THE 7TH INTERNATIONAL CONFERENCE RESEARCH AND DEVELOPMENT OF MECHANICAL ELEMENTS AND SYSTEMS

ALMANAC OF INFORMATION MATERIALS, 3D IMAGES, ANIMATIONS AND OTHER VISUALIZATIONS AS AN AID IN STUDYING MACHINE ELEMENTS

Peter NENOV
Vyarka RONKOVA
Emilia ANGELOVA
Trifon TRIFONOV

***Abstract*:** *The objective of this paper is to present the achievements of the authors in the course of preparation of a collection of technical datum, visualizations and animations integrated in the format of an Almanac which serves as a complement to a new textbook for the subject of Design of Machine Elements. Being placed at student's disposal as a supplementary CD, this Almanac will provide them with the opportunity for a self-dependant exploration of the subject and will assist them in the course of a group study too. It is reasonable to expect that the impressive and imaginative presentation of the complicated matter of the subject will aid the students in the process of acquiring of this knowledge and will always be at the disposal of the future designers at the back of their mind. This can contribute to reduce the quite natural initial stress characterizing every new task and will relieve the vigor for the solution of the main point issues of the construction under design. The authors hope to enlist colleagues from other universities in a co-work enlarging the scope and enriching the content of the Almanac mentioned above*

Key words: Illustration, animation, visualization, training clips, training movies.

1. INTRODATCION

The idea for creation of this Almanac evolved when a course of university lectures in Machine Elements was composed. As we chose to supplement the traditional drawings, figures and drafts with more comprehensible and easy to remember information materials, clips and other visualizations.
We have specific experience in this field and some of the results obtained are also included in our collection of excerpts of author's computer software programs for checking and project calculations of cylindrical gear drives and reduction gears (Fig. 1).

Fig.1 Title page of CD to a collection of programs for calculating cylindrical gear drives (visualizations are included)

It contains views and descriptions of the individual features of more than 20 designs of reduction gears and geared motors, brief reports of typical applications and assembly of real structures, representative excerpts of the engineering design process, etc. Animations concerning the parameters of gear meshing quality, as well as space visualization of the reducer structure and its basic elements are also presented.

2. BASIC STANDPOINTS OF THE AUTHORS

The objective of the Almanac, presented here by an extract of its essential part, is not only to provide some more examples but also to launch larger scale activities on expanding these important teaching aids with additional and, if possible, joint efforts of all parties concerned and who could support the visualization process.
Different sporadic examples in this respect are mentioned in many places. It might be appropriate to enlarge, integrate and present them in a more unified style that will facilitate their use. It's is good that there are no language barriers and everything is easy to exchange.
Visualization aids and possibilities are available in various variants. In this case, it is not an obstacle and duplication topic is not confusing. There is nothing better than to make clarifications or to give suggestions from different points of view and in a different way, provided that they are well prepared, balanced and put emphasis on something specific.
In order to clarify the strategy implemented in the visualizations and animations, as well the views on their

future development, we present our basic standpoints on the discussed issues. They could be brought to the following summarized **requirements** to the scope of the developments and the **expectations** of their implementation:

The purpose of our paper is not to exhaust the theoretical formulations of visualization, but to give some examples we consider successful to a certain extent.

We are closely committed to the problems of the engineering practice, because we are familiar with the theory and we are teaching theory, so we are aware, that everyone creates their own opinion about a certain animation, also when they saw it for the first time. What is more, advice can be obtained from those who have had to review it over and over again to catch the meaning of the problem. There is no harm, as when after seeing the animation one starts to explain very excitedly what and how was supposed to have been done rather than appearing as shown, they have grasped then the core of the issue and the purpose in focus has been achieved.

The further development of the idea presented in this report in a collection of more animations, not only in the field of the machine elements, but in other related subjects of the GMD group, is considered a very good continuation. The authorship of those who will respond to our call will be acknowledged by displaying their names under the corresponding animation in the next edition of the Almanac (please refer to the contact information about this issue on the last page of this presentation).

We consider this description in a way that can be summarized as follows:

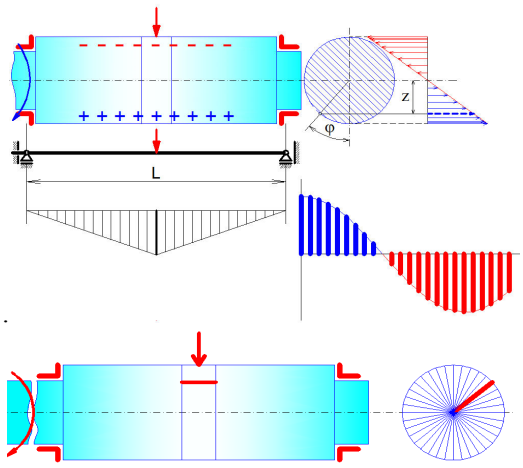
The smartest clip it even be
In words delivered with the greatest of precision
Will in no way get hold of thee
The way it will if you might only see it.

For that reason, several topics are only formally mentioned and supplemented with stationary samplings. The rest is evident through the information in the enclosed figures and can be extended by a direct computer-based presentation in case of a direct communication.

3. A REVIEW OF THE REPRESENTATIVE MATERIALS INCLUDED IN THE ALMANAC

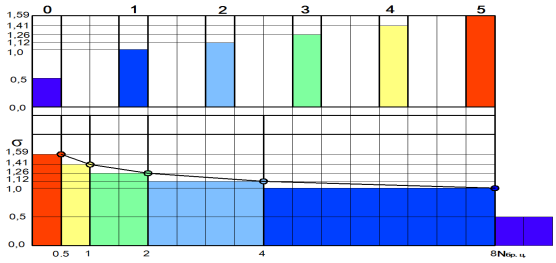
What is claimed in the present paper is not at all fundamental definitions and a strict and complete conception regarding the scope and the structure of the necessary informative and illustrative materials, and not at all the lay down of the corresponding requirements either. It is the objective of this paper from the standpoint of the present achievements to review the basic version of the Almanac and to comment some issues concerning its future development with the participation of an enlarged team including colleagues of other universities.

The visualization presented on fig. 2A clarifies the origin of alternating stresses when a shaft is loaded with a bending moment due to the action of a force with constant value and direction. The alternating forces are consequence of the rotation of the shaft. At certain point this action can result in fatigue fracture represented with the corresponding Wöhler curve (fig. 2B) .



$$\sigma_A = \frac{M_y}{J_y} z = \frac{M_y}{J_y} r.\cos\omega t \qquad (1)$$

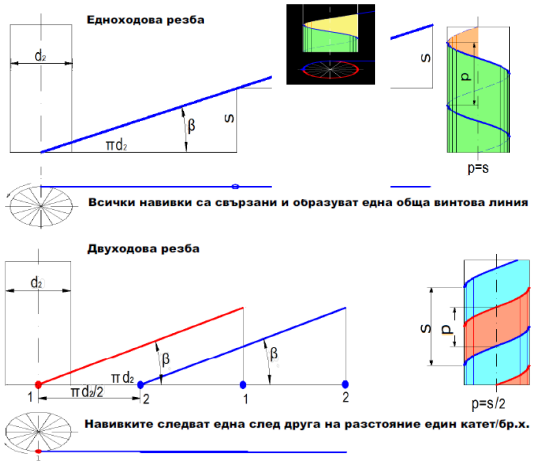
Fig.2A Alternative stresses
(when constant transverse force and rotation are applied)



$$\sigma_{r1}^{\ m} N^1 = \sigma_{r2}^{\ m} N_2 = ... = const \qquad (2)$$

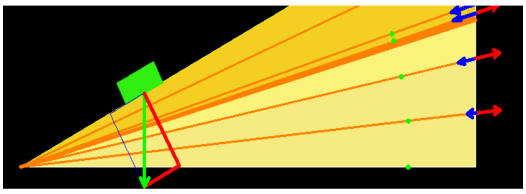
Fig.2B Building a fatigue curve
(«Wöhler curve»)

Fig. 3A represent a clip illustrating the creation of single-start and multi-start threads on the analogy of wrapping of a right-angle triangle around a cylinder. There is a limit value of the corresponding helix angle when the thread is no-longer self-locking and respectively a longitudinal motion of the nut is in progress.



$$tg\beta = \frac{s}{\pi d_2} = \left(\frac{n\ p}{\pi d_2} \right) \qquad (3)$$

Fig.3A Building a helical line
(on the analogy of a right-angled triangle, wrapped around a cylinder)



$$\rho = \operatorname{arctg}\mu \quad (4)$$

$$\rho' = arctg\ \mu' \quad (5)$$

$$\mu' = \frac{\mu}{\cos 30^{\circ}} \approx 1{,}16\ \mu \quad (6)$$

Условието за самозадържане е: $\beta \le \rho'$.

Fig.3B Thread self-locking

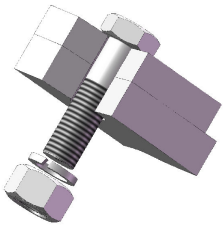


Fig.3C Threaded joint

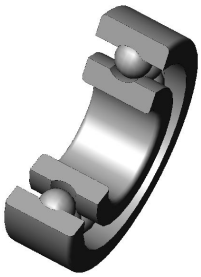
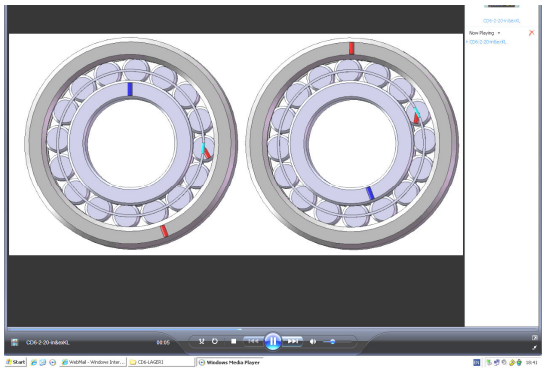


Fig.4A A packet of rolling bearings – design features



$$F_1 = F_o \cos^{3/2}\gamma,$$
$$F_2 = F_o \cos^{3/2} 2\gamma, \quad (7)$$
$$\ldots\ldots\ldots\ldots\ldots\ldots$$
$$F_n = F_o \cos^{3/2} n\gamma$$

$$F_o = \frac{F_r}{1 + 2\sum_{i=1}^{n} \cos^{5/2} i\gamma} = \frac{z}{1 + 2\sum_{i=1}^{n} \cos^{5/2} i\gamma} \frac{F_r}{z} = k_c \frac{F_r}{z} \quad (8)$$

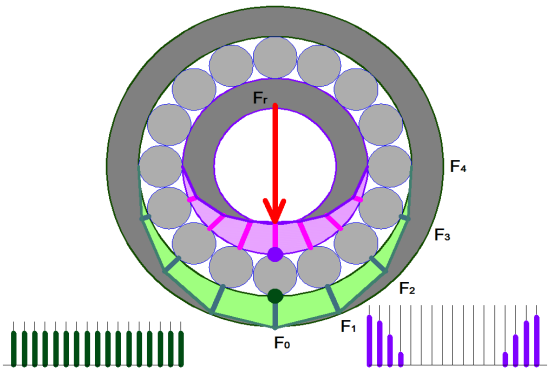


Fig.4B Rotation of bearings rings, rolling elements and cage (when only the inner rings rotates, the ring periphery will be loaded, refer to the scheme)

The maximal contact stresses related to the internal ring are higher if compared with those related to the outer ring, so the case presented on fig. 3B is preferable to the one presented on fig. 3C.

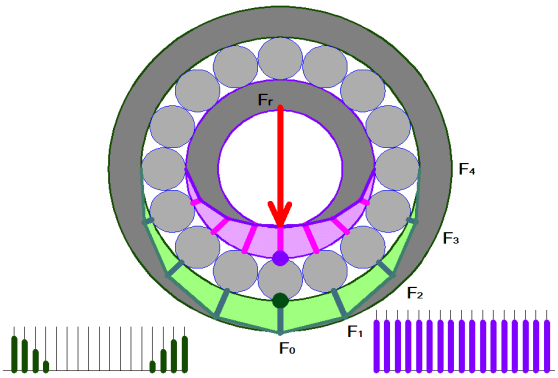
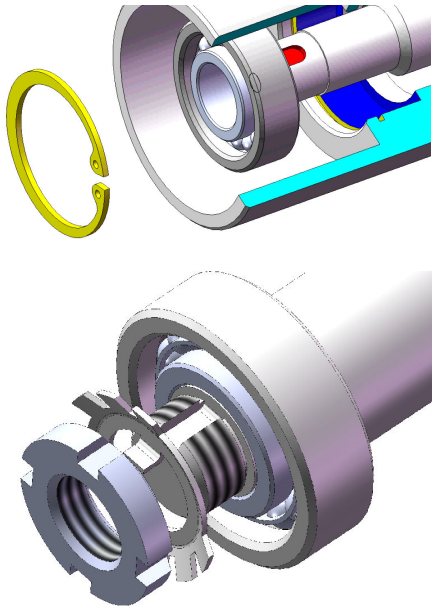


Fig.4C Rotation of bearing rings, rolling elements and cage (when the inner ring does not rotate, then the inner ring has point load, i.e. disadvantage)



Fig,4D Rolling-bearing fastening (above- to the case by means of a spring ring; below - to the shaft by means of a round nut and a safety washer)

Fig. 5A depicts the specific design of Hooke's joint and the peculiarities concerning its assembly. The clip of fig. 5B show the operation of a cardan transmission.

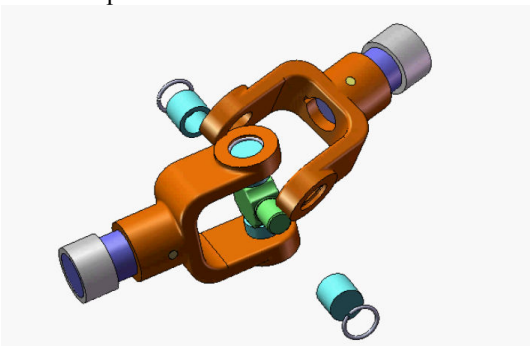


Fig.5A Hook's joint assembly

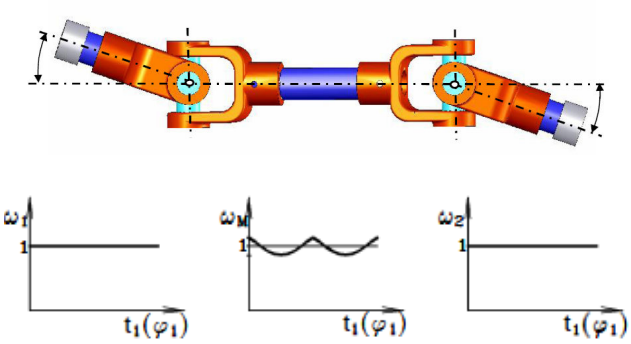
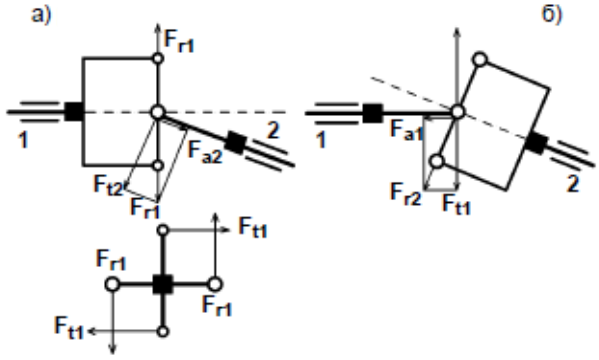


Fig.5B Cardan shaft drive with 2 hinges (synchronization conditions are fulfilled)



$$\omega_2 = \frac{\cos\gamma}{(1-\sin^2\gamma)\cos^2\varphi_1}\omega_1 \qquad (9)$$

$$T_2 = (H - lp)F_{t2} = (H - lp)F_{t1}/\cos\gamma = T_1/\cos\gamma \qquad (10)$$

$$P_1 = P_2, \quad \text{респ.} \quad T_1\omega_1 = T_2\omega_2 \qquad (11)$$

$$T_1\omega_1 = T_2\omega_2 = T_1\cos\gamma\ \omega_2 \qquad (12)$$

или $$\omega_2 = \omega_1/\cos\gamma = \omega_{2\max} \qquad (13)$$

Fig.5C A scheme about the simple derivation of non-uniform rotation of the cardan gear countershaft

An attention is paid to one of the important peculiarities – the unequaled speed of rotation of the intermediate shaft even when the cardan transmission is operated in compliance with the corresponding **requirement for synchronization.**

Fig. 5C and equations (9-13) represent the simplified method implemented in order to deduce the corresponding equations for determination of the maximal and minimal values of the speed of rotation of the intermediate shaft on the basis of the equality of input and output power.

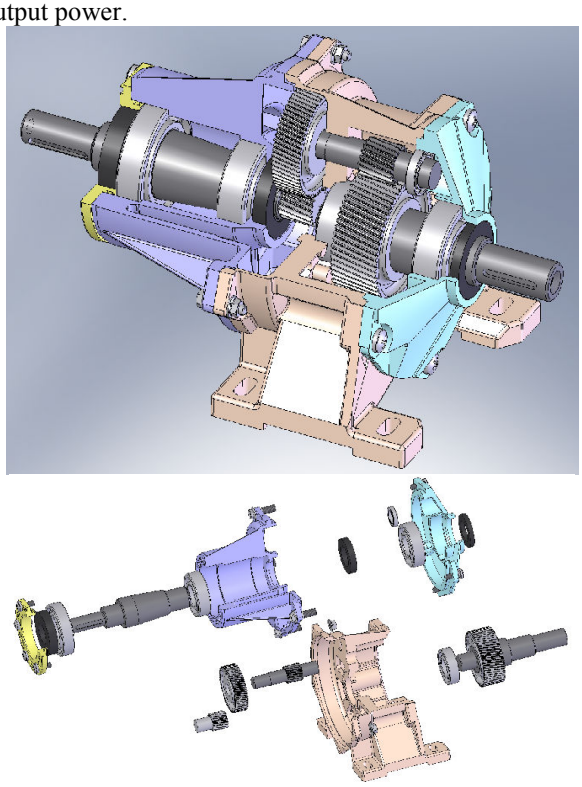


Fig.6A Double-step coaxial reducer (above – running] below – constructive elements)

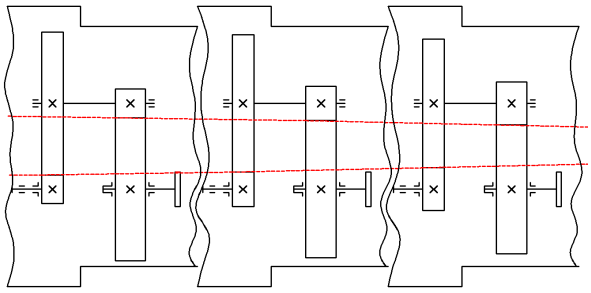


Fig.6B Design development of the coaxial reducer, presented as a 3 members of a family

The visualization of fig. 6A represent an interesting design of a coaxial two-stage gear reducer in operation. The basic elements of the gear reducer are depicted too and the way of assembly and disassembly of the unit is clarified too.

In fig. 6B and in the corresponding animation an attention is paid that in cases of building of families gear units a certain approach in the process of design is advisable to be implemented, and namely the one when the shape and dimensions of the major and most expensive machine elements remain constant and it is only change of the gear

wheels and shafts that lead to a creation of plurality of gear units with different values of the total gear ratio. Such an approach is advisable from the standpoint of cost-effectiveness.

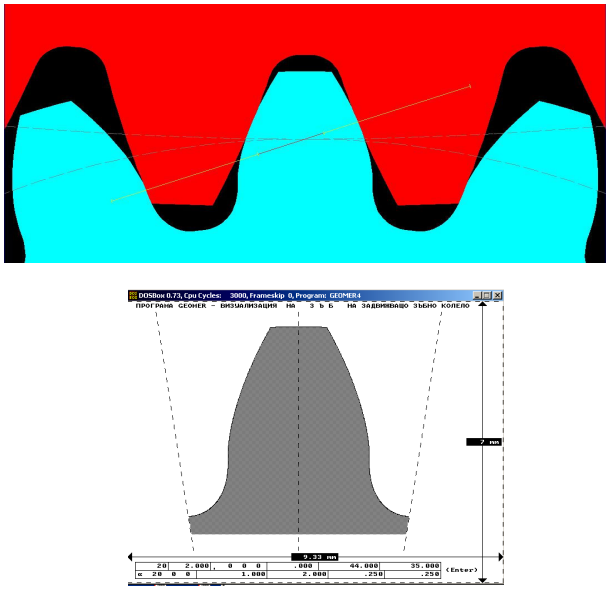


Fig.7A Type of gear meshing: scaled drawing of the teeth used for repairing the teeth by gear secondly cutting

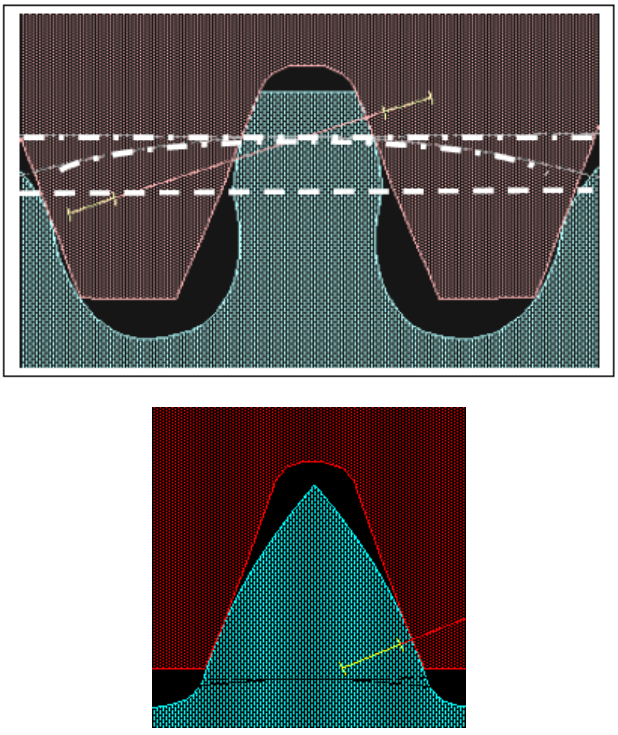


Fig.7B Parameters of meshing quality –undercutting, sharpening, etc..

Fig. 7A and 7B illustrate the operation of an involute gear mesh, the shape of the teeth and the basic parameters concerning the quality of the gear pair, such us undercutting, arc-tooth thickness at the outside diameter of the gear wheels, etc. Fig. 7C illustrates the way of load-shearing between the gear pairs and the corresponding load diagram over the toothed profile of the gear wheels.

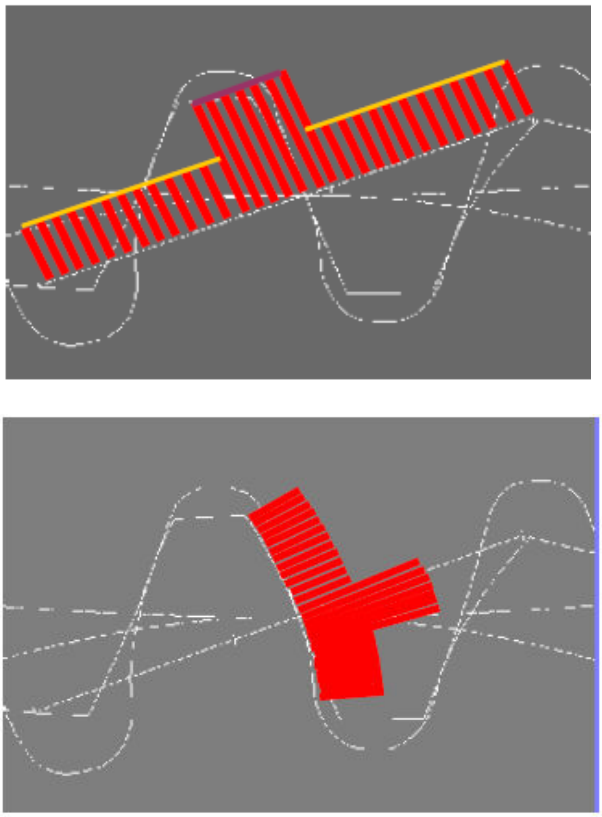


Fig.7C Load distribution in the gear meshing zone and on the working profile

The values of those parameters are of major importance for the operation of the gear drive and they should be a matter of a careful purposive evaluation throughout the design process.

4. IMPLEMENTATION OF 2D-BLOCKING CONTOURS OF "X-aW" TYPE

What is aimed is a better clarification of the way of elaboration and implementation of contours of "coefficient of addendum modification – center distance" type and various their modifications.

Despite the fact that the blocking contours have been known quite a while ago, they had a limited implementation in the process of design of gear units. Recently the elaboration of new modifications of those contours and the comprehensive methods for their elaboration is the basis for a new evaluation of their significance for raising the quality of the design process to higher levels. Some of the new conceptions are presented in Fig. 8. In the upper part of the figure is depicted a wide region, every single point of the region representing a gear drive with one and the same module and tooth numbers, but different values of the center distance and different values of the parameters characterizing the quality of the gear mesh. Under consideration is a family of gear drives of unlimited number of representatives and the implementation of blocking contours places the opportunity at designers' disposal to reach the optimal decision from different standpoints.

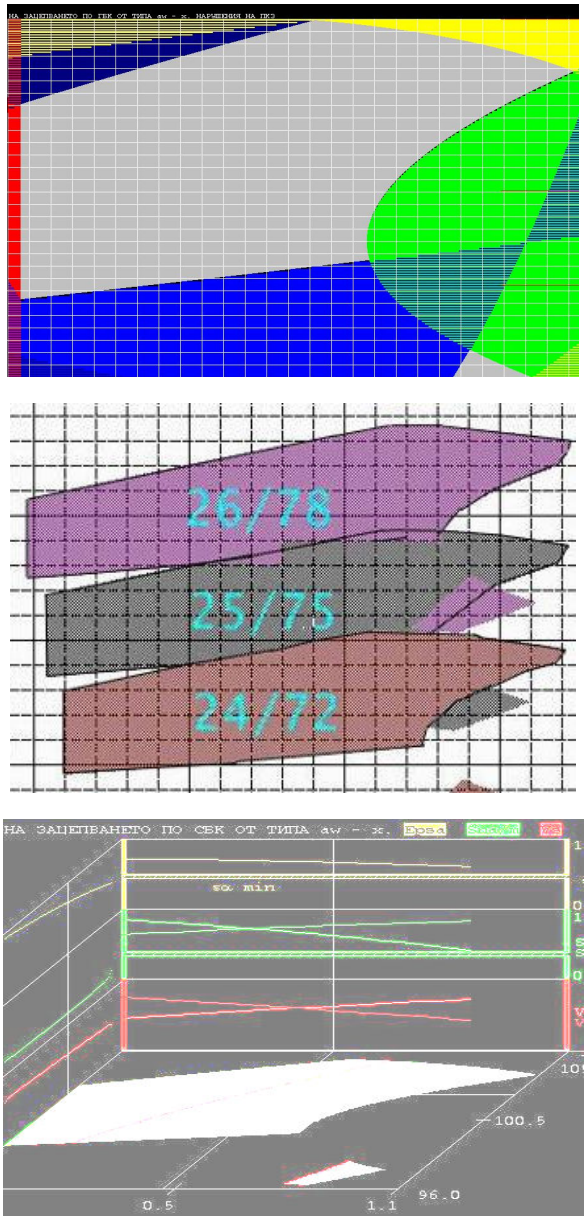


Fig.8 Geometric blocking contours in the co-ordinate system
«addendum modification coefficient – centre distance»
Above - a view with decoded limitations
Middle - in a version for join gear-drives
Below - in 3D version, for a complex evaluation on the base of non-power parameters

The gear drives of the middle part of the figure are of equal module and gear ratio, but as a group they cover a wide region of admissible center distance. This makes them appropriate for integration in gear boxes of machines with strict requirement concerning the gear ratio when no deviation from the required gear ratio is admissible.
The blocking contour of the lower part of the figure enables the determination of the optimal solution from standpoint of providing of higher values of the corresponding coefficient of contact ratio and, respectively, ensuring lower levels of noise in the gear drive.

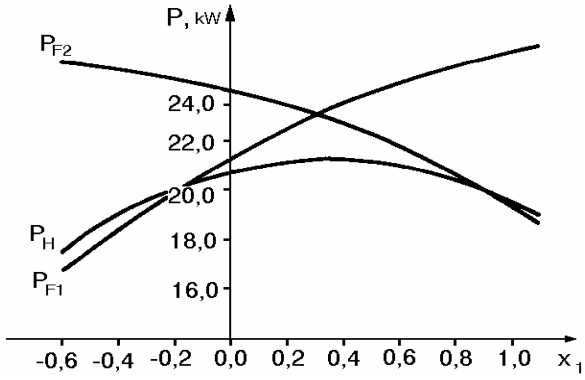


Fig.9 Power blocking contours and their possibilities for optimizing the distribution of addendum modification coefficients of the initial tooth contour

The load capacity blocking contours of fig. 9 represent a family of gear drives with a constant gear ratio and center distance and unspecified values of the addendum modification of the gear wheels. This enables the optimization of the gear drives from standpoint of providing of higher values of the parameters representing the load capacity characteristics.

The clip of fig. 10 illustrates the approach in finding an appropriate solution of the task for distribution of the total gear ratio

$$u_o = u_1 \cdot u_2 \qquad (14)$$

to each of the stages of a two-stage coaxial cylindrical gear drive. The design process is carried out through optimization of the parameters representing the load capacity characteristics of the stages through the implementation of a special software package named COMPLEX2 and including a corresponding control ensuring avoidance of any interference of the gear wheels with the opposite shafts.

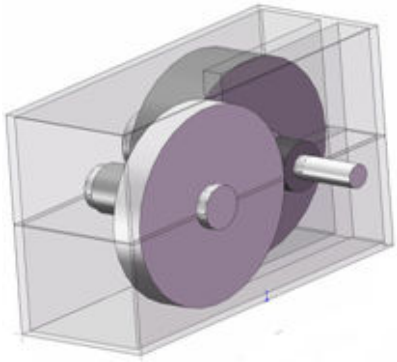


Fig.10 Basic 3D-construction of a reduction gear of optimal parameters, # COMPLEX2

A portion of the software package is implemented for the purpose of preliminary visualization of the design of two-stage gear reducer via appropriate 3D-constructions.

5. 3D-BLOCKING CONTOURS

The superstructure of the Geometrical Blocking Contours (Fig.11) with load capacity, cinematic and other

parameters expands to a much larger scale the possibilities for optimization of the gear drive on the basis of various criteria.

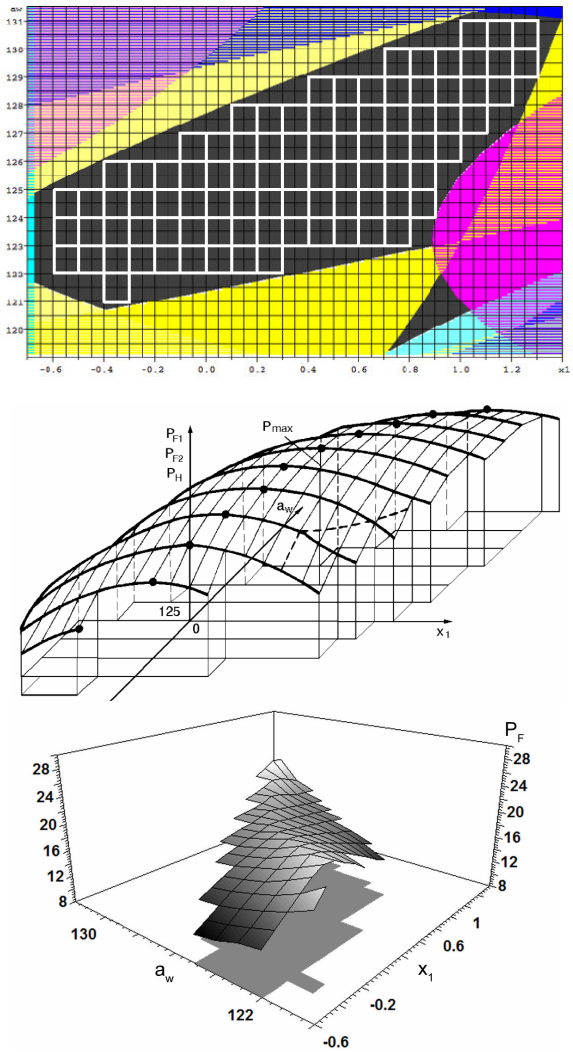


Fig.11 Parametric blocking contours
Above - GBC base (in system x-aw), for PBC;
Middle - Power blocking contour (PBC) – for Padm;
Below - Power blocking contour (PBC),
for P_{Fadm}= max (P_{F1}, P_{F2}).

The Parametrical Blocking Contours elaborated in this way, according to the objective of the design process and the means of the specific software package, can serve as a basis of a superstructure of various absolute and comparative information of a diverse nature. All to often the datum are confined to the parameters concerning the load capacity of the gear drive on the basis of various criteria (the mid of fig. 11), sliding velocities of the points in contact of the tooth profile, etc. The lower part of fig. 11 represents a Parametrical Blocking Contour elaborated automatically and comprising the load capacity parameters of a particular gear drive determined with the implementation of ISO 6336 methods of rating of cylindrical involute gear drives.

6. CLOSING PART

An important prerequisite for the further development of the informative visualization package is its subjection to an uniform method of approach, which needs the definition of general requirements concerning the style, the scope, the format and the way of presentation and implementation of the results (for clarification of the tasks, gaining design experience, for self-education and self-control, for examination, etc.) . At present the objectives are outlined as complex ones and **the Almanac** as a complement to the textbook of Design of Machine Elements, **should conform to the requirements for :**

- Simplicity and usability of the felicitous solutions and examples.
- Stimulating self - education.
- Practical purpose and applicability in real situations in order to quickly gain own design experience.
- Compliance of figures with the learning contents of the subject.
- To provide reference materials and explanatory texts.
- Mutual dependency between the separate components in the process design, calculation, representation, testing etc.
- It focuses on the traditional style lectures as well as on the teaching material for laboratory exercises, course projects and course assignments.
- Clear and logical structure to assist students in their orientation in the structure of the teaching materials.
- Appropriate self- and external-control conditions for learning the teaching material.
- Based on the modern formulations and science development.
- Corresponding well to the language and terminology in the field of design.
- Presentation of typical information materials using parallel terms in several languages that are leading for the respective topics.
- Recommendations for the implementation of suitable symbols, measurement units and transformation of the basic parameters from one measuring system into other.
- Precise determination of the basic conclusions accompanied by a proper comment.
- To define the basic concepts and theoretical formulations.
- Visual presentation of the basic conclusions in effective way to remember them.
- To understand the intra-subject and inter-subject relationships.
- Co-ordination of the graphic concept with the specifics of the subject.
- Complies with the ergonomic and aesthetic standards (of technology and operation)
- Corresponds to the cognitions (the educational preparation of many people was taken into account).
- The name of the structural components (chapters, sections, subjects) complies with the logic of the educational programs.
- Compliance with the modern forms of the graphic design.
- Compliance with the new technologies and parameters of the polygraphic performance.
- Uniform style of the graphic composition.
- Different types of images are correctly balanced.

We neither pretend to have a complete concept on the scope and structure of the necessary information and visual materials, nor to have defined the requirements to them. On the grounds of our experience we will try to

direct the attention to some more important model requirements to the scope and contents of an enlarged version of the ALMANAC.

Fig.12 Proceeding of Int. Conf. By General Machine Design (GMD'09), Univ. of Ruse, Ruse, Bulgaria, 2009

On fig. 12 is depicted the cover page of the proceedings of the international scientific conference on General Machine Design (GMD) arranged by us and carried out in the University of Ruse at the end of 2009. Some of the topics of the conference have been related with the matter of the present paper.

7. CONCLUSIONS

7.1. Our experience suggests that the visualization when elaborated with comprehensive means have a much more enduring and strong impact if compared with the conventional ex-cathedra methods of teaching and this is the reason that makes them preferred by lecturers and students.

7.2. It is advisable the implementation of animations to be enlarged in the process of presentation of the complex matter of the subject of Design of Machine Elements and General Machine Design and the corresponding acquired knowledge will always be at the disposal of the future designers at the back of their mind.

7.3. The elaboration of training aids of the type of an Almanac of Machine Elements by enlarged teams of authors and the exchange of the achievements in that field can result in a much higher level of acquiring the complex knowledge of this matter. Further co-work of teams of different university may have a wholesome impact to the process of implementation of comprehensive means in General Machine Design.

REFERENCES

[1] NENOV P., ANGELOVA E., DOBREVA A., DOBREV V. Design of Machine Elements (with Almanac), Ruse, UR, 2010 (bulg)

[2]NENOV P., ANGELOVA A., DIYULGERIAN T. Design of gear drives & speed reducers,Ruse, 2008(bulg)

[3] Manuals by Design of Machine Elements, included in the References of the Book, from pos.1(above) because the first version of the Almanac we discus is a part of it

CORRESPONDENCE

Peter NENOV, Prof. Ph.D.
University of Ruse
Faculty of Transport
Studentska 8
7017 Ruse, Bulgaria
pnenov@hotmail.com

Vyarka RONKOVA, Ph.D.
University of Ruse
Faculty of Transport
Studentska 8
7017 Ruse, Bulgaria
vronkova@uni-ruse.bg

Emilia ANGELOVA, Assoc.Prof. Ph.D.
University of Ruse
Faculty of Transport
Studentska 8
7017 Ruse, Bulgaria
ang@uni-ruse.bg

Trifon TRIFONOV, Assoc. Prof. Ph.D.
University of Ruse
Faculty of Transport
Studentska 8
7017 Ruse, Bulgaria
trifonow@uni-ruse.bg

ADRESS for CORESPONDECE, concerning:

- the interest in using this Almanac and our authors software for calculus and optimizing cylindrical gear drives in the teaching process of your University;
- the desire to participate in further developing of the Almanac, together with us

pnenov@gmail.com , ET „EDITA DESIGN",

The study was supported by contract № BG051PO001-3.3.04/28, "Support for the Scientific Staff Development in the Field of Engineering Research and Innovation". The project is funded with support from the Operational Programme "Human Resources Development" 2007-2013, financed by the European Social Fund of the European Union.