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Oleksandr Kachur[1], Vitaliy Korendiy[2], Volodymyr Havran[3]

[1] Department of Technical Mechanics and Engineering Graphics, Department of Computer-Aided Design, Lviv Polytechnic National University,12 S. Bandera Street, Lviv, Ukraine, E-mail: oleksandr.y.kachur@lpnu.ua, ORCID 0000-0003-2263-6360

[2] Department of Technical Mechanics and Engineering Graphics, Department of Computer-Aided Design, Lviv Polytechnic National University,12 S. Bandera Street, Lviv, Ukraine, E-mail: vitalii.m.korendii@lpnu.ua, ORCID 0000-0002-6025-3013

[3] Department of Computer-Aided Design, Lviv Polytechnic National University, 12 S. Bandera Street, Lviv, Ukraine, E-mail: volodymyr.b.havran@lpnu.ua, ORCID 0000-0002-6046-6094

DESIGNING AND SIMULATION OF AN ENHANCED SCREW-TYPE PRESS FOR VEGETABLE OIL PRODUCTION

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Abstract. *Problem statement*. The production of oil crops and products of their processing has significantly increased in recent decades. Vegetable oils are mainly produced by pressing oil-containing raw materials using screw-type presses. During the press operation, there is a need to adapt its working regimes to the seeds of individual crops while ensuring the possibility of adjusting certain operation parameters that are set technologically. *Purpose*. The main purpose of the present research consists in analyzing the design peculiarities of the enhanced screw-type press for extracting oil from different oil crops and oil-containing raw materials. In addition, there is set a goal of analyzing the screw for stresses and strains. *Methodology*. The finite-element method integrated into the SolidWorks software is used for analyzing the stress-strain state of the pressing screw at the hardest loading conditions. *Results*. The obtained results are presented in the form of the stresses and strain distribution along the screw shaft and flights. The corresponding 3D and 2D stress-strain diagrams are plotted and thoroughly analyzed. *Originality*. The zones of the screw overloading are defined and the possibilities of providing the screw reliability and durability are considered. *Practical value*. The proposed design of the screw-type press can be implemented in practice for performing pressing operations while extracting oil from different oil crops and oil-containing raw materials. The results of testing the screw stress-strain state can be used for predicting the screw reliability and durability at the stage of its designing. *Scopes of further investigations*. Further investigations on the topic of the present research can be focused on deriving the mathematical model describing the force and pressure conditions applied to the screw shaft and flights.

Keywords: oil-containing raw materials, working regimes, operation parameters, design peculiarities, finite-element method, stress-strain state, overloading zones, reliability, durability.

Introduction

The growing demand for oil crops and products of their processing in the domestic and foreign markets in recent decades has allowed agricultural companies to expand their sown (cultivated) areas by almost three times and take one of the leading positions in the structure of agricultural crops [1]. Oil crops include sunflower, flax, mustard, rapeseed, castor, oilseed poppy, sesame, peanuts, safflower, palm, camelina, corn, pumpkin, etc. The extruded oil is used in various industries, medicine, pharmaceutics, the food production sector, energetics (for biofuels and biolubricants) [2], etc., and the wastes of the oil production can be used in agriculture, in particular, the oilcake and the biomass can be used as animal feed [3]. The oilcake can be processed for manufacturing the edible membranes and packaging materials [4, 5].

Problem Statement

Vegetable oils are mainly produced by pressing oil-containing raw materials using screw-type presses [6, 7]. The selected pressing technology and design parameters of the press largely determine the quality of the oil obtained [8, 9], the completeness of oil separation (degree of extraction) from oilseeds [10], energy consumption, press productivity [11], etc. In order to maximize the automation of the process of pressing various oil-containing raw materials using unified press equipment, there is a need to adapt its working regimes to the seeds of individual crops while ensuring the possibility of adjusting certain operating parameters (in particular, temperature, pressure, dose, screw angular speed) that are set technologically and affect the above characteristics (quality, productivity, energy consumption, etc.).

Review of Modern Information Sources on the Subject of the Paper

Numerous researches are dedicated to the design and operational peculiarities of the screw-type (worm-type) presses intended for extracting different oils. The influence of the material feeding level on the working conditions of the screw-type press is considered in [12]. The novel press design for processing moringa seeds is developed, experimentally tested, and optimized in [13]. The paper [14] is focused on studying the force, pressure, and energy distribution along the specific screw developed for pressing palm kernels. The enhanced design of a flexible single-screw press was developed in [15]. In [16], the authors derived the mathematical model and investigated various working regimes of the screw-type press for processing safflowers. The comprehensive research on modeling, simulation, and experimental testing of various dynamic processes and operational conditions of double-screw (twin-screw) presses is presented in [17, 18]. The paper [19] is dedicated to the implementation of a finite-element method for analyzing the working regimes of domestic press for extruding different vegetable oils. In [20], the authors developed a modernized screw-type press for sunflower oil production. The present paper considers the enhanced design of the screw-type extruder and analyzes the screw for stresses and strains at the hardest loading conditions with the help of the finite-element method integrated into the SolidWorks software.

Objectives and Problems of Research

The main purpose of the present research consists in analyzing the design peculiarities of the enhanced screw-type press and analyzing the screw for stresses and strains at the hardest loading conditions. In order to reach the mentioned goal, the following problems are to be considered: developing the enhanced design of the press; analyzing the design peculiarities of the screw; simulation of the screw loading in the SolidWorks software; applying the finite-element method for analyzing the strass-strain state of the screw; defining the zones of overloading and considering the possibilities of providing the screw reliability and durability; implementing the obtained results and presenting the scopes of further research.

General Design of the Screw-Type Press

The enhanced design of the screw-type press for extracting oil from different oil crops and oil-containing raw materials is presented in Fig. 1. The body and drive of the press are mounted on the unmovable (stationary) base 1. The screw 12 is driven by the geared electric asynchronous motor 1 through the safety coupling 4 with rubber-bushed studs. The nominal power of the motor is 1.5 kW and the single-stage worm gear drive provides the maximal rotational frequency of the screw of 60 rpm. The screw shaft is supported by the single-thrust radial ball bearing 6 and single-thrust taper roller bearing 11. The press body consists of flanges 5, 18, 19, housing 7, sleeves 8, 11, gasket 9, spacers 13, 15, 16, pressing chamber 14, and discharging chute 17. The material to be pressed is manually or automatically filled in the hopper feeder 3, which supplies it inside the sleeve 11. The screw 12 conveys the material to the pressing chamber 14, where the oil is extruded. On the front end of the pressing chamber, there is installed the flange 18 with the holes for discharging the processed material. In order to change the output capacity (throughput) of the holes and the pressure inside the working chamber, additional flange 19 is installed on the part 18. When the holes in the flanges coincide, the output capacity takes its maximal value. The slight turning of the flange 19 allows for closing the holes in the part 18 and the pressure inside the working chamber increases. Additional flexible (canvas, paper, or polyethylene) hose is pulled on the flange 18 to store the discharged material. The pressed oil is flowing out of the working chamber 14 through the discharging chute 17.

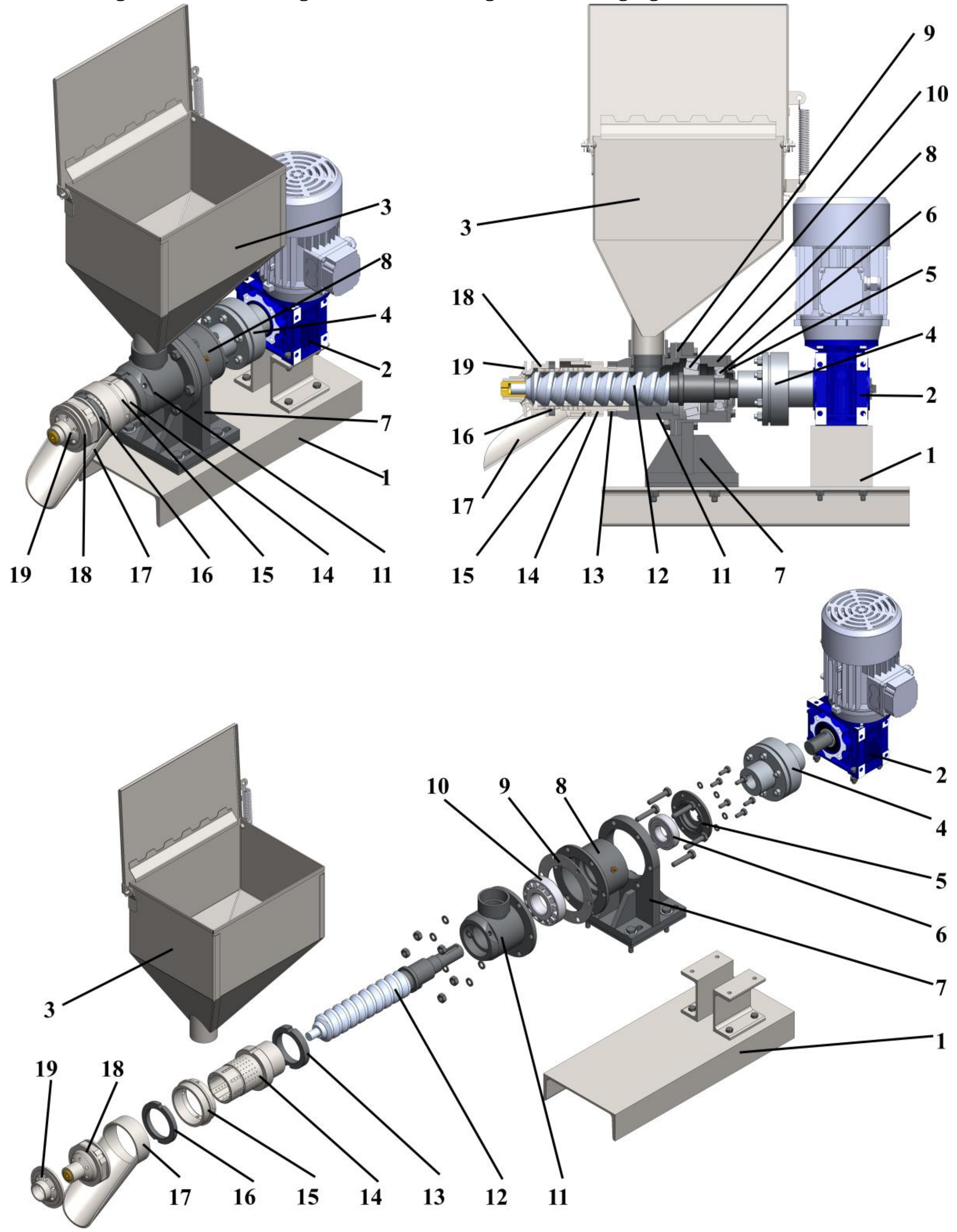
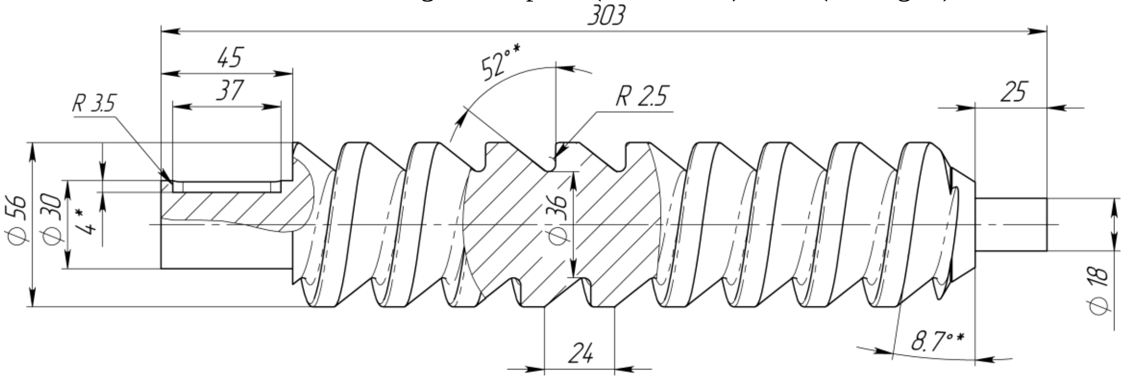


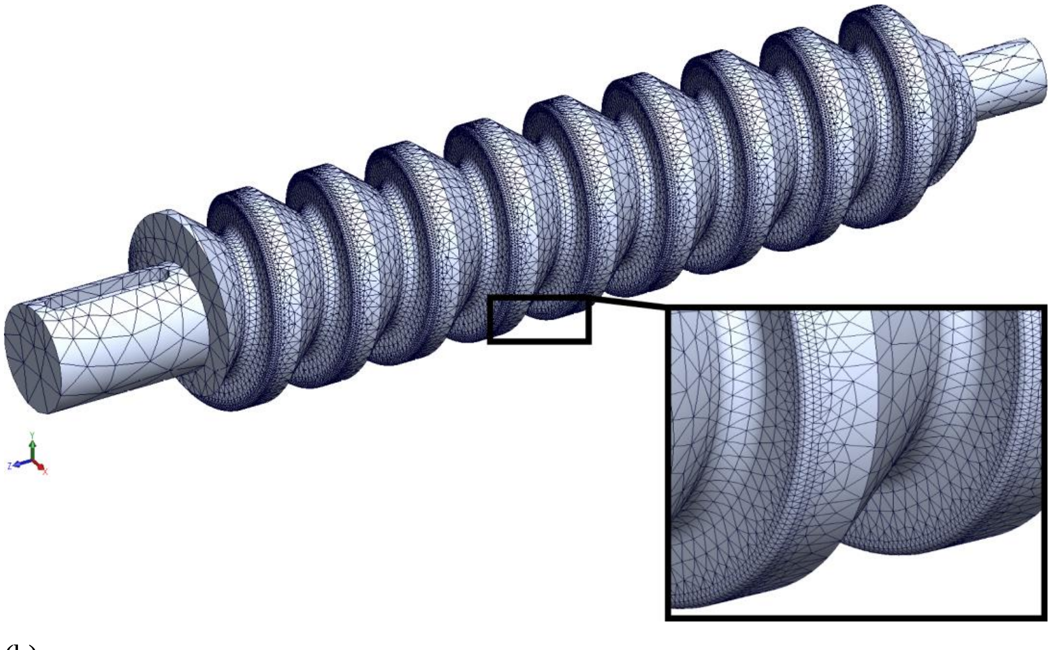
Fig. 1. General design of the screw-type extruder for the vegetable oil production:
1 – stationary base; 2 – geared motor; 3 – hopper feeder; 4 – coupling; 5, 18, 19 – flanges; 6, 10 – bearings; 7 – housing; 8, 11 – sleeves; 9 – gasket; 12 – screw; 13, 15, 16 – spacers; 14 – pressing chamber; 17 – chute

Design Peculiarities of the Pressing Screw and Its Finite-Element Model

The general design of the pressing screw is shown in Fig. 2(a). The screw shaft is supported by the plain journal bearing at its right (front) end and is connected to the driving flange by the keyed joint at its left (rear) end. Considering the supporting function of the shaft's right (front) end, its nominal diameter is 18 mm, while the diameter of its driving left (rear) end is 30 mm. The pressing angle of the screw flights is 52°, and the number of flights is 10. The lead of the screw is 24 mm and is equal along its whole length. The depth of the flight is about 10 mm. The shaft is manufactured of the alloyed steel AISI 420 (or X40Cr13). The maximal rotation frequency is 60 rpm, and the nominal driving torque does not exceed 20 N·m providing the maximal pressure of the material inside the working chamber of approximately 20 MPa. In order to perform the computer simulation of the screw hardest loading conditions, its finite-element model is developed in the SolidWorks software using the adaptive (intellectual) mesh (see Fig. 2).



(a)



(b)

Fig. 2. General design of the screw (a) and its finite-element model (b)

Analyzing the Stress State of the Screw

In order to perform the finite-element modeling of the screw stress-strain state, the following SolidWorks add-ins (applications) are used: Simulation and Flow Simulation. The experimental data of the shelled (peeled) sunflower pressing process modeled in the Flow Simulation software is exported to the Simulation software, in which the static stress-strain analysis of the screw is performed (see Fig. 3).

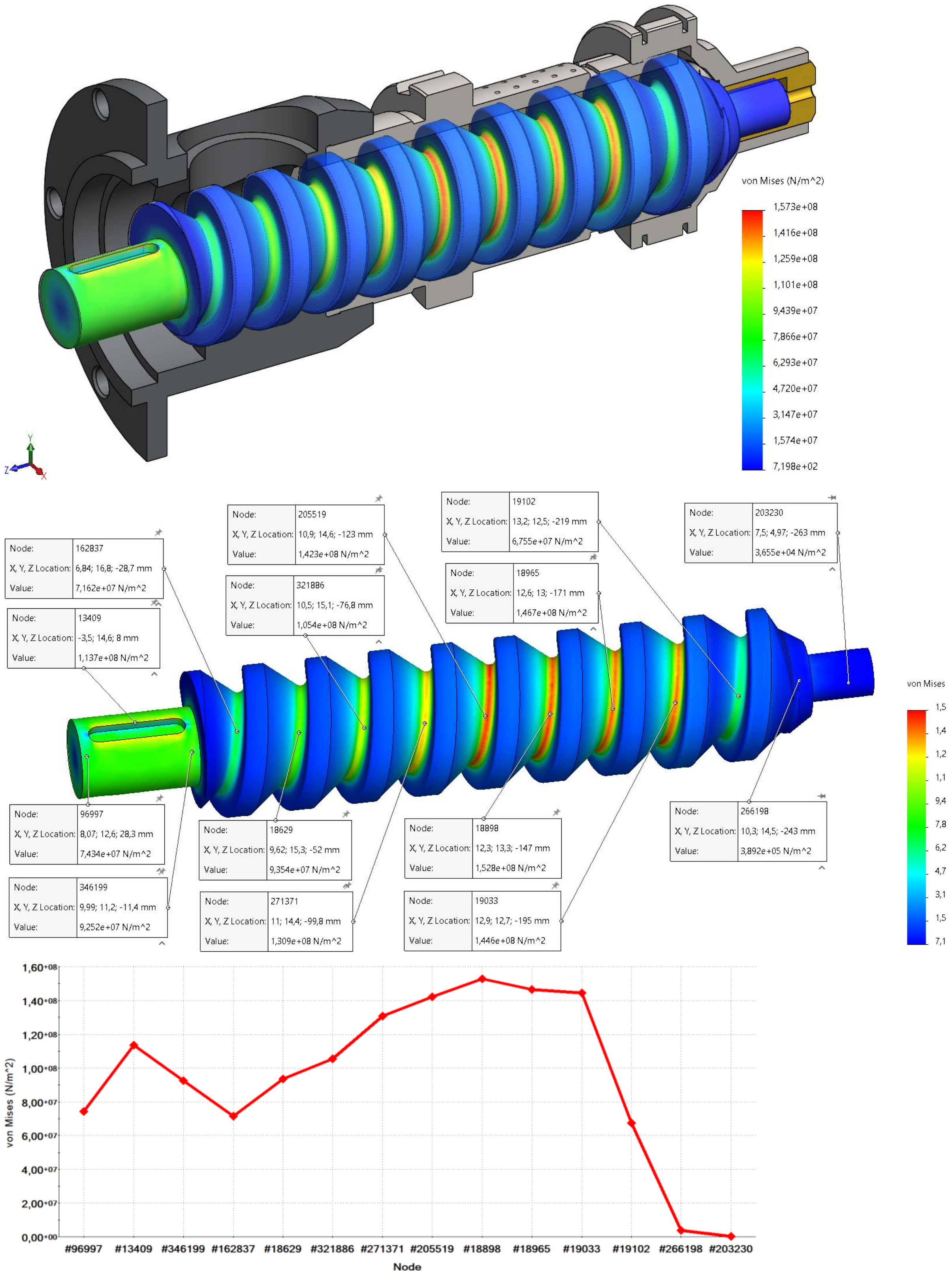


Fig. 3. Results of finite-element modeling of the stress state of the screw

The results of simulating the stress state of the pressing screw (Fig. 3) show that the maximal stresses are concentrated in the zone of the key groove (keyway) reaching values of over 150 MPa. Also, the overloading (in the range of 140…160 MPa) takes place in the central zones of connection of the screw flights to the shaft, i.e., in the surface of the dents of the screw flights. Considering the alloyed steel AISI

420 (or X40Cr13) as the material used for manufacturing the screw, its yield strength is not less than 300 MPa and can reach larger values depending on the heat treatment technology. Therefore, it can be concluded that the yield strength is at least twice larger than the maximal stress simulated by the finite-element method in the SolidWorks software. Therefore, the safety factor is approximately equal to 2.

Simulating the Deformations of the Screw

The analysis of the strain state of the pressing screw is carried out in the SolidWorks Simulation software based on the experimental results obtained in the Flow Simulation application. The corresponding diagrams of the screw deformations are presented in Fig. 4. It can be concluded that the screw torsional strain is caused by the friction forces generated due to the relative motion of the screw flights' surfaces and the material being pressed. This force depends on the material pressure and temperature in the working chamber, screw rotational frequency, and physico-mechanical properties of the material being pressed.

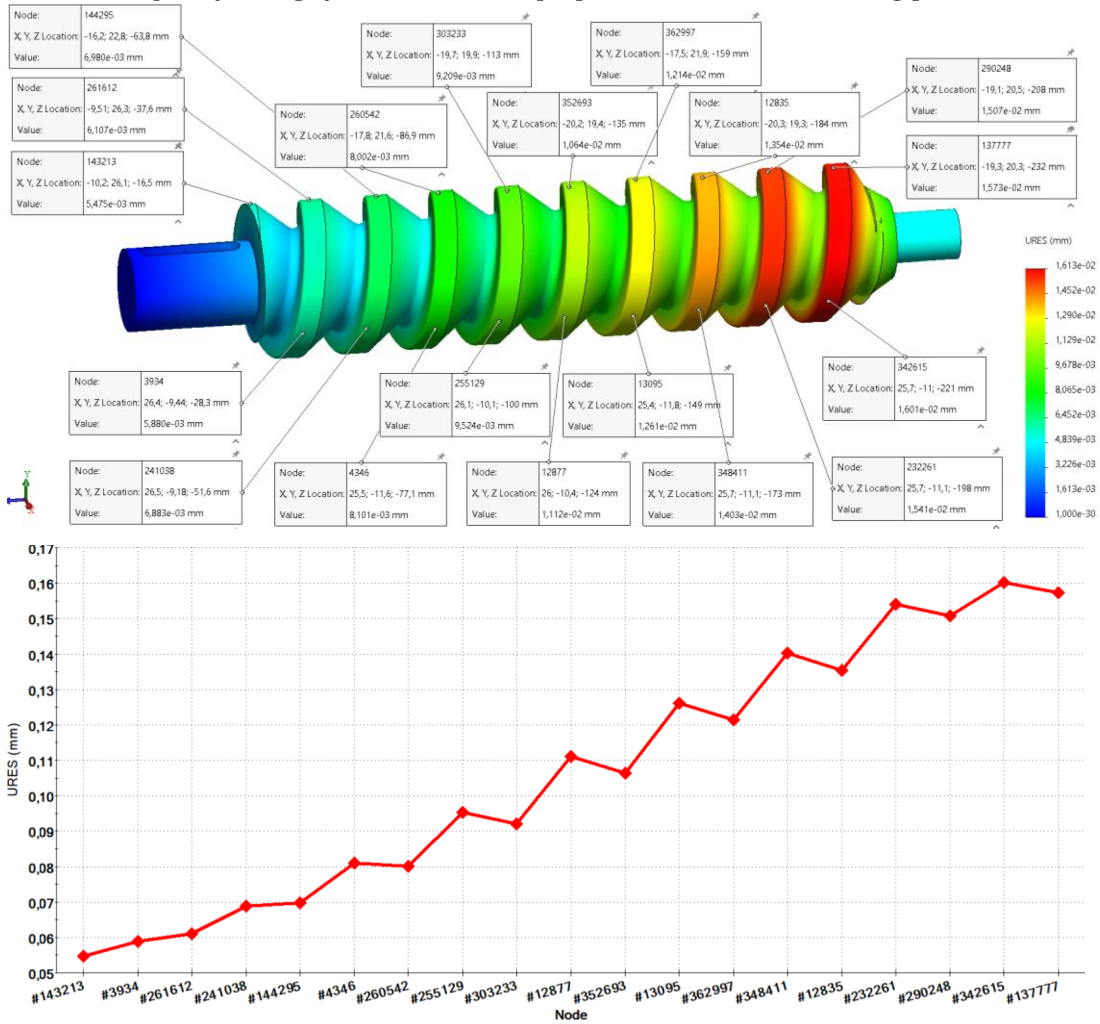


Fig. 4. Results of finite-element modeling of the strain state of the screw

The results of the finite-element simulation of the strain state of the pressing screw (Fig. 4) show that the largest deformations of the screw reach 0.16 mm and are observed on its front flights. The rear end of the screw, which is connected to the driving flange, is obviously characterized by the smallest (almost zero) deformations. Therefore, considering the presented above simulation results, it can be concluded that the chosen material (alloyed steel AISI 420 or X40Cr13) of the developed screw (see Fig. 3) allows for its reliable and durable operation under the prescribed operational conditions: the maximal rotation frequency of 60 rpm and the nominal driving torque reaching 20 N·m providing the maximal pressure of the material (shelled (peeled) sunflower) inside the working chamber of approximately 20 MPa.

Conclusions

The paper deals with the enhanced design of the screw-type press (Fig. 1) for processing oil crops and oil-containing raw materials. The proposed electric drive based on the geared electric asynchronous motor of the 1.5 kW power allows for regulating the rotational speed of the screw in the range of 0…60 rpm. The drive is additionally equipped with a safety coupling with rubber-bushed studs in order to restrict the possible overloading. The pressure inside the working chamber can be controlled by manual turning of the flanges installed on its front end. The general design of the pressing screw is considered and the corresponding 3D-model is developed in the SolidWorks software (see Fig. 2). The finite-element method is used to analyze the stress-strain state of the pressing screw at the hardest loading conditions. The obtained results are presented in the form of the stresses and strain distribution along the screw shaft and flights. The corresponding 3D and 2D stress-strain diagrams are plotted in Figs. 3 and 4. The obtained simulation results allow for defining the zones of overloading of the screw shaft. The largest stresses are observed at the zone of the key groove (keyway) reaching the values of over 150 MPa. Also, the overloading (in the range of 140…160 MPa) takes place at the zones of connection of the screw flights to the shaft. The largest deformations of the screw reach 0.16 mm and are observed on its front flights. The obtained results allowed for choosing the alloyed steel AISI 420 (or X40Cr13) as the material used for manufacturing the screw. Depending on the heat treatment technology, its yield strength is not less than 300 MPa and is at least twice larger than the maximal stress simulated with the help of the finite-element method in the SolidWorks software. Therefore, the safety factor is approximately equal to 2.

The proposed design of the screw-type press can be implemented in practice for performing pressing operations while extracting oil from different oil crops and oil-containing raw materials. The results of testing the screw stress-strain state can be used for predicting the screw reliability and durability at the stage of its designing. Further investigations on the topic of the present research can be focused on deriving the mathematical model describing the force and pressure conditions applied to the screw shaft and flights.

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Олександр Качур[1], Віталій Корендій[2], Володимир Гавран[3]

[1] Кафедра технічної механіки та інженерної графіки кафедра автоматизованого проектування, Національний університет «Львівська політехніка», вул. С. Бандери, 12, Львів, Україна, E-mail: oleksandr.y.kachur@lpnu.ua, ORCID 0000-0003-2263-6360

[2] Кафедра технічної механіки та інженерної графіки кафедра автоматизованого проектування, Національний університет «Львівська політехніка», вул. С. Бандери, 12, Львів, Україна E-mail: vitalii.m.korendii@lpnu.ua, ORCID 0000-0002-6025-3013

[3] Кафедра автоматизованого проектування, Національний університет «Львівська політехніка», вул. С. Бандери, 12, Львів, Україна E-mail: volodymyr.b.havran@lpnu.ua, ORCID 0000-0002-6046-6094

ПРОЕКТУВАННЯ ТА МОДЕЛЮВАННЯ ВДОСКОНАЛЕННОГО ШНЕКОВОГО ПРЕСУ ДЛЯ ВИРОБНИЦТВА РОСЛИННОЇ ОЛІЇ

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Анотація. *Постановка проблеми.* За останні десятиліття значно зросло виробництво олійних культур і продуктів їх переробки. Рослинні олії виробляють в основному пресуванням масловмісної сировини на шнекових пресах. Під час роботи преса необхідно адаптувати режими його роботи до насіння окремих культур із забезпеченням можливості коригування певних параметрів роботи, які задані технологічно. призначення. *Основна мета* даного дослідження полягає в аналізі конструктивних особливостей удосконаленого шнекового преса для віджиму олії з різних олійних культур та олійної сировини. Крім того, поставлена мета аналізу гвинта на напруги та деформації. *Методологія*. Метод скінченних елементів, інтегрований у програмне забезпечення SolidWorks, використовується для аналізу напружено-деформованого стану натискного гвинта при найважчих умовах навантаження. *Результати.* Отримані результати представлені у вигляді розподілу напружень і деформацій вздовж валу шнека та муфт. Відповідні тривимірні та двомірні діаграми напруження-деформації будуються та ретельно аналізуються. *Оригінальність.* Визначено зони перевантаження шнека та розглянуто можливості забезпечення надійності та довговічності шнека. *Практична цінність*. Запропонована конструкція шнекового преса може бути реалізована на практиці для виконання операцій пресування при віджимі олії з різних олійних культур і олійної сировини. Результати випробувань напружено-деформованого стану гвинта можуть бути використані для прогнозування надійності та довговічності гвинта на етапі його проектування. *Обсяги подальших досліджень.* Подальші дослідження за темою цього дослідження можуть бути зосереджені на виведенні математичної моделі, що описує умови сили та тиску, що прикладаються до гвинтового валу та муфт.

Ключові слова: нафтовмісна сировина, робочі режими, робочі параметри, конструктивні особливості, метод скінченних елементів, напружено-деформований стан, зони перевантаження, надійність, довговічність.