

CONSTRUCTIVE OPTIMIZATION BY METHOD OF FINITE ELEMENT ANALYSIS OF HEMP FIBRE PROCESSING EQUIPMENT

Mihai Olan, Alexandru Zaica, Anisoara Paun, Paul Gageanu

National Institute of Research-Development for Machines and Installations

Designed to Agriculture and Food Industry, Romania

vibrobloc@yahoo.com

Abstract. Finite element analysis (FEA) is a computerized method for predicting how a product reacts to real-world forces, vibration, heat, fluid flow, and other physical effects. Finite element analysis shows whether a product resists under the working conditions, wears out, or works the way it was designed. Hemp fibre is a natural renewable material used in important areas of industry. The primary processing is performed on special equipment that ensures hemp fibre processing. In this study, the structural analysis module will be used for static analysis (resistance checking) and modal analysis (frequency analysis or calculation of a number of structure's own frequencies) for the important assemblies. The pressing and crushing rollers, their spindles and bearings and the frame (machine frame) of the hemp fibre processing equipment are analyzed and verified constructively and functionally. The results obtained are used in redesigning the equipment. Thus, it is expected that the new design of the hemp fibre processing equipment will have better performance in terms of metal consumption, energy efficiency and the quality of the obtained products. The equipment comprises a system with 8 pairs of processing rolls, and a vibrating system for separating the pieces from the remaining stems in fibre. The work is aimed at checking the dimensioning and the resistance to the efforts by the method of the finite element analysis (FEA) both for the construction of the rollers and the support frame.

Keywords: hemp fibre, decorticator, press, equipment.

Introduction

For the production of hemp fiber, special equipment is required for primary processing of the stems. Their construction comprises an assembly of pairs of rollers (rollers) that perform different technological phases within the primary processing, namely: crushing, breaking the wood part of the stems, separating the wood part [1-3]. In order for these equipments to withstand maximum stresses and also to use optimal materials consumption in the construction of the equipment, it is necessary to carry out a dimensional analysis of the components subjected to maximum effort with the FEA method [3-5]. After calculating the maximum force required in the technological phase with maximum effort, that is to break the stems with maximum section, the dimensioning and verification at maximum effort of the respective rolls will be started. In the work the constructive project is verified before being delivered in execution [6; 7]. The constructive analysis of the equipment for the production of hemp fibre with the verification of the resistance of the equipment in the areas with maximum effort from the design phase is very important [8-10].

The studies performed according to this article allowed the analysis and dimensional re-design of the main components subjected to the maximum effort of the equipment for primary processing of hemp fibre [11; 12].

Materials and methods

For processing hemp fibre to 5-day harvested strains, special equipment with 8 pairs of rollers for breaking and separating the hemp fibre from the woody part was designed. Fig. 1.

In order to perform all the operations necessary to obtain high quality hemp fibre, the 8 sets of rollers have different profiles and are mounted in successive order starting from the supply port of the equipment (Fig. 2):

1. The first set of rollers of the equipment is presented in part A, it has rollers with circular channels and rectangular section for driving stems and breaking leaves.
2. Set of 2 rollers is presented in part E, it has rollers with axial channels and circular section with a depth of 3 mm and has the role of pressing the fibre on the hemp stem.
3. Set of 3 rollers is presented in part B, has rollers with circular channels and triangular section for longitudinal notching of the fibre.

4. Set of 4 rollers is presented in part C, where the lower roller has a set of laminated profiles type U5 and the upper roller is provided with a set of laminated profiles type T5, which will allow the primary rupture of the wooden part of the hemp stem.
5. Set of 5 rollers is presented in part D, it has rollers provided with axial knives that have triangular teeth that intertwine and will clean the pieces of fibre stem.
6. Set of 6 rollers is presented in part B, it has rollers with axial channels and circular section with a depth of 6 mm and has the role of pressing the fibre on the hemp stem.
7. Set of 7 of rollers is presented in part D, it has rollers provided with axial knives that have triangular teeth and that intertwine and will clean the pieces of the fibre stem.
8. Set of 8 rollers is presented in part B, it has rollers with axial channels and circular section with a depth of 12 mm and has the role of pressing the fibre on the hemp stem.

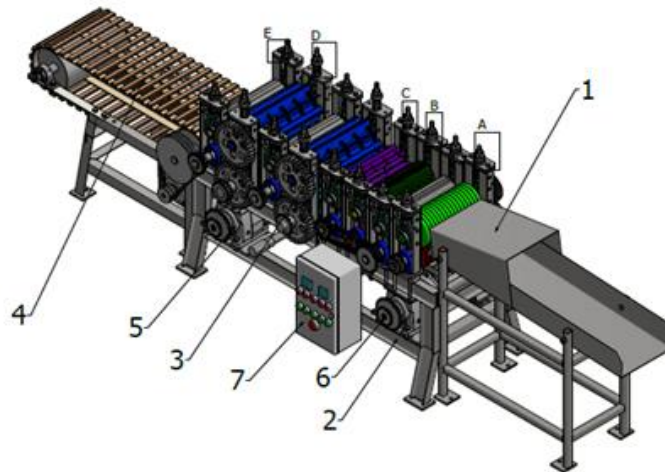


Fig. 1. **Hemp fibre processing equipment:** 1 – mouth of supply; 2 – beat; 3 – set 8 pairs of rollers with different profiles for the technological phases of pressing, crushing, breaking stems; primary separation; breaking pieces of stems; final separation; 4 – final separator for hemp fibre; 5, 6 – gear motors for drive; 7 – electric panel

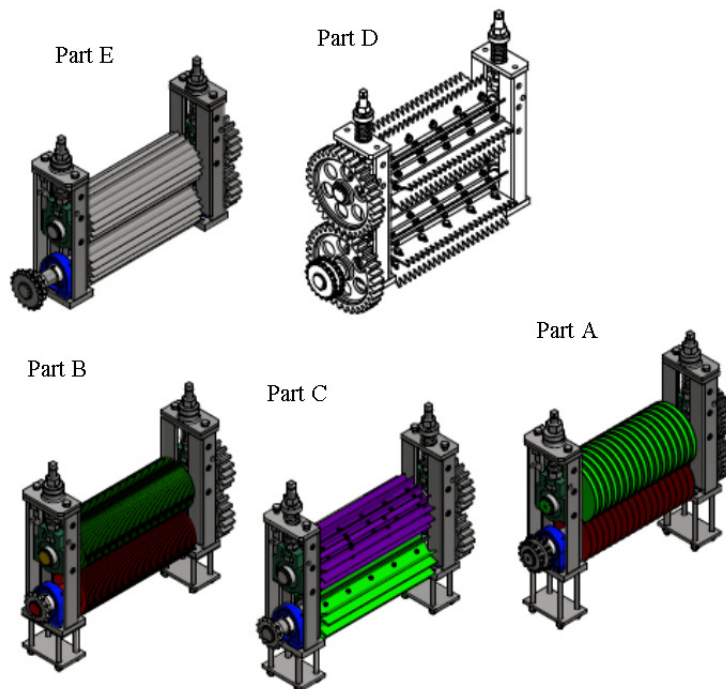


Fig. 2. **Constructive types of rollers**

Each set of rollers is mounted at one end a pair of cylindrical wheels to be rotated simultaneously. Between each set of rollers a transmission is mounted with wheels and Gall chain to transmit the

rotational movement from set 1 to set 3 of rollers and from set 2 to set 4 of rollers and receives the rotational movement of each group of 4 sets of rollers from a gear motor.

For the analysis with the finite element method (FEA), the following representative type will be chosen: circular channel roll for pressing hemp stems.

Determination of the characteristic elements of the circular channel roller used in the construction of hemp fibre processing equipment is shown in Fig. 3 and 4.

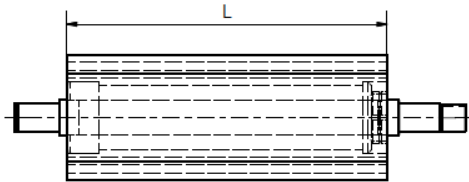


Fig. 3. Roller-longitudinal view

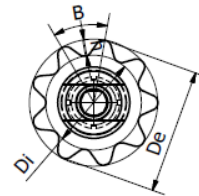


Fig. 4. Roller section

Table 1

Roller profile geometric calculation

No.	Name of constructive element	Numerical application
1	The angle corresponding to the step of the grooves (α) is measured between the radii passing through the centre of the roll and the ends of two adjacent grooves. $\alpha = 360/n_c$. In which: n_c = number of grooves	$\alpha_2 = 360/9 = 40^\circ$
2	The pitch of the grooves on the arch is measured on the outer circumference of the respective wave, between the ends of two adjacent grooves. $P_{ca} = \pi \cdot D_{ext} / n_c$	$P_{ca2} = \pi \cdot 158 / 9 = 55.12$ mm
3	The height of the grooves (h), in mm: $h = R_{ext} - R_i$	$h_2 = 78 - 60 = 18$ mm
4	The distance between the rotation axes of the pair waves (D), in mm: $D = D_{ext} - i$. In which: i is the size of the interpretation of the grooves of two pairs, in mm.	$D = 158 - 12 = 146$ mm
5	The angle of the crushing field (β), formed from the radii passed through the initial and final points of the crushing field $\beta = 2^\circ \arccos D/2R_{ext}$	$B = 40^\circ$
6	The average number of grooves (n_m) at the same time in the crushing field: $n_m = n_c \cdot \beta/180$	$n_m = 9 \times 40/180 = 2$
7	Passing speed of the stems through the pair of grooved rollers, in $m \cdot \min^{-1}$. $V_t = L_f \cdot n$, where n – rotation of grooved cylinders, rpm	$V_t = 2$ m.l.

For the maximum effort verification of the circular channel roller, the FEA method of the Autodesk Inventor software will be used.

Stress Analysis Report, project information, physical:

- mass – 40.1533 kg;
- area – 495696 mm²;
- volume – 5115070 mm³;
- centre of gravity – $x = 9.24911$ mm; $y = 0.253161$ mm; $z = 4.22152$ mm.

Static Analysis, general objective and settings:

- design objective – Single Point.
- study type – Static Analysis.

Material settings:

- type: 40Cr10 steel;
- density – 7.850 g·cm⁻³;

- modulus of elasticity – 200 GPa;
- Poisson’s ratio – 0.3;
- tensile yield strength – 380 MPa;
- tensile ultimate strength – 281 MPa.

Operating conditions: Pressure – 0.400 MPa.

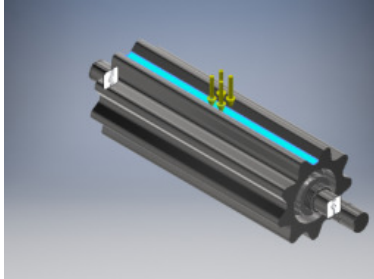


Fig. 5. Selected faces

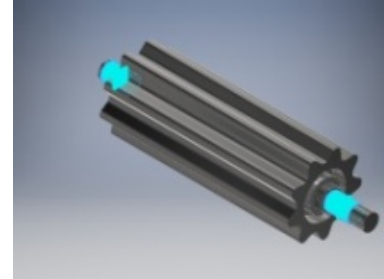
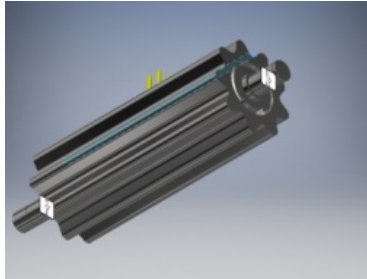


Fig. 6. Fixed Constraint: 1

Boundary condition: as the roller is simply supported, so all degrees of freedom of the roller are fixed at the bearing position. The force is distributed linearly on the bottom of the channel to analyze the stress resistance of the minimum section of the roller.

Table 2

Results -Reaction force and moment on constraints

Constraint name	Reaction force		Reaction moment	
	Magnitude	Component (X,Y,Z)	Magnitude	Component (X,Y,Z)
Fixed Constraint: 1	2276.74 N	0 N	8.9043 Nm	0 N m
		0 N		8.9043 N m
		2276.74 N		0 N m

Table 3

Result Summary

Name	Minimum	Maximum
Volume	5115070 mm ³	
Mass	40.1533 kg	
Von Mises Stress	0.0000000126786 MPa	10.0902 MPa
1st Principal Stress	-4.14146 MPa	13.0666 MPa
3rd Principal Stress	-10.9627 MPa	4.13444 MPa
Displacement	0 mm	0.0027229 mm
Safety Factor	15 ul	15 ul
Stress XX	-10.2556 MPa	12.8878 MPa
Stress XY	-2.2523 MPa	2.17526 MPa
Stress XZ	-2.75327 MPa	3.43195 MPa
Stress YY	-4.96621 MPa	4.95798 MPa
Stress YZ	-2.31881 MPa	2.22248 MPa
Stress ZZ	-8.66676 MPa	7.06237 MPa
X Displacement	-0.000819876 mm	0.000805317 mm
Y Displacement	-0.000160841 mm	0.000168816 mm
Z Displacement	-0.0027229 mm	0.000000995897 mm
Equivalent Strain	0.000000000000551805 ul	0.0000459576 ul
1st Principal Strain	-0.00000117322 ul	0.0000521372 ul
3rd Principal Strain	-0.0000466529 ul	0.00000125418 ul
Strain XX	-0.0000418966 ul	0.0000504761 ul
Strain XY	-0.00001464 ul	0.0000141392 ul
Strain XZ	-0.0000178962 ul	0.0000198897 ul

Table 3 (continued)

Name	Minimum	Maximum
Strain YY	-0.0000111289 ul	0.0000101204 ul
Strain YZ	-0.0000134386 ul	0.0000129663 ul
Strain ZZ	-0.0000366289 ul	0.0000279321 ul
Contact Pressure	0 MPa	14.2606 MPa
Contact Pressure X	-12.4986 MPa	10.0855 MPa
Contact Pressure Y	-2.56587 MPa	1.81009 MPa
Contact Pressure Z	-3.50994 MPa	7.2686 MPa

Maximum shear stress, total deformations are calculated as static analysis results. To check the resistance to stress of the roller with circular channels we will use the Autodesk Inventor software. Results are shown in Fig. 7-13.

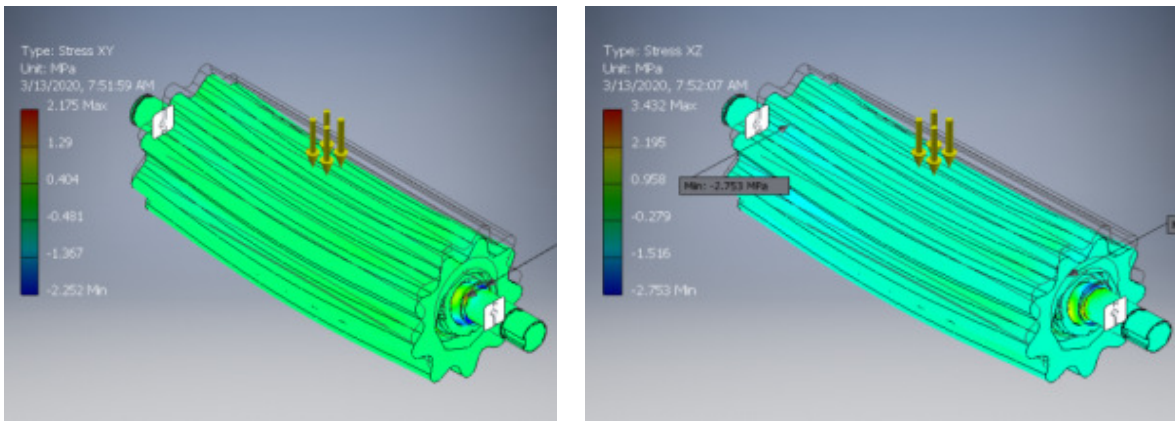


Fig. 7. Stress – Von Mises stress, XY max is 2175 MPa

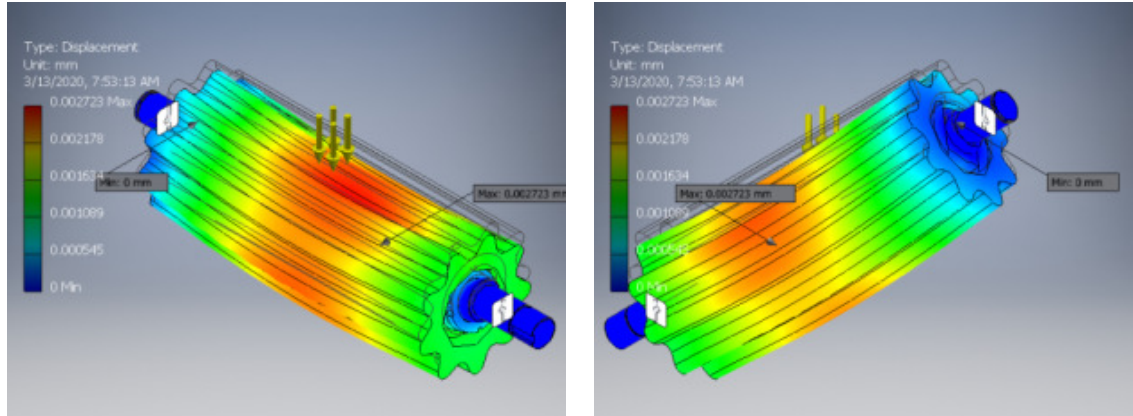


Fig. 8. Maximum value of displacement is $27.23 \cdot 10^{-4}$ mm

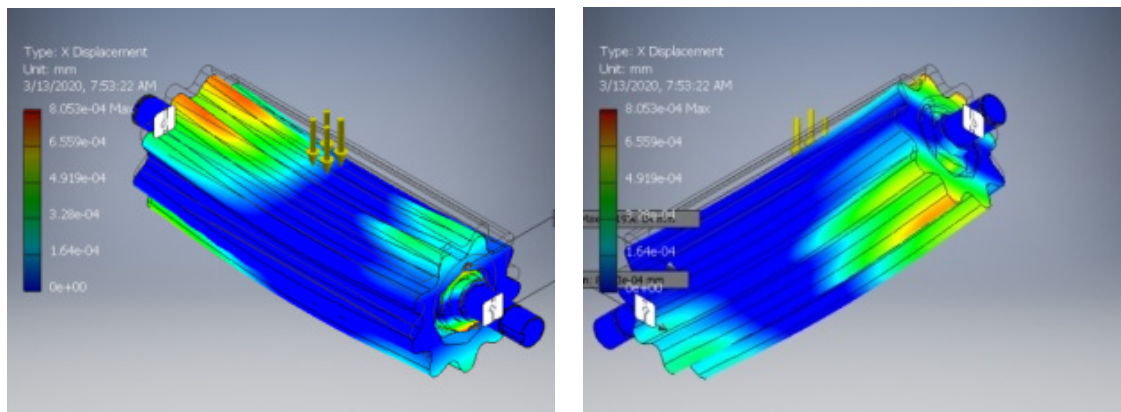


Fig. 9. X Displacement max is $8.063 \cdot 10^{-4}$ mm

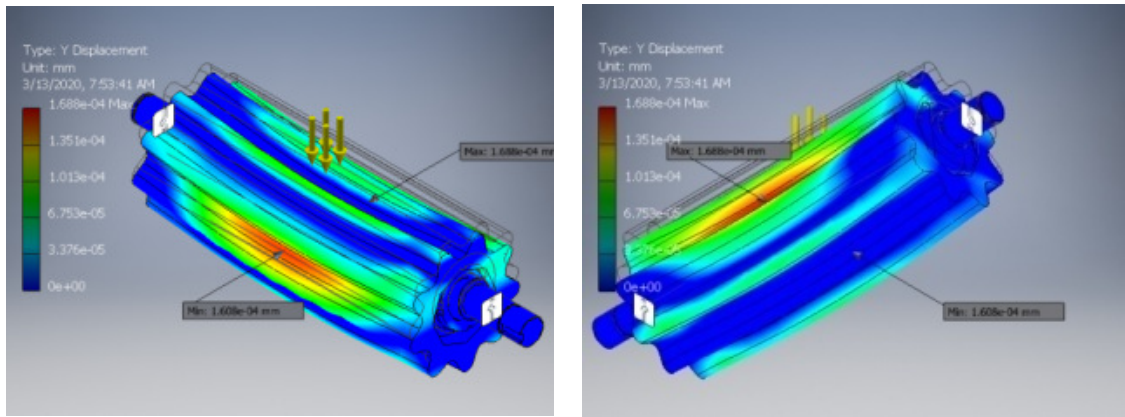


Fig. 10. Y Displacement max is $1.688 \cdot 10^{-4}$ mm

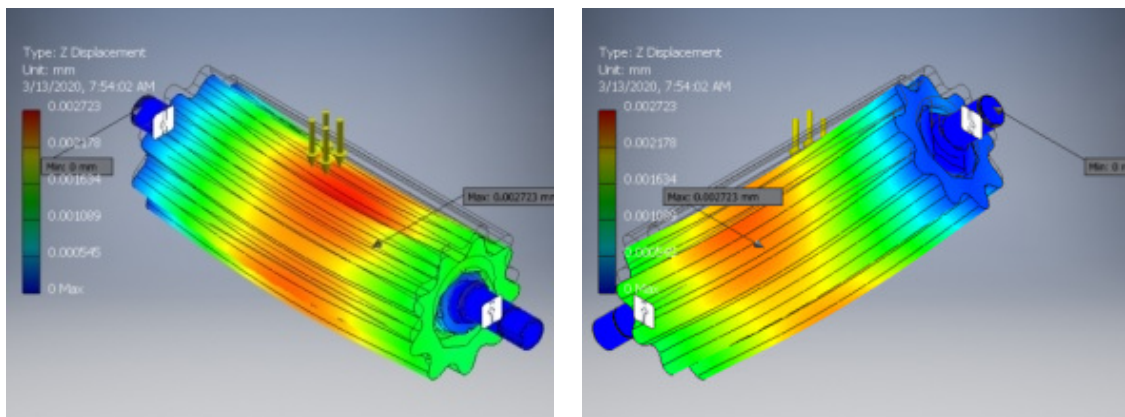


Fig. 11. Z Displacement is $27.23 \cdot 10^{-4}$ mm

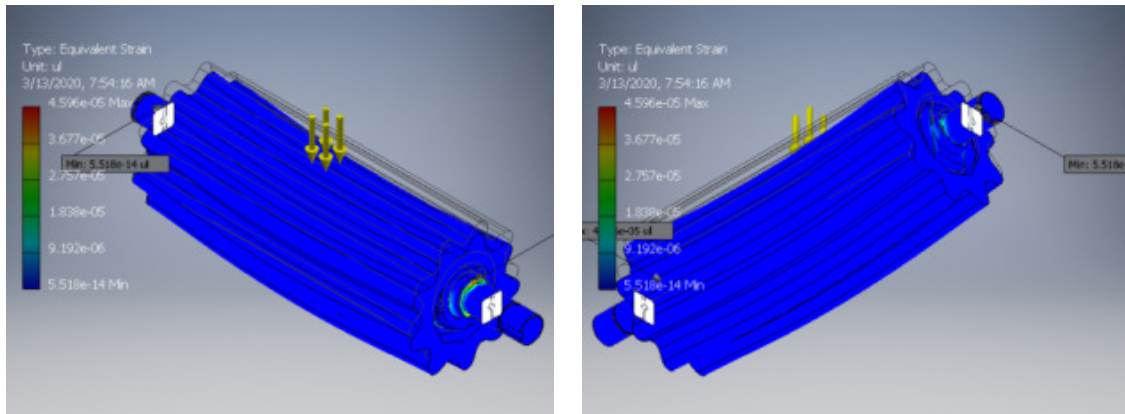


Fig. 12. Equivalent strain

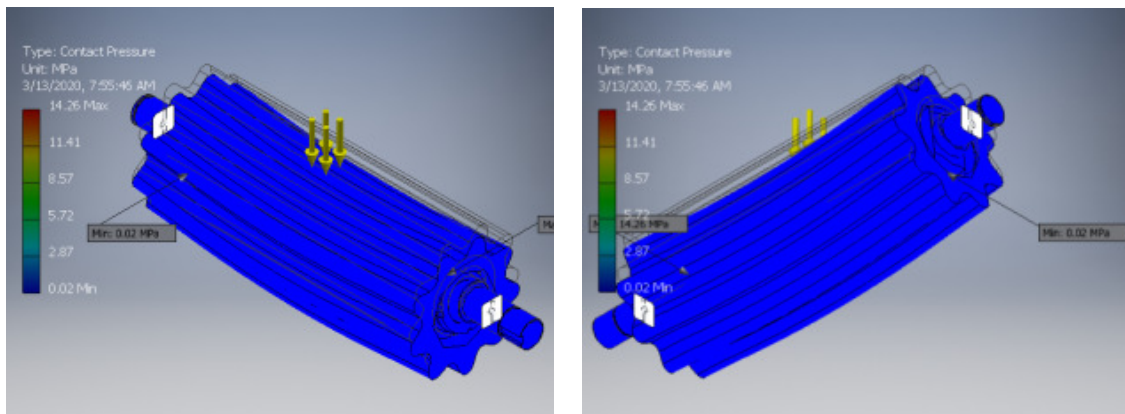


Fig. 13. Contact pressure

Maximum value of shear stress is 14.26 MPa, which is at the bearing position of the top roller. Maximum value of shear stress is within limit, so the shaft is safe. Minimum value of shear stress is 0.02 MPa at bearing. Contact pressure calculation results are given in Fig. 14-16.

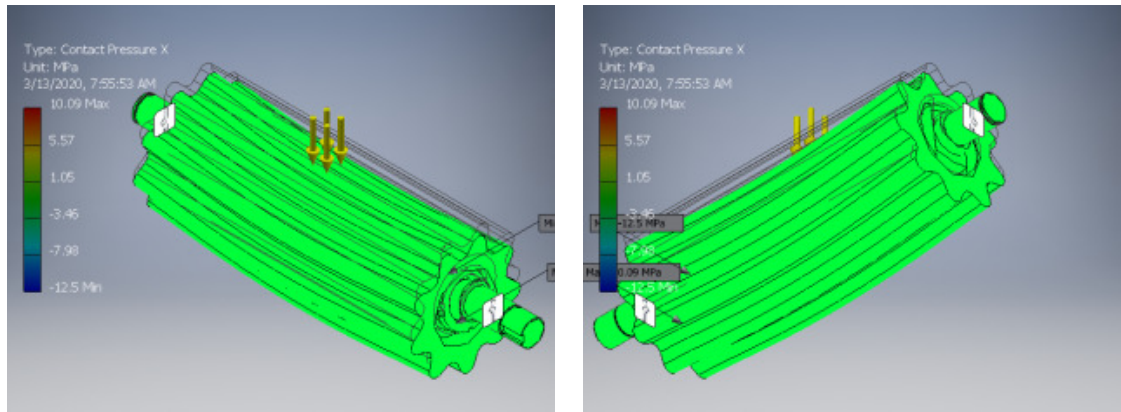


Fig. 14. Contact pressure X max is 10.09 MPa

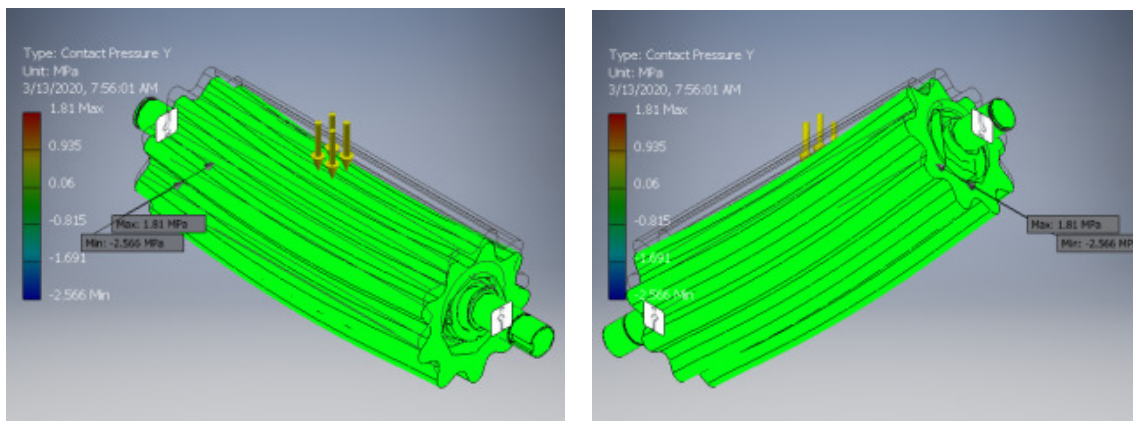


Fig. 15. Contact pressure Y max is 1.81 MPa

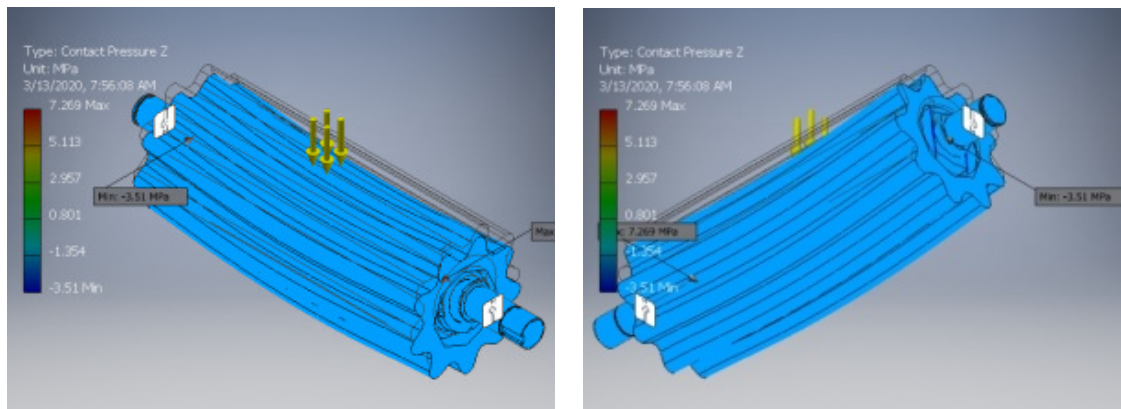


Fig. 16. Contact pressure Z max is 7.269 MPa

Results and discussion

The static analysis of the two profiled rollers is done using alloy steel to analyze the maximum shear stress, total deformation and the mass of the press rollers. The maximum value of the theoretical and numerical shear force is compared to validate the results. Maximum value of shear stress is 14.26 MPa, which is at bearing position of the top and front rollers. Maximum value of shear stress is within limit, so the shaft is safe. Minimum value of shear stress is 0.02 MPa at bearing.

The studies performed according to this article allowed the analysis and dimensional re-design of the main components subjected to the maximum effort of the equipment for primary processing of hemp fibre.

The designed standard roller has a minimum wall thickness of 12.5 mm next to the channels with a radius of 20 mm. and has a deformation of 0.002723 mm in the Z direction.

Table 3 shows the minimum and maximum values obtained by using Autodesk Inventor, but in practice we only work with 3 decimals from case to case.

The present study allowed the dimensional design of the pressing rollers (Fig. 16) and the design of the roller set assembly with bearings (Fig. 16) and then the constructive design of the entire equipment (Fig. 1). The FEA analysis allowed the choice of the optimal materials for the rollers and the reduction of the material consumption in accordance with their minimum deformations in the technological phases with maximum effort. Their construction comprises an assembly of pairs of rollers (rollers) that perform different technological phases within the primary processing, namely: crushing, breaking the wood part of the stems, separating the wood part.

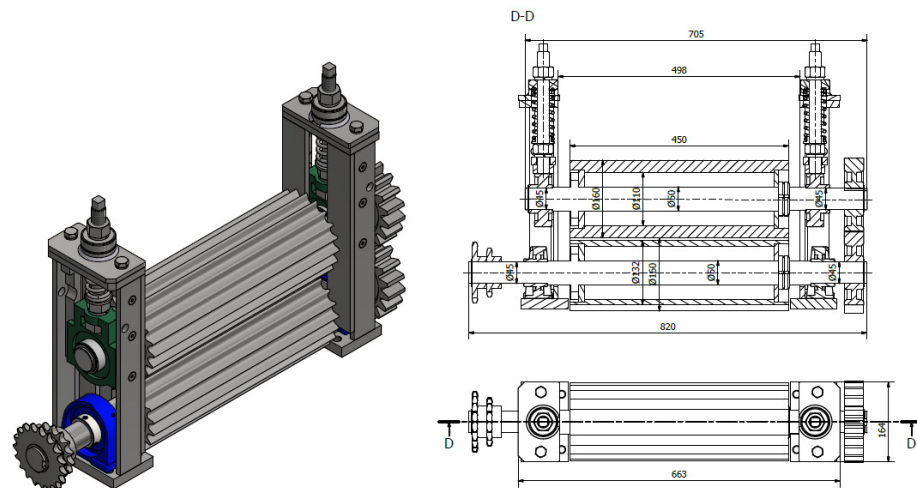


Fig. 15. Assembly of roller bearings comprising the pair of rollers with 9 or 15 circular channels

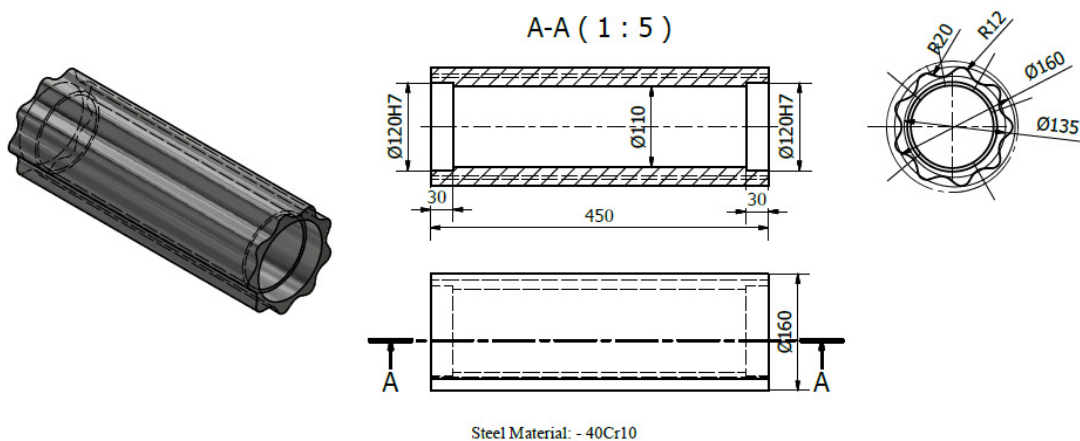


Fig. 16. Roller element profiled with 9 circular channels redesigned dimensional according to FEA analysis

Conclusions

Modeling with Autodesk Inventor software and FEA analysis is performed for the bottom and top rollers, which are subjected to the same effort and have the same dimensions both in the working area and at the grip. Analyzing the diagrams obtained in the FEA analysis we will conclude the following.

1. The maximum value of the shear stress is less than the shear strength of the chosen material, so the two rollers are safe.
2. The shear stress is very small, so there is the possibility to optimize the weight of the components.
3. Analyzing the total deformation, we find that the material chosen (40Cr10) is very good.

Acknowledgement

This work was supported by a grant of the Romanian Research and Innovation Ministry, through Programme 1 – Development of the national research-development system, sub-programme 1.2 – Institutional performance – Projects for financing excellence in RDI, contract No. 16 PFE.

A grant of the Romanian Research and Innovation Ministry, PN 19 10 01 03-Substantion of the technology for harvesting and primary processing green hemp stalks, contract no. 5N/07.02.2019.

References

- [1] Canadian Hemp Trade Alliance, Hemp production e-guide, 2019, [online][11.02.2020] Available at: <http://www.hemptrade.ca/eguide>.
- [2] Gusovius H.J., Paulitz J., Current developments for efficient raw material supply procedures enforcing cost-effective bast fibre production in Europe, *Journal of Biobased Materials and Bioenergy*, vol. 3, no. 3, 2009, pp. 262-264.
- [3] Xu J., Peng Q., Chen Y. Conceptual Design of Hemp Fibre Production Lines in Virtual Environments, *Computer-Aided Design and Applications*, August 2013.
- [4] Carus M., The European hemp industry: Cultivation, processing, and applications for fibres, shivs, seeds, and flowers, Huerth, Germany: European Industrial Hemp Association. 2017, [online][11.02.2020] Available at: https://eiha.org/media/2017/12/17-03_European_Hemp_Industry.pdf.
- [5] Munder F., Füll C. Effective processing of bast fiber plants and mechanical properties of the fibers, ASAE/CSAE Meeting Paper No. 046091. St. Joseph, Mich., 2004.
- [6] Choudhary A.K., Arnold C.B. Automated concept generation using branched functional models, *Proceedings of the ASME IDETC/CIE 2010, DETC2010-28775*.
- [7] Desanlis F. Basics of hemp growing, *Proceedings of the 4th International Conference of the European Industrial Hemp Association*, Hurth, Germany, November 2006.
- [8] Fresner J., Jantschgi, J., Birkel S., Brnthal J., Krenn C., The theory of inventive problem solving (TRIZ) as option generation tool within cleaner production projects, *Journal of Cleaner Production*, DOI: 10.1016/j.jclepro.2009.08.012
- [9] Turunen L., van der Werf H. The Production Chain of Hemp and Flax Textile Yarn and Its Environmental Impacts. November 2007. *Journal of Industrial Hemp* 12(2), pp. 43-66. DOI: 10.1300/J237v12n02_04.
- [10] Mahapatra. N.N. Extraction, processing, properties and use of hemp fiber. [online][11.02.2020] Available at: <https://www.textiletoday.com.bd/extraction-processing-properties-and-use-of-hemp-fiber/>
- [11] Pecenka R., Luhr C., Gusovius H.J. Design of Competitive Processing Plants for Hemp Fibre Production, *International Scholarly Research Network ISRN Agronomy Volume 2012*, Article ID 647867, 5 pages DOI: 10.5402/2012/647867.
- [12] Pecenka R., Füll C., Gusovius H. J., Hoffmann T. Optimal plant lay-out for profitable bast fibre production in Europe with a novel processing technology, *Journal of Biobased Materials and Bioenergy*, vol. 3, no. 3, 2009, pp. 282-285.