To the theory and practice of creating modern roller machines

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Abstract. The article describes the areas of application of roller machines, trends in the
development of their designs, research work on the modernization and creation of new roller
machines. Special attention given to the roller machines with a variable center distance of the
working shafts. The descriptions of the gear-lever differential transmission mechanisms created
by authors are given. In particular, the correct applications of the created mechanisms in roller
machines of six types are shown; they are 1. One of the working shafts has the ability to rotate
around its own axis, and the second working shaft, in addition to rotation around its own axis,
moves relative to the first working shaft along the line, passing through the center of the axes
of rotation of both working shafts; 2. Both working shafts have the ability to rotate around their
own axes and move symmetrically along a line passing through the same axes of rotation
relative to each other; 3. One of the working shafts has the ability to rotate around its own axis,
and the second working shaft, in addition to rotation around its own axis, moves relative to the
first working shaft along an arc with a certain radius of curvature; 4. Both working shafts can
rotate around their own axes and move symmetrically relative to each other along an arc with
some symmetrical centers of rotation; 5. One of the working shafts has the ability to rotate
around its own axis, and the second working shaft, in addition to rotation around its own axis,
moves relative to the first working shaft along a complex trajectory; 6. Both working shafts can
rotate around their own axes and move symmetrically relative to each other along a complex
trajectory.

1. Introduction
Currently, in the industry of our Republic and abroad, roller machines are widely used for various
purposes. In metallurgy, roller machines are used for the metal treatment under pressure. In
mechanical engineering, roller machines are used in expansion and rolling operations. Roller machines
are also widely used in agriculture, in light industry (textile, leather, and paper production). In
particular, in the tannery, fleshing and planing machines to remove hair and clean the grain leather
surface; double belt machines, machines for squeezing and spreading leather and fur, staking and
softening machines, machines for processing leather by pressure, grinding and dedusting machines and
units, machines for leather dyeing and many others are the roller machines [1].

Despite the wide applicability and great variety, roller technological machines are poorly
researched [2-4].
The main advantage of roller machines is their fit into production lines and the possibility of
continuous or piece-by-piece continuous execution of the technological process.
All roller machines can be divided into two groups according to the degree of freedom of roll modules:

1. roller machines with a constant roll-to-roll distance between the working shafts;
2. roller machines with varying roll-to-roll distances between the working shafts.

The first group of roller machines is mainly used in the metallurgical industry, and the second group is used in light industry, agriculture, etc.

In tanneries, a roller pressing machine VOPM-1800-K is used for pressing chrome leather semi-finished product [1]. An AORU-1800-K, developed by VNIILTekMash is also a well-known unit [1], designed for squeezing and distributing pigskin chrome semi-finished leather and bovine semi-finished leather. To squeeze out bovine leather semi-finished products, a squeezing machine produced by "SWIT" company is used [1]. To soften the leather semi-finished product, the staking-softening machine TMPH-1800-K is used [1]. For rolling hard skins, the PK-P machine is used [1]. To squeeze the moisture out of chrome-tanned leather, squeezing rollers machines MOV-K and MOP-1800-K [1] are used, in which the squeezing of semi-finished products is performed by smooth steel shafts covered by a rubber coating. To wring out semi-finished leather from a bovine hide, a feed-through squeezing machine RS-40 by Menechetti (Italy) [1] and 594 machine by “Turner” are used.

In agriculture, for the primary processing of bast fibers, a roller machine is used with corrugated working shafts [1]. The harvesting apparatus of a cotton picker for picking raw cotton also presents a roller technological machine [5].

In all of the above listed and many other roller machines, due to the features of the technological process, the center distance of the working shafts changes.

Roller technological machines used in various industries do not fully meet the agrotechnical and technological requirements imposed on them, such as work without geometric sliding between the processed material and the working shafts, ensuring the required pressure on the processed material, ensuring the required velocity parameters, constancy in dimensions and positions of working bodies, etc. This results in poor product quality, low productivity and durability of the machine. This happens not only because of the wrong choice of the scheme and design errors of the working body of these machines, but also because of the flaws and wrong choice of their actuators, especially inter-roll transmission mechanisms [2 - 4]. The research carried out by the authors makes it possible to conclude that in some roller machines the transmission mechanisms are selected and designed without considering the structural, kinematic, dynamic properties of these mechanisms. Such design flaws are due to insufficient research of roller technological machines and their actuating mechanisms, in general, and inter-roller transmission mechanisms, in particular, as well as due to the lack of methods for structural, kinematic, dynamic analysis and synthesis of these transmission mechanisms.

2. Materials
Currently, the laboratory "Theory of Mechanisms and Machines"of the Institute of Mechanics and Seismic Stability of Structures named after M.T. Urazbaev of the Academy of Sciences of the Republic of Uzbekistan conducts research and design study aimed at improving the design and methods of analysis and synthesis of roller machines, their mechanisms and working bodies [6-10]. Articles [11-14] are devoted to solutions of contact interaction in two-roll modules. Mathematical models of roll contact curves, friction stresses and contact stress distribution patterns were obtained. The variety of operations performed by roller machines has not allowed creating a unified system for their design, which is associated with the difference in technological tasks and processes occurring in the contact zone of the rollers with the material being processed [15]. In the contact zone, each point of the surface at a given moment of time corresponds to the velocity of the material and the contact stress determined by the magnitude and direction, which together forms a vector field. A necessary condition for the machine to perform a certain function is the creation of stress and velocity fields with a given value and permissible deviation on the contact surface of the rollers. Thus, the main task of designing roller machines is to ensure the above conditions, for which it is necessary to know the fields and their influence on the performance of the given functions by the mechanism, and the
characteristics of the fields that most affect the function to be performed. To date, issues related to the stress field in the contact zone are partially solved, although without considering the velocity characteristics, while the problem of velocity characteristics and their effect on the stress of the contact zone, depending on the functional purpose of machine, awaits its solution. Consequently, the main task of designing a roller machine is to create a machine design that provides for the required value and permissible uniformity of velocities and stresses in the contact zone of the working rollers to perform technological tasks. Hence, the development of calculation methods, new designs of actuators, especially inter-roller transmission mechanisms, which increase labor productivity, improve the quality of the product, save energy and resources in machining processes, is an urgent problem.

In the context of solving these problems, a number of studies were completed and published [1-15]. However, the insufficient choice of schemes of inter-roll transmission mechanisms, the lack of an effective classification of these mechanisms, the working bodies of roller technological machines and roller machines in general, considering the agrotechnical and technological requirements for these machines, do not give designers the opportunity to correctly choose the schemes of the working bodies of these machines and their transmission mechanisms.

In order for the designers to facilitate the correct choice of the scheme of the working bodies of the roll machines according to the technological requirements and the correct choice of the transmission mechanism for the selected scheme of the working bodies, we have compiled a classification of the roll modules (working bodies of the roll machines).

The structures of roller modulus with variable inter-axial distance of working shafts depending on the types of paths with displaced centers of rotation of movable working shafts relative to base box, may be of the following types (figure 1):

I. One of working shafts has an ability of axial rotation, and the second working shaft besides axial rotation has an ability to move relative to the first working shaft along the line crossing the center of axes of rotation of both working shafts;

II. Both working shafts have an ability for axial rotation and symmetric movement relative to each other along the line crossing the same axes of rotation;

III. One of working shafts has an ability for axial rotation and the second one, besides axial rotation, has an ability to move relative to the first working shaft along the arc with a certain radius of curvature;

IV. Both working shafts have an ability for axial rotation and symmetric movement relative each other along the arc of circle with certain symmetric centers;

V. One of working shafts has an ability for axial rotation, and the second working shaft, besides axial rotation has an ability to move relative to the first working shaft along a complex path;

VI. Both working shafts have an ability for axial rotation and symmetric movement relative to each other along complex path.

To satisfy technological requirements to such roller modulus it is necessary to construct different transmission mechanisms with corresponding characteristics.
The stages of creating these machines are varied. They depend on such factors as urgency, preparedness, availability of similar research and design work, inventions, etc. One of the most important stages in the creation of machines and mechanisms is the synthesis of mechanisms, on the basis of which the structural-kinematic diagram of the machine is developed. N.I. Levitsky wrote that synthesis is the main stage in the creation of machines, after the creation of the structural diagram of the machine; further stages do not significantly affect the structure and it does not change substantially [16]. After the synthesis of the basic scheme, the next important working body is the frame, then the other schemes of actuators and devices are developed. Then comes the stage of design, working and technological documentation, and finally a mechanism or machine is manufactured. Further modernization mainly takes place on the basis of primary structural diagrams, and sometimes the primary diagram, due to the lack of research and development, inventions, rationalization proposals and other ideas in this area, may not fully meet the technological requirements.

Many years of experience in creating the scientific foundations of roller technological machines for the light industry, in particular for the leather industry (in this area, roller machines are used everywhere) have shown that:
- some roller machines do not fully meet the technological requirements for these machines, due to errors inherent in the structural-kinematic diagram showing the location of the working bodies on the frame with their possible degrees of freedom;
- in some roller machines, although the structural-kinematic diagram showing the location of the working bodies on the frame with their possible degrees of freedom meets the presented technological requirements, however, the actuators, especially the inter-roll transmission mechanisms, do not meet the requirements for inter-roll transmission mechanisms, dictated by the technological process. This discrepancy between the actuators and the technological requirements leads to the fact that the whole machine does not meet the requirements [1 - 4]. This is especially common in roller machines with a variable center distance of the working shafts, that is, in roller machines in which at the time of the technological process the center distance of the working shafts changes.

One gets the impression that the designers at the time of designing have ignored the phenomenon of changing the center distance of the working shafts. There are many examples such as: a gear-lever transmission mechanism for the machine for processing bast of kenaf stalks [1 - 4]; a gear-lever transmission mechanism used in the harvesting machine of a cotton picker; a gear transmission mechanism used in the VOPM-1800-K squeezing machine; a gear-lever transmission mechanism used in staking-softening machine TMPH-1800-K; chain transmission mechanism of the squeezing machine of the “SWIT” company [1 - 4]. The above mentioned mechanisms are designed to transfer torque from one working shaft to another with a constant gear ratio as well as ensure the constancy of the gear ratio only with a constant center distance of the working shafts, and at the moment of changing the center distance of the working shafts, the gear ratio changes, which leads to a violation of the implementation of agrotechnical and technological requirements for the machines.

Such violations, ultimately, lead to a deterioration in the quality of the processed material, sometimes to their damage, and to a decrease in productivity and a decrease in the durability of machines [1 - 4]. Such shortcomings in the design of roller machines are apparently due to the absence of such materials as reference books on roller machines, atlases on the design and effective classification of roller machines and their inter-roller transmission mechanisms. These materials cannot be developed without a thorough study of roller technological machines and their actuating mechanisms in general, inter-roller transmission mechanisms in particular, without the development of methods for structural, kinematic, dynamic analysis and synthesis of inter-roller transmission mechanisms.

In addition, the aforementioned shortcomings in the design of roller machines may be due to the lack of a systematic approach to the design of these machines, which is as follows: 1) when choosing a structural diagram of a machine, the potential functionality of mechanisms of a particular structure is taken into account in advance, which is then implemented at the stage of kinematic synthesis [17]; 2) the kinematic synthesis of mechanisms is performed considering the whole complex of provisions of
the technical specifications for its design, including all kinds of constructive and kinematic constraints, and the quality criteria of motion transmission, not only based on the requirement to reproduce a given motion of the executive body (working rollers); 3) kinematic analysis is considered not only as a stage in the study of synthesized mechanisms, but as a procedure repeatedly used in the process of optimization synthesis of mechanisms. At this stage, in the case of a comprehensive analysis of the "roll module-actuators" system, some discrepancy between the kinematics of the machine and the technical requirement may be revealed, which implies the choice or development of a new structural diagram of the machine. The systematic approach to design also lies in the fact that for all three stages, appropriate systems of algorithms must be developed, with which the automation of the design of roller machines and their inter-roll transmission mechanisms.

We have developed the classifications of roller machines and their inter-roll transmission mechanisms [18]. We have also developed and investigated a gear-lever differential transmission mechanism in relation to a leather roller squeezing machine, in which one of the working shafts has one degree of freedom (rotation around its own axis), and the second shaft has two degrees of freedom (rotation around its own axis and reciprocation along the axis passing perpendicular to the processed material) [19]. The structure, kinematics and dynamics of the developed transmission mechanism were theoretically investigated. The synthesis of this mechanism was conducted for the above-mentioned squeezing machine. It was proven that a squeezing machine with a newly developed toothed-lever differential transmission does not have the above disadvantages. However, as shown above, existing roller machines are diverse. They differ both in purpose and structure, and their transmission mechanisms are also diverse. All the disadvantages of roller machines and their transmission mechanisms, described above, apply to other roller machines. Due to the fact that the purpose and structure of various roller machines are different, despite some identical disadvantages of different roller machines, the ways to eliminate these disadvantages are also different. Therefore, it is necessary to develop a generalized design theory applicable to various roller machines and their mechanisms.

Modern roller machines are a system of mechanisms, consisting of a set of complex working bodies (rollers), executive, auxiliary mechanisms and devices interconnected in a certain way and designed to perform mutually coordinated movements dictated by various technological, agrotechnical requirements. In this system of mechanisms, as in any other, the parameters of functioning, i.e. position, velocity and acceleration of the executive links of individual mechanisms, control and monitoring devices must be coordinated, which is achieved by a purposeful control impact on the object. With an Automatic Control System (ACS), when the impact is realized without direct human involvement [20], the conditions in roller machines have radically changed towards improving the quality of the processed material and saving resources and energy. The MMM laboratory conducted research on the development and implementation of the ACS in production. One of these developments is a system for continuous monitoring and control of uniform feeding of sheet material into the processing zone of the working rollers, which includes tracking and control facilities, a guidance means and a tool for adjusting the tension of the sheet material. Currently, research is underway to determine the geometric, kinematic, and dynamic parameters of the system, which will provide the mechanisms with interconnected operations in a given mode.

In the above five transmission examples, the three transmission mechanisms and the one newly developed by authors, are gear-link transmissions. In recent years, foreign specialists in the field of mechanical engineering and instrument making have shown increasing interest in the theory and practice of using gear-lever mechanisms. This is due to the fact that with gear-lever mechanisms, it is possible to implement diverse and complex patterns of links motion. Numerous combinations of the lever kinematic chain and the kinematic chain composed of gear wheels are diverse and allow us to obtain a wide range of movements of the output link.

Some remarkable properties of gear-lever mechanisms recently revealed, make it possible to consider them as one of the most promising units for the creation of modern machines and devices. [21, 22] Therefore, today the development of roller machines with ACS, inter-roll transmission
mechanisms, in particular inter-roll transmission mechanisms of gear-lever type and the development of methods for their structural, kinematic and dynamic analysis and synthesis, in order to provide designers and engineers and calculators of machine-building factories, scientific workers of research and educational institutes with recommendations for the calculation and design of these machines and their mechanisms, is an urgent problem in the theory and practice of creating roller machines.

3. Conclusions
From the above arguments, the following needs arise:
- to develop new, modern and efficient roller machines.
- to develop automated control systems (ACS) for roller technological machines, including programmed control systems (PCS).
- to develop existing and new methods for calculating the geometric, kinematic, dynamic parameters of the ACS actuating mechanisms and their synthesis;
- to develop new transmission mechanisms of roller machines with characteristics that meet certain technological or agrotechnical requirements for roller machines;
- to develop existing and new methods of structural, kinematic, dynamic analysis and synthesis of newly developed and existing transmission mechanisms;
- to research and develop the existing classifications of roll modules and their actuators;
- to develop a classification of roll modules, taking into account the technological and agrotechnical requirements for these modules;
- to develop a classification of inter-roll transmission mechanisms taking into account the design of roller modules and technological, agrotechnical requirements for them.

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