope exceeds a certain value. One of the most used solutions are forest cableways, used for clear cut or selective cutting in hilly or mountain terrains. These installations are usually composed of cable drums driven by mechanical power units placed on mealy sleds that allows the system to be self-propelled to the place of operation, usually at the top of the slope *(Lates et. al, 2022)*. To ensure that the mechanical transmission of the forest cableway can cope with the high torque levels specific to such application, a thorough analysis of the components is required. In this article the structural analysis of the gears is performed using Finite Element Analysis (FEA), aiming to evaluate the geometry. By using FEA the potential weak spots in the analysed structure can be identified in the design stage, before the actual build of the component. The are several steps that are required for such an analysis: defining the 3D geometry, assigning the materials, setting the constraints, applying forces and pretensions, meshing, processing and post-processing, followed by refining the model for the next iteration, if required *(Zah, M., Lates, D., Besoiu, S, 2012)*.

GEAR DRIVE DESCRIPTION

The studied gear drive, shown in Figure 1 a), consists of two cylindrical gears, with a 1:5 ratio. The first gear has 22 teeth, while the second one has 110 teeth. Figure 1 b) presents a detail of the system, showing the profile of the two gears' teeth.


(a)
(b)
Figure 1 – Cylindrical gear drive, a) 22/110 Gears; b) detailed view

GEAR DRIVE ANALYSIS

The studied drive system is part of the mechanical transmission of a forest cableway used for transporting the logs downhill from the cutting location to the base of the slope, where the logs are handled for storage and transportation. The same system must be able to develop high torque levels required for transporting the logs from their initial location to somewhere beneath the carrier cable, for distances up to 50 meters. Also, in for the initial set–up stage, the entire cableway must be self–propelled uphill to the top of the slope.

Based on geometrical dimensions of the gears obtained in the design stage, a 3D model of the system was created in

Kissoft, a FEM–based simulation software. Since the system is exposed to wear when not properly lubricated, the mechanical endurance of the gears is studied, focusing on the analysis of teeth shape, lubrication process and the backlash.

TEETH SHAPE ANALYSIS

For a smother translation between the two gears the teeth shape is very important. The specific nominal values of the two gears are included in Tables 1 and 2.

Table 1

Calculation of Gear 1 (A_s= –0.090 mm)		
Tooth from, Gear 1		
Pressure angle	[alfn]	20.0000 °
Normal module	[mn]	5.0000 mm
Data of the corresponding topping cutter:		
Addendum	[ha0]	6.2500 mm (ha0*=1.250)
Radius	[roa0]	1.9000 mm (roa0*=0.380)
Dedendum	[hf0]	5.1076 mm (hf0*=1.022)

Table 2

Calculation of Gear 2 (A_s= –0.160 mm)		
Tooth from, Gear 2,		
Pressure angle	[alfn]	20.0000 °
Normal module	[mn]	5.0000 mm
Data of the corresponding topping cutter:		
Addendum	[ha0]	6.2500 mm (ha0*=1.250)
Radius	[roa0]	1.9000 mm (roa0*=0.380)
Dedendum	[hf0]	5.1963 mm (hf0*=1.039)

DRIVE LUBRICATION ANALYSIS

The importance of the lubrication process analysis comes from the need to reduce gear friction wear and to ensure an efficient and smooth gear roll. During the gear drive operation, it is recommended that a grease is always present between the two teeth that are in contact. Table 3 shows the values that were considered for the simulation, based on standard AGMA925–A03.

Table 3

Effect of Lubrication on Gear Surface Distress (AGMA925–A03) Risk of scuffing / Risk of wear		
General and Geometry input data		
Profile modification		
Material input data		
Average surface roughness at L_x, pinion	[R_{a1x}]	0.6300 µm
Average surface roughness at L_x, gear	[R_{a2x}]	0.6300 µm
Filter cutoff of wavelength x	[L_x]	0.8000 mm
Mean coefficient of friction	[µm]	0.135600
Method for approximate mean coeff. friction	:	Constant, with formula (85)
Welding factor	[X_w]	1.000

The local movement between the two gears is not purelly rotational, a small slip also occures. Depending on the rotation angle and the relative position of the the two teeth that are in contact, the sliding and also the rotational contact are identified in the diagram in Figure 2, showing the specific angle positions A,B,C,D and E.

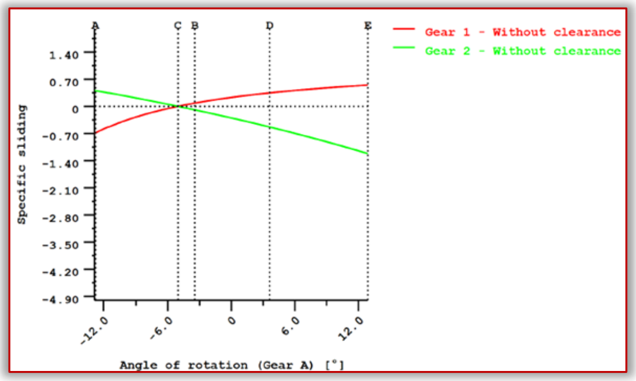


Figure 2 – The specific sliding between two teeth depending on the angle of rotation

— Teeth backlash analysis

In order to avoid the tightening of the gear drive the design process considers a minimum backlash value. Table 4 shows the values that were obtained in the simulations.

Table 4. Meshing gear 1 – gear 2

Accuracy of calculation		Medium
Partial load for calculation [w_t']		120.0000 (%)
Working flank		Right tooth flank
Centre distance	[a]	330.7437 (mm)
Single pitch deviation	[f_{pt}]	7.0000 (µm)
Coefficient. of friction	[µ]	0.0853
Proportional axis deviation error	[$f_{\Sigma b-p}$]	0.0000 (µm)
Proportional axis inclination error	[$f_{\Sigma d-p}$]	0.0000 (µm)
Torque	[T_1]	1970.1104 (Nm)
Speed	[n_1]	385.0000 (1/min)

Figure 4 shows the reference rack and the gear profile, using the following values, for the refference diameters and gaps: d_{a1}= 125.2235 mm; d_{f1}= 102.5082 mm; A_{s1}= –0.09 mm; d_{a1}= 556.1975 mm; d_{f2}= 533.3049 mm; A_{s2}= –0.16 mm.

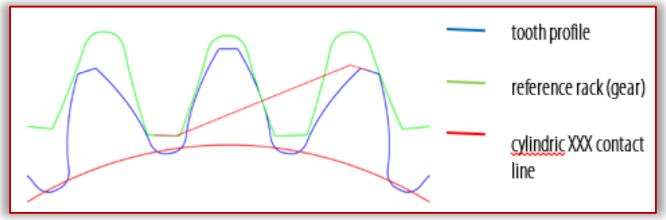


Figure 3 – Gear profile

The stiffness depending on the rellative position of the two teeth is presented in Figure 4.

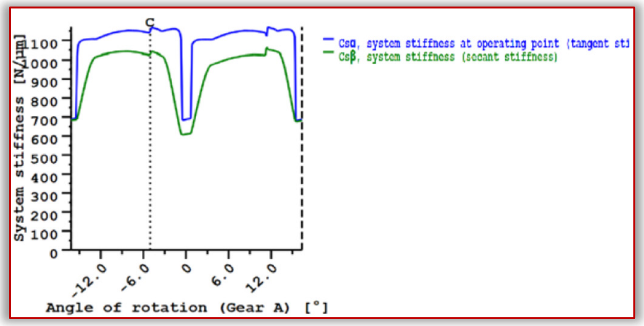


Figure 4 – System stiffness

— Finite element analysis of the gear drive

The optimal teeth shape is obtained using Finite Element Analysis for the cylindrical gear drive *(Moaveni, S., 2003)*.

The mesh is obtained using the automatic generation tool, allowing the definition of the node coordinates, the optimal numbering of the nodes and the connection between the elements, as shown in Figure 5.

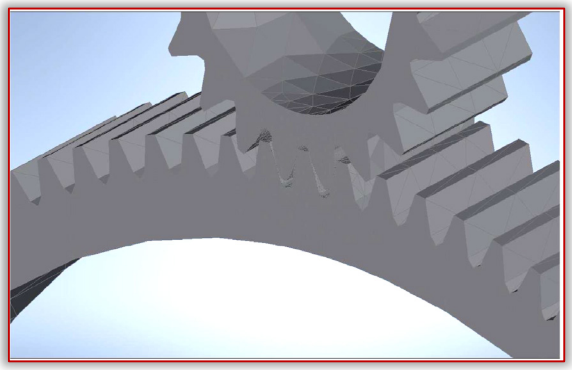
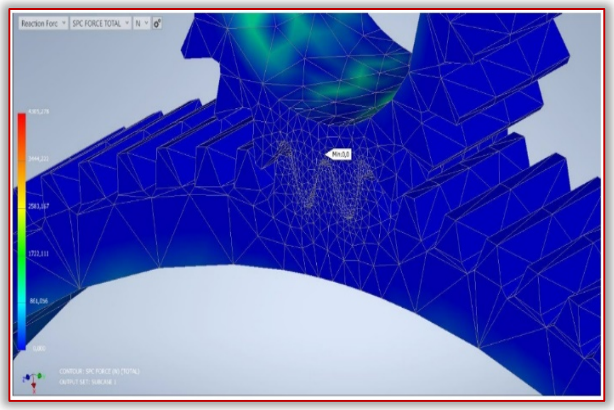
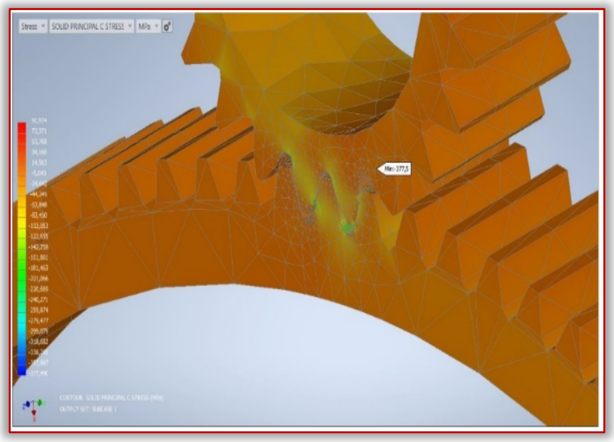


Figure 5 – The mesh

During the processing, the FEM software, starting from the input data, determines the nodal variables, such as the relative displacement of the nodes. Based on these the tension is determined, along with valued derived from the primary variables. Figure 6 a) shows the force repartition in the structure, while Figure 6 b) shows the total pressure forces *(Rares, M. 1992, Noveanu, S. et al, 2020, TTuğrul, Ö., Erol, Z., 2005)*.



(a)



(b)

Figure 6 – FEA analysis. (a) Reaction force distribution; (b) Pressure forces in the system

The finite element method (FEM) used for deformation analysis is the most widely used method for solving engineering problems and mathematical models *(Daryl, L., 2011, Chaskalovic, J., 2008, Zienkiewicz, O. C.,Taylor, R. L. et al, 2005, Baie, K. J., 1976)*. This is achieved by a certain discretization space in the dimensions of the space, which is implemented by constructing a mesh of the object: the numerical domain for the solution, which has a finite number of points. The method approximates the unknown function over the gear domain in which it has been successfully applied.

CONCLUSIONS

The analysis of the drive system, considering the teeth geometrical shape, the lubrification process and the backlash between the teeth that are in direct contact, allows a more precise design of the gear drive. This a vital requirement for the considered application, where high forces are applied when the logs are handled by the forest cableway.

The paper presents the results obtained following the numerical analysis of the mechanical structure with the help of a FEM based commercial software, with an emphasis on sensitive areas (stress concentrators, deformations) in order to develop an optimal structure such as resistance and robustness.

Based on the results obtained in this analysis the gear drive will be manufactured and integrated in the mechanical transmission of the cableway.

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