Perspective directions of mechanical power transmission research

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Abstract. A lot of publications are devoted to the study of gear transmission, which cover all the features of their design, operation and repair. An in-depth analysis of factors that were not taken into account a decade ago was carried out. The efficiency of the drive, taking into account air resistance, and the stress-strain state of the tooth, taking into account centrifugal deformations, were determined. Thus, there are constant complication of the tasks that researchers set themselves. At the same time, recent achievements in the natural sciences have led to a narrowing of the field of use of gears. Thus, the electric motor replaced the internal combustion engine, which was an important object of research for mechanical engineers. The widespread use DC motors with speed control has led to the abandonment of gearboxes in electric vehicles and metalworking machines. Application of mechanical gears in devices. starting with ordinary watches, and ending with the mechanisms of computer disk drives, is a thing of the past. Further in-depth studies of gears, in some cases, don't make sense, since the object of research disappears. It is important to identify areas of research that remain relevant in the 21st century. First of all, these are transmission studies that use the latest achievements in other areas of science. These include: the use of new materials in gears; use of new forms of tooth profiles and longitudinal forms of the tooth, without technological restrictions; analysis of the operation of the gear drive based on indirect indicators - the spectrum of noise and thermal fields of housings. Also, the study of gears in which the tooth is a working body, such as chain conveyors and pumps, will never lose relevance. Or, in which the gear train combines a number of functions, for example, the worm gears of elevators, which reduce the angular velocity and serve as a fuse.

1 Introduction

Recently, we have witnessed stunning progress in battery capacity. Electric cars have become commonplace and are replacing cars with internal combustion engines.

The first samples of sea vessels and aircraft with electric drive were manufactured. Scientists and specialists in the field of transmissions have lost such an important object of research as the internal combustion engine, and after it the gearbox, automatic gearbox transmission for hybrid drive. Three-wheeled compact, ultra-light vehicles have been developed for urban use, which have one drive wheel and no differential (Berkeley T60, BMW Isetta, Reliant Robin, Nobe GT100). These vehicles do not use gear, belt or chain drives. At the same time, the number of publications devoted to automotive transmissions is huge.

The example described is part of a general trend. The theory of a post-industrial society, which was perceived as a utopia or a matter of a distant future, is being realized before our eyes. The solar power plant does not have stuff and machinery equipment. Such a power plant is able to replace a thermal power plant, which is supplied with coal mined in the mine. In this case, there is no need to manufacture machinery for a thermal power plant and a mine. As a result, there is no need for metalworking machines and presses for the manufacture of this equipment. The next step is to reduce the demand for metal and equipment for steel mills.

This trend raises the question of the directions of research in the field of mechanical transmissions, which continue to be relevant in the new model of the economy, which must meet the requirements of: circular economy, decarbonization, green economy, digitalization and zero waste.

2 Literature review and problem statement

Consider the topics of publications that, in our opinion, can remain relevant in the context of deindustrialization. First of all, this is research in the field of wind energy, as part of green energy. There are

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wind turbines with hydraulic and electromechanical transmission. We are interested in the second one, since the electromechanical system of the wind turbine includes a gearbox. It is noted that the transmission including the gearbox has a higher efficiency than the hydraulic transmission [1]. Wind turbine transmissions have a complex dimensional layout with a change in the direction of rotation. The analysis of contradictions arising during the development of wind turbine designs with high efficiency values was carried out using the TRIZ method. Innovative designs of wind turbines are proposed [2]. The widely used designs of continuously variable transmissions (CVT) in comparison with gearbox that have a constant gear ratio. The advantages of using CVTs on wind turbines compared to gearboxes are shown.

A detailed comparative analysis of the advantages and disadvantages of three types of transmissions is given:mechanical, hydraulic and hydro-mechanical type (CVSWTs). The authors believe that it is preferable to use hydro-viscous transmission CVSWTs in powerful wind turbines [3].

We also note the research in the field of mining machines. Here, rack and pinion began to be used in an unexpected way. Gear instead of wheel, rack instead of rail (Longwall Shearer Haulage System [4]. The so-called chainless drive was implemented. The role of the chain is performed by a guide, consisting of separate hinged elements connected to each other. The guides are slats made from pins. The leading element of the chainless system - the drive sprocket is located on the Longwall Mining Shearer, which moves along the guides.

In Ukraine, the improvement of the chain drive of long escalators led to the removal of the drive sprocket to a straight section of the chain [5]. The chain is bush-roller, the profile of the chain is involute. Thus, an involute rack and pinion transmission are implemented.

In the new design of the escalator drive, the upper and lower sprockets have lost the role of drives and perform the function of properly tension a chain drive. Two additional sprockets have been introduced into the design, which act as drive sprockets. They engage with the chain in a straight section. Thus, the upper and lower sprockets were unloaded, as well as the efforts in meshing the chain with the drive sprockets were reduced. [5].

In the design of the rack and pinion of the Longwall Mining Shearer and the escalator, the same meshing is used – involute-pin [6]. The wheel is called involute, because the profile of the tooth addendum is involute, however, unlike conventional involute wheels, the root of the tooth is performed by a radius equal to the radius of the pin.

For transmissions of long escalators, which are also used in conveyors, the problem of gear ratio fluctuation is relevant. Manufacturers are moving towards replacing one drive with a number of modules with separate drives. A double-sided toothed chain is used. One side of the chain engages with the drive and idle sprockets, the other side of the chain transfers the load to the escalator links. Each link of the escalator is equipped with a rack. The part of the chain placed on the sprocket, while turning, engages with the teeth of the rack. On a straight section, a chain in the form of a rack and a rack connected to the escalator links move as one. Thus, a caterpillar drive is implemented. This drive was first proposed by WestingHouse and has been further developed [7]. Currently, escalators of this type are also produced by Mitsubishi.

To solve the problem of "rectangling" in chain drives, an involute sprocket profile and its modifications are also used. [8]. The sprocket has an involute profile, and the chain teeth are outlined with a straight line. This allows for smoother chain engagement. A way has been found to compensate for the influence of the variability of the center distance on dynamic forces in a silent chain drive [9]. The involute profile is corrected, by analogy with profile shifted gears by changing the position of the production tool rack relative to the wheel axis. For a smoother chain engagement, it is proposed to change not only the profile of the teeth, but also to use rolling joints of a complex profile [10].

The most widely used type of gear pumps are gerotor pumps. This is a relatively new type of pump, which has been the subject of a large number of publications. The gerotor pump uses a planetary gear with internal meshing. The most commonly used for tooth profiling is cycloidal meshing. To study pumps, advanced numerical methods are used to study in detail the pressure in the pumped liquid, the stresses in the teeth, the temperature distribution in the liquid and gears, as well as visualize the results of the study and the design stages of the pump. These methods are: finite element [11], computational fluid dynamics (CFD) simulations [12], Virtual Prototype [13] and articles combining these methods [14 - 16].

Advances in gear technology have given a new lease of life to the use of external gear pumps. The parameters of the pump are almost completely determined by the parameters of the gear train. Modern technologies for the manufacture of gears by casting, stamping and sintering make it possible to avoid the mandatory connection of the tooth profile with the parameters of the gear tooth cutting tool [17, 18]

The use of CNC machines (computer numerical control) allows you to make a tooth of an arbitrary profile. Thus, technological restrictions for the use of non-involute gearing have been removed [19]. In this regard, many publications have appeared on the use of various types of profiles for gear pumps [19, 20]. New manufacturing technologies also make it possible to modify gerotor systems, for example, to use an asymmetric tooth profile [21].

A certain idea of the relevance of a particular topic can be obtained using the Google Trends tool. As can be seen from Figure 1, interest in mechanical transmissions in 2004-2006 was much greater than at present. After a decline in interest in the field of mechanical transmissions in 2007-2010, the number of searches for these keywords has remained constant. However, this may be due to the fact that cars with a hybrid drive have appeared as a transitional option from cars with an internal combustion engine. This is a rather complex and interesting object for researchers. The number of publications devoted to this topic has almost tripled since 2004 (Fig. 2). The trend towards a full transition from hybrid to electric drive in all vehicles will also lead to a decrease in requests for mechanical transmissions.

Along with the general decline in interest in gears, the centuries-old traditional use of gear pumps is showing a significant increase in the search for Google (Fig. 3).

In the above short review, we see that the TRIZ heuristic method was used to search for an innovative wind turbine drive design.

When developing a chain drive, a new involute-pin engagement was developed. We note the use of modifications of involute gearing, including an asymmetric profile, in chain transmission and pumps; and also the solution of such a technologically complex problem as the use of hinges of a complex profile in the links of chain. In external gear pumps, instead of involute gearing, a cycloidal one is proposed. Data on the use of new modifications of cycloidal gearing in gerotor pumps are constantly appearing. It is obvious that the basis of these studies is new manufacturing technologies that make it possible to obtain any tooth profile.

The latest publications on pumps are an excellent example of the use of a wide variety of modern research methods: FEM, CFD, Virtual Prototype etc. At the same time, a comprehensive study of the stress-strain state of the gearing, the distribution of pressures in the pumped liquid, temperature fields in the parts of the pump and liquid, issues of lubrication and wear are carried out.

The preliminary analysis given above for the three areas of use of transmissions showed that there are areas of application of transmissions and, accordingly, objects of research that have the right to exist in a new type of economy - for example, mechanical pumps. For such research objects, publications based on the latest achievements in the field of natural sciences and new manufacturing technologies, as well as the use of heuristic methods in design, are relevant.

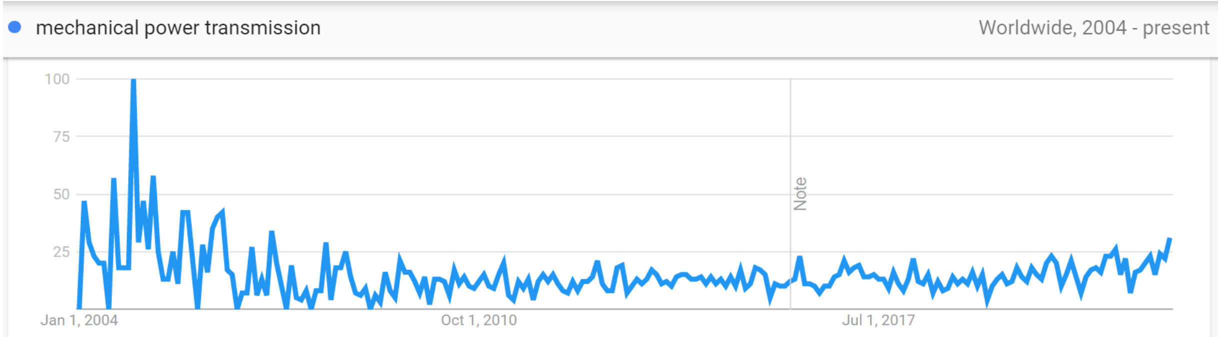

Fig. 1. The dynamics of queries for the keywords “Mechanical power transmission” from 2004 to the present.

Fig. 2. Dynamics of requests for the keywords “Hybrid transmission” from 2010 to the present.

Fig. 3. Dynamics of requests for the keywords "Gear pump" from 2004 to the present.

3 Types of transmissions that remain widespread in the new economy and promising areas of research

The search for promising areas of transmission research will begin with the definition of research objects. These can be new types of transmissions and widely used transmissions that do not lose their relevance. We have already established that gear pumps are an object that has not lost its relevance. What is the key feature of the constant demand for such pumps?

Pump gears perform the function of transmitting rotation from one shaft to another. This problem can be solved using, for example, friction and belt transmission. The gear train, in this case, not only performs the function of transmitting rotation - the teeth are the working parts of the pump. Transmission, which performs both the function of transferring movement and the function of a working body, is the key to finding objects of study that do not lose their relevance.

We can say the same about the rack and pinion drive of tunnelling machines - here the sprocket performs the function of a working body, namely the vehicle wheel. Chain and belt drives of conveyors are indispensable. The chain transmission of escalators and travelators is the drive and at the same time is part of the working body - the moving belt (Table 1). Transmissions may also perform other additional functions. For example, a worm gear in elevator mechanisms is indispensable, like a mechanical safety mechanism holding the elevator in a fixed position in the event of an engine failure [22]. The belt drive performs the function of protecting the electric motor from overloads (Table 1).

Table 1. Promising objects of research.

Properties of transmission types	Object of study
Gear tooth or chain link - working body	Gear pumps
	Gears for grinding ore
	Chainsaws, dredges
	Gear-rack transmissions in the drive mechanism of mining machines
Chain or belt tape is working body	Chain conveyors
	Belt conveyors
	Chain transmission of escalators and travelators
Mechanical safety mechanism	Worm gear in lifting mechanisms
	Belt transmission for transmitting rotation from the rotor of the electric motor
Changes in the direction of rotation, complex spatial layout	Propeller-steering columns of vessels
	Helicopters drive
	Lever and cam mechanisms in presses
Operation at low angular speeds and high torques	Wind turbine drive
	Mine hoist drive
	Turn-over mechanism of floating cranes
	Screw jacks

The propeller assembly in ships does not have enough space to accommodate the engine. Everywhere, the transmission of rotation to the propeller shaft is carried out by propeller-steering columns [23]. In addition to the function of transmitting rotation to the propeller, they also change the orientation of the propellers. Thus, the gear transmission performs the function of spacing the engine and the working body in space, as well as the transmission of rotation and changing the orientation of the working body.

The reciprocating movement in the presses is most rationally provided with the help of gear-lever mechanisms. Electric motors are not economical at low speeds and cannot generate large torques. Therefore, transmissions in the drives of rotary mechanisms of floating cranes and mine hoists remain in demand.

Let's take the liberty of pointing out the areas in which the use of gears will constantly decline. These are transmissions of vehicles and metalworking machines (Fig. 4). Also, the scope of gears in instrumentation is constantly narrowing. Let's consider the actual directions of research of transmissions from the point of view of progress in other scientific disciplines. Let's start by using the most common approaches - heuristic methods and reverse engineering. Heuristic methods are used in the search for new designs of CVTs. Here they are perhaps the most in demand [24] (Table 2).

Table 2. Promising areas of research.

Groups of research methods	Research methods
Heuristic methods	DSM
	TRIZ
	Methods use graph
Reverse engineering	Deciphering gearing parameters and transmission design based on metrological data
	Transmission damage detection and analysis
	Making copies and repairing gears
Advances in related fields of technology	Study of the performance of transmissions made from new materials
	Research of new designs of transmissions obtained using new technological possibilities
An in-depth study of transmissions using new research methods developed in other fields of knowledge	Comprehensive fluid dynamics research for gears, bearings and pumps
	Comprehensive studies of temperature fields in parts and lubricants of transmissions
	Comprehensive studies of transmission efficiency

The DSM (Design Structure Matrix) method is the most popular among transmission researchers [25, 26]. It is used to find rational options for the layout of transmissions, as well as to analyze the root cause of damage. The TRIZ method is no less often used, both to search for new structures and to analyze the technological possibilities of their manufacture [2]. This method was used to integrate mechanical and electronic systems in the transmission control system [27].

Various heuristic methods using graphs are in demand, which allow analyzing the spatial arrangement of transmission elements [28]. The graph is also a convenient tool for studying planetary mechanisms [29-32].

Reverse engineering of gearing requires the use of the latest advances in metrology and manufacturing technology [33, 34]. In the event of a failure of a transmission part, this technology makes it possible to make a copy of it as soon as possible [35, 36]. The gear tooth is scanned using special devices and decoded on the basis of software developed specifically for gears [37]. The found tooth profile and the longitudinal shape of the tooth are reproduced using CNC machines.

Recognition of gearing parameters and transmission design based on a limited number of measurements can be considered the first stage of reverse engineering. Modern technologies allow, without stopping and disassembling the transmission, to investigate the presence and nature of gear damage based on vibroacoustic analysis [38].

Of great importance is the use of new materials, for example, the use of "carbon nanotube composites" to strengthen the surface of teeth [39]. And of course, the use of new types of plastics [40]. As well as new lubricants that meet environmental requirements. These are specialized and synthetic water-based lubricants [41].

Gearing with any tooth profile and longitudinal tooth shape can be obtained not only on a CNC machine, but also by sintering using powder metallurgy, printing on a 3-D printer, injection moulding, etc. [42]. In this regard, the interest of engineers in the longitudinal modification of the teeth, which used to mean barrel-shaped, is understandable. The optimal profile can be determined and made for each of the transmission gears [43-45].

Relevant are studies using the achievements and methods of natural sciences. They made it possible to raise the study of losses in the transmission to a new level [46]. In the introduction to the materials of the “Best of Gears 2022” conference, it is loss studies that are noted as the most promising [39]. Much attention is paid to the comprehensive study of fluid dynamics in pumps, which is also a lubricant for gears and bearings [47].

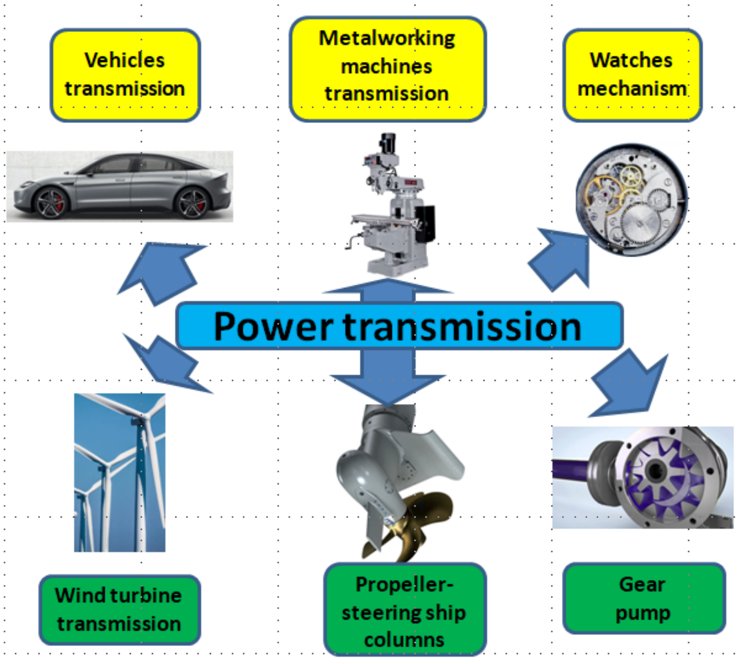

Fig. 4. Promising research objects (bottom row) and research objects whose scope is narrowing (upper row).

4 Conclusions

The analysis of a large number of publications showed that there is a contradiction between the number of publications devoted to the object of research and the area and the prospects for its use. There is still a huge focus on vehicle transmissions, especially hybrid transmissions. At the same time, progress in the production of electric vehicles may lead to the complete disappearance of this object of study.

The features of transmissions have been established, which allow us to assert that these objects of research will be preserved in the new economy. These are mechanisms in which the tooth is used as a working body. Namely, gear trains of pumps, rack-pinion trains of tunnelling machines and chainsaws.

The working body can be a chain or belt tape in conveyors. Also irreplaceable are mechanisms in which the transmission, along with speed reduction, performs additional functions, for example, a worm gear in elevator mechanisms is a safety mechanism.

There are areas of application of gear trains where an electric drive and a hydraulic drive without a mechanical component are ineffective. For example, with a complex spatial arrangement of working bodies relative to the engine. And also, when converting rotational motion into other types of motion and when working with low angular velocities and large values of moments.

Promising areas of research for these objects of study are indicated. First of all, these are universal methods for searching for new designs - heuristic methods and techniques. New to transmissions is the use of reverse engineering methodology, including:

- recognition of the parameters of meshing and the design of gear wheels, based on the latest methods of metrological measurements;
- recognition of the presence, nature and root cause of damage to transmissions, including without stopping their operation.
- express copying and repair of transmission parts and their installation to replace damaged ones.

It is necessary to study gears and chain transmissions made from new materials, including plastics and made using new technologies, primarily 3-D printing. Of the traditional areas of research, efficiency studies are the most relevant, including using Fluid Dynamics methods and related studies of temperature distribution in transmission parts and lubricants.

References

1. H. Polinder, J. A. Ferreira, B. B. Jensen, A. B. Abrahamsen, K. Atallah and R. A. McMahon, "Trends in Wind Turbine Generator Systems," in IEEE Journal of Emerging and Selected Topics in Power Electronics, vol. 1, no. 3, pp. 174-185, Sept. 2013, doi: 10.1109/JESTPE.2013.2280428.
2. Vlastimir Nikolić, Shahin Sajjadi, Dalibor Petković, Shahaboddin Shamshirband, Žarko Ćojbašić, Lip Yee Por, Design and state of art of innovative wind turbine systems, Renewable and Sustainable Energy Reviews, Volume 61, 2016, Pages 258-265
3. Xiuxing Yin, Wencan Zhang, Xiaowei Zhao, Current status and future prospects of continuously variable speed wind turbines: A systematic review, Mechanical Systems and Signal Processing, Volume 120, 2019, Pages 326-340

4. 5. Kotwica, K., Stopka, G., Kalita, M., Bałaga, D., & Siegmund, M. (2021). Impact of Geometry of Toothed Segments of the Innovative KOMTRACK Longwall Shearer Haulage System on Load and Slip during the Travel of a Track Wheel. Energies, 14(9), 2720.
5. S. V. Bondarev, O. V. Zakora The Application of C Involute Gearing in the Escalator Drive - Research Bulletin of NTUU" Kyiv Polytechnic Institute", 2011, 2: 108-115.
6. Ivanov, V., Karaivanov, D., & Ghumachenko, I. Study of the geometry of rack train of a shearer loader's haulage system. In Proceeding 5-th Internacional Conference "Mechanical Engineering in XXI Centure", (nov. 2010), Nish, Serbia.
7. Fargo, R. N. (2006). *U.S. Patent No. 7,137,500*. Washington, DC: U.S. Patent and Trademark Office.
8. Jurj, L., Velicu, R., & Săulescu, R. (2018). Geometry of silent chain-involute sprocket. In MATEC Web of Conferences (Vol. 184, p. 02003). EDP Sciences.
9. Sun, W., Liu, X. L., Liu, J. J., & Zhang, W. (2012). Center Distance Change of Silent Chain Drive Effect on Sprocket Tooth Profile Modification. In Key Engineering Materials (Vol. 522, pp. 574-577). Trans Tech Publications Ltd.
10. SU, Wen Yi; WU, Yu Ren. Design Optimization of a Rocker-Joint Silent Chain and Sprocket Drive Based on the Mesh Performance Indices. In: Applied Mechanics and Materials. Trans Tech Publications Ltd, 2012. p. 104-109.
11. S. Roy, D. (2021). Mechanics and FEM estimation of deformation, gaps and stresses generated in star-ring active contacts of GEROTOR units during operation. Journal of the Brazilian Society of Mechanical Sciences and Engineering, 43(9), 1-20.
12. Pellegri, M., Manne, V. H. B., & Vacca, A. (2020). A simulation model of Gerotor pumps considering fluid–structure interaction effects: Formulation and validation. Mechanical Systems and Signal Processing, 140, 106720.
13. Huang, M., Shi, C., Zhu, Y., Zhang, J., & Zhang, F. (2021). Design of Gerotor Pump and Influence on Oil Supply System for Hybrid Transmission. Energies, 14(18), 5649.
14. Pareja-Corcho, J., Moreno, A., Simoes, B., Pedrera-Busselo, A., San-Jose, E., Ruiz-Salguero, O., & Posada, J. (2021). A Virtual Prototype for Fast Design and Visualization of Gerotor Pumps. Applied Sciences, 11(3), 1190.
15. Roy, D., Maiti, R., Das, P. K., Antoniak, P., & Stryczek, J. (2021). Estimations of leakages through gaps at 'transition'contacts using computational fluid dynamics and photoimaging of core-flow cavitation features in Gerotor pumps. Proceedings of the Institution of Mechanical Engineers, Part E: Journal of Process Mechanical Engineering, 235(5), 1748-1770.
16. K. Mori, T. Maeno, Y. Fukui CIRP annals, 60(1), 299-302 (2011)
17. K. Gupta, N. Jain The International Journal of Advanced Manufacturing Technology, 72(9-12), 1735-1745 (2014) 3. C. (3) Özel The International Journal of Advanced Manufacturing Technology, 54(1-4), 203-213 (2011)
18. Ivanov, V., Karaivanov, D., Ivanova, S., & Volkova, M. (2019). Gear mesh geometry effect on performance improvement for external gear pumps. In MATEC Web of Conferences (Vol. 287, p. 01007). EDP Sciences.
19. Saleem, A. M., Alyas, B. H., & Shaalan, Z. A. (2021). Numerical analysis of standard-unstandard gears for an external gear pumps. International Journal of Fluid Machinery and Systems, 14(1), 25-33.
20. Asal, C. (2021). Düz dişli profil ve istikamet sapmalarının pompalarda ses ve verim üzerindeki etkilerinin incelenmesi (Master's thesis, Tekirdağ Namık Kemal Üniversitesi).
21. Mithun, M. G., Koukouvinis, P., Karathanassis, I. K., & Gavaises, M. (2019). Numerical simulation of three-phase flow in an external gear pump using immersed boundary approach. Applied Mathematical Modelling, 72, 682-699.
22. Göksenli, A., & Eryürek, I. B. (2009). Failure analysis of an elevator drive shaft. Engineering failure analysis, 16(4), 1011-1019.
23. Radojcic, D. (1997, September). Tip-Driven Marine Propellers and Impellers-A Novel Propulsion Concept. In SNAME 8th Propeller and Shafting Symposium. OnePetro.
24. Ivanov, V., Urum, G., Ivanova, S., & Volkova, M. (2018). Development of the positive engagement continuously variable transmission design with the application of graph theory. Восточно-Европейский журнал передовых технологий, (3 (1)), 43-50.
25. Andrew Harold Tilstra, Carolyn Conner Seepersad & Kristin L. Wood (2012) A high-definition design structure matrix (HDDSM) for the quantitative assessment of product architecture, Journal of Engineering Design, 23:10-11, 767-789
26. Wang, S., Li, Z., He, C., Liu, D., & Zou, G. (2021). An Integrated Method for Modular Design Based on Auto-Generated Multi-Attribute DSM and Improved Genetic Algorithm. *Symmetry*, *14*(1), 48.
27. Moulick, E., & Wani, K. (2019). Development of an Innovative Transmission System for Two-Wheelers Using TRIZ Methodology (No. 2019-26-0369).
28. Ivanov, V., Dimitrov, L., Ivanova, S., & Naleva, G. (2019). A heuristic method for transmission design. In MATEC Web of Conferences (Vol. 287, p. 01013). EDP Sciences.
29. K. Arnaudov, D. Karaivanov, Higher compound planetary gear trains, VDI-Berichte 1904-1, 327-344 (2005)

30. Xue, H. L., Liu, G., & Yang, X. H. (2016). A review of graph theory application research in gears. Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science, 230(10), 1697-1714.
31. Pennestri, E., & Belfiore, N. P. (2015). On Crossley's contribution to the development of graph-based algorithms for the analysis of mechanisms and gear trains. *Mechanism and Machine Theory*, *89*, 92-106.
32. D.P. Karaivanov, S. Troha, Optimal selection of the structural scheme of compound two-carrier planetary gear trains and their parameters, 339-403 in: Radzevich, S.P., (Editor), Recent Advances in Gearing: Scientific Theory and Applications, Springer, 1st ed. (2022)
33. Maier, J. R., & Fadel, G. M. (2009). Affordance-based design methods for innovative design, redesign and reverse engineering. Research in Engineering Design, 20(4), 225-239.
34. Ivanov, V., Dimitrov, L., Ivanova, S., & Volkova, M. (2021, June). Reverse Engineering in the Remanufacturing: Metrology, Project Management, Redesign. In *International Conference "New Technologies, Development and Applications"* (pp. 169-176). Springer, Cham.
35. Chandra, M., Dan, P.K. (2019). A Novel Gear Shifting Strategy for Dual Clutch Transmission System Using Reverse Engineering and Robust Design Technique. In: Uhl, T. (eds) Advances in Mechanism and Machine Science. IFToMM WC 2019. Mechanisms and Machine Science, vol 73. Springer, Cham.
36. G. Dúbravčík, M., & Kender, Š. (2012). Application of reverse engineering techniques in mechanics system services. *Procedia Engineering*, *48*, 96-104.
37. Gonzalez-Perez, I., & Fuentes-Aznar, A. (2022). Reverse engineering of spiral bevel gear drives reconstructed from point clouds. Mechanism and Machine Theory, 170, 104694.
38. Y. Benabid and S. Mansouri, (2016) "Dynamics study and diagnostics with vibration analysis from worm gear manufactured by reverse engineering techniques," *Journal of Vibroengineering*, Vol. 18, No. 7, pp. 4458–4471
39. K. Nikolov, V. Ivanov, O. Cankaya, L. Dimitrov, Use of carbon nanotube composites in gearing, Proceedings of BAPT 2016, 23-30, 5-8 Oct. (2016), Ohrid, Makedonia
40. Urbas, U.; Zorko, D.; Vukašinović, N.; Černe, B. Comprehensive Areal Geometric Quality Characterisation of Injection Moulded Thermoplastic Gears. Polymers 2022, 14, 705. https://doi.org/10.3390/polym14040705
41. Stahl, K. (2022). Foreword "Best of Gears 2022". Forschung im Ingenieurwesen, 86, 249 (2022) 1-1
42. Winkler, K. J., Schmitt, M., Tobie, T., Schlick, G., Stahl, K., & Daub, R. (2023). Characterization and Influences of the Load Carrying Capacity of Lightweight Hub Designs of 3D-Printed Gears (16MnCr5, PBF-LB/M-Process). In Proceedings of the Munich Symposium on Lightweight Design 2021 (pp. 160-174). Springer Vieweg, Berlin, Heidelberg.
43. Wang, W.S., Fong, Z.H.: A dual face-hobbing method for the cycloidal crowning of spur gears. Mech. Mach. Theory **43**(11), 1416–1430 (2008)
44. D. Ivanov, V., Urum, G., Ivanova, S. (2020). Achieving Crowning Contact of Spur Bevel Gears Through Deliberately Introduced Mounting Errors. In: Karabegović, I. (eds) New Technologies, Development and Application III. NT 2020. Lecture Notes in Networks and Systems, vol 128. Springer, Cham.
45. Tsuji, I., Kawasaki, K., Gunbara, H., Houjoh, H., Matsumura, S.: Tooth contact analysis and manufacture on multitasking machine of large-sized straight bevel gears with equi-depth teeth. J. Mech. Des. 135(3), 034504 (2013)
46. Ding, H., Li, H., Chen, S., Shi, Y., Wang, Y., Rong, K., & Lu, R. (2022). Energy loss and mechanical efficiency forecasting model for aero-engine bevel gear power transmission. International Journal of Mechanical Sciences, 231, 107569.
47. Hu, X., Li, P., Quan, C., & Wang, J. (2022). CFD Investigation on Oil Injection Lubrication of Meshing Spur Gears via Lattice Boltzmann Method. Lubricants, 10(8), 184.