Hyperboloid gear transmissions: innovations, experimental and manufacture realization

Valentin Abadjiev[1] and *Emilia* Abadjieva[1,2*]

[1]Institute of Mechanics, Bulgarian Academy of Sciences, Bulgaria
[2]Graduate School of Engineering Science, Faculty of Engineering Science, Akita University, Japan

Abstract. This work is a review of researches carried out by the authors on prototyping processes and testing of hyperboloid gears. These activities are preceded by modeling for synthesis and design of these gear sets. It contains also a description of the innovative and inventive activities of the authors over the years. The twenty-five years period of studying hyperboloid gear mechanisms with an exact linear contact between the active tooth surfaces is entirely subordinated to the transfer of the obtained scientific results into scientifically applied and applied ones, in order to create adequate innovative products. The time interval of the researches, done from 1980 to 1990, is divided into two parts: - till 1985, the actions are oriented into transforming a part of the obtained scientific - applied results into technological innovations in the field of high-reduction gear mechanisms; - the period 1985 -1990 is identified with attempts to implement these gear transmissions into various technological devices and transport machines. From a practical view point, the 1980-1990 interval covers all activities for elaboration of functional models of reductors and technological models of high-reduction gears of type Helicon. The time period after 1990 is characterized by the elaboration of three types of Helicon reductors.

1 Introduction

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 economical 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 [1]. 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 innovation*s. The Lisbon process requires instruments to be found in order to promote the competitive manufactures 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 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) [2] 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*.

The objectives and measures, endorsed by the national innovation strategies, are pursued through the studies (realized through the years) in the field of hyperboloid gear transmissions.

2 A brief review of the created innovations in the field

The created inventions in the field of Spiroid and Helicon gear mechanisms (Spiroid and Helicon are registered trade mark of Illinois Tool Works, Chicago,

* Corresponding author: abadjieva@gipc.akita-u.ac.jp

Illinois) can be divided into three groups, depending on their technical application [3]:

First type. This type covers the main part of the created author's patents for inventions [4 - 11]. In them, a patent protection of the constructive varieties of gear transmissions, which are analogues to the Spiroid and Helicon gear-set, is realized. The cited author's patents provide protection for orthogonal and non-orthogonal high-reduction gear drives, with different geometry of the pinions and, therefore for the crown' tooth surfaces, and for characteristic ratios between the basic geometric parameters of the gear set. In the core of the created and protected author's claims are the researches in the thesis, which have started before 1983 and have been related to the preparation of the Ph. D. thesis of Prof. Valentin Abadjiev [12].

Second type. To the second type, an author's copyright certificate [13] can be included and it is related to the technical and technological improvement of a hobbing machine. By means of the created device for the universal hobbing machine, its hobbing possibilities to generate Spiroid and Helicon gears with a big number of teeth and a big tooth module are expanded.

Third type. Here, an invention [14] belongs, which claims protect a device for an electro-mechanical control of a special transport system. In the mechanical part of this device, a reductor - driving of the type of the studied spatial gear mechanisms is included.

3 Development of the process of creation of the hyperboloid gear drives of type helicon

Authors dedicate researches on Spiroid and Helicon gears. The gears of type Spiroid and Helicon are relatively new variety of hyperboloid gear mechanisms, and the specialists define them as one of the most attractive high reduction spatial gear transmissions. First information on this class transmissions can be found in publications of F. Bohle [15], O. Saari [16], N. Nelson [17-19], D. Dudley [20] and others in the period 1955 – 1962. From that time, the first patents and the beginning of the implementation of these gears in USA from the Chicago company "Illinois Tool Works" date back. This company is the first which developed Spiroid gear pairs and has organized a serial manufacturing of Spiroid-reductors and motors reductors with general purpose. Later, Spiroid Gearing provoke the scientific interest of a number of European researchers. Here a special place should be given to the Russian scientists A. Georgiev [21-27], V. Goldfarb [28-32], S. Lagutin [33] , V. Bolos [34], I. Dudas [35] and others, dedicated to these transmissions numerous publications and patents.

The authors of the current publication have devoted most of their theoretical and applied researches over the last thirty years on the kinematic, geometric - technological synthesis and analysis of the spatial gear mechanisms [6, 12, 36 - 39]. The main focus in the researches are put on defining and substantiating concepts of kinematically oriented approaches to the synthesis of spatial gear transmissions and on this basis constructing of adequate mechanical and mathematical models for calculation and design of real engineering objects.

Researches, conducted in Bulgaria during the period 1980 - 1990. Here, the type and amount of the work done in the creation of the spatial Helicon gear sets during the first ten years after 1980 would be summarized briefly. During the realized researches, related to the elaboration of article [12], a number of variants of convolute, Archimedean and involute Spiroid gear mechanisms, with an arbitrary crossed shafts of the movable links (orthogonal and non-orthogonal), were calculated using the algorithms and the computer program. From all of the studied gears, after analyzing the obtained data and taking into consideration the technological capabilities of the factories engaged in the manufacture of gear mechanisms in Bulgaria, it was chosen for an experimental research an Archimedean gear set of the above type, which basic geometrical parameters are: gear ratio $u = 56$ (number of teeth of the Helicon pinion $z_1 = 1$, number of teeth of Helicon crown $z_2 = 56$); offset $a_w = 105mm$; axial module $m_x = 4mm$; type of active teeth surfaces of the pinion - Archimedean cylindrical helicoids; outside diameter of the Helicon pinion $d_{a,1} = 70mm$; outside diameter of the Helicon crown $d_{a,2} = 330mm$. They are obtained from a computer program that applies the approach for an *optimization synthesis upon a pitch contact point*.

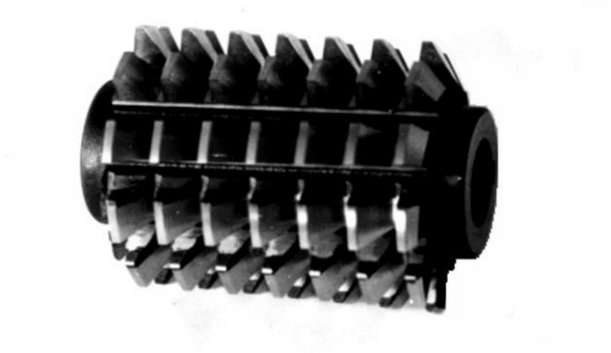


Fig. 1. Hob of type Helicon: type of the active tooth surfaces- Archimedean cylindrical helicoids; orientation of the active tooth surfaces – right ones; axial module $m_x = 4mm$; reference diameter $d_1 = 62mm$; axial profile angles $\alpha^{(1)} = 7^\circ 05'$; $\alpha^{(2)} = 32^\circ 58'$.

These data were used to create the necessary constructive and technological documentation as well for the elaboration of the necessary cutting tools - Helicon hob (see Fig. 1), used for cutting the Helicon crown (Fig. 2) and for the elaboration of the corpus details and the rest of the elements that assemble the designed Helicon reductor. Here, it will be noted that parallel with the basic variant of the reductor, by using the created instrumental equipment (the same Helicon hob), a pair of

conjugated Helicon type gear mechanisms, with other geometrical characteristics (gear ratio $u = 41$ and offset $a_w = 75mm$) is elaborated. It is shown on Fig. 3.

By using the created structural-technological documentation there were elaborated, as it is shown in Fig. 1, a specialized hob of type Helicon at a Cargo Truck Company "Madara" – Shoumen city and it was also realized there, an experimental hobbing of Helicon crowns for the two types Helicon gear sets, which are shown above.

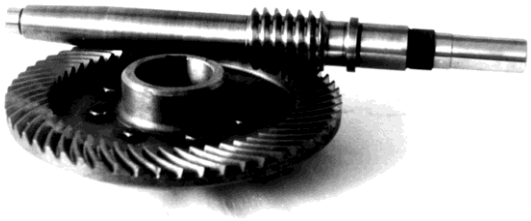


Fig. 2. A pair of conjugated gear mechanism of type Helicon: type of the gear pair – Archimedean; offset $a_w = 105mm$; axial module $m_x = 4mm$; number of the teeth of the Helicon pinion $z_1 = 1$, number of the teeth of the Helicon crown $z_2 = 56$.

Fig 3. A pair of conjugated gear mechanism of type Helicon: type of the gear pair – Archimedean; offset $a_w = 75mm$; axial module $m_s = 4mm$; number of the teeth of the Helicon pinion $z_1 = 1$, number of the teeth of the Helicon crown $z_2 = 41$.

The generation of the gear-pair was realized on an universal hobbing machine brand TOS OF 71 (Czechoslovakia). The Helicon gear set with a gear ratio $u = 56$ and an offset $a_w = 105mm$ was incorporated into the housed corpus (elaborated for this purpose). Thus, the first two identical functional model samples were created. According to their constructive documentation, they are general purpose reductors having an input angular velocity $n_1 = 750min^{-1}$ (revolutions per minute) and a nominal input torque $M_{1,H} = 80Nm$, i.e., the reductor is for nominal power supply $6,0kW$ (see Fig.4).

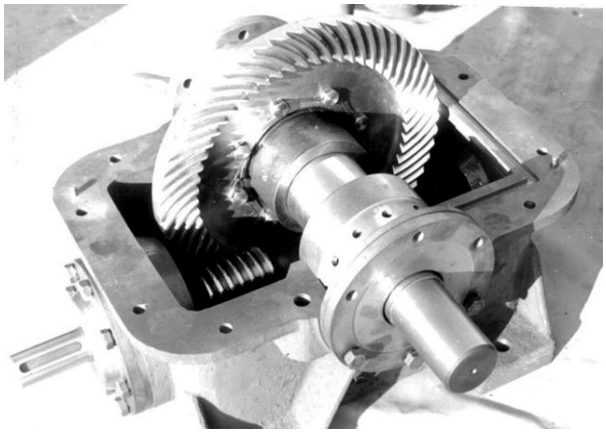


Fig. 4. Functional model reductor of type Helicon: offset $a_w = 105mm$; gear ratio $u = 56$; nominal input power $N_1 = 6,0kW$; an input angular velocity of the Helicon pinion (revolutions per minute) $n_1 = 750min^{-1}$.

Two functional models were tested for reliability on a stand (Fig. 5). The test was conducted in the Automotive Test Vehicle Testing Laboratory of the Institute of Engines and Vehicles - Sofia (now TECHNOTEST – JSC) in accordance with the preliminary developed methodology and program [3, 12]. According to them, a faster test was carried out both on the velocity (frequency of rotation) and on the loading moment: on the drive shaft (Helicon pinion), as it was given to it a rotation motion with an angular velocity (revolution per minute) frequency $n_{2,u} = 850min^{-1}$, and on the output shaft (the Helicon shaft of the crown) - a loading moment $M_{2,u} = 5376Nm$.

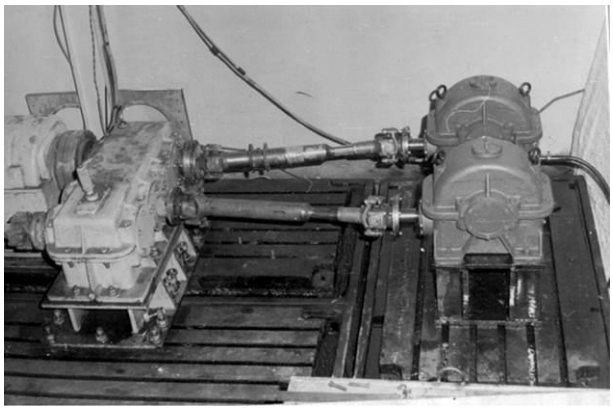


Fig. 5. Reliability test of functional reductors of type Helicon (offset $a_w = 105mm$; gear ratio $u = 56$; nominal power supply $N_1 = 6,0kW$; angular velocity of the Helicon pinion (revolution per minute) $n_1 = 750min^{-1}$).

In other words, according to the test methodology [3], the angular velocity coefficient is $k_0 = 1,1$, and for the load (loading torque) $k_M = (1,2)^4 = 2,07$. According to the applied methodology, the selected operating time of the reductor (realized as a functional model) without damages is $500\ h$ according to BDS

14382-77 and the required test time is $500h/(K_y = 2,28) = 219,2h$.

During the period 1987 -1989 in connection with the implementation of the scientific-research topic "Exploring of the Opportunities for Creating Spiroid Gear Sets for Heavy Mechanical Engineering" by the Institute of Heavy Investment Mechanical Engineering – Rousse city, a test of the considered Helicon reductor construction was carried out in order to determine its efficiency (see Fig. 6 and Fig. 7). The driving of the test-reductor 4 is accomplished by a pendulum-motor 1 having a power of 3.0 kW.

The loading torque on the output shaft of the gearbox 4 is realized by a belt braker 7. The connection between the drive shaft of the reductor 4 and the pendulum motor 1 as well as the connection between its driven shaft and the belt braker 7 are realized by the cardan shafts 3. The Input (driving) torque and the loading torque are registered by the scale 2 and the dynamometer 8, respectively.

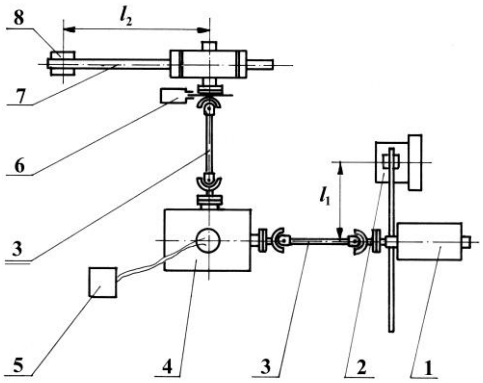


Fig. 6. Schematic diagram of the test procedure for determining the Helicon efficiency: 1 - pendel motor; 2 - scale; 3 - cardan shaft; 4 - Helicon reductor ($a_w = 105mm$; $u = 56$; $N_1 = 6kW$; $n_1 = 750min^{-1}$); 5 – thermometer; 6 – tachometer; 7 – belt braker; 8 - dynamometer.

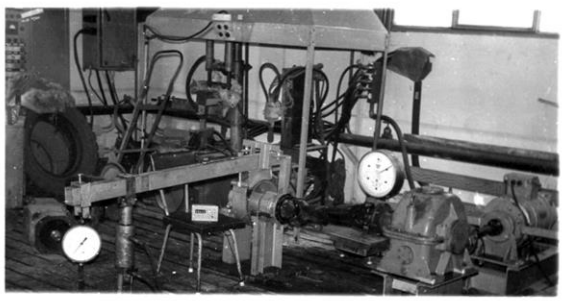


Fig. 7. Testing of the Helicon reductor ($a_w = 105mm$; $u = 56$; $N_1 = 6kW$; $n_1 = 750min^{-1}$).

The accomplished researches, carried out at the Institute of Heavy Investment Mechanical Engineering – Rousse city, gave an approximate estimation of the efficiency of the created reductors of type Helicon in accordance with the technical level of the equipment used in the research - measuring devices.

The researches for establishing the efficiency of the reductor were carried out with the following combinations of the gears' materials of the conjugated pinion and crown: I option: steel (BDS 6354-85) -bronze (according to BDS 10092-75); II option: steel (according to BDS 6354-85) - gray cast iron with lithographic graphite (according to BDS 1799-74); III option: steel (according to BDS 6354-85) - ductile cast iron (according to BDS 6990-84).

Further below, it will be illustrated only the research of the *I option* gear mating, which is related to the manufacture practice, developed in our country. These studies were accomplished in accordance with the following procedure:

- ***Rotation of the conjugated gears in a direction corresponding to "low-side driving"***[12]*:*

On Fig. 8, the graphics of the variation of the efficiency function of reductor on a "*low side driving*" are shown, i.e.

$$\eta_{p\to g} = \eta_{p\to g}\left(\frac{M_{2,i}}{M_{2,max}}\right),$$

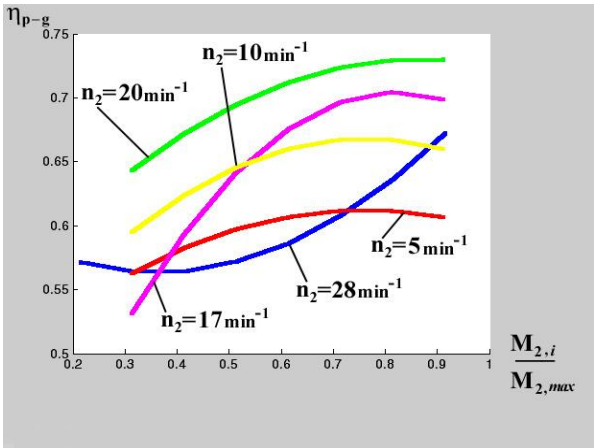


Fig. 8. Graphics of the efficiency variation of the tested Helicon reductor ($a_w = 105mm; u = 56$), when the gears are rotated in a "*low-side driving*" (the obtained value of the measurements are processed by polynomial-linear approximation in MATLAB).

where $M_{2,i}$ is the current value of the loading torque in Nm for the corresponding angular velocity $n_2 = constant$; $M_{2,max} = 1455,6Nm$ - maximum value of the same moment, for the corresponding $n_2 = constant$.

For the studied case, it is established that $\eta_{p\to g}$ has a maximum value $\eta_{p\to g,max} = 0,732$ when $n_2 = 20min^{-1}$ and $M_{2,i} = 1170,1Nm$. The behavior of the efficiency'

functions is law-governed, when $n_2 = 17min^{-1}$, $n_2 = 10min^{-1}$ and $n_2 = 5min^{-1}$ in accordance with the variation of the efficiency for $n_2 = 20min^{-1}$. This can be explained by the worsening of the hydrodynamic conditions of the forces' transmission in the region of mesh, by decreasing the frequency of the rotations of the gears. It results is a decrease of the total circumferential velocity of the contact points and therefore to a worsening of the conditions for the formation of the oil film between the meshed tooth surfaces. It is more difficult to describe the behavior of the function $\eta_{p\to g} = \eta_{p\to g}(M_{2,i}/M_{2,max})$, when $n_2 = 28min^{-1}$. Lower efficiency values and the steepness of the curve could be explained by the fact that the data were obtained during the first stage of the reductor' test, when the degree of overlapping of its active teeth surfaces was insufficient. However, the characteristic of the curve of the efficiency function indicates that the reductor has a maximum efficiency, when the values of $M_{2,i}$ are high, which corresponds to the power supply of the testing installation.

- ***Rotation of the conjugated gears in a direction corresponding to "high-side driving"***[12]*:*

The illustrated on Fig. 9 character of variation of the function $\eta_{p\to g} = \eta_{p\to g}(M_{2,i}/M_{2,max})$ is similar to the shown in Fig. 8 variation with respect to the magnitudes of the angular velocities of the movable links of the gear transmission. The decreasing of the efficiency with increasing of the load $M_{2,i}$ is explained by the raising of the losses in transformation of the rotation from the pinion into a rotation motion of the Helicon crown, because of the less favorable conditions of the normal forces transmission between the conjugated tooth surfaces.

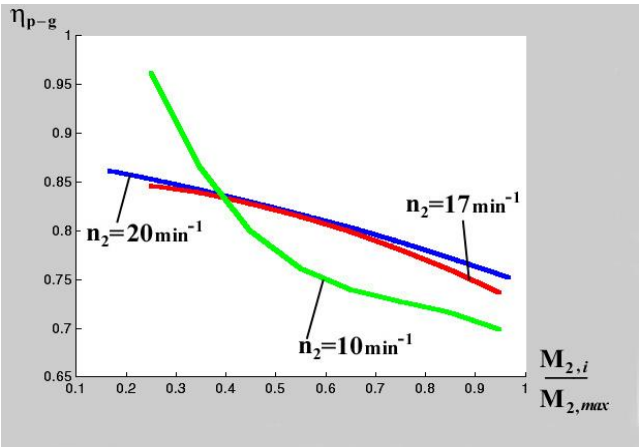


Fig 9. Graphics of the efficiency variation of the tested Helicon reductor ($a_w = 105mm$; $u = 56$), when the gears are rotated in a "*hide-side driving*" (the obtained values of the measurements are processed by polynomial-linear approximation in MATLAB).

The conjugated Helicon gear-pairs, incorporated into the reductor, when the conducted tests was to determine its efficiency, were manufactured at the State Factory "Heavy Mechanical Engineering" – Rousse city. The hobbing of the Helicon crowns was carried out on a ZFWZ 1250 universal hobbing machine with the power of the main electric motor - $12,5kW$.

In practice, the cutting process is accomplished by moving the hob mandrel forward to the hobbing saddle i.e., by means of exposing the cutting area beyond the reach of the hobbing saddle. This effect is achieved by the device, shown in Fig. 10, an object of an Author's certificate for invention - Patent No 51497, MPK B 23F1/06 "A Device for Hobbing Machine" [13]. As can be seen from Fig. 10 a, it consists of a "tilted" (relative to the vertical axis of the machine) gear mechanism and an "inclined" console, between which an additional tool mandrel is mounted. In this case, the "inclined" gear mechanism is placed to the right of the hobbing saddle and obtains a motion from the original hobbing spindle by means of a gear mounted to it (see Fig. 10 c). The output pinion of the gear mechanism serves to drive the additional tool mandrel, which right end is supported by a right bearing (Fig. 10 d). The left bearing support of the hobbing slide is mounted to the left "inclined" console and serves as a bearing of the left end of the additional tool mandrel (see Fig. 10 b). The created device is designed to work with hobbing machines that generate gears by an enveloping approach.

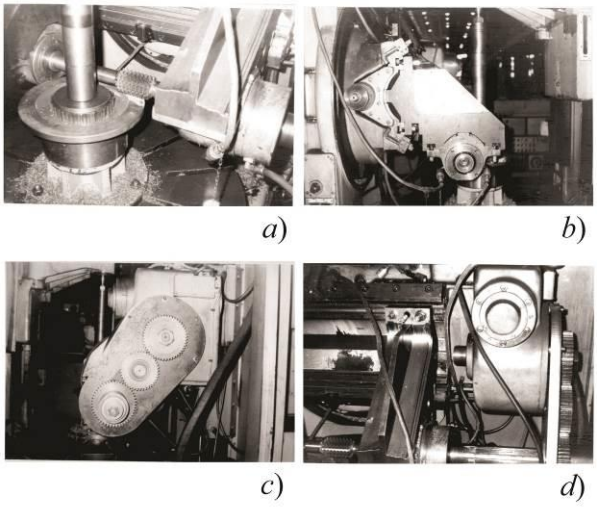


Fig. 10. A device for ZFWZ 1250 hobbing machine: a) general type of the device; (b) "inclined" console and left bearing for the working tool mandrel; c) "inclined" gear mechanism for a motion transformation to the working tool mandrel; d) a front view of the "inclined" gear mechanism and the right bearing support of the working tool mandrel.

Through it, the possibilities of generating gear-pairs not only cylindrical ones, but as well conic and plane disk blanks with big dimensions at different offsets are expanded. By using the illustrated on Fig. 10 device, series of technological experiments (see Fig. 11) were carried out at the "Heavy Mechanical Engineering" State Company – Rousse city. The created and tested Helicon

gear set with the defined geometric parameters, practically belongs to the structural type high reduction gears protected with a Patent No 39931, MPK F 16H1 / 14 "Helicoid type gear mechanism" [5].

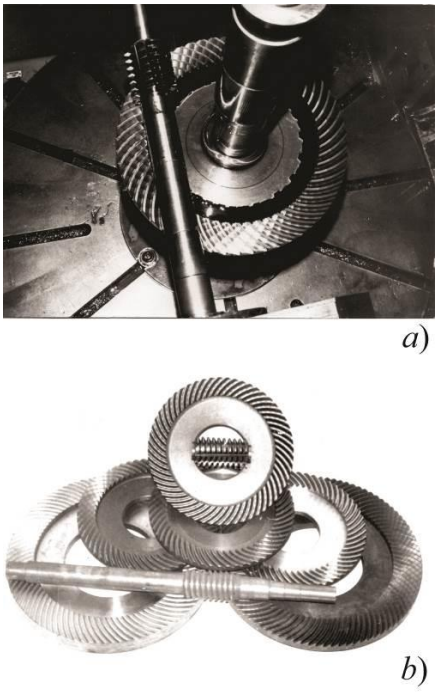


Fig 11. Generation of Helicon gear transmission on the hobbing machine according to Patent No 51497, MPK B23F1/06 "Device for Hobbing Machine": (a) a process of cutting the Helicon crown; (b) Helicon hob, Helicon pinion and Helicon gears elaborated while technological experiment and testing were realized.

During the above mentioned period of time, when using the shown on Fig. 11 instrument, a technological test was carried out, that consists of generating two models of non-orthogonal high-reduction gear-pairs which basic geometrical parameters are as follows: $a_w = 113mm$; $u = 56$ ($z_1 = 1, z_2 = 56$); $\delta = 95^\circ$ (see Fig. 12) and $a_w = 84mm$; $u = 41$; ($z_1 = 1, z_2 = 41$); $\delta = 95^\circ$ (see Fig. 13).

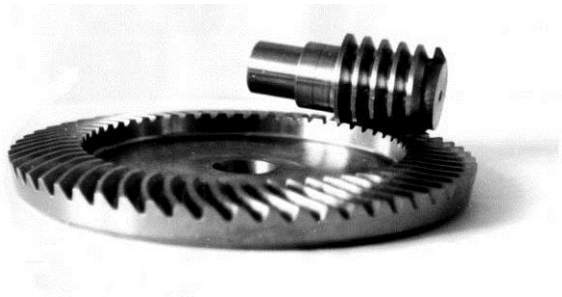


Fig 12. Constructive-technological model of a non-orthogonal high-reduction gear set with the following basic parameters: offset $a_w = 113mm$; gear ratio $u = 56$ ($z_1 = 1$, $z_2 = 56$); crossed angle of the axes of rotation $\delta = 95^\circ$.

Fig 13. Constructive-technological model of a non-orthogonal high-reduction gear set with the following basic parameters: offset $a_w = 84mm$; gear ratio $u = 41$ ($z_1 = 1, z_2 = 41$); crossed angle of the axes of rotation $\delta = 95^\circ$.

As can be seen from the illustrated figures, the characteristic of these gear sets is that their pinion is cylindrical one with asymmetrical helical teeth (threads), and the big crown has a conic shape with curvilinear teeth. The angle between the axes of rotations of both gears is 95°. This constructive variation of the high-reduction spatial gear set exists if certain geometrical conditions are kept, when they are imposed between the non-orthogonal crossed angle δ of the axes of rotations (an angle between angular velocities vectors $\overline{\omega}_1$ and $\overline{\omega}_2$) and the angle defining the conic shape of the crown δ_2 (this is the angle which is formed between the plane of the pitch circle H_2^c and the pitch normal $m-m$) and it is an object of protection of Patent No. 36455, MPK F16H1/6 "Gear Mechanism" [4]. The experimental generation of the conic gears was carried out on a TOS OF 71 hobbing machine (Czechoslovakia). It was realized at Cargo Truck Company "Madara" – Shoumen city.

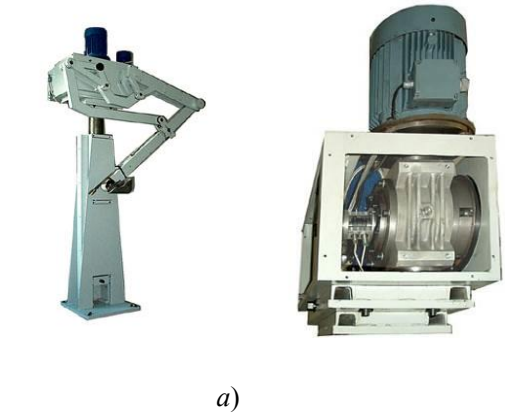
Implementation of Helicon reductors in regular manufacturing. During the period 1994 - 2006, three types of Helicon reductors were created and implemented at Business Innovation Centre CIME JSCo – Sofia city. The main technical data, characterizing each reductor-type are given in Table 1.

Each of the created type reductors is a result of the need to realize adequate rotations transformation for various mechanical systems. For example, the type RH 31 (Fig. 14) happened as a result of a request from the "BELIN" Ltd. - Sofia city to be driven children swings of type “Kiddie Rides” and Carousel type cradles. The type RH 45 (see Fig. 15) was created for the manufacturing needs of the MELSIKON Ltd. – Sofia city (manufacturing a grinding equipment), and the Helicon gear-sets of type RH 50 (see Fig. 16) were designed to meet the manufacturing needs of SILOMA Ltd. – Silistra city for driving of the band-saw cutting machine of type OL220 DG.

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

Technical characteristics	**RH 31**	**RH 45**	**RH 50**
Offset, mm	31,5	45	50
Gear ratio	13,3...105	20...80	20...80
Maximum input power, kW	0,370	1,1	1,5
Rated driving torque, Nm	50	100	150
Rated inlet revolutions, min^{-1}	1500	1500	1500
Theoretical efficiency, %	40...92	40...92	40...92
Weight without the motor, with:			
- cast iron housing parts, kg	12	34	38
- aluminum housing parts, kg	6	24,5	26,6

Fig. 14. Motor-reductor MRH 31 and motor-reductor MRH 50



a) *b*)

c)

Fig 15. The Helicon motor – reduction gears MRH 31 and MRH 50, manufactured by the BIC Centre CIME JSCo are used for the production of manipulators for proportioning and pouring of melts of aluminum and magnesium alloys in horizontal machines for casting under pressure FEEDMAT 1.

The motor-reductors MRH 31 and MRH 50 (Fig. 14) were experimentally implemented by the company SPESIMA Ltd. – Sofia city into the created and manufactured by it manipulator for proportioning and pouring of melts of aluminum and magnesium alloys in horizontal machines for casting under pressure FEEDMAT 1 (Fig. 15).

Motor-reductor of type MRH 31 is built into the driving system of a thermos-insulated garage door - model "wing", designed for the needs of BULSTRAD Insurance Agency. The construction is elaborated at Business Innovation Centre CIME JSCo and it is mounted at the transport entrance of the building of Insurance Agency "BULSTRAD" – Sofia city (Fig.16). The synthesis, design and elaboration of the constructive-technological documentation of each type reductors, as well as of each specific product, is a result of the realized scientific-applied researches and engineering constructive- technological projects of the authors.

a) *b*)

Fig 16. Mechanical thermo-insulated garage door of a transport entrance of BULSTRAD Insurance Company - Sofia: a) general type; (b) driving of the door by means of a propulsion and shut-off mechanism built on the basis of MRH 31.

Here, it should be reminded once again that the strategy used to create those types Helicon reductors is based on the combined approach to the synthesis of these spatial gear mechanisms. In other words, one or more representatives of the reductors' family are synthesized by application of the "*pitch contact point"* optimization approach. The rest of the members of these type reductors are synthesized by controlling the meshing quality in the "*region of mesh*" for each particular pair of conjugated gear sets.

Thus, all of the synthesized reductors for a concrete constructive-technological size are protected by the claims of Patent No. 41950/1994 [9].

In conclusion, we will note that some of the researches carried out in the field of high-reduction hyperboloid gear mechanisms were partially financially supported by the National Fund "Scientific Research" at the Ministry of Education and Science under two contracts between the Institute of Mechanics – Bulgarian Academy of Sciences and National Fund "Scientific Research" during the time-periods 1993 - 1996 and 1998 – 2001.

4 Conclusion

- The twenty-five years period of studying hyperboloid gear mechanisms with an exact linear contact between the active tooth surfaces of the conjugated gears is entirely subordinated to the transfer of the obtained scientific results into scientifically applied and applied ones, in order to create adequate innovative products.
- The time interval of the researches, done from 1980 to 1990, is divided formally into two parts:

- Till 1985, the actions are oriented into transforming a part of the obtained scientific - applied results into technological innovations in the field of high-reduction gear mechanisms. The most of the author' patents are from this period.
- The time period from 1985 to 1990 is identified with attempts to implement these gear transmissions into the system of *State trust* "*Balkancar"* - Sofia and *State trust* "*Heavy Mechanical Engineering*" - Rousse, characterizing with an elaboration of structural and technological documentation of Spiroid and Helicon gear sets for incorporation into propulsion of the mixing drum of a self-conveying concrete mixer (according to Contract No. 514223/04, 1985) and participation into a research process for establishing the possibility for incorporation the above mentioned gear mechanisms into devices for work in the field of heavy mechanical engineering.

- From a practical view point, the 1980-1990 interval covers all activities for elaboration of functional models of reductors and technological models of high-reduction gears of type Helicon, as well as testing their reliability and for the determination of the efficiency of the created reductors. The elaborated prototypes and technological models are protected by the Bulgarian author's patents.
- The time period after 1990 is characterized by the elaboration of three types of Helicon reductors and Helicon motor-reductors that are introduced in mass production (in small quantities) in *Business Innovation Centre "CIME" JSCo* - Sofia. The organized manufacture is realized according to the design and technological documentation, developed by an author of the present study, both of the mechanisms (prototypes) and the necessary basic cutting tools, which are used for generating the active tooth surfaces of the conjugated gears for each specific type reductor. The created types of Helicon reductors are an object of a Bulgarian patent.

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