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Fatmir Azemi
University for Business and Technology, fatmir.azemi@ubt-uni.net

Xhemajl Mehmeti
University for Business and Technology, xhemajl.mehmeti@ubt-uni.net

Bekim Maloku
SHMT "Lutfi Musiqi", bekim.m70@hotmail.com

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Fatmir Azemi[1], Xhemajl Mehmeti[2], Bekim Maloku[3]

[1] UBT – Higher Education Institution, Lagjja Kalabria, 10000 p.n., Prishtinë, Kosovë

fatmir.azemi@ubt-uni.net

[2] UBT – Higher Education Institution, Lagjja Kalabria, 10000 p.n., Prishtinë, Kosovë

xhemajl.mehmeti@ubt-uni.net

[3]SHMT"Lutfi Musiqi" Vushtrri, Rr. "Kruja", 42000 p.n., Vushtrri, Kosovë

bekim.m70@hotmail.com

Abstract. Computer Aided Design (CAD) and Computer Aided Engineering (CAE) are the most important technology tools that today designers are using in development of product (design and in process of optimization). Thus, this study is carried out to present the importance of CAD/CAE system on process of design and process of optimization of spur gear. The paper presents the usage of CAD system for modeling parts and CAE software for analysis of stress-strain of spur gear and the results of calculation of pair spur-gears that it used in the gearbox transmission of the bucket wheel excavator located in "Bardhi i Madh - Fushë Kosovë", and after that will be optimized the shape of the spur gear with usage of ANSYS software. Consequently, the aim of this research is to calculate stress-strain structure of parts (gears) and reduce weigh of the gears.

Keywords: CAD/CAE, spur gear, product design, stress-strain analysis, process of optimization

1 Introduction

As it knows, in the past, for verification design of product needed physical prototype testing. Results came from making of prototype, loading it with forces, taking results and then on engineering judgement make changes based on the results. Today, demands of costumers are more complex, initiatives like continuous cost improvement and quality of product in shorter time have put greater demands on product performance, and as a results, required innovative design and engineering. The radical change of technology in today world market, product innovation is a key factor for success across nearly all industries. The aim is to make a new class of products in order to be competitive. Most companies are working in innovative design products through a combination of technology, process and people to translate knowledge of customer requirement into variable products. If companies want to stay in business competitive they must know their customers, develop ideas based on engineering fundamentals and use computer based tools such as CAD [1], CAE [2], etc., to develop and refine designs accurately and quickly as much as possible [3].
Computer Aided Design (CAD) and Computer Aided Engineering (CAE) are tools of recent technology that assist in engineering processes such as creation, design, simulation, analysis, optimization and modifications, and so on [4]. It is an integration of Mechanical and Computer Technology to aid in the design process like Modeling, Assembly, Drafting, Die Design, Tool Design, Sheet metal, analysis of products etc. In this paper we have used CATIA software as CAD software for modeling of spur gears as well as their assembly, Inventor and ANSYS Workbench 14.0 software for stress-strain analysis and process of optimization. In our case a real case study is used for Stress-Strain Analysis of the spur gear of the gearbox transmission (gear-box reduction) of the working wheel of Excavator.

2 Statement of the problem, objectives and purpose of the study

The real case study has been draw from gear transmission (gear-box reduction) of the excavator which is located in open-cast coal mines in Kosovo mines, and during Excavator arm movement from right side to left the bucket wheel works with maximum capacity and in that case have been caused damage in spur gear 9 and spur gear 10 of gear- box reduction of the Excavator. Objective and purpose is to determine stress-strain structure of spur gear 9 and spur gear 10 with CAD and CAE system in order to find out if the gears accomplish working conditions, which factors aren't fulfilling conditions and finding a solution and optimization of the spur gear. Figure 1 shows type of the excavator.

Fig.1. Type of Excavator SRs 1300 and working wheel

1.2 Determination of working loads in gear transmission of bucket wheel of Excavator with measurement

Based on the conditions and characteristics of the operating environment in terrain bucket wheel of excavators are produced as unique and are supposed to excavate coal. Bucket wheel excavators are produced mostly as unique products according to the conditions and characteristics of the operating environment where they are supposed to excavate coal or ore (Fig.1).
Excavating process is periodical, because excavating material realized by bucket cyclin during entering and exiting and have in mind that material of coal (lignite in this case) isn't homogenize, determination of torque on the output shaft through mathematical formula is near impossible. Therefore, tenzometrike measurements so-called Winston bridge method of deformation has been done [5], figure 2.

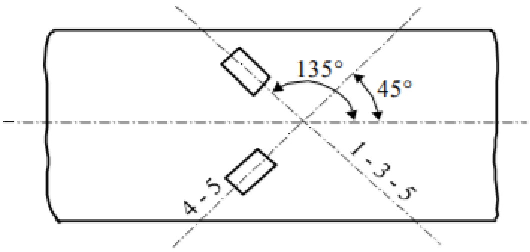

Fig.2. Winston bridge method for measurement deformation

Based on this method has been calculated the value of torque as a main parameter for calculus of all other parameters of the gearbox transmission.
Tangential deformations have calculated as follows:

$$\tau_{xy} = \frac{E(\varepsilon_{45} - \varepsilon_{135})}{2(1+\mu)} = \frac{E \cdot \varepsilon}{2 \cdot (1-\mu)} \quad (1)$$

Where are:
E – module of elasticity for material of shaft,
ε45,135 – relative deformation in the directions,
μ - Poisson's coefficient,
The torque on working wheel T which is required for further calculation for elements of gearbox transmission and in our case for design of spur gear and shape optimization of it is:

$$T = \frac{E}{1+\mu} \cdot W_0 \cdot \varepsilon \tag{2}$$

W_0 - polar moment of resistance of the cross section.
Based from equations (1), (2) and from diagram of oscilogram (fig.3) measuring the deformation in the shaft during work of bucket wheel are achieved value of the torque *T* as below [5]:

- from 3899 to 4260 [Nm] – at the time of starting work of Excavator,
- from 2635 to 4729 [Nm] – at the maximum capacity of Excavator.

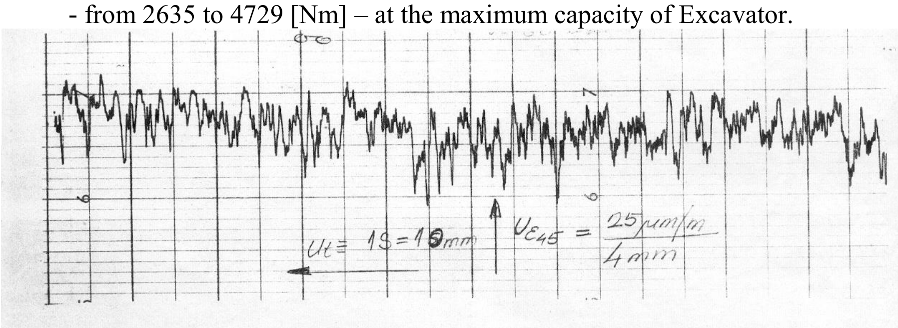

Fig.3. Oscilogram measuring the deformation in the shaft during working of bucket wheel

Based on the calculation of gear box the torques on the gear 9 and gear 10 are [6]:

$$T_9=195635.282\ [N\cdot m] \text{ and } T_{10}=1070451.049\ [N\cdot m] \tag{3}$$

2 Method and Materials

Computer Aided Design tools are used for the creation of 3D solid or surface models, or 2D drawings of physical components. There are many CAD environments available for creating new engineering designs or concepts. As a new design or modification to a current design is developed in a package such as CATIA or Autodesk Inventor, the model can then be created in a short time to have an actual prototype for further testing. This prototype, along with analysis tools, helps to quickly define the success and failures of the new design [7].

In this case we have used CATIA V5, Autodesk Inventor Professional and ANSYS software for design, analysis and shape optimization of parts and their assembly.
This design of parts has been done in CATIA Software and will be used for analyses of stress-strain structure of assembly with the application Finite Element Method. Ansys Workbench 14.0 is used for analyses, design of assembly has been imported from CATIA saved as IGES file to ANSYS software for analyses [8],[9] figure 4.

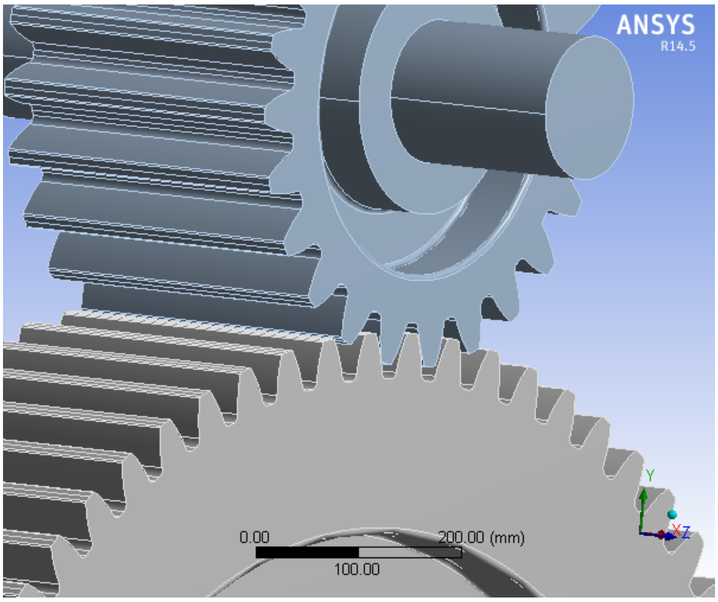

Fig.4. Assembly parts opened in ANSYS WORKBENCH 14.0

2.1 Data materials and parameters of assembly

Autodesk Inventor professional 2015, Spur Gears Component Generator is used to generate a pair of gears with same geometry and material as shown below on tables. Method of Strength Calculation based on ISO 6336:1996.
Parameters, geometrical data, materials and loads are given through tables as below [10]:

Table 1. Common parameters of assembly (parts)

Gear Ratio	i	5.5833 ul
Desired Gear Ratio	i_{in}	5.5833 ul
Module	m	20.000 mm
Helix Angle	β	0.0000 deg
Pressure Angle	α	20.0000 deg
Center Distance	a_w	1600.000 mm
Product Center Distance	a	1580.000 mm

Total Unit Correction	Σx	1.0458 ul
Circular Pitch	p	62.832 mm
Base Circular Pitch	p_{tb}	59.043 mm
Operating Pressure Angle	α_w	21.8831 deg
Contact Ratio	ε	1.4226 ul
Limit Deviation of Axis Parallelity	f_x	0.0290 mm
Limit Deviation of Axis Parallelity	f_y	0.0140 mm

Table 2. Main geometric data of gears

		Gear 9	Gear 10
Type of model		Component	Component
Number of Teeth	z	24 ul	134 ul
Unit Correction	x	0.8869 ul	0.1589 ul
Pitch Diameter	d	480.000 mm	2680.000 mm
Outside Diameter	d_a	553.646 mm	2724.522 mm
Root Diameter	d_f	465.478 mm	2636.354 mm
Base Circle Diameter	d_b	451.052 mm	2518.376 mm
Work Pitch Diameter	d_w	486.076 mm	2713.924 mm
Facewidth	b	640.000 mm	640.000 mm
Facewidth Ratio	b_r	1.33 ul	0.2388 ul

Table 3. Materials of spur gears

		Gear 9	Gear 10
		User material	User material
Ultimate Tensile Strength	S_u	700 MPa	700 MPa
Yield Strength	S_y	340 MPa	340 MPa
Modulus of Elasticity	E	206000 MPa	206000 MPa
Poisson's Ratio	μ	0.300 ul	0.300 ul
Bending Fatigue Limit	σ_{Flim}	421.0 MPa	490.0 MPa
Contact Fatigue Limit	σ_{Hlim}	1195.0 MPa	1370.0 MPa
Hardness in Tooth Core	JHV	210 ul	210 ul
Hardness in Tooth Side	VHV	600 ul	600 ul

Table 4. Loads

		Gear 9	Gear 10
Power	P	676.067 kW	662.546 kW
Speed	n	33.00 rpm	5.91 rpm
Torque	T	195635.282 N m	1070451.049 N m
Efficiency	η	0.980 ul	
Radial Force	F_r	323314.557 N	
Tangential Force	F_t	804957.669 N	
Axial Force	F_a	0.000 N	
Normal Force	F_n	867461.326 N	

3 Results and Discussion

With the usage of CAD and CAE software we can read that the minimum of stress is 0.0027365 MPa and maximum stress is 662.33 MPa, whereas the minimum of Equivalent Elastic Strain is 2.4689e-008 mm/mm and the maximum of Equivalent Elastic Strain is 0.0038289 mm/mm 0.0027365 MPa and maximum of stress is 662.33 MPa. Graphically are presented in figure 5.

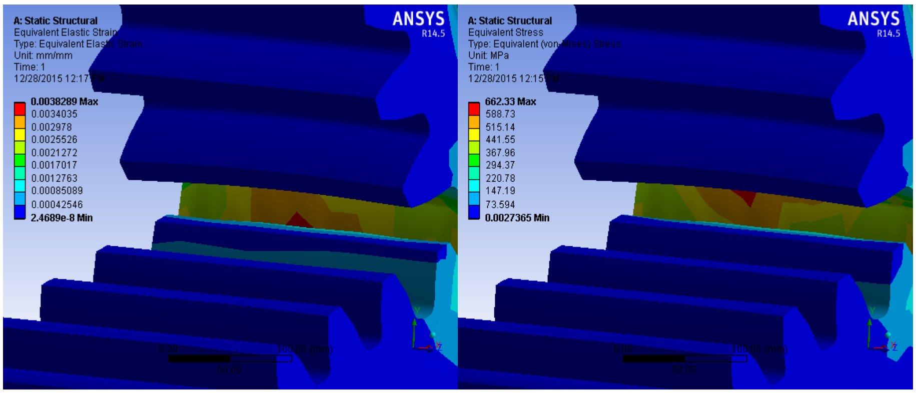

Fig.5. Static structural of Stress-Strain

After the analyses of Stress-Strain of gears, the gears (pinion and gear) are calculated in Inventor, the tools Spur Gears Component Generator has created components after application method of "Type of Strength Calculation-Material Design". Results are given on tables as below.

Table 5. Results after analyses of Stress-strain

		Gear 1	Gear 2
		User material	User material
Ultimate Tensile Strength	Su	700 MPa	700 MPa
Yield Strength	Sy	340 MPa	340 MPa
Modulus of Elasticity	E	206000 MPa	206000 MPa
Poisson's Ratio	μ	0.300 ul	0.300 ul
Bending Fatigue Limit	σFlim	604.5 MPa	623.8 MPa
Contact Fatigue Limit	σHlim	1331.4 MPa	1121.6 MPa
Hardness in Tooth Core	JHV	210 ul	210 ul
Type of Treatment	type	2 ul	2 ul
Factor of Safety from Pitting	SH	2.138 ul	2.138 ul
Factor of Safety from Tooth Breakage	SF	8.248 ul	7.659 ul
Static Safety in Contact	SHst	1.204 ul	1.204 ul
Static Safety in Bending	SFst	19.181 ul	17.894 ul
Check Calculation		**Positive**	

ANSYS WORKBENCH Software has been used for analysis and shape optimization of spur gear with Finite Element Method[11].

Figure 6 shows that area with red color are parts which should be removed for shape optimization.

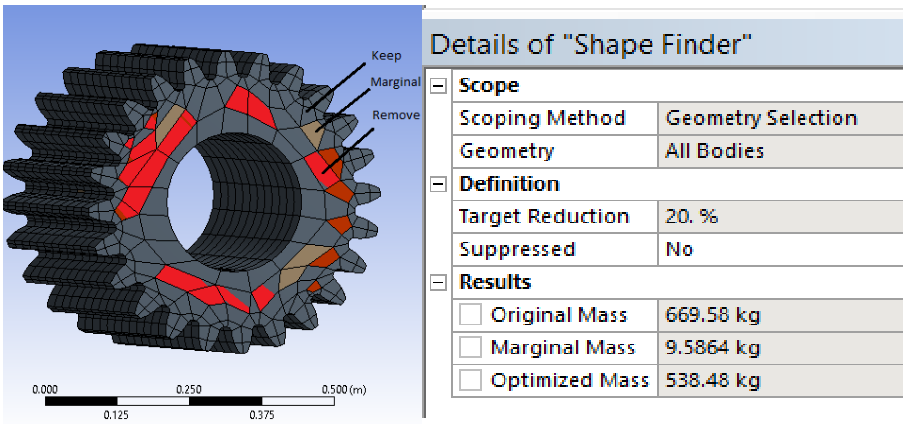

Fig.6. Shape optimization of spur gear in ANSYS software and mass reduction

4 Conclusion

This paper has presents the importance of CAD and CAE in process of product development. Are many components that indicating in product development, such as calculations, design, material strength, manufacturing quality and etc. First, has been used CAD software for designing parts and their assembly in order to import files to CAE software for analysis of stress-strain structure. After that, analyses shown that the material and dimensions that have been used for making gears are not fulfilling conditions in case when Excavator works with maximum capacity. It can be concluded that for fulfilling conditions needed to change the material of gears or should be increased dimensions. In this paper geometry integration of the spur gear is used in order for relational design to be successfully implemented, all parts and products need to be parameterized. The spur gears geometry can be generated using mathematical calculations done in Autodesk Inventor professional and CATIA supports parametric design, through which gear geometry formula and relations are created. The model of spur gear 9 has been exported in ANSYS software for shape optimization. The design optimization helps in reducing 20.5% of the structure weight (the initial and final mass of the spur gear are 669.58 kg and 538.48 kg, respectively), which in turn reduces the cost of the spur gear with safe design.
Use of CAD/CAE also helps to create the better innovations in the product. By integrating analysis and process of design in development of product at the earlier stages the productivity can be enhanced and could be obtained superior designs.

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