DOI 10.25140/2411-5363-2023-3(33)-111-120
UDC 621.88.082.8

Pavlo Protsenko
PhD in Technical Sciences, senior lecturer of the Department of machine design,
National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute" (Kyiv, Ukraine)
E-mail: pavloprocenko64@gmail.com. **ORCID:** https://orcid.org/0000-0001-9390-0718

ANALYSIS OF THE INFLUENCE OF THE SCREW PITCH OF THE SPIRAL GROOVE ON THE PROCESS OF PROFILING A SPIRAL TUBE BY ROLLER SPINNING

In this work, a numerical analysis, based on the finite element method, of the process of roller spinning of the spiral groove on the tube and the influence of its screw pitch on the stress-strain state of the tube in the zone of plastic deformation was carried out. The obtained graphical dependences of the influence of the screw pitch of the mandrel spiral groove on the maximum values equivalent strain ε_i show that with a tenfold increase in the screw pitch of the spiral groove of the mandrel the maximum equivalent strain increases by 1.5 times. The increase in the equivalent strain is caused by a decrease in the width of the groove at large steps of its screw in a section that is perpendicular to the direction of the screw line, which reduces the size of the roller rounding radius that affects the dimensions of the local zone of plastic deformation of the tube.

The obtained results can be applied during the development of technology for the production of heat exchange surfaces for heat exchange devices with high efficiency coefficients (up to 40%).

Keywords*: spiral tube, spiral groove, roller spinning, heat exchanger, stress-strain state of the tube.*
Fig.: 10. References: 19.

Urgency of the research. Today, the development of energy-saving technologies is an important task that contributes to reducing the consumption of energy resources, especially fossil fuels. This allows to increase the efficiency of the equipment, reduces harmful emissions into the atmosphere and dependence on non-democratic states, whose economy is usually based on the extraction of minerals.

One of the methods of energy saving is the use of secondary heat from a spent energy resource. For these purposes, heat exchange devices with specific heat exchange surfaces that intensify heat exchange processes are used [1-3].

The scope of application of such devices is quite wide. For the most part, they are used in power engineering, hot water supply and heating systems, refrigerating plants, a promising direction of use is in regenerators and gas heaters of gas turbine plants.

At the Department of Aircraft Production Technology of Education and Research Institute of Mechanical Engineering, work was carried out on the development of technology for the production of heat exchange surfaces of the heat exchanger (Fig. 1) for the heat regenerator of the gas turbine installation of the gas transportation system of Ukraine. The heat exchanger includes 33 spiral brass tubes with a diameter of 16 mm with a screw pitch of 8 mm and a depth of about 1 mm.

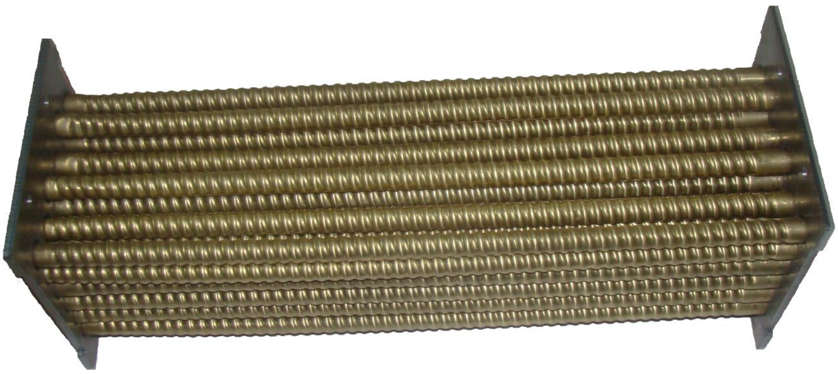


Fig. 1 The heat exchanger, developed at the department of Aircraft Production Technology of Education and Research Institute of Mechanical Engineering [4]

Studies of the heat exchange of spiral tubes have shown [1-4] that they provide a two-fold increase in the intensity of heat exchange compared to a smooth tube, while it should be noted that the aerodynamic resistance also increases by 5-10 times.

Target setting. The production of heat exchange devices requires the development of a simple, waste-free, productive and low-cost manufacturing technology for their heat exchange surfaces.

Actual scientific researches and issues analysis. The roller spinning processes and heat exchange of corrugated tubes are considered in works [5-9]. Turbulization of the flow flowing in the middle of the spiral tube depends on the ratio of the depth of the spiral groove in relation to the diameter of the tube. Intensification of heat exchange is achieved due to the creation of a turbulent vortex in the middle of the tube, which mixes the wall layers and the central layers of the coolant. Research has shown [9] that at ratio values e/D >0.6 (Fig. 2) the increase in resistance to coolant flow is twice as great as the increase in heat transfer in the tube.

In work [10], to achieve optimal values for the increase in heat transfer intensity in relation to the growth of the aerodynamic resistant, it is recommended to turbulize the wall ball with a thickness of up to 5% of the radius of the tube. Further research [4] showed that the optimal geometric parameters of a spiral tube are: depth h = 1.0...1.5 mm and the width of the spiral grooves t = 8 ... 12 mm (Fig. 2).

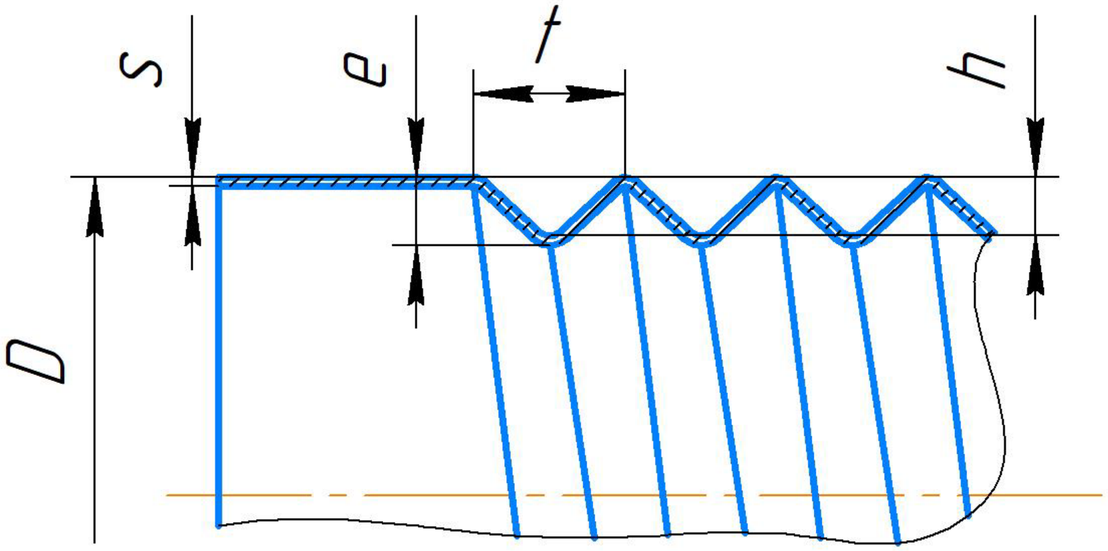


Fig. 2 Geometrical parameters of a spiral tube

In addition to the roller spinning process, hydroforming is also used to obtain profiled tubes. The process of hydroforming is performed by creating a high pressure liquid in the chamber where the tube is placed, due to which plastic deformation of the tube occurs in accordance with the template in which or on which it was installed. In works [11-13], the processes of hydroforming of bellows and spiral stainless steel tubes are considered. Research on the hydroforming of steel tubes [13] with a wall thickness of 5 mm at various temperatures for this process (22-800°C) showed that an increase in the process temperature by 100°C provides a pressure drop of 100 MPa, which makes the hydroforming process much easier. In the cited works [11-13], during the hydroforming process, a change in the thickness of the tube wall is observed in local areas with the maximum equivalent strain.

In National Technical University of Ukraine “Igor Sikorsky Kyiv Polytechnic Institute”, work was carried out on the development of the technology of manufacturing such products by methods of hydroforming [4, 14] and roller spinning [4, 15-16]. Precisely the roller spinning method (Fig. 3) produced the tubes, photos of which are shown in Fig. 4.

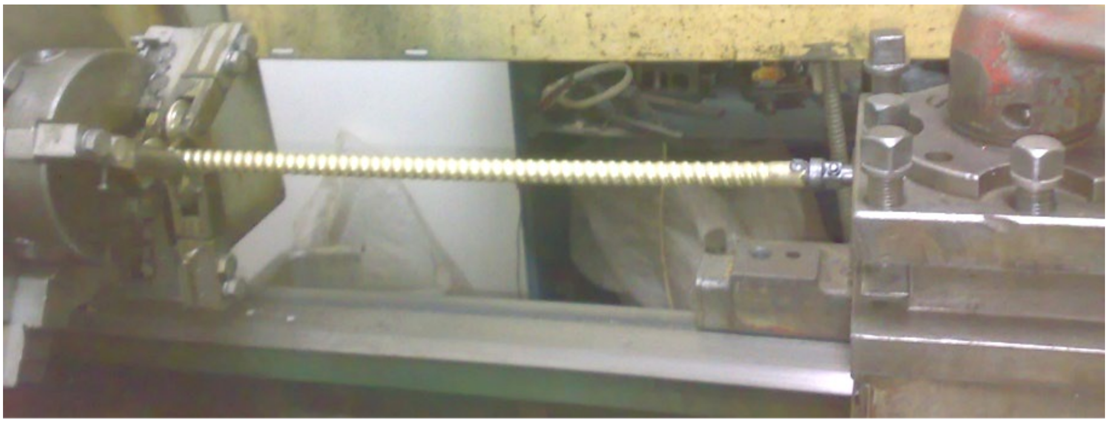


Fig. 3. The process of manufacturing a spiral corrugated tube by the method of roller spinning on the 16K20 screw lathe [4]

The process of roller spinning of spiral tubes is performed in two stages [4]:
- pressing the roller into the tube;
- rotation of the tube with the roller pressed into it.

a)

b)

Fig. 4 Spiral corrugated tubes: a - brass (it is a component of the heat exchanger shown above) with a screw pitch of 8 mm and a diameter of 16 mm; b - made of X18H10T(AISI 304) steel with a screw pitch of 12 mm and a diameter of 38 mm [4].

The analysis of the roller spinning process of spiral corrugated tubes can be performed on the basis of its first stage. This is due to the fact that the spiral profile on the tube is formed as a result of the thinning of its wall and the dent is formed the same way, when the roller is pressed into the tube at the first stage.

In the process of developing the technology for manufacturing such products by roller spinning, it is important to choose such process parameters that make it possible to reduce the equivalent strain in the local zone of plastic deformation of the tube, which makes it possible to ensure the quality of the product, namely the absence of cracks.

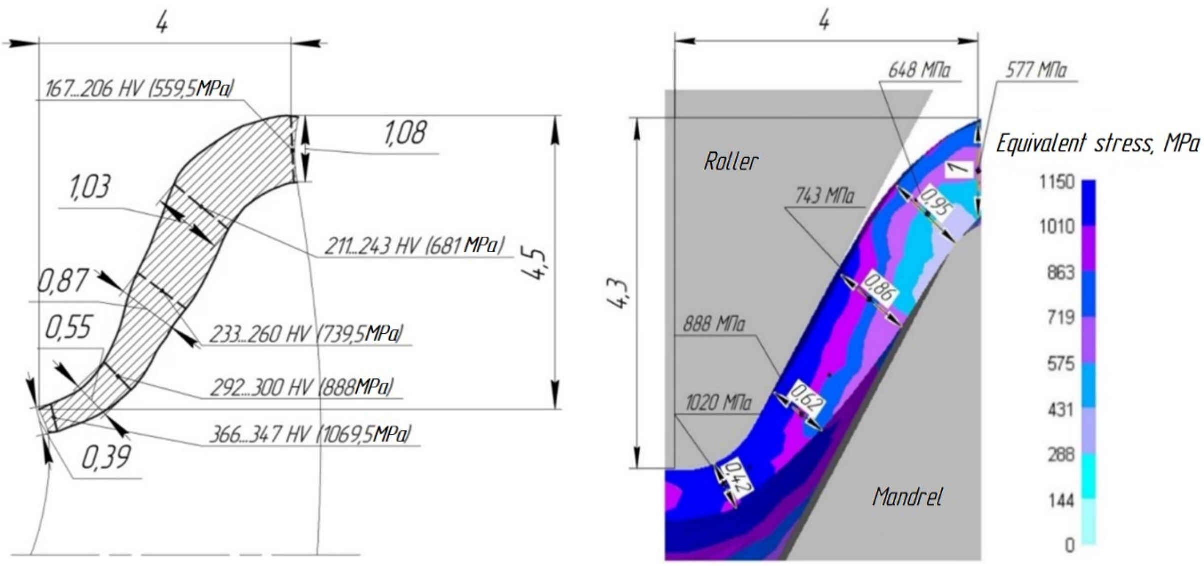
To implement the roller spinning process, you can use a screw lathe with special equipment, which is named a rolling head that is fixed in the cutter holder or on the machine's support. The implementation of the hydroforming process requires the purchase of press equipment with a special stamp with an integrated high-pressure fluid control system. The simpler implementation of the process of roller spinning of tubes and the ability to perform profiling of long tubes (more than 2 m) [17] by using this process were the main reasons why this process was studied rather than hydroforming.

Both experimental and numerical studies were carried out on the process of roller spinning of spiral corrugated tubes, the results of which are shown in the papers [4, 18]. The process of roller spinning of the tubes from stainless steel X18H10T (AISI 304) and aluminum-2017 was researched.

Experimental studies of the roller spinning process of tubes were performed by measuring the microhardness of points in cross-sections of formed grooves on the tubes. Local sections of the tube, where plastic deformation occurs, are strengthened as a result of strain hardening and, accordingly, the hardness of the metal in these sections increases. Using the G. Del's experimental-analytical approach [19], the hardness distribution in the cross section of the groove formed on the tube was recalculated into an equivalent stress distribution according to the following dependence:

$$\sigma_i = K \cdot HV , \quad (1)$$

where $K = 0{,}3$ (for steel [19]), HV is Vickers hardness. The results of the microhardness experimental study of the groove sample of the spiral tube with the screw pitch of 8 mm are shown in Fig. 4, a.



a) *b)*

Fig. 4 Equivalent stress distributions in the cross section of the groove: a) experiment, b) simulation in DEFORM 3D

Numerical studies were performed in the DEFORM 3D program using the finite element method (Fig. 5). Modelling of roller spinning of a spiral stainless steel (AISI-304) tube stainless steel, the hardening curve of which is shown in Fig. 6 with a screw pitch of 8 mm showed similar results (see Fig. 4, b) of the equivalent stress distribution in relation to the experimental results (see Fig. 4, a). The created model of the roller spinning process of spiral tube in the specified program reproduces this process with permissible accuracy (the error is about 6...10%).

By means of numerical modelling in previous studies [4, 18], it was established that the greatest influence on the process of roller spinning of a spiral tube has the next parameter ratios: the relative radius of rounding of the roller r/t and the relative depth *h/t*.

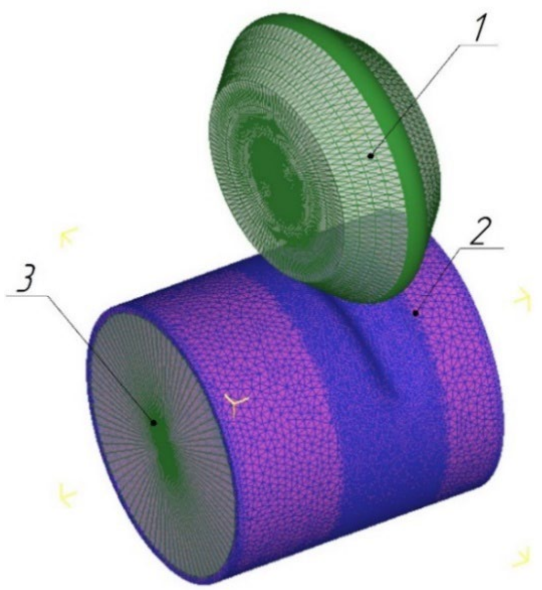


Fig. 5 Model of the roller spinning process of a spiral tube : 1 – roller, 2 – tube, 3 – mandrel

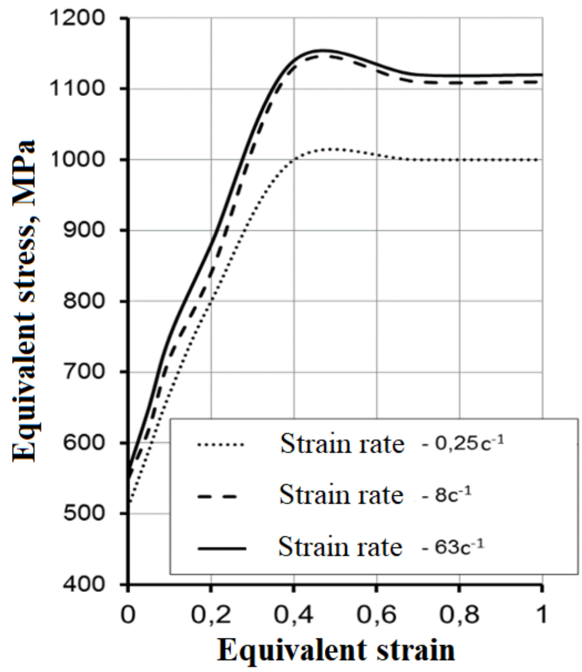


Fig. 6 Hardening curve of AISI 304 steel

In order to minimize values of the equivalent strain in the local section of the tube, the specified ratio of parameters should be limited: $h/t \leq 0.4$, $r/t \geq 0.25$. Other parameters, such as D_r/D and the number of roller passes j, for which the final profile of the spiral groove is obtained, have a smaller effect on the progress of the roller spinning process. When implementing the roller spinning process, it is recommended to take the diameter of the roller as:

$$D_r = 3D, \quad (2)$$

where D is the diameter of the tube.

Due to the use of large-diameter rollers ($D_r \geq 100$ mm), the local degree of tube deformation can be reduced. This happens due to an increase in the contact area of the roller with the tube, which increases the area of the local area of the tube where plastic deformation occurs [18].

Uninvestigated parts of general matters defining. In previous works [4, 18], numerical and experimental studies were conducted on the production of tubes with the width of the spiral grooves and their screw pitch: 6, 8, 12, and 20 mm. A study of the roller spinning process at large screw pitches of spiral grooves was not conducted.

The research objective. To analyze of the influence of the screw pitch of the spiral groove on the stress-strain state of the tube in the zone of plastic deformation in the process of rolling spinning.

The statement of basic materials. A series of numerical simulations was performed to study the stress-strain state of a screw groove on a tube with a large screw pitch during the roller spinning process. In each numerical simulation, the following kinematic parameters were set:

- the rotation frequency of the tube with the mandrel: $n_1 = 160$ rpm;
- the rotation frequency of the roller, depending on the rotation frequency of the tube with the mandrel and the depth of the formed groove: $n_r = \dfrac{n_1\left(\dfrac{D}{2} - h\right)}{R_r}$, where R_r is the roller radius;

- the speed of the roller's longitudinal movement: $V_r = \dfrac{tn_1}{60}$.

The mechanical characteristics of the tube material corresponded to AISI 304 steel according to Fig. 6. Tube geometry: outer diameter – D = 38 mm, thickness – s = 1 mm, width of the formed groove – t = 8 mm. The roller diameter was D_r = 40 mm. An important parameter in the roller spinning process is the rounding radius of the roller, which is determined by the parameters of the formed screw groove (Fig. 7) and its helix angle. The optimal rounding radius of the roller can be calculated using the following dependence:

$$r = \cos\left(arctg\left(\frac{k}{\pi D_m}\right)\right)\sqrt{\left(\frac{t}{2}-\frac{s}{\cos\left(\frac{\gamma_g}{2}\right)}\right)^2+\left[\left(\left(\frac{t}{2}-\frac{s}{\cos\left(\frac{\gamma_g}{2}\right)}\right)^2-h^2\right)\Big/2h\right]^2}, \qquad (3)$$

where k is the groove screw pitch; D_m is the mandrel diameter; t is the groove width; s is the tube thickness; γ_g is the angle between the side walls of the groove of the mandrel; h is the depth of the formed groove on the tube.

The tube was divided into a grid of finite tetrahedral elements. In the local deformation zone of the tube, the dimensions of the elements were 0.4 mm. According to the work [4], this size of elements ensures sufficient accuracy of calculations.

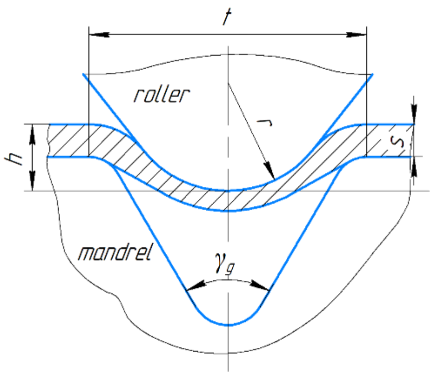


Fig. 7 Geometric parameters of the cross section of the spiral groove

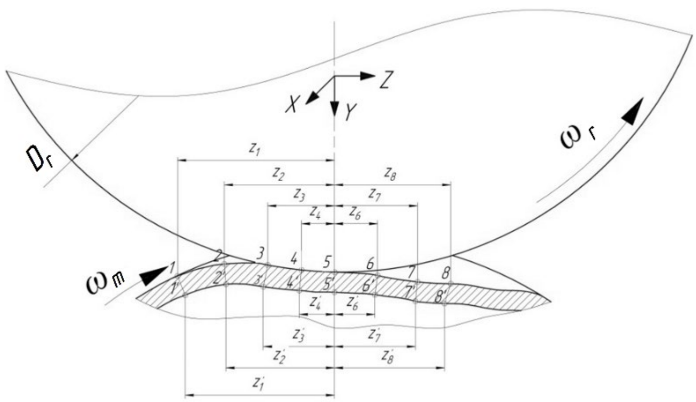


Fig. 8 Points along the z axis and their coordinates in the tube cross-section, which were used to analyze the roller spinning process of a spiral tube

To analyze the roller spinning process, points were selected in the tube cross-section in accordance with Fig. 8, in each of which the stress-strain state was analyzed. Graphs of the distribution of equivalent stress σ_i and strains ε_i were drawn up based on the values of the stress-strain state at selected points, which were further approximated by a quadratic dependence.

An example of the graph of the distribution of the equivalent strain ε_i, which was used in the further analysis of the influence of the screw pitch of the spiral groove on the stress-strain state on the inner surface of the tube, is shown in Fig. 9.

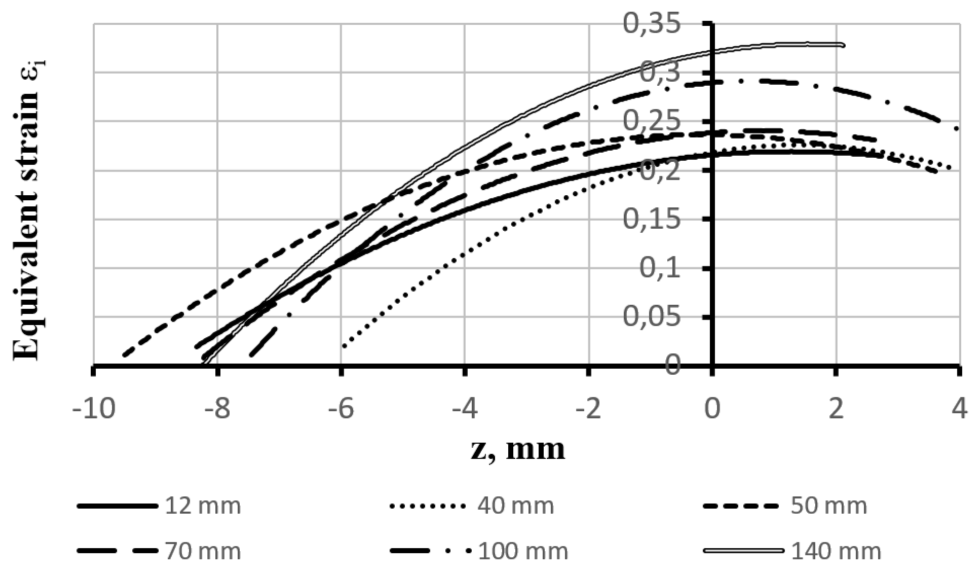
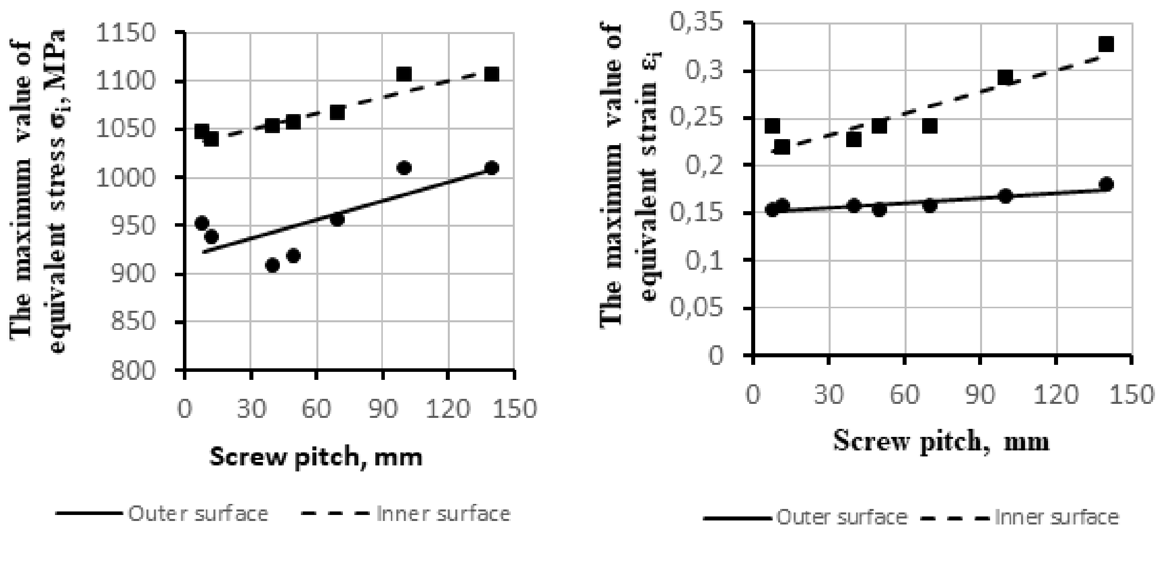


Fig. 9 Distributions of the equivalent strain ε_i on the inner surfaces of the tubes in the process of roller spinning at different values of the screw pitch of the grooves

Further analysis of the roller spinning process was carried out on the basis of the graphs of the influence of the pitch of the spiral groove formed on the tube on the maximum values of the equivalent stress and strain (Fig. 10). These graphs were obtained from the equivalent stress and strain distributions graphs, as shown in Fig. 9.

Shown in Fig. 10 dependences, especially the dependences of the equivalent strain on the screw pitch of the spiral groove can be used during the development of the roller spinning technology of spiral tubes. As can be seen from the graphs in fig. 10-b, when developing the roller spinning technology of a tube, it is desirable to limit the value of the screw pitch in relation to the width of the groove *k/t*<8.



a) *b)*

Fig. 10 The influence of the screw pitch of the spiral groove on the maximum values of: a) equivalent stress, b) equivalent strain

Further research is aimed at obtaining analytical dependencies of the influence of the geometric parameters of the tools and the kinematic parameters of the roller spinning process on the maximum values of equivalent stress and strain in the local zone of plastic deformation of the tube.

Conclusions: 1. The process of roller spinning of a tube with the formation of a spiral groove on it takes place due to the thinning of its wall. To intensify this process, it is necessary to increase the local zone of plastic deformation. This can be achieved by using a roller with an optimal rounding radius, which can be determined from the geometrical conditions of the spiral groove of the mandrel by formula (3).

2. An analysis was carried out of the influence of the screw pitch of a spiral groove with a width of $t = 8$ mm, formed on a tube with a diameter of 38 mm and a thickness of 1 mm, on the stress-strain state of the tube. The obtained dependences of the maximum values of the equivalent stress and strain (Fig. 10), from which it can be seen that with a large screw pitch of the spiral groove, the value of the equivalent strain increases. With a 10-fold increase in the screw pitch of the spiral groove, the equivalent strain increases by 1.5 times. Therefore, when performing the process of roller spinning a one-groove tube, it is desirable to make the pitch of its spiral groove equal to the groove width t.

3. In the process of profiling multi-grooves tubes, a large number of grooves and, accordingly, their larger screw pitch causes an increase in the equivalent strain (Fig. 10, b) in the zone of local plastic deformation, which is associated with a decrease in the roller rounding radius. Therefore, when developing the technology of manufacturing spiral tubes by roller spinning, it is desirable to take into account the limitation of $k/t<8$.

References

1. Теплообмен и аэродинамика пакетов винтообразных труб с равноразвитой поверхностью / [Е. Н. Письменный, В. А. Рогачев, А. В. Баранюк та ін.]. // Современная наука. Исследования, идеи результаты, технологии. – 2013. – №1(12). – С. 13-18.

2. Розробка рівнорозвинених поверхонь теплообміну для регенераторів теплоти ГТУ газотранспортних систем і дослідження їх теплоаеродинамічних характеристик : звіт про НДР (заключ.) НТУУ ”КПІ” / кер. роб. Є. М. Письменний. – Київ, 2013. – 206 с.+CD-ROM. – Д/б №2538-п.

3. Письменный Е. Н. Равноразвитые поверхности теплообмена и методика численных исследований их гидравлических характеристик / Письменный Е. Н., Баранюк А. В., Вознюк М. М. // Промышленная теплотехника. – 2012. – Т. 34, №1. – С. 45-54.

4. Розробка технології та обладнання для профілювання гвинтоподібних та ребристих труб та створення високоефективних теплообмінників : звіт про НДР (заключ.) НТУУ ”КПІ” / кер. роб. М. І. Бобир. – Київ, 2017. – 313 с.+CD-ROM. – Д/б №2925-п.

5. Sadighi Dizaji H. Experimental studies on heat transfer and pressure drop characteristics for new arrangements of corrugated tubes in a double pipe heat exchanger / H. Sadighi Dizaji, S. Jafarmadar, F. Mobadersani // International Journal of Thermal Sciences. – 2015. – Vol. 96. – С. 211-220. DOI: 10.1016/j.ijthermalsci.2015.05.009

6. Ball Spin Forming for Flexible and Partial Diameter Reduction in Tubes / [S. Hirama, T. Ikeda, S. Gondo та ін.]. // Metals. – 2020. – Vol. 10 (12), 1627. DOI: 10.3390/met10121627

7. Eyvazian, A. Experimental Study of Corrugated Metal-composite Tubes under Axial Loading / A. Eyvazian, H. Mozafari, A. M. S Hamouda // Procedia Engineering. – 2017. – Vol. 173. – С. 1314-1321. DOI: 10.1016/j.proeng.2016.12.169

8. Use of corrugated pipe heat exchangers in waste heat recovery steam generators / [S. Nayak, S. Jena, A. Sharique S. Khan та ін.] // Materials Science and Engineering : IOP Conf. Series. – 2021. – Vol.1123. – С. 1-12. DOI:10.1088/1757-899X/1123/1/012037

9. Eiamsa-ard S. Counter-rotation vortex flows and heat transfer mechanisms in a V-spirally-corrugated tube / S. Eiamsa-ard, P. Promthaisong // Proceedings of the Institution of Mechanical Engineers, Part A: Journal of Power and Energy. – 2019. – Vol. 233(7). – С. 821-958. DOI:10.1177/0957650919829367

10. Калинин, Э. К. Интенсификация теплообмену в каналах / Э. К. Калинин, Г. А. Дрейцер, С. А. Ярхо. – Москва : Машиностроение, 1990. – 199 с.

11. Changshuai Shi External high-pressure forming of metal spiral tube of equal wall thickness / Changshuai Shi, Jinping Li, Juan Deng, Xiaohua Zhu // Proceedings of the Institution of Mechanical Engineers, Part E: Journal of Process Mechanical Engineering. – 2021. – Vol. 235(2). – С. 151-656. DOI:10.1177/0954408920967786

12. Paunoiu, V. Numerical study of tube hydroforming technology / V. Paunoiu, O. Ciocan, D. Nicoara // International Journal of Modern Manufacturing Technologies. – 2010. – Vol. II. No. 1. – P. 67-72.

13. Shi, C. Research on Hydroforming Micro-Sized Spiral Pipe With Equal Wall Thickness [Electronic resource] / Changshuai Shi, Jinping Li, Xiaohua Zhu // Research Square. – 2021. — Access mode: https://doi.org/10.21203/rs.3.rs-694676/v1.

14. Патент 85412 UA, МПК B 21 D 15/00. Штамп для формування канавок на трубі / В. О. Маковей, П. Ю. Проценко (UA) – № u201301239; заявл. 01.02.2013; опубл. 25.11.2013, Бюл. №22.

15. Патент 60663 UA, МПК B 21 D 15/00. Спосіб формування гвинтових канавок на трубчастих тонкостінних заготовках роликовим обкочуванням з використанням внутрішнього протитиску / В.О. Маковей, Ю. П. Бородій П. Ю. Проценко А. В. Кліско. – № u201014396; заявл. 01.12.2010; опубл. 25.06.2011, Бюл. 12.

16. Патент на корисну модель №107828 UA, МПК B2lD 15/00. Спосіб профілювання довгомірних гвинтоподібних труб / М. І. Бобир, В. О. Маковей, В. С. Мельник. – № u201512274; заявл. 11.12.15; опубл. 24.06.16, Бюл. № 12.

17. Маковей В. О. Удосконалення технологічного процесу виготовлення трубок з гвинтоподібним профілем / В. О. Маковей, В. С.Мельник // Обработка материалов давлением. – 2015. – № 1 (40). – С. 81-84.

18. Маковей, В. О. Профилирование винтообразных труб теплообменников / В. О. Маковей, М. І. Бобир, П. Ю. Проценко. – Балті : LAP Lambert Academic Publishing, 2017. – 226 с.

19. Дель, Г. Д. Определение напряжений в пластической области по распределению твердости. – Москва : Машиностроение, 1971. – 200 с.

References (in language original)

1. Pysmennyi, Y., Rohachev, V., Baraniuk, O., Reva, S., Panasiuk, A. (2013). Heat transfer and aerodynamics of spiral corrugated tubes packages with the uniformly developed surface. *Modern science. Research, ideas, results, technologies*, *1(12),* 13-18.

2. Pysmennyi, Y. (2013). Development of uniformly developed heat exchange surfaces for heat regenerators of gas turbine installations of gas transportation systems and research of their thermo-aerodynamic characteristics: report on research work (final). National Technical University of Ukraine "Kyiv Polytechnic Institute", Kyiv, Ukraine, Tech. Rep. 2538-п, 2013.

3. Pysmennyi, Y., Baraniuk, O., Vozniuk, M. (2012). Uniformly developed heat exchange surfaces and methods for numerical studies of their hydraulic characteristics. *Industrial Heat Engineering*, 34(1), 45-54.

4. Bobyr, M. (2017). Development of technology and equipment for profiling spiral corrugated and finned tubes and creating highly efficient heat exchangers: report on research work (final). National Technical University of Ukraine "Kyiv Polytechnic Institute", Kyiv, Ukraine, Tech. Rep. 2925-п, 2017.

5. Sadighi Dizaji, H., Jafarmadar, S., Mobadersani, F. (2015). Experimental studies on heat transfer and pressure drop characteristics for new arrangements of corrugated tubes in a double pipe heat exchanger. *International Journal of Thermal Sciences*, *96,* 211-220. DOI: https://doi.org/10.1016/j.ijthermalsci.2015.05.009.

6. Hirama, S., Ikeda, T., Gondo, S., Kajikawa, S., Kuboki, T. (2020). Ball Spin Forming for Flexible and Partial Diameter Reduction in Tubes. *Metals*, *10(12),* 1627. DOI: https://doi.org/10.3390/met10121627.

7. Eyvazian, A., Mozafari, H., Hamouda, A.M.S. (2017). Experimental Study of Corrugated Metal-composite Tubes under Axial Loading. *Procedia Engineering*, *173,* 1314–1321. DOI: https://doi.org/10.1016/j.proeng.2016.12.169.

8. Nayak, S., Jena S., Khan, A.S.S., Paswan, M.K., Sharma, V. K. (2021). Use of corrugated pipe heat exchangers in waste heat recovery steam generators. *IOP Conf. Series: Materials Science and Engineering*, *1123,* 1-12. DOI: https://doi.org/10.1088/1757-899X/1123/1/012037.

9. Eiamsa-ard, S., Promthaisong, P. (2019). Counter-rotation vortex flows and heat transfer mechanisms in a V-spirally-corrugated tube. *Proceedings of the Institution of Mechanical Engineers, Part A: Journal of Power and Energy*, *233(7),* 821-958. DOI: https://doi.org/10.1177/0957650919829367.

10. Kalinin, E., Dreytser, G., Yarho, S. (1990). Intensification of heat transfer in channels. Moscow: Mashinostroenie.

11. Shi, C., Li, J., Deng, J., Zhu, X. (2021). External high-pressure forming of metal spiral tube of equal wall thickness. *Proceedings of the Institution of Mechanical Engineers, Part E: Journal of Process Mechanical Engineering*, *235(2),* 151-656. DOI: https://doi.org/10.1177/0954408920967786.

12. Paunoiu, V., Ciocan, O., Nicoara, D. (2010). Numerical study of tube hydroforming technology. *International Journal of Modern Manufacturing Technologies, II(1),* 67-72.

13. Shi, C., Li, J., Zhu, X. (2021). Research on Hydroforming Micro-Sized Spiral Pipe With Equal Wall Thickness. *Research Square.* https://doi.org/10.21203/rs.3.rs-694676/v1.

14. Protsenko, P., Makovei, V. (2013). Stamp for forming grooves on the tube. UA Patent 85412, Nov. 25, 2013.

15. Makovei, V., Protsenko, P., Borodii, Yu., Klisko, A. (2011). The method of forming spiral grooves on thin-walled tubular blanks by roller spinning using internal back pressure. UA Patent 60663, Jun. 25, 2011.

16. Bobyr, M., Makovei, V., Melnyk, V. (2016). The method of profiling long spiral corrugated tubes. UA Patent 107828, Jun. 24, 2016.

17. Makovei, V., Melnyk, V. (2015). Improvement of the technological process of manufacturing tubes with the spiral corrugated profile. *Materials working by pressure, 1(40),* 81-84.

18. Makovei, V., Bobyr, M., Protsenko, P. (2017). Profiling of spiral corrugated tubes of heat exchangers. Balti: LAP Lambert Academic Publishing.

19. Del, H. (1971). Determination of stresses in the plastic region by hardness distribution. Moscow: Mashinostroenie.

Отримано 18.09.2023

UDC 621.88.082.8

Павло Проценко

К.т.н. кафедра конструювання машин, Національний технічний університет України «Київський політехнічний інститут імені Ігоря Сікорського» (Київ, Україна)

E-mail: pavloprocenko64@gmail.com. **ORCID:** https://orcid.org/0000-0001-9390-0718

АНАЛІЗ ВПЛИВУ ВЕЛИЧИНИ КРОКУ ГВИНТОВОЇ КАНАВКИ НА ПРОЦЕС ПРОФІЛЮВАННЯ ГВИНТОПОДІБНОЇ ТРУБИ ОБКОЧУВАННЯМ РОЛИКОМ

В даній роботі проводився аналіз процесу роликового обкочування гвинтової канавки на трубі та впливу її кроку гвинта на напружено-деформований стан труби в зоні пластичної деформації.

Процес роликового обкочування, на ряду із гідроформуванням, є перспективною технологією виготовлення поверхонь з високими теплоаеродинамічними характеристиками, на базі яких можна розробити теплообмінні апарати з високими коефіцієнтами корисної дії (біля 40%). Розробка високоефективних теплообмінних апаратів позитивно вплине на споживання енергоресурсів, що, відповідно, зменшить витрати на функціонування системи, яка пов'язана з теплообмінним апаратом, знизить шкідливі викиди в атмосферу та залежність від недемократичних держав, які зазвичай будують свою економіку на основі видобутку корисних копалин.

Створена чисельна модель, на базі методу скінчених елементів, процесу обкочування гвинтоподібної труби дала можливість виконати аналіз впливу величини кроку гвинта гвинтової канавки оправки на розподіл напружено-деформованого стану труби в зоні її пластичної деформації. Для виконання процесу обкочування труби в чисельній моделі використаний ролик з оптимальним радіусом скруглення, що визначався по залежності, яка враховує геометрію гвинтової канавки оправки та її кут підйому гвинтової лінії.

Отримані графічні залежності впливу кроку гвинта гвинтової канавки оправки на максимальні величини інтенсивності напружень σ_i та деформацій ε_i показують, що зі збільшенням кроку гвинта гвинтової канавки без зміни її геометричних параметрів, в першу чергу ширини, збільшуються максимальні величини інтенсивності напружень σ_i та деформацій ε_i. Більш важливо знати характер росту інтенсивності деформацій, як фактор оцінки можливості вичерпання пластичності матеріалу. При десятикратному збільшенні величини кроку гвинта гвинтової канавки оправки максимальна величина інтенсивності деформацій зростає в 1,5 рази. Ріст величини інтенсивності деформацій спричинений тим, що при більших значеннях кроку гвинта гвинтової канавки відбувається зменшення її ширини в перерізі, який перпендикулярний до напрямку гвинтової лінії. Це впливає на величину радіусу скруглення ролика, який може бути використаний в процесі обкочування труби, та на розміри локальної зони пластичної деформації труби.

Отримані результати можуть бути застосовані під час розробки технології виготовлення гвинтоподібних труб обкочуванням роликом.

Ключові слова: *гвинтоподібні труби, гвинтова канавка, обкочування роликом, теплообмінники, напружено-деформований стан труби*

Рис.: 10. Бібл.: 19.

Protsenko P. Analysis of the influence of the screw pitch of the spiral groove on the process of profiling a spiral tube by roller spinning. *Technical sciences and technologies,* (3 (33)). С. 111-120.