On intensifying the research processes of regular motions transformation

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Abstract: The study is a review of the scientific and applied content of the research carried out over the years on the topic, both worldwide and by the authors. The research is structured in a way that presents the topic in its active development over the years, which substantially proves its permanent relevance. The development of the researches of the spatial transformation of motions, oriented towards the synthesis and analysis of spatial transmissions with innovative characteristics, at this stage and up to the present moment for Bulgaria are realized exclusively at the Institute of Mechanics at Bulgarian Academy of Sciences (BAS). The content of the researches carried out at the Bulgarian Academy of Sciences clearly determines their market orientation and, therefore, their place of development was in the “Centre of competence MIRACLE – Mechatronics, Innovation, Robotics, Automation, Clean Technologies” at the Institute of Mechanics. The above said makes it inexplicable the decision of the former management of the institute, in the face of Prof. Vasil Kavardjikov (Director) and Asoc. Detelina Ignatova (Project Manager), to ignore this topic when designing a project for the creation of the Competence Centre.

Keywords: SPATIAL TRANSMISSIONS, MATHEMATICAL MODELLING, ANALYSIS, SYNTHESIS, INNOVATIONS, COMPETENCE CENTRE

1. Introduction
1.1. Field of Researches

The activities of this type of researches are oriented towards serving one of the strategic directions of the science "Applied Mechanics" - "Analysis and Synthesis of Mechanical Transmissions". They constitute a systematic set of activities, differentiated in directions of the science and technology, and serving the theoretical and technical development and improvement of both the approaches to the research of processes of regular defined motions transformation, as well as the construction of more sophisticated adequate mathematical models, that describe them. The searched final result of the theoretical studies is the creation of algorithms and computer programs oriented to the synthesis of improved existing and new innovative products – multibody systems for the transformation of motions.

Actual existing multibody systems can be considered as a set of a finite number of interconnected material bodies, as the location and the motion of an arbitrary body is in dependence on the locations and motions of the rest of the bodies included in the system. In the context of the above definition, the body systems can be divided into two main groups, according to the way the relationships and interactions of the constituent bodies are formulated:

Multibody systems with random (spontaneous) occurred connections and interactions. These systems are a result of accidentally occurring and ongoing events. In this case, the connections and intersections between the bodies of the system are not subjected to a regularity. These systems could include those that occur in different types of accidents, catastrophes, and natural disasters.

Multibody systems with forced (regular) occurred connections and interactions. These systems are purposefully designed in such a way that they, as a whole or separate bodies (respectively parts) of them, to realize specific law for the motions transformation. In this case, the connections and interactions between the bodies exist indefinitely, or the duration of their existence is precisely defined. These systems may include predominant mechanisms and machines. The prevailing mechanisms and machines can be referred to these systems.

1.2. Object and Purpose of the Researches

The object of the researches extends to the second direction of the multibody systems in their most general type "spatial mechanical systems", which are dedicated to realizing a preliminary defined law of spatial motions transformation.

The purpose of the researches:

The existing incompleteness and imperfections in the theoretical and applied researches of the spatial mechanical transmissions is a motive to realize an adequate analysis of the state and development of this direction of the science of “Applied Mechanics” - the “Theory of Gearing”, while adequate researches are planned subordinated to the idea on one hand of expanding the theoretical basis (on which synthesis is based) and on the other hand – on the basis of the obtained new theoretical results to be developed adequate practices in order to create innovative products.

2. Review of the Current State of Research Problems

The methods of the science, studying the processes of the regular motions transformation by means of preliminary defined law between coplanar and non-coplanar axes of rotations and between the axis of rotation and axis of rectilinear translations, by means of three-links mechanisms, having one or more high kinematic joints, will be applied in the present researches. This science should be treated as an autonomous direction of the scientific field “Applied Mechanics”. It studies the kinematic and the dynamic behavior of the mechanical multibody systems, in relation to the geometric characteristics of the elements of the high kinematic joints.

Structurally and functionally, the above mentioned three-links multibody systems can be divided into three main types [1, 2]:

- Mechanisms, realizing rotations transformation by means of one high kinematic joint. For them, the motions transformation is realized due to the friction forces between the elements of the joint, which have a tangential contact, caused by normal contact forces induced in the contact zone. Mechanisms that work on this principle are called friction drives.
- Mechanisms, for which the rotations transformation between coplanar and non-coplanar axes are realized by means of the system of high kinematic joints, which elements come into and go out from a tangential contact. These mechanisms are known in the literature as "gear drives". For them, the rotations transformation occurs as a result of the action of normal forces in the places of tangential contact of the elements of high kinematic joints.
- Mechanisms in which, for a given rotational motion of one of the movable links relative to the posture (the fixed link ), the other link performs an uniquely defined rectilinear translation, by means of a system of high kinematic joints, which are called rack drives. The rack drive can be considered as a special case of the gear set, i.e. as a gear drive obtained from a three-link gear.
mechanism, with the following structural and kinematic changes:
- increasing to “infinity” the number of the teeth (elements of high kinematic joints) belonging to one of the rotating links;
- the number of contacting elements (meshed gear surfaces) remains finite;
- the axis of rotation of the link with an “infinite” number of teeth moves to “infinity”;
- the rotation of the same movable link is transformed into a rectilinear translation.

In the years of the second half of the 20th century and the beginning of the 21st century, the vast amount of scientific and industrial (applied) researches in the mentioned direction of the science “Applied Mechanics”, called as a “Science of Gear Mechanisms”, gave a strong impetus for its development toward the formation of two relatively autonomous scientific directions: The Theory of Gearing and The Geometry of Gearing (Geometrical Theory of Gear Mechanisms).

**Theory of Gearing.** In essence, it is a theory of high kinematic joints, considering their application in closed multi-body systems, which the main representative is “gear mechanisms”. The “theory of gearing” deals with the common principles to which the regular motions transformation is subjected, by means of three-links mechanisms with high kinematic joints, for all possible placement of the axes of rotation and direction of rectilinear translation. This theory offers a method for analytical and computational (computer) study of the various types of gearings. In this sense, the current theory is divided into the “theory of plane gearing” and the “theory of spatial gearing”.

**Geometry of Gearing.** It represents the geometric theory of concrete types of gear mechanisms. This direction of the science emerges as a result of the constantly changing demands of industry to the technological and exploitation qualities of mechanical transmissions. On the basis of the elaborated analytical method, in the theory of gearing, the following tasks are solved to a greater or lesser extent:

- Choice of rational form and geometry of the teeth of different types of gear mechanisms.
- Establishment and scientific justification of methodologies for defining of the quality characteristics of the theoretically conjugated and non-conjugated tooth surfaces (tooth profiles).
- Creation of specialized computational methods for basic and optimization synthesis of new classes of the modern gear transmissions.
- Providing an adequate classification of the gear systems based on new and actual characteristics.
- Defining relations between the elements of the tooth geometry and the essential technological and exploitation features of modern gear mechanisms and etc.

Quite naturally, the first steps in the development of geometric theory are realized in the field of plane gearing, and in particular in the scientific fields dealing with involute gear mechanisms.

In the context of the commented studies, we will make a brief overview on that group of problems dealing with the spatial gear mechanisms, the solution of which has given a strong impetus and provided a rapid development of the geometric theory of the spatial gearing and as a final result - wide application of spatial gear mechanisms in various branches of technics. An object of analysis here is the spatial gear sets with crossed axes (shafts) of rotation (skew-axis type gears), known in the technical literature as "hyperboloid gear drives". The family of these gears comprises the following two main groups:

- Gear mechanism, which mesh region is placed on the fixed surface that is located close or passing through the axis of the crossed axes, around which the rotation of the gears is realized. Typical representatives of these gear sets are helical and worm gear sets, as well as the gear mechanisms of type "Wildhaber".
- Here it includes spatial gear drives, which mesh region is displaced from the axis (offset axis) of the crossed lines (axes of rotation) in the general case, both along one of the lines, as well as the other one. Hypoid gear sets, as well as Spiroid, Helicoid and Planooid gears, belong to this group. Here, it should be included as well, the gear mechanisms that mesh region is displaced from the axis of the crossed axes (lines) of rotation, along only one of the rotations’ axis (lines).

They are some type of toroid gear mechanisms.

A number of scientists, in their researches, have elaborated tasks related to the geometry of gearing of different types of hyperboloid gear sets.

The geometry of helical gears with increased loading capacity was developed by V. Schultz and F. Litvin [Russia][3]. A number of monographs have been dedicated entirely or partially, as well as a number of publications, on the geometry of the helical surfaces and their application to the synthesis and design of worm gears. Methodological instructions for their geometric and strength calculations can be found in specialized handbooks. Cylindrical worm gears with a nonlinear profile of helical worm threads were studied by G. Nieman, E. Heyer, F. Litvin [Germany, USA] [3, 4, 5].

Widespread industrial application of hypoid gear drives is a result of the foundation of their geometric theory and technology of manufacture on the basis of a variety of advanced scientific and engineering studies, related to the theory and practice of their basic and optimization synthesis. Over the last few decades, scientists have been actively working on methods for the synthesis of hypoid gear drives. The researches of F. Litvin [USA] [5,6], K. Pismanik [7], G. Lopato, N. Kobatov, M. Segal [Russia][8], K. Minkov [Bulgaria] [9-15] and many others are devoted to this scientific and technological problem. The Gleason systems – USA, Oerlicon - Switzerland, Klingelberg– Germany are well-known to the specialists, as they are applied in the world of industrial practice for the generation of the tooth surfaces of the hypoid gears.

The skew-axis gear drives of type Spiroid and Helicon are a relatively new type of hyperboloid gear transmissions, and it is not without reason that specialists consider them as one of the most attractive types of spatial high-reduction gear sets. The first information about this class of transmissions is contained in the publications of F. Bohle [16], O. Saari [17], N. Nelson [USA] [18-20], and others for the period of1955-1962. From the same period of time, the first patents and the beginning of the introduction of these gears in the USA from the Chicago Company “Illinois Tool Works” have been started. At the end of the mentioned period, the Spiroid gearing rises the scientific interest of a number of European researchers. Special attention should be paid here to the Russian scientists A. Georgiev [21-27], V. Goldfarb [27-33], S. Lagutin [34], V. Ganshin [Russia] [35, 36] and others who have devoted numerous publications, including their dissertations, to these gear sets. In this filed are the studies of European scientists D. Schwager [Germany] [37-38], V. Bolos [Romania] [39], I. Dudas [Hungary] [40] and others.

In the context of the defined purpose, tasks and object of study here are briefly analyzed the current actual researches, which are grouped as follows:

- Summarizing much of the researches realized over the years by the Russian researchers L. Korestiliev, A. Georgiev, V. Goldfarb [Russia], etc., as well as his own theoretical results, S. Lagutin [Russia] [41, 42] introduces into “scientific circulation” the term “space of gearing”, which is a fixed three-dimensional space defined by the rotation axes of the movable links of a three-links gear mechanism. The elements of this space - the vectors of relative velocities and the normals at them at each point, iso-surfaces and iso-lines in which the synthesized gear set has
certain features, etc. - are characteristics applicable to the synthesis of spatial gear drives.

- Geometric theory of spatial gearing includes studies defining geometric-kinematic characteristics that provide optimum conjugation quality for the specific types of hyperboloidal transmission with an exact meshing of teeth. It should be noted that in the field of spatial conjugate gearing, a series of works have been written, oriented towards creating algorithms that limit and eliminate singularity of the active tooth surfaces. The most attractive publications in this field belong to I. Bernatsky [Russia] [43], A. Georgiev [Russia] [23, 24], V. Ganshin [Russia] [35, 36], K. Minkov [Bulgaria] [11, 12], F. Litvin [USA], W. Nelson [USA] [18], and others.

- Publications by L. Korestilev [44] and S. Lagutin [Russia] [41, 42, 44] also refer to the theme dealing with the type and quality of the mesh region. They propose the idea of worm gear sets’ design which conjugated tooth surfaces have instantaneous contact over the closed-loop contact line. Based on the defined hypotheses related to the character of the lubrication and the resulting from it hydrodynamic loading capacity, criteria for its control are formulated by control of the type and size of the tooth surfaces (limited in the frame of the contact line), lubricating fluid, etc.

- As a result of the analysis of the scientific research in the reference literature sources, the fourth group of publications was formulated oriented towards the creation of hyperboloidal gear sets with linear tooth contact and reduced sensitivity to manufacturing and assembly errors, having the qualities for simple and secure regulation and elimination of backlashes in the gearing. The only gear drives that have these qualities as “organic” features are the high-reduction spatial skew-axes gears, of type Spiroid and Helicon.

3. Own Experience in This Field of Study

3.1. Brief Review

The authors of this review are devoted their theoretical and applied researches during the last few decades to the kinematic and geometric, and technological synthesis of spatial gear motions transformers.

The main focus in the researches is put on the definition and justification of concepts for kinematically oriented approaches for the synthesis of spatial gear sets, and on this basis - for the creation of adequate mechanical and mathematical models for the calculation, design, and construction of real engineering objects with innovative characteristics.

For many years, among the various gear mechanisms, from the viewpoint of the character of the tooth contact, the gear mechanisms with an exact meshing dominate. These gear drives, when achieving the optimal accuracy of elaboration and assembly, realize motions transformation with high accuracy of the preliminary given gear ratio.

The realized researches, as well the planned ones, are dedicated to the hyperboloidal gear mechanisms with an exact meshing and spatial rack drives with exact meshing. The researches, summarizing the experience of the scientists from the Institute of Mechanics- Bulgarian Academy of Sciences, are a summary of their many years of researches on the analysis, synthesis, and practical experimentation of the mentioned transmissions.

The created approaches of the modeling are applied in the elaboration of new algorithms and computer programs for the design of less known and applied in the world practice and unknown for Bulgaria, classes of spatial gear mechanisms. The conducted theoretical researches are the basis for the created algorithms and computer programs for synthesis.

By using the elaborated algorithms and the computer programs, prototypes of hyperboloidal gear sets and spatial rack drives (design specimens) are synthesized and designed.

On their basis, constructive-technological documentation for the realization of selected technological models as well as for the organization of regular manufacture of new type Helicon reductors and Helicon motor-reductors are elaborated. Twelve Bulgarian patents are elaborated in this scientific field, as two of them are implemented.

The researches over the last 10 years are summarized in the dissertations of the authors of the present research [1, 2]:


Scientific significance of the solved problems in the dissertations.

The development of mathematical models adequately describing the spatial motions transformation applicable to the construction of algorithms for the synthesis of the hyperboloidal gear mechanisms and spatial rack drives determine the scientific significance of the studied problems in the dissertations. At the core of its theoretical essence, each of the dissertations is based on the definition and elaboration of mechano-mathematical models, which, as well as the corresponding computer software products, can be assigned to:

- Models and programs, realizing theoretical studies in order to establish new kinematic characteristics (properties) of the researched gear transmissions;

- Models and programs, oriented to the geometric and technological synthesis and to the virtual prototyping.

Practical usefulness and applicability of elaborations.

The theoretical methods, elaborated in the dissertations, are created the preconditions for defining new and advanced approaches for solving tasks, related to the analysis and synthesis of the spatial gear drives. On their basis, the following is realized:

- There are elaborated mathematical models, algorithms and computer programs for the synthesis of hyperboloidal gear mechanisms of type – Spiroid, Helicon, Planoid and Wildhaber (see Fig. 1);

- There are elaborated mathematical models, algorithms and computer programs for the synthesis of conic, cylindrical and spatial rack drives from convolute, Archimedean and involute type (Fig. 2).

Fig. 1 Family of special hyperboloid gears
The results of the study for the practice are as follows:

- creation of innovative constructions of hyperboloid gear mechanisms and technological and instrumental equipment for their elaboration (manufacture), for some of them there are 12 Bulgarian patents.
- Development of constructive-technological documentation and elaboration of computer and technological models of the studied gears;
- Elaboration and implementation in regular manufacture of three types of Helicon gear reducers, which are the object of Bulgarian patent (see Table 1, Fig. 3).

### Table 1: Technical characteristics of motor-reductors type Helicon.

<table>
<thead>
<tr>
<th>Offset, mm</th>
<th>RH 31</th>
<th>RH 45</th>
<th>RH 50</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gear ratio</td>
<td>13.3...105</td>
<td>20...80</td>
<td>20...80</td>
</tr>
<tr>
<td>Maximum input power, kW</td>
<td>0.370</td>
<td>1.1</td>
<td>1.5</td>
</tr>
<tr>
<td>Rated driving torque, Nm</td>
<td>50</td>
<td>100</td>
<td>150</td>
</tr>
<tr>
<td>Rated inlet revolutions, min⁻¹</td>
<td>1500</td>
<td>1500</td>
<td>1500</td>
</tr>
<tr>
<td>Theoretical efficiency, %</td>
<td>40...92</td>
<td>40...92</td>
<td>40...92</td>
</tr>
<tr>
<td>Weight without the motor, with:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>cast iron housing parts, kg</td>
<td>12</td>
<td>34</td>
<td>38</td>
</tr>
<tr>
<td>aluminum housing parts, kg</td>
<td>6</td>
<td>24.5</td>
<td>26.6</td>
</tr>
</tbody>
</table>

### 3.2. 3D Software Technology

"3D software technology" is a specific technological approach for the elaboration of a small series of highly accurate hyperboloid gear sets with a small tooth module and miniature sizes of gear drive. In the last few years on its basis, models of gear transmissions with crossed axes and face mating gears, which is intended for incorporation into drivings of two type’s robots: bio-robot hand and a walking robot with four insect-type legs, are elaborated.

In the future, bio-robots will perform various complex tasks in communicating with the user-human. Such robots will be equipped with many anthropomorphic fingers, similar to the human ones. The main purpose of this mechatronic system is to replace the human presence when dangerous tasks are accomplished in areas such as industrial production, space, the seabed, and other similar places.

One of the other future applications of the bio-robot hand is to be a prosthesis for people with disabilities and also as a device for medical diagnostics. Therefore, the requirement for such bio-robot hands is to possess characteristics of exact positioning and smooth motion.

The five-fingered bio-robot hand (Fig. 4) is elaborated in "Kawasaki & Mouri Laboratory" at the Engineering Department of Gifu University, Gifu Japan. The aim of this robot-hand is to be applied as a standard platform for an adequate grasping and manipulating of the various objects as well as for diagnostics of the tumors in female breasts.

A summarized study commented below is conducted by authors together with Prof. Kawasaki and Associate Professor Mouri at Gifu University, Japan.

The purpose of the research is dictated by the need to improve the exploitation properties of the bio-robot.

One of the tasks related to the above-mentioned goal is to find a solution of the problems related to the necessity of increasing the number of simultaneously contacting (meshing) tooth surfaces as well as to create preconditions for controlling the coefficient of overlapping between the mated active teeth surfaces of the conjugated gear pairs, which drive the fingers of this hand. This is achieved by the replacement of the plane bevel gear with straight teeth from the mechatronic driving of the robot-hand with the kinematic and strength equivalent spatial gear pair of type Spiroid or Helicon.

The realized researches conducted over the years at the Institute of Mechanics at Bulgarian Academy of Sciences made it possible to formulate three approaches for the synthesis of hyperboloid gear sets (skew-axis type gears):

- Synthesis upon a pitch contact point:
- Synthesis upon a mesh region:
- Synthesis upon a pitch contact point and region of mesh.

On the basis of the constructed mathematical models and algorithms, that described them, computer programs for preliminary and optimization synthesis of Spiroid and Helicon gear drives are elaborated.

The third approach is applicable for the creation of "3D software technology", oriented to the virtual and real prototyping of special small modules and small sizes Spiroid and Helicon transmissions.

In this concrete case, two types of Spiroid and two types of Helicon drives (with gear ratios respectively $z_2 : z_j = 32 : 8$ and $z_2 : z_j = 40 : 10$; $z_i (i = 1$ - number of threads of pinion and $i = 2$ - number of teeth on gear ) were developed (see Fig. 4 - Fig. 8) [45 - 47]. The gear sets were specially synthesized by choosing an optimal structure and geometric characteristics, after that - CAD modeled. From an exploitation viewpoint, these gear drives are suitable for integration into the existing construction of the bio-robot-hand, as they have to be an alternative to a conic plane gear drive with the same gear ratio. The hypoid displacement (offset) $a_w$ (see Fig. 1) and the curvilinear character of the meshing tooth surfaces (in the alternative chosen type of transmissions) result in an increasing of the overlap coefficient of the new types of gear drives. This and the possibility for the control of the backlash...
in the mating teeth, lead to improvement of the technical accuracy of the transmissions, which drive the robot hand’s fingers.

The novelty of this design solution is that the synthesized Helicon and Spiroid gear drives have small boundary gear ratios. This is a challenge for both their synthesis and design, as well as their technical realization. The reason for this is that Spiroid and Helicon gear sets usually ensure rotations transformation with a gear ratio $z_2:z_1 > 10$ to 400. The extreme difficulty of elaboration with the available technical and technological equipment, as well as the high production cost, determine the reason for using “3D software technology” to produce the above-mentioned gear systems. With this technology, the final stage is 3D printing.

We will summarize in conclusion that the offered “3D software technology” includes the following stages:

- mathematical modeling for an optimization synthesis of hyperboloid gear sets “upon a pitch contact point”;
- elaboration of the mathematical model for synthesis upon “region of mesh” (development of 3D CAD model);
- 3D printing of the synthesized transmissions.

By using the same prototyping approach, two types of Helicon gear sets with gear ratios: $z_2 : z_1 = 41:2$ and available $z_2 : z_1 = 76:1$ (Fig. 9 and Fig. 10) are created.
They are intended to be tested as alternative mechatronic drives when they are incorporated in the transmissions of insect-type legs for a walking robot.

The usage of “3D software technology” is a guarantee for:

- Shortening the cycle “innovative idea - innovative product”;
- Impetus the development of innovative strategies and enhancing the quality of prototypes by improving their accuracy and rapid realization of various modifications (variants) of the physical prototype;
- Speeding the process of establishing a competitive environment;
- Stimulating the innovation activity of engineers, designers, and scientists.

4. Partnerships with Companies and Scientific-Researches Centers

4.1. Partnerships with Companies in Bulgaria

- During the period 1980-1990, with the cooperation of the Madara Group- Shumen, the first generation (cutting) of the gear pairs of type Helicon are realized. For the same period of time, prototypes of non-orthogonal hyperboloid gear drives with face mating, an object of Bulgarian Patent, are elaborated. During that time the first Helicon reducer is elaborated and tested (with the cooperation of the Madara Group -Shumen, Laboratory for Testing Automobile Aggregates at the Institute of Engines and Vehicles– Sofia and the Institute of Heavy Investment Mechanical Engineering – Ruse, with the assistance of State Enterprise “Heavy Machinery” – Ruse), a “Device to the Tooth Milling Machine” was experimentally implemented in accordance with another Bulgarian invention. Large-sized Helicon gear pairs were generated through the device with a big hypoid displacement (offset).

- During the period 1994–2006, three types of Helicon reducers were created and implemented at Business Innovation Centre “CIME” JSCo—Sofia city. The created products are the result of a license agreement for a patent implementation. The technical design documentation was developed by the patent author.

These partnerships are realized under the leadership and management of Prof. Sc.D. Valentin Abadjiev.

4.2. Partnerships with Non-Bulgarian Scientific Institutions

The next two partnerships are realized by Assoc. Prof. PhD Emilia Abadjieva:

- In the period November 2012 - November 2014 a post-doctoral specialization at the University of Gifu, Gifu city, Japan is realized. The subject of specialization is “Mathematical modelling for the synthesis of spatial gear mechanisms, oriented to integration in precision mechanical systems”. During the specialization period, an optimization synthesis of two constructive types of Spiroid gear sets and two constructive variants of Helicon type hyperboloid gears with \( \frac{z_2 \cdot z_2}{z_1} = 40:10 \) and \( \frac{z_2 \cdot z_4}{z_1} = 32:8 \) gear ratios are realized. These are small module micro-gears designed to be incorporated in a bio-robot hand, belonging to the Engineering Faculty of Gifu University, Japan, as an alternative of the plane bevel gear sets with straight teeth – an element of the bio robot-hand construction. The novelty of this design solution is that the elaborated Helicon and Spiroid gear transmissions have small boundary gear ratio. This is a challenge for their optimization synthesis and design in terms of their technological realization. The reason for this is that traditional gear-pairs of this type ensure reduction transformation of rotations with gear ratios above 10 to 400.

Transmissions with boundary gear ratios (in this case, 4) are rarely used in the technique. The necessity to use such gear mechanisms incorporated into the driving of the Japanese bio-robot hand is determined by the requirements for smoothness of the rotations transformation and to control the backlash between the mating teeth.

- The time between December 2014- October 2015 is determined for participation in post-doctoral specialization in the Department of Embedded Intelligent Technologies at the Institute of Information and Communication technologies-BAS under the project AComIn: „Advanced Computing for Innovations“ - FP7-REGPOT-2012-2013-1, Contract 316087. The subject of the specialization is “Analytical and software synthesis of spatial three-links mechanisms through 3D software technology”. As a result, the opportunity appears to formulate the principles of innovative technology through 3D printing, in the practical realization of the analytical and software synthesized small modules hyperboloid gear drives of type Spiroid and Helicon with a small gear ratios. In this way, participation in this project created an opportunity to continue the ongoing researches in Japan.

- From November 2015 to the present time, Dr. Abadjieva works as an Associate Professor at Akita University, Akita, Japan. This period is characterized by work on improving the 3D software technology for the practical implementation of small-module, small sizes miniature spatial gear transmissions.

5. Future Development

The process of Bulgaria’s joining to the European Union is accompanied by a continuous and extreme increase in the importance of enhancing the competitiveness of the Bulgarian industry companies and their ability to withstand competitive pressure and economic factors. In this regard, the implementation of scientific achievements and new technologies as well as the development of innovation potential are crucial for strengthening the Bulgarian manufacture and hence for increasing employment and achieving an economic growth. In accordance with the objectives set in the Economic Reform Program accepted by the European Union (EU) in 2000, Lisbon, expanded in Gothenburg and improved in Stockholm and Barcelona, the actions of the countries, which are members of EU have to be focused on certain priority areas and the crucial importance between them has given to the promotion of the innovations.

The Lisbon process requires instruments to be found in order to promote the competitive industries with a potential for future development that could have a major impact on the restructuring of the economy. A key instrument for achieving a high competitiveness of our economy is the elaboration and consistent application of a policy for the implementation of the Bulgarian (national) innovations.

Without going into details on our national innovation policy, we will note that by Decision No 723/08.09.2004, “The Innovative Strategy of the Republic of Bulgaria” was accepted by the Council of Ministers of the Republic Bulgaria; and the constructed and further improved “Innovative Strategy for Smart Specialization 2014-2020” (Council of Ministers Decision No 384 of 13.07.2017) again puts the emphasis on the development of the scientific-researches and innovation infrastructure of the Bulgarian industry, as well as on the technological modernization in the manufacturing sector.

One of the permanent main goals of the Innovation Strategy is to create conditions for stimulating researches, in order to create innovative technologies and products and their subsequent integration into companies. The commented strategy envisages a number of measures for its realization, among which the essential one is an optimization of the science-technology-innovation relations.
On 03.11. 2015, with the Decision No 875 (Council of Ministers of the Republic Bulgaria) the new project of the innovation strategy 2014-2020 is approved. Its aim is: By 2020, Bulgaria will move from the group of "modest innovators" to the group of "moderate innovators".

The objectives and measures contained in the two national innovation strategies show unequivocally that the traveled road of researches in the treated field is right. The optimal realization of what has been done so far and the adequate continuation and refinement of the research results would be guaranteed in the conditions of a laboratory established within the “Centre of competence MIRACle – Mechatronics, Innovation, Robotics, Automation, Clean Technologies” at the Institute of Mechanics.

6. Strategy for Achieving the Purpose

6.1. Summary Tasks

- Improvement of the created and applied kinematic approach to the mathematical modeling of spatial transmissions. The theoretical researches in this direction are dictated from the necessity of the motions transformers with non-typical characteristics, in order to be incorporated in various technical systems (transport systems, lifting equipment, robots and manipulators, measuring instruments, devices for military and space industry and etc.).
- Elaboration of theory of gearing and geometry of new spatial mechanical transmissions with internal and border (face) mating, intended for transformation of type “rotation into rotation”.
- Elaboration of hyperboloid friction mechanisms: application of the kinematic theory and kinematic geometry for analysis and synthesis.
- Elaboration of “3D software technology” with application of 3D printing for synthesis and prototyping of gear transmissions with crossed axes of rotations.
- Elaboration of models and prototypes of the synthesized innovation products by applying classical metal-cutting technologies, by means of 3D printing engineering plastics, polymers, including polymer nano-composite with graphene and etc.
- Synthesis, design and technical realization of hyperboloid transmissions, including nano-gear transmissions from nano-carbon materials.
- Incorporation of the innovative “pilot” spatial gear mechanisms in industry and mechatronics products.
- Testing of the functional characteristics of the created innovative products.

6.2. Activities to Solve the Tasks

- Formulation of the common approaches for conducting of the theoretical studies and researches: construction of the elements of the kinematic geometry of the spatial motions transformation.
- Expanding the field of application of the geometric and kinematic primitives (kinematic and geometric pitch configurations) of the synthesis.
- Creation of algorithms and computer programs for analysis and synthesis of the primitives, as elements of the kinematic geometry of the spatial motions transformation.
- Elaboration of the elements, which construct different technological approaches for virtual and real prototyping of the innovative products. Application of 3D printing using polymer nano-composites.
- Patenting of the created (established) innovative methods and devices.
- Development of methodologies in accordance with current world standards, for evaluation of the quality characteristics of the created products.

6.3. Educational Programs in the Research Field

- Studying the principles and approaches of virtual prototyping.
- Studying the technologies of the usage of software and hardware for implementation of the processes of 3D scanning and 3D printing processes.
- Studying of the modern technology for teeth generation by cutting, when the researched spatial gear transmissions are elaborated, as well as through the application of 3D printing and adequate nanotechnology.
- Study of nanotechnologies for the realization of nano-gear drives by using carbon nanotubes.
- Studying the European and world regulatory base, which controls the quality of existing spatial mechanical transmissions. Creating of databases.

7. Conclusion

This review-study was part of the authors' offer to establish a laboratory for the analysis, synthesis, design and technical implementation of innovative spatial mechanical transmissions, as a structural element of mechatronic actuators in robotics. This laboratory, in our opinion and proposal, had to be structured within the framework of the elaborated Project NoBG03SM20IP001-1.002-001, with which the Institute of Mechanics - BAS applied to the Ministry of Education and Science of Bulgaria for the construction of the “Centre of competence MIRACle – Mechatronics, Innovation, Robotics, Automation, Clean Technologies” in 2019.

Competence centers are known to be established in order to meet the basic requirement of the measures envisaged within the Operational Program "Science and Education for Intelligent Growth", namely to reverse the negative trends in the development of Bulgarian science (outdated facilities, lack of modern management approaches, lack of professionally trained staff, lack of coordination and complementing the available facilities) in the direction of enhancing top-level and market-oriented scientific research.

Despite the theoretical and applied results achieved by the authors in the field of the theory and practice of spatial mechanical transmissions, which are corresponding to the above mentioned requirements, the management of the Institute of Mechanics, represented by its former director Prof. Vasil Kavardjikov and the head of the Scientific and structural unit "Mechatronics" - Assoc. Prof. Detelina Ignatova (project leader), they ignored the scientific topics presented. They did this authoritarian without informing us. In our opinion, this voluntarism in the policy of the former leadership of the Institute of Mechanics destroys an important part of the innovative competence of this institution and, consequently, of the Bulgarian Academy of Sciences! The authors of this review, publishing the study at this prestigious international scientific conference, express their disagreement with the unjustified action of the former management of the Institute of Mechanics - BAS. We will be grateful to the scientific community for its opinion on the usefulness of this type of researches for Bulgaria.

8. References


