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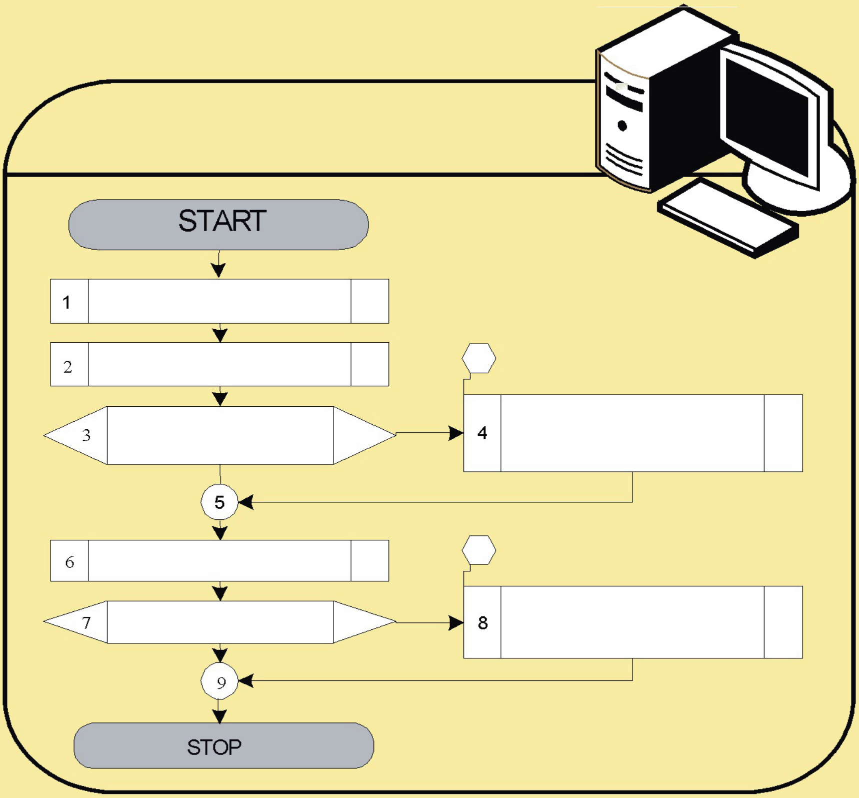

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injection molding, warpage, anchor plane

Ivan GAJDOŠ[*], Tomasz JACHOWICZ[**], Ján SLOTA[***], Volodymyr KRASYNSKYI[****]

INTERPRETATION OF WARPAGE SIMULATION RESULTS IN ASMI

Abstract

The article describes the problematic of interpretation of warpage simulation results in Autodesk Simulation Moldflow Insight. Warpage results are relatively easy to obtain from injection molding analysis, but the result interpretation demands higher skilled user. For detailed warpage evaluation based on specific dimensions is application of anchor plane necessary. Theory of anchor plane creation is described and anchor planes were applied for inspection of critical dimension on molding "terminal box".

1. INTRODUCTION

It would be difficult to imagine the modern world without injection molded plastics products. Today, plastics are an integral part of everyone's life. Properties of the plastic materials such as high strength to weight ratio, the volume to price ratio, corrosion resistance, ease and speed of production have resulted in an ever-increasing use of them. Nowadays, in new part designs, plastics are used not only as a material for producing parts but also as alternative to metal materials [1].

The design of molded plastic parts as well as design of molds for plastic injection processes is comparatively complicated process. It is needs takes into the account costs, production time, part design, ergonomic and aesthetic requirements. The part development process includes conceptual design – CAD model, engineering analysis, process simulation, manufacturing of prototype and testing [1, 2].

[*] Technical University of Košice, Faculty of Mechanical Engineering, Institute of Technologies and Management, Mäsiarska 74 Str., 04001 Košice, Slovakia, ivan.gajdos@tuke.sk
[**] Lublin University of Technology, Faculty of Mechanical Engineering, Department of Polymer Processing, Nadbystrzycka 36 Str., 20618 Lublin, Poland, t.jachowicz@pollub.pl
[***] Technical University of Košice, Faculty of Mechanical Engineering, Institute of Technologies and Management, Mäsiarska 74 Str., 04001 Košice, Slovakia, jan.slota@tuke.sk
[****] Lviv Polytechnic National University, Department of Chemical Technology of Plastics, S. Bandery 12 Str., 79013 Lviv, Ukraine, vkrasinsky82@gmail.com

The utilization of CAE methods allows through simulation to speed up the mold design process and the injection molding process optimization. Research in plastic injection molding area has brought a many scientific papers with the aim to improving optimization algorithms of mold design [3].

Injection molding with its excellent dimensional tolerance is one of the most common methods in mass production of plastic parts. Generally, injection molded products do not need any finishing or secondary operations [1]. This process consists of four stages that include melting, injection, holding and cooling [2]. Process parameters, plastic material properties and product design criteria are the critical factors in determining the final product quality.

1.1. Utilization of CAE technologies in process of molded part development

Nowadays technical drawing of injection molded part is not sufficient to describe complex shapes in 2D drawing. Reason for using 3D CAD model are wide opportunities to exact describe shape of part, easy making of cut views and detail views. More important reason to use 3D CAD model is direct import into CAE process simulation of injection molding and mold manufacturing with CAM software. Using 3D CAD model for CAM software has become integral part of mold manufacturing. CAE process simulation of injection molding is becoming stepwise integral part of mold manufacturing process.

With help of CAE simulation mold designer can test various construction solution of injection mold without need cost a time consuming mold corrections [6, 7]. Whole process of integration CAE simulation in this process can be described as shows on Fig. 1.

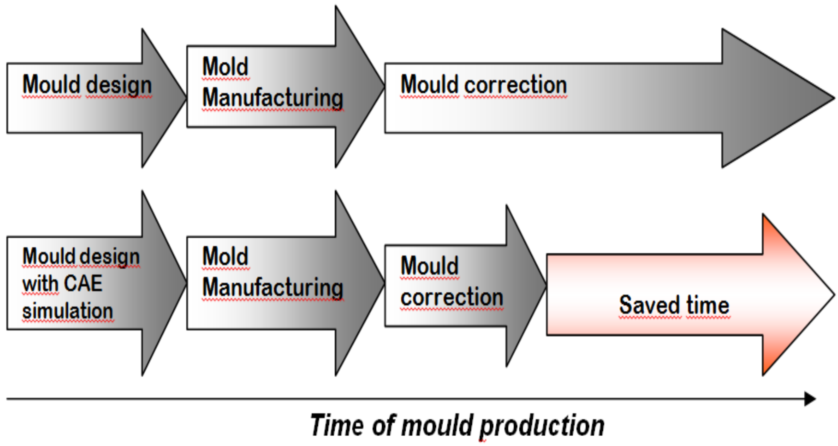

Fig. 1. Time dependence of CAE simulation integration in mould production process [source: own study]

2. WARPAGE OF INJECTION MOLDED PARTS

Warpage of the molded plastic parts is one of the most important problems occurring on final injection molded part. Warped parts may not be functional, visually acceptable or fit into assembly. Different shear rate profiles, cooling profiles and packing pressure history along the cross-section of part cause differences in orientation, density and these phenomena affect the shrinkage. Therefore, there will be variation in shrinkage in the part. Imbalance of shrinkage in any section of a part will produce a net force that could warp it. The stiffness of the part and the shrinkage imbalance level determine the warpage amount. If the part is too stiff to allow deflection, residual stresses will be created in the part that may cause problems later in its life [1]. If the shrinkage of a material is completely isotropic with respect to thickness, flow direction and distance, and packing pressure plastic parts will not warp. Asymmetric shrinkage and unequal contraction in the different directions cause warpage. When considering the contributors to warpage, it is convenient to identify shrinkage due to:

- variation in shrinkage from region to region (differential shrinkage), as shown Fig. 2,
- temperature differences from one side of the mold to the other (differential cooling) – Fig. 3,
- variations in the magnitude of shrinkage in directions parallel and perpendicular to the material orientation direction (orientation effects), as shown Fig. 4.

The Fig. 2 (left) shows a thin rib attached to a thick top. In general, the cooling rate of the top will be lower than that of the thin section. The top will have increased crystalline content and therefore, will shrink more and cause the warpage shown.

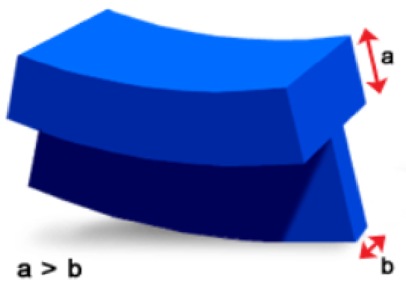

Fig. 2. Warping of molding due differential shrinkage [4]

Figure 2 (right) (a) shows saddle warping of a centrally gated disk with high shrinkage at the center. Conversely, if the shrinkage is higher around the outer part of the disk, the resulting warpage may cause the disk to dome, shown in (b).

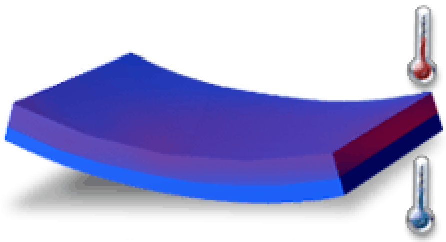

Fig. 3. Warping of molding due differential cooling [4]

Shrinkage due to differential temperature typically results in bowing of the component, as shown in the figure below. Usually this type of shrinkage is due to poor cooling system design. While the part is in the mold, temperature differences from one side of the mold to the other cause variations in shrinkage through the thickness of the component. In addition to this, any temperature differences at ejection will cause further warpage as both sides of the part cool to room temperature.

Orientation causes variation in the magnitude of shrinkage in directions parallel and perpendicular to the material orientation direction [5]. This type of shrinkage can produce warpage similar to that of differential shrinkage. Figure (a) below shows the warpage when parallel shrinkage is greater than perpendicular shrinkage. On the other hand doming can be produced if the perpendicular shrinkage is higher than parallel shrinkage, see (b).

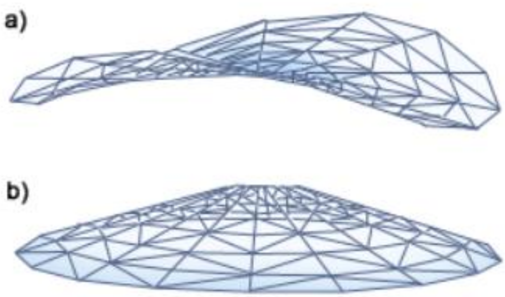

Fig. 4. Warping of molding due orientation effect [4]

Each of these types of shrinkage will contribute to the total warpage of the product. Moreover, process parameters such as melt temperature and holding pressure have an effect on the rate of shrinkage in the different directions [5, 6].

Thus, different melt temperature and holding pressure will affect the warpage amount of the part. Non-uniform shrinkage in different directions could be determined using the material pressure-volume-temperature (pVT) relation diagrams [4].

2.1. Warpage simulation in CAE

Warpage analysis of injection molded part is available in all major CAE simulation software for injection molding process. Autodesk Simulation Moldflow Insight (ASMI) is capable to perform warpage with all three types of FEM mesh (midplane, Dual Domain, 3D) used in this product to simulate injection molding process. Default displaying of molding warpage is visualized with "best fit" technique, where the mutual position of original model and deformed part is aligned in the sense of minimal difference between original and warped positon of all (or selected) nodes as presented in Fig. 5.

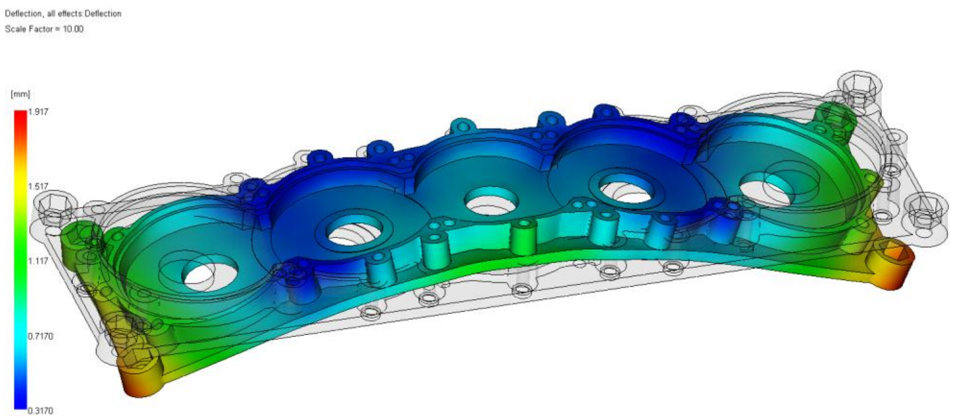

Fig. 5. Visualization of molding warpage (10x magnified) [source: own study]

Using of "best fit" technique for warpage visualization is preferable in early stages of product development, where is important to obtain visual behavior of molding warpage to identify problem areas. The designer can fast identify the changes in warpage when a change in design or molding condition is made [7].

When evaluating if the molding meets the dimension requirements specified in production drawing is using of "best fit" technique very problematic if not even impossible. In case when evaluating of specific dimension is necessary application of anchor planes.

2.2. Anchor planes

After a Warp analysis has been run, a reference plane against which warpage will be measured must be defined. This is the anchor plane, which is defined by three points called anchor points being selected on an undistorted part. Position of the anchor plane has to be performed carefully and each evaluating each dimension necessitates an individual anchor plane. Critical is the location of anchor plane, mostly across a flat part section where is easy to visualize the deflections, where the implications of the deflections can be most clearly interpreted and where the specific dimension values readout. The possible locations for an anchor plane include the: base of a part that is required to lie flat on a surface, the joining plane to a mating component.

The anchor plane is defined by selecting three locations (nodes) on the part. This plane is used to measure the deflections, and the sequence in which the anchor points are defined is important as this affects the warpage results. The anchor points do not have to be on the corners of the part. Typically they are placed at fixing points of the finished assembly, or along edges where two parts meet.

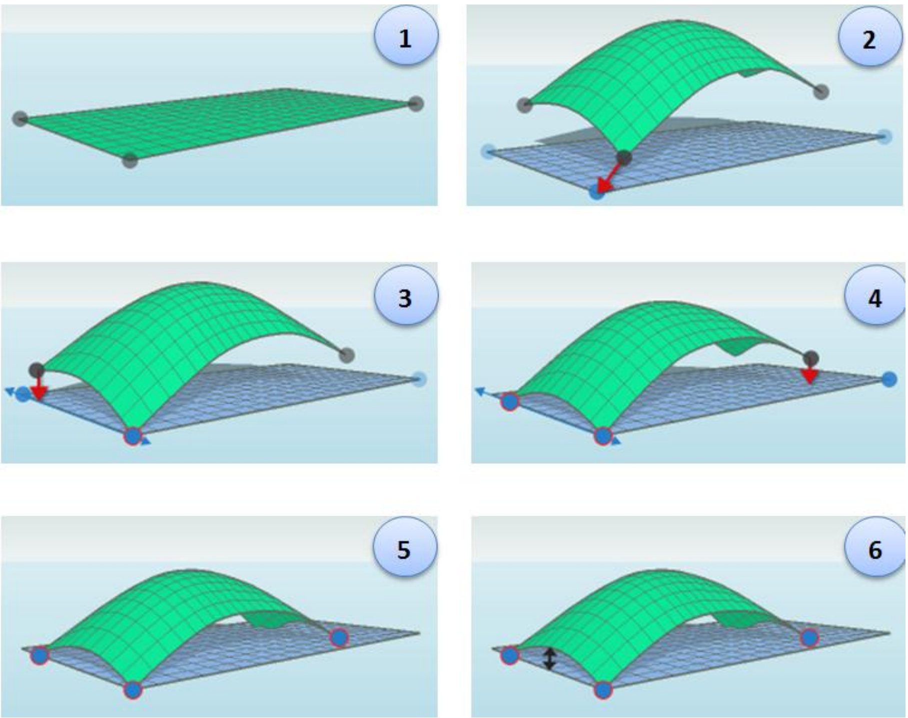

Fig. 6. Defining of anchor plane (1–5) and measurement of displacement from undistorted geometry [4]

Setting up an anchor plane is presented on Figure 6 (steps 2–4). Three anchor points set on an undistorted part (Fig. 6–1). The distorted part must be oriented in relation to this plane for measurement. The first anchor point defined is the front center point (Fig. 6–2). The corresponding point on the part to be measured must always align with this anchor point. The second anchor point defines a line from the first anchor point (Fig. 6–3). The corresponding second point on the part to be measured must be placed along this line while still maintaining the positioning of the first anchor point. The third anchor point defines the anchor plane.

The third point on the part to be measured is now placed on this plane while maintaining the position of the first two anchor points (Fig. 6–4). The part is now oriented correctly in relation to the anchor plane. The distance from the anchor plane to the part is now a repeatable measurement of the warpage (Fig. 6–6).

3. EVALUATION OF PART WARPAGE

Evaluation of part warpage using an anchor plane is presented on simulation result for molding "terminal box" (Fig. 8), made of Latamid 66 H2 G/25-V0CT1. On the drawing are specified critically dimensions that must be maintained if the molding has to meet the quality criteria.

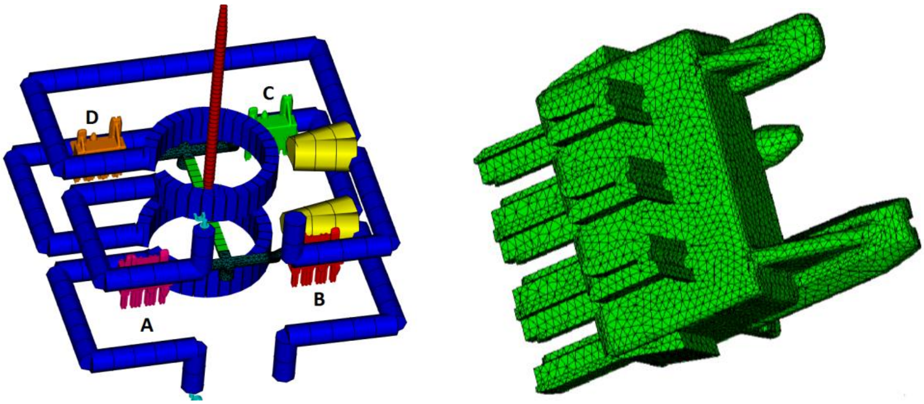

Fig. 7. FEM mesh for injection molding simulation of "terminal box" in 4-cavity mold [source: own study]

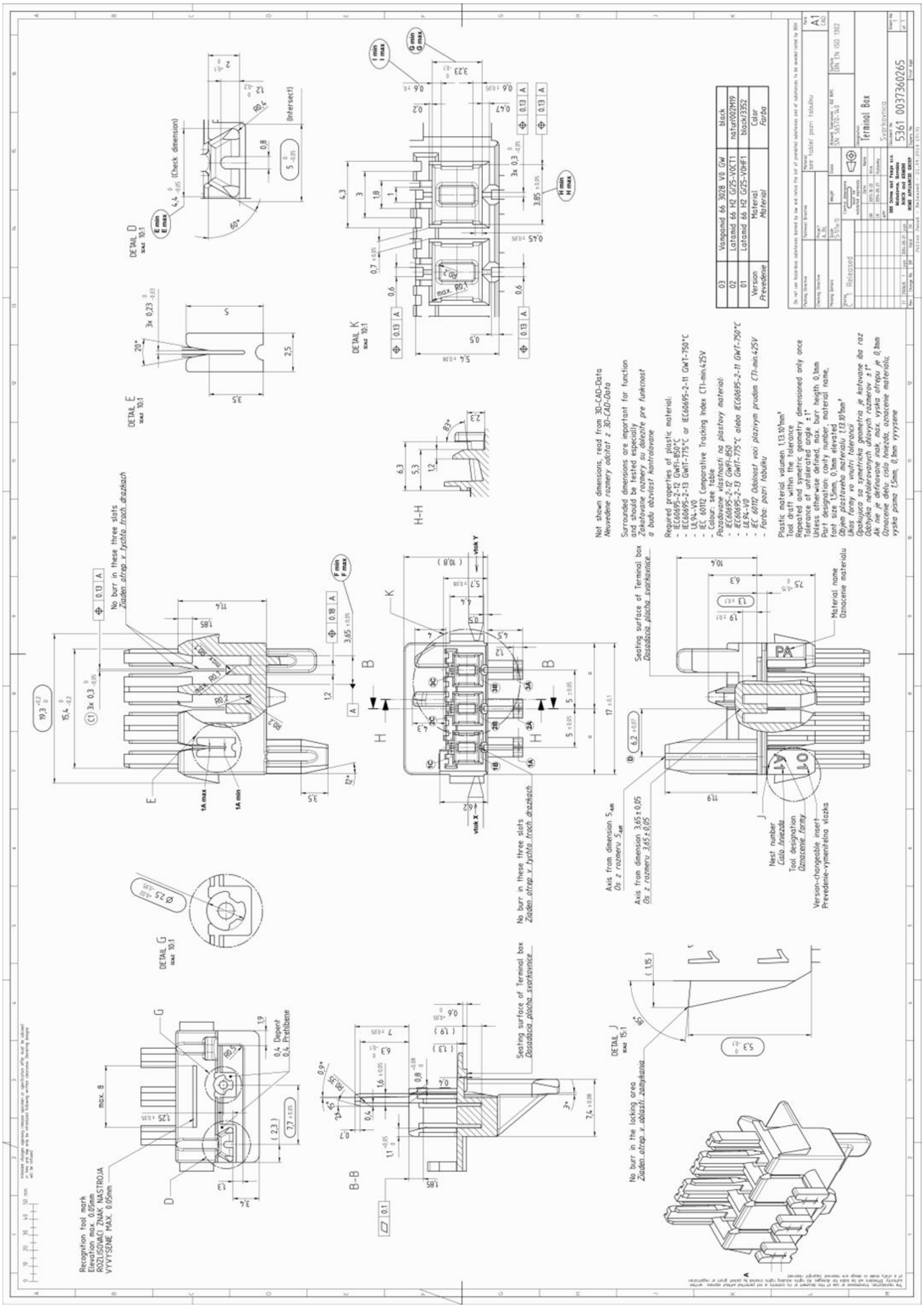

Fig. 8. Production drawing for molding "terminal box" [source: own study]

Molding is injection molded in four cavity mold. For this mold was a 3D mesh prepared, with 1552000 elements (including runner system, cooling lines and mold block (Fig. 7). Each cavity was marked with letter according to figure 8, to easily identify differences in warpage between molding from different cavities. Issue when defining the anchor planes in multi-cavity mold, is to pick-up always the same three corresponding nodes on each cavity when evaluating the same dimension. It has to be noticed that the gating location was not the same for all four cavities. Cavity A and C have the same gating location, that differs from gating location for cavities B and D (B and D same gating location). Injection molding conditions were chosen as default for this material. Injection time and packing profile was set as "automatic".

3.1. Warpage of specific dimension

To present application of anchor plane when evaluating molding warpage a dimension on the part was selected from "Detail D" 4,4 $_{-0,05}$ mm, Fig. 9 (left). Using anchor planes in ASMI has some limitations. Anchor plane is not suitable for evaluating dimensions from cylindrical sections (Fig. 9 – "Detail G") and the anchor plane must be placed on molding nodes, so is not possible to place anchor plane on virtual construction axis (Fig. 9 – right).

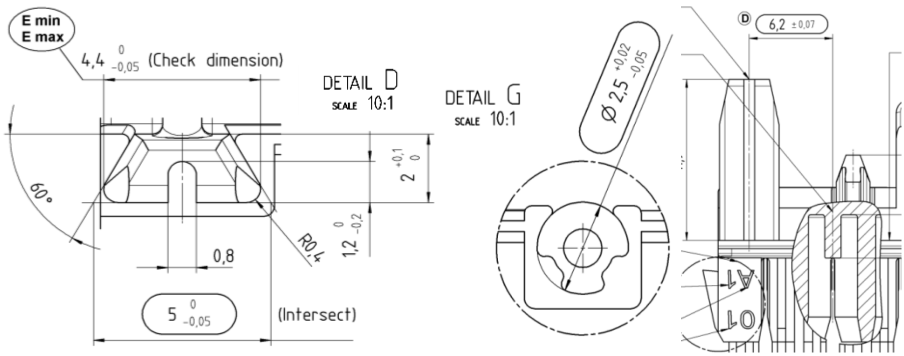

Fig. 9. Inspected dimension on "terminal box" molding (left) and dimensions where the anchor plane is not applicable [source: own study]

For the specified dimension were created anchor planes on the side of the slider. The distortion of the nodes on the opposite side was calculated. Results are presented in Fig. 10. Best result for this evaluated dimension was obtained in cavity D. Three nodes representing the anchor plane are shown as grey spheres.

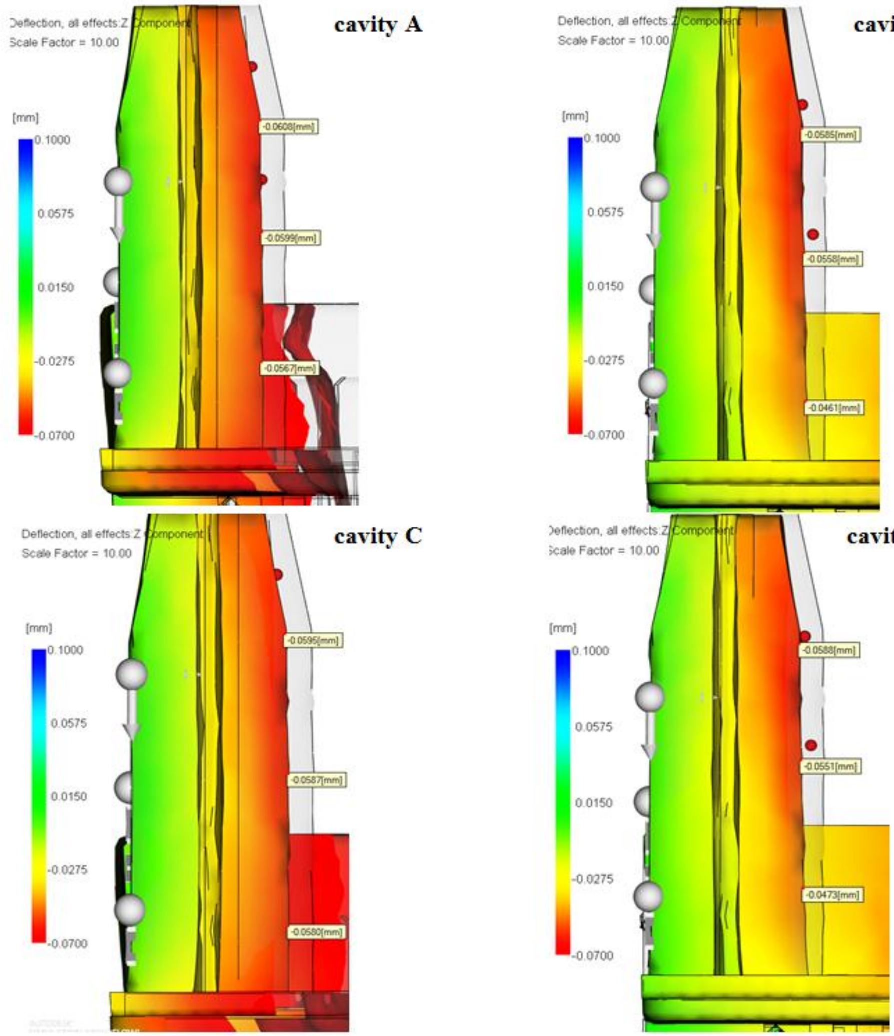

Fig. 10. Distortion of slider side regarding to anchor plane (visualization 10x magnified) [source: own study]

It is obvious from the figure 10, that the gating position (same for cavity B-D and vice-versa) has influence on the distortion value and final warpage.

4. CONCLUSIONS

The injection process is one of the most important methods of polymer processing, so he became the subject of a comprehensive analysis using specialized engineering software CAD/CAM/CAE. The simulation of the temperature distribution and polymer flow in the channels and the cavity mold and cooling conditions affecting the change in the size, shape and deformation of an injection molding part is essential both to modify the same compact structure and proper design of the mold, which is one of the most expensive processing tools. The ability to analyze the injection molding process in the form of the computer simulation allows to optimize the process parameters, the geometric features of an injection molding part with injection mold and the best selection of materials and processing equipment having suitable properties (e.g. volume and weight of the injected polymer, injection pressure, clamping force closing of the mold). The results of the simulation of the injection molding process is influenced by many factors, including detailed description of material properties, accuracy of models, molds and runner system, and the type and characteristics of the mathematical model describing the phenomenon subjected to simulation.

In this paper a problematic of warpage evaluation was described. Evaluation of molding warpage with “best fit” technique is relatively easy and does not place great demands on the skills of Autodesk Simulation Moldflow Insight (ASMI) users. However if there is a need to check the warpage results for exact inspected dimensions the anchor plane must be used. Defining an anchor plane expect Autodesk Simulation Moldflow Insight (ASMI) user with higher skill level. On the sample of “terminal box” molding was a warpage of inspected dimension evaluated.

Acknowledgement

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tricycle, brake disc, mass optimizing

Patryk SOKOŁOWSKI[*], *Paweł MAGRYTA*[**]

MASS OPTIMIZING OF THE BRAKE DISCTOLIGHTTRICYCLE

Abstract

The article presents an optimization process of the brake disc in terms of mass and strength resistance. A model of the disc was made using three-dimensional software – Catia V5 (CAD). Model has been subjected to the parameterization process for the strength calculations. A brake disc was fixed at the location of the mounting screws and subjected to torque resulting from the braking process. As a result of calculations, a set of parameters that meet the established boundary conditions was obtained as shown in the article.

1. INTRODUCTION

Shell Eco Marathon competitions are organized regularly since1985 [1]. The best technical university students from around the world take part in them. Competition is to build a vehicle that will be characterized by a very low energy consumption. The competition Shell Eco Marathon Europe 2015 is to overcome 10 laps of the track, that is specially built for this purpose. The track is located on the streets of Rotterdam, with a total length of the entire distance equal to slightly more than 16km. This distance must be overcome in less than 39 minutes [2]. It is worth mentioning, that it is possible to start in two classes of body styles and several classes of power supply such as diesel, petrol, electric or fuel cell. The vehicle, which consumes the least energy during the trip is the winner in one of the class.

Hydrogreen Pollub [3] as one of two teams from the Lublin University of Technology is involved in the construction of a light vehicle for the Shell Eco Marathon competition. Vehicle design is based on the concept of tricycle

[*] Lublin University of Technology, Faculty of Mechanical Engineering,
Department of Thermodynamics, Fluid Mechanics and Aviation Propulsion Systems,
Lublin 20-618, Nadbystrzycka 36, p.sokolowski@pollub.pl
[**] Lublin University of Technology, Faculty of Mechanical Engineering,
Department of Thermodynamics, Fluid Mechanics and Aviation Propulsion Systems,
Lublin 20-618, Nadbystrzycka 36 r. 605a, p.magryta@pollub.pl

with two front steering wheels and one rear wheel drive. Figure 1 shows the initial sketches of the vehicle shape and solid models created using three-dimensional printing technique. In order to succeed in competition, the work was focused not only on optimizing the shape of the vehicle [4], but also every aspect of the configuration and all the mechanical components of the vehicle. This publication focuses on the optimization of the mass [5] of the brake disc with achieving adequate, sufficient mechanical properties of this part.

Fig. 1. 3D printed, conceptual models of hydros [source: own study]

This project was mainly made by students from students research circle "Aviation Propulsion Systems". This organization is an academic organization that belongs to the Department of Thermodynamics, Fluid Mechanics and Aviation Propulsion Systems [6], what allows students belonging to this organization to have the opportunity to use all the tools available in the Department. During the design process of the vehicle, CAD software Dassault Systems – CatiaV5 was used, what allows to make fine-tune solutions to the smallest detail. In the case of geometry optimization of brake disc, Part Design, Generative Structural Analysis and Product Engineering Optimizer modules were used. This article focuses on showing the possibility of a geometric model parameterization process and linked of parametric geometric model with an iterative strength analysis carried out by using Finite Element Method (FEM).

Parameterization setting in Catia V5 software allows to describe the geometric model with the different parameters and equations (Formula) [7] in order to easily modify the model, preparation or use of the model parameters to optimize the geometry. In figure 2 the exemplary view including the optimization tools is shown. If the model will be prepare in adequate way, it will be also possible to build auto generative models, those which are able to intelligently adapt to a pre-existing model geometry.

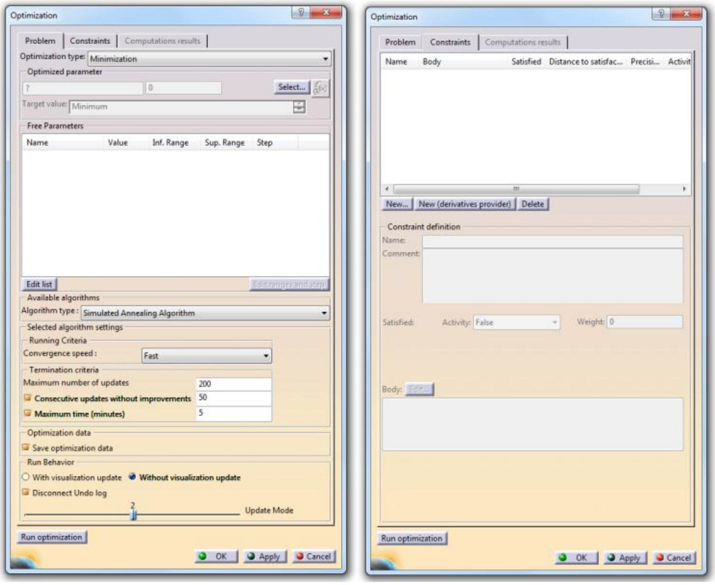

Fig. 2. Dialog boxes from optimization tools in Catia V5 [source: own study]

2. RESEARCH OBJECT

Standard bicycle brake discs of diameter 160 mm, although it meets the strength requirements, at the same time its mass is usually above 0.1 kg. Alligator Windcutter 160 mm brake discs (fig. 3) with a weight of 0.092 kg was acquired, thanks to the cooperation with the bike shop MetroBikes.pl. But during the meetings of the team, it was decided that new brakes discs, which will be at least about 30% lighter than original will be design.

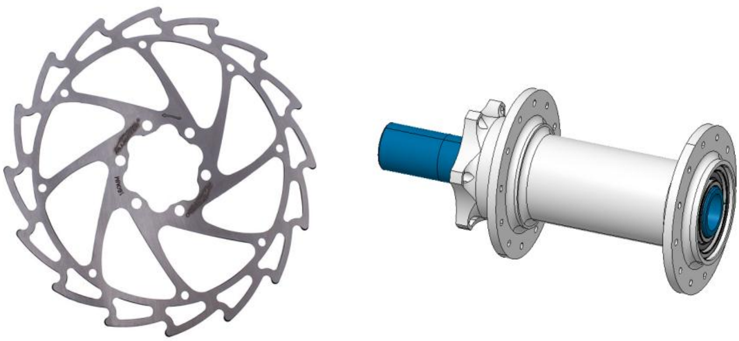

Fig. 3. Alligator Windcutter brake discs and wheel hubs designed by a team of Hydrogreen Pollub [source: own study]

The second purpose to start work on lighter brake discs, were hubs designed by our team (fig. 3), which due to the small size, had changed diameter of brake discs mounting bolts spacing compared to standardized bicycle wheels – from 44 mm to 34 mm.

3. BOUNDARY CONDITIONS OF SIMULATION

The tested brake disc was initially designed in the Catia V5, in Part Design module as part of a solid with a predefined arms distribution and pre-imposed outer diameter, width of the friction surface and bolts spacing distance. In the optimization process, parameters such as arm radius, arm thickness, arm angle, diameter and thickness of the stiffener ring, radius 1 (R1), radius 2 (R2) were taken into account (fig. 4).

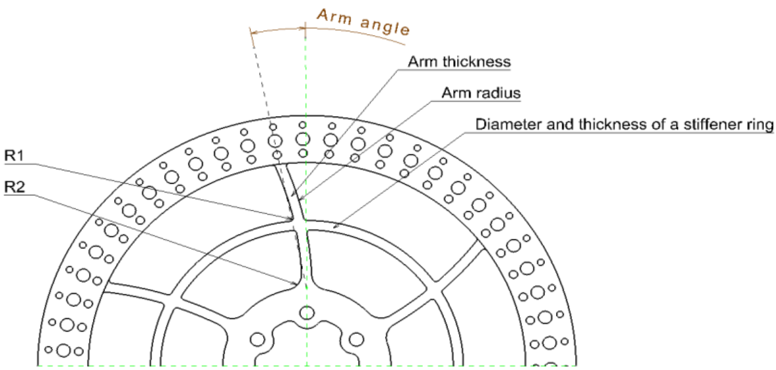

Fig. 4. Description of the parameters on the projection of the 3D model [source: own study]

Thus prepared parametric 3D model was opened in the environment (Workbench) Generative Structural Analysis, where the boundary conditions and load for a preliminary analysis of FEM were given. The holes of the brake disc were virtually connected to each other by means of a Rigid Virtual Parts (fig. 5). Brake disc was fixed in place with a clamp bonds (fig. 6), receiving all degrees of freedom.

Only the torque acting on the brake disc was introduced in the model. In this optimization process, the effects of the axial forces for a brake disc, and thus buckling analysis of the brake disc were not performed. While the value of the torque that has been given to the proposed friction surfaces of the brake disc [8] was calculated from the analysis and design principles that have been adopted.

$$M_s = (F_n \cdot \mu) \cdot [9], \tag{1}$$

where: F_n – force acting on ground,
μ – friction coefficient rubber – asphalt,
R – wheel radius.

$$M_s = (882{,}9 \cdot 0{,}9) \cdot 0{,}239 = 190\ Nm \tag{2}$$

Vehicle with driver weighs about 90 kg, which gives 882.9 N force which acts on the surface by the tire footprint. Multiplying this force by the coefficient of friction for rubber and asphalt equal to 0.9 F_t = 794.61 N is obtain. While stopping the vehicle, the torque equal to 190 Nm (the force F_t multiply by the radius of the tires fitted to the vehicle R = 0.239 m) is acting on the main axle. As a result, there is no need to stop the vehicle by using only one brake (due to the nature of driving during the competition), the torque was divided into individual wheels. It was assumed that 65% of the vehicle mass is acting on the front axle of the vehicle, and therefore, there are two front wheels, so the torque was divided into two. It turned out that the front wheel brake will operate in succession torque 64 Nm [9]. But because of security reasons, the resulting torque has been multiplied by a safety factor x_B = 1.2. Safety factor was obtained to have 20% more strength than needed because of the dynamics load occurred during braking onto rough surface. Finally a load value of the brake disc torque was equal 75 Nm (fig. 7).

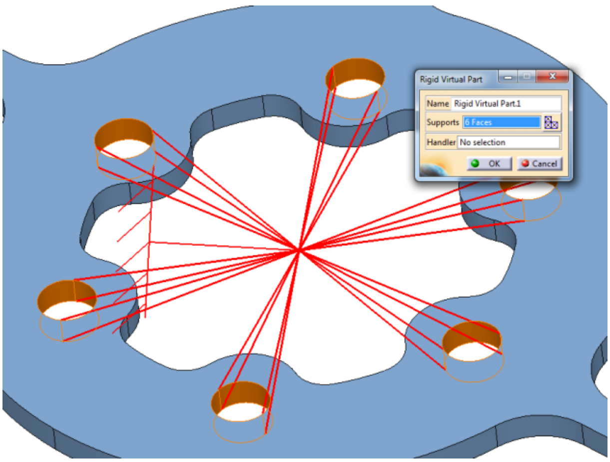

Fig. 5. Binding type of Rigid Virtual Part assigned to the mounting holes [source: own study]

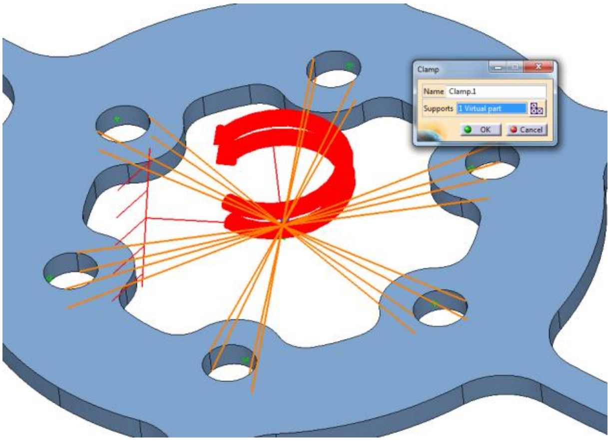

Fig. 6. Fixing of holes in brake disc [source: own study]

After preparing the FEM simulation model new optimization model was developed in Product Engineering Optimizer environment. With this module it is possible to carry out design optimization using several algorithms adapted for this optimization [10]. Constraints for the parameters and boundary conditions have the ability to transmit the conditions criteria (fig. 8).

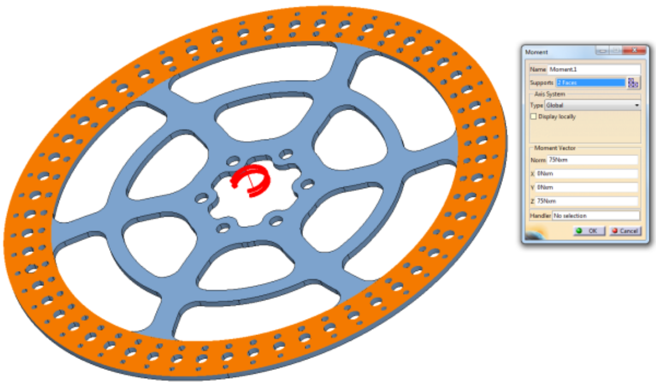

Fig. 7. Load torque of the brake disc [source: own study]

During the simulation the Simulated Annealing Algorithm [11] was used, this is the default algorithm, which operation is based on stochastic search for a set of solutions to meet the job criteria. Optimization process has been set as the minimization. In this way, the process will focus on minimizing the mass having assigned to the function limitation.

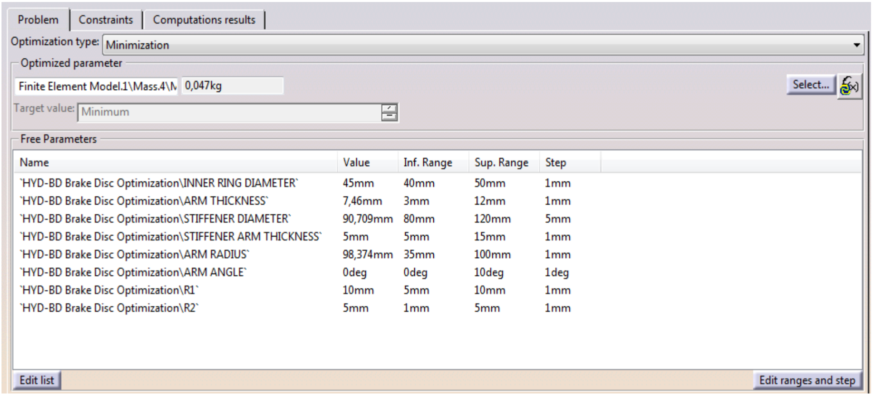

Fig. 8. Parameters and their limitations selected for optimization [source: own study]

After selecting parameters to optimize process, parameters and the imposition of restrictions and iteration with which parameters have to change were created. Additional restrictions on the strength of the structure were also assumed. The maximum von Mises equivalent stresses shall not exceed in the whole model 230 MPa and maximum deformation cannot exceed 0.05 mm.

Tab. 1. The material properties used in the calculation

Young Modulus	70 000 MPa
Poisson Ratio	0.346
Density	2710 kg/m^3
Thermal Expansion	2.36*10^{-6} K^{-1}
Yield Strength	95 MPa

Limitations associated with the maximum stresses are directly related to the material from which the brake discs are made, it is the aluminum alloy 2017A. Thus, the maximum stress in the brake disc with the given boundary conditions cannot exceed the Yield Strength of the material. In Catia V5 software, there is a default library of materials that can be used for numerical analysis. Aluminum material from the library materials without modifying the material properties was used (tab.1).

Tab. 2. Optimization algorithm setting

Algorithm type	Simulated annealing Algorithm
Running Criteria	Medium
Maximum number of updates	100
Consecutive updates without improvements	20
Maximum time (minutes)	60

The optimization algorithm setting are shown in table 2. The maximum time in which the process proceeded, was set to 60 minutes, consecutive updates without improvements to 20 and the maximum number of updates 100. Also the process of data registering that will be generated at the time of analysis was enable.

4. RESULTS

During the iterative optimization of the brake disc geometry, program is changing a set of variable and makes the strength analysis by checking whether the geometry of the model that was created satisfy two strength conditions. During the entire optimization process, 27 iterations were performed. Each of iteration result has been saved in a spread sheet and using the MS Excel it was possible to compare each of the steps. For the purposes of publication, six iterations were choose.

Figure 9 shows the results of simulation of the selected iteration, generated during the optimization process. Results are in the range of 0 to 230 MPa, in order to visualize the iterations in which the maximum stresses exceed the maximum allowable stress resulting from the boundary conditions of analysis. It can be seen that the iteration 0 and 25 have very low mass (respectively 0.047 kg and 0.05 kg), however, for those iterations assumptions concerning strength have not been met. In both iterations, the maximum equivalent stresses were about 1000 MPa, which is several times more than the allowable stress.

In the iteration 11, 17, 23 and 26 boundary conditions for the maximum stress and strain were met. In figure 9, presented iterations have slightly different stress distribution for each of them. The mass of the disc between each iteration is slightly different, the maximum difference is about 0.0014 kg between 26 and 23 iteration. Although the differences between the generated discs in the case of both the mass and stress distribution are hardly visible, but in the case of the disc geometric representation, the differences of these iterations are clearly visible (fig. 12).

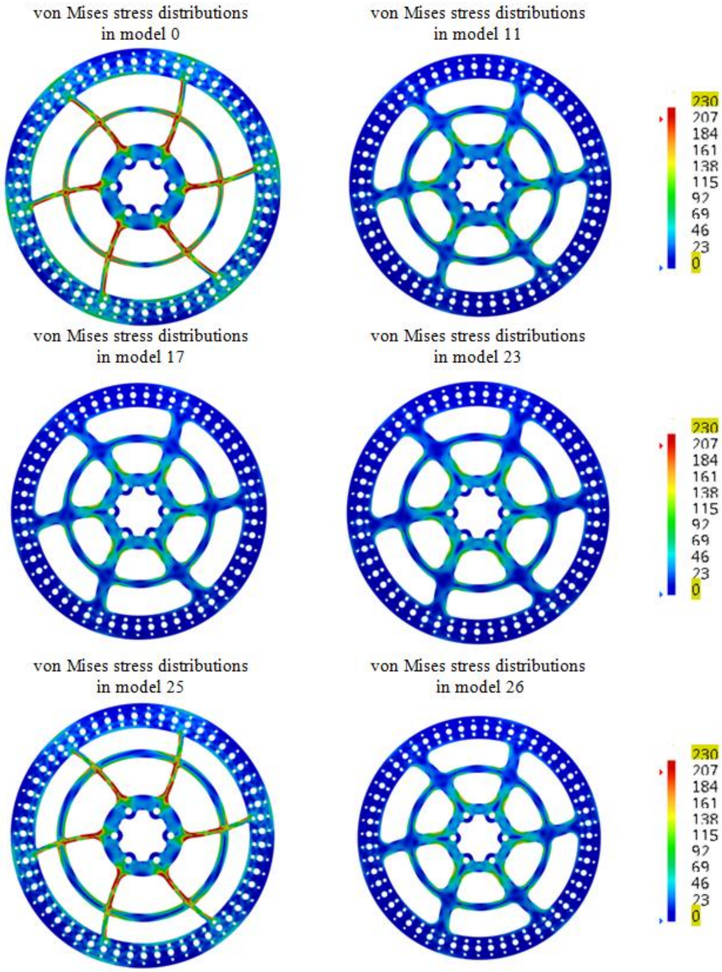

Fig. 9. Summary of simulation results – von Mises stress distributions [source: own study]

Referring intermediate iterations to the final model (model 26) it can be seen that the differences in radius and other geometric parameters are greatly. Significant variations in the diameter of the stiffener ring parameter can be seen in the figure 10. The differences of the other parameters in each iteration are shown in figure 10 and 11.

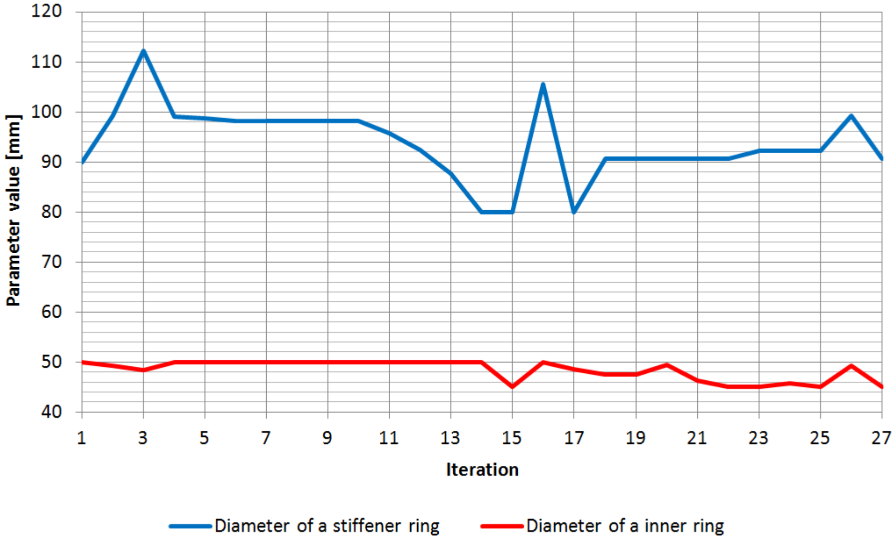

Fig. 10. Differences in diameter of a stiffener ring and inner ring [source: own study]

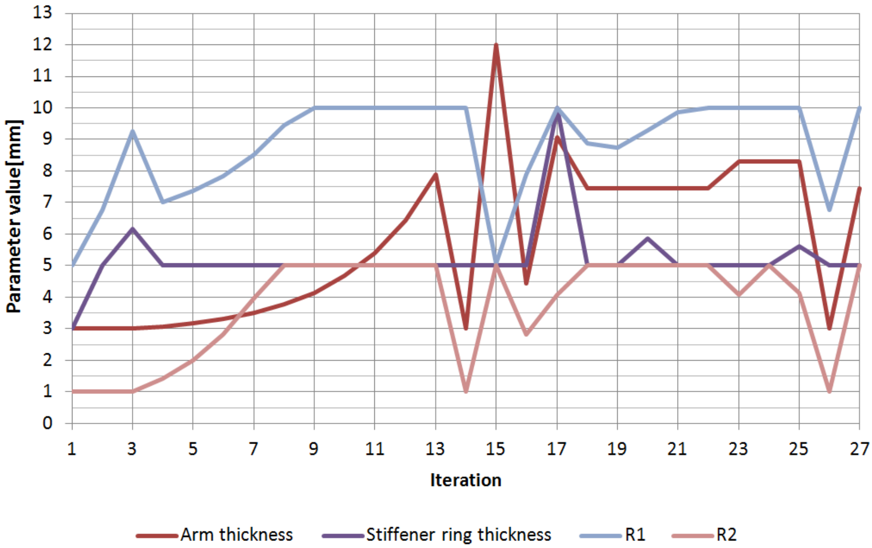

Fig. 11. Differences in other parameters [source: own study]

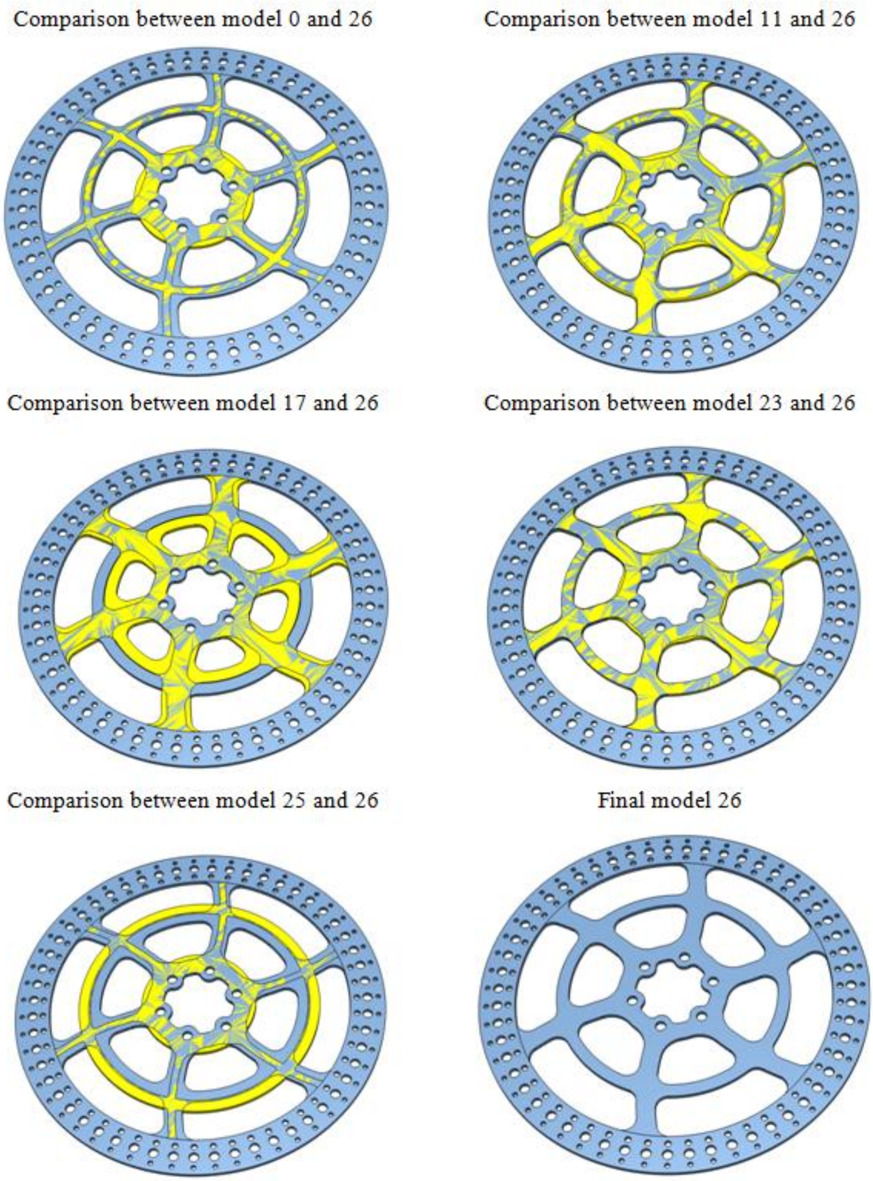

Fig. 12. Summary of simulation results – geometric comparison of the brake disc, yellow color – present model, blue color – final model [source: own study]

5. SUMMARY

As a result of the optimization process, it was possible to meet all the initial design intent. It was possible to get the brake disc mass equal to 0.0549 kg, which means that in comparison to a standard bicycle disc, new disc has about 40% less mass. It was also shown that in the Catia V5 software, iterative process of the optimization is possible. It is possible to prepare the simulation using the parameterization of the model, strength analysis and optimization module. This kind of optimization process can be used in the future for reducing the mass of others mechanical components of the tricycle.

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grammatically augmented ontology, language processing, machine translation, grammatical analysis

Maksym DAVYDOV[*], *Olga LOZYNSKA*[**]

SPOKEN AND SIGN LANGUAGE PROCESSING USING GRAMMATICALLY AUGMENTED ONTOLOGY

Abstract

The mathematical model of grammatically augmented ontology was introduced to address this issue. This model was used for grammatical analysis of Ukrainian sentences. Domain specific language named GAODL for description of grammatically augmented ontology was developed. The grammar of the language was defined by means of Xtext extension for Eclipse. The developed language was used as an auxiliary part of the information technology for bidirectional Ukrainian sign language translation.

1. INTRODUCTION

The problem of developing a machine translation system for sign language has been studied by scientists for a long time [1]. The solution to this problem can provide new communication opportunities for people with hearing impairments. The challenge of translation from Ukrainian sign language (UKL) to Ukrainian Spoken language (UKR) refers to tasks of machine translation.

One of the problems that arises when translating from one language to another is the problem of word sense disambiguation (WSD), i.e. the selection of one of possible meanings of a word listed in linguistic resources. The fuzziness of the problem suggests that there is no exact solution, but there are numerous heuristic methods developed to tackle it: methods of learning with and without a teacher [2], knowledge based methods [3], etc. Despite this, the problem of word sense disambiguation is not completely solved yet, because the solution of this problem requires structuring of human knowledge in different subject areas for each of the target languages.

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[*] Information Systems and Networks Department, Lviv Polytechnic National University, S. Bandery Str., 12, Lviv, 79013, UKRAINE, +38 (032) 258 26 38, maks.davydov@gmail.com
[**] Information Systems and Networks Department, Lviv Polytechnic National University, S. Bandery Str., 12, Lviv, 79013, UKRAINE, +38 (032) 258 26 38, kanmirg@gmail.com

For a long time a source of knowledge for translation systems were glossaries and bilingual dictionaries [4]. Later ontological dictionaries replaced glossaries, because glossaries were not complete and lacked special structure for expressing semantic relationships between words and concepts [2]. Modern ontological dictionaries contain lexical and semantical information: antonyms, synonyms, relative words, nominalization, hypernymy and meronymy relations, etc. This information is used to decrease word ambiguity in different ways. However, the ontological vocabularies do not describe language constructions (predicates, templates) for expressing semantic relations between words. Thus, more detailed models and dictionaries are required for better language processing and translation.

The article describes a new model of grammatically augmented ontology (GAO), as well as examples of its usage for syntactic and semantic analysis of Ukrainian sentences. The work is a part of a larger project conducted by authors to tackle bidirectional Ukrainian sign language translation problem.

The article consists of problem statement, analysis of related work, description of GAO mathematical model and GAODL language, sentence parsing results and discussion.

2. PROBLEM STATEMENT

Extending ontologies with grammatical information is a task that requires analysis of possible language constructions or "templates" that are used to develop a discourse. The knowledge of these "templates" can be used to generate better translation and to perform semantic and syntactic parsing.

During the development of UKL translation system the following information was proved to be important and thus was included into GAO:

1) synonymous grammatical constructions and their relationship to concepts or synsets;
2) grammatical attributes of words: which one can be freely changed across templates, which one should be consistent, and which one can't be changed at all.

The inclusion of grammatically augmented ontology into the machine translation system requires the development of tools for description of ontologies. The main problem of the research was to extend ontological dictionaries with a grammatical information in a way that is expressive, extendable, consistent, and friendly to users and applications. In order to solve this problem a mathematical model of GAO was developed. The developed model was used to support storage format for ontology dictionaries.

An approach based on domain specific language was utilized to describe the storage format. GAO description language (GAODL) was developed for this purpose. Xtext extension for Eclipse was used to develop GAODL rules and to create user-friendly editing environment based on Eclipse.

3. RELATED WORK

Ontologies are widely used today for structuring knowledge from different subject areas. They are useful for formal specification of concepts and relations between them. Ontologies can be used to describe a particular area of knowledge (domain ontology) or to develop common sense relationships (upper ontologies). The main advantage of ontologies is their formal structure that facilitates computer processing [5].

Well-known example of domain ontologies are Gene Ontology for the annotation of biomedical data [6], the Unified Medical Language System (UMLS) [7], ontology in the field of goods and services such as UNSPSC [8], etc.

Upper ontologies are widely used for research in the field of computer linguistics. Such ontologies include WordNet for English [9], plWordNet for Polish language [10], CWN (Chinese Wordnet) for Chinese [11], WOLF (WordNet Libre du Français) for the French language [12], MultiWordNet project for Italian language [13], BalkaNet project for six European languages (Bulgarian, Czech, Greek, Romanian, Turkish and Serbian) [14], GermaNet for the German language [15], IndoWordNet for Indian language [16], the project RussNet [17] for the Russian language.

WordNet it is one of the largest electronic database, organized in a semantic network, which consists of various relations between words that includes synonymy, antonymy and generalization.

In Ukraine an ontology similar to WordNet is being developed by scientists Kulchitsky I. M. and others [18]. For now scientists have developed a small fragment of Ukrainian common ontology, which consists of 194 synsets, related to each other by links of hypo-/hypernymy, antonymy, and in addition by connections of meronymy/holonymy.

The scientists of Taras Shevchenko National University of Kyiv developed Ukrainian ontological lexical-semantic knowledge base UkrWordNet (UWN) [19]. The project lasts for several years and it was successful in creation and filling of UWN database. Special tools were used to fill the database. At the moment, the ontology contains about 80,000 concepts.

Ontologies are widely used for word sense disambiguation. In article [3] scientists A. Romaniuk and others have investigated the problem of word sense disambiguation and have analyzed the main methods of its solution. It was revealed that the WordNet network can be successfully used for automatic disambiguation of word meaning, however no percentage of correctly disambiguated words was given.

Ontologies are often used in conjunction to statistical models for word sense disambiguation that take into account the frequency of word mutual occurrence in a particular context [2]. This approach can provide high-quality translation only when large training corpuses are used. Besides that this approach has an obvious limitation because of the combinatorial explosion.

Thus, an alternative approach is required in order to use ontologies for translation between languages that have no large bilingual corpuses. It was shown that the use of grammatical rules itself is not sufficient for WSD [20]. A better approach can be developed when using ontologies in conjunction to language grammar and common expression templates to disambiguate word meaning.

Modern software tools for building ontologies such as DOE (Differential Ontology Editor) [21], Ontolingua [22], OntoEdit [23], WebOnto [24], Protege [25] have no means for linking concepts to possible grammatical constructions were they can be used. As to the authors' best knowledge, there are no papers that describe models of ontologies supplemented by grammatical relations and expression templates.

4. MATHEMATICAL MODEL OF GRAMMATICALLY AUGMENTED ONTOLOGY

There are several alternative mathematical models of classic ontologies [26]. The mathematical model of ontology from article [27] was chosen as the basis of the developed grammatically augmented ontology. It is defined as a tuple $O = \langle L, C, F, R_c \rangle$, where $L = \{w_i\}$ is a vocabulary of a subject area, $C = \{c_i\}$ is a set of the subject area concepts, $F \subset L \times C$ – a relation between appropriate terms and concepts, R_c is a set of relations on concepts (hyponymy, hyperonymy, meronymy, holonymy, etc).

The introduced grammatically augmented ontology was defined as a tuple:

$$O_G = \langle O, P, E, T, R_p \rangle \tag{1}$$

where: O is an ontology,

$P = \{p_i\}$ is a set of predicates,

$E = \{e_i\}$ is a set of expressions, where each expression $e_i = ((w_1, g_1), (w_2, g_2), \ldots, (w_n, g_n))$ is a tuple of grammatically augmented ontology terms (w_i, g_i),

$T = \{t_j\}$ is a set of parametrized expressions, where $t_j = (e_j, f_j, p_j)$ is a triple of expression e_j, argument positioning function $f_j : \{1,2,...,Len(e_j)\} \to \{0,1,...,N(p_j)\}$, and a related predicate p_j. $Len(e_j)$ denotes the length of tuple e_j, $N(p_j)$ is the number of places of predicate p_j,

R_p is a relation that matches predicates to verb concepts.

For some predicate p_j and some expression e_j argument positioning function $f_j(k)$ was defined to be 0 for the term in position k of the expression e_j that can't be changed without breaking the expression relation to predicate p_j. The value $f(k) > 0$ means that appropriate term in position k represents an argument of the predicate with ordinal number $f(k)$, and it can be replaced with another term from the set of hyponyms of term w_k. If the related predicate has n places and for each $i \in \{1,2,...,n\}$ exists $k \in \{1,2,...,Len(e_j)\}$ such that $f(k) = i$ then expression e_j completely defines predicate p_j. Otherwise, some arguments of the predicate are considered to be undefined in the sentence. They can be either completely unknown or can be devised from the context of speech or from a situation.

The definition of grammatically augmented ontology provided the possibility to express links between concepts, predicates and means of their expression in the form of language constructions.

For example, the predicate $GIVE(a,b,c)$, where a is someone who gives, b is someone who obtains and c is something that is passed, can be expressed using expressions $e_1 =$ "(somebody) (give) (somebody) (something)" or $e_2 =$ "(somebody) (give) (something) (to somebody)" (or in Ukrainian $e_3 =$ "(хто) (давати) (кому) (що)"). Both statements completely define the predicate and their argument position functions are $f_1(1) = 1$, $f_1(2) = 0$, $f_1(3) = 2$, $f_1(4) = 3$, and $f_2(1) = 1$, $f_2(2) = 0$, $f_2(3) = 3$, $f_2(4) = 2$ (Ukrainian expression e_3 has argument positioning function $f_3(1) = 1$, $f_3(2) = 0$, $f_3(3) = 2$, $f_3(4) = 3$).

In spoken languages the grammatical forms of subject, object, predicate, and complement comply to certain grammatical rules. These rules in the grammatically augmented ontology are defined by grammatical attributes of the expression terms.

These grammatical attributes were divided into 3 groups:

1) attributes that can't be modified (for example, preposition and casus of a complement);
2) attributes that can be freely modified (usually, number and gender of an object);
3) attributes that should be matched (like person and number of a subject or predicate).

In the example above expression e_1 has two terms “somebody”. The first of them has a grammatical attribute of subject, and the second has an attribute of object. It means that person and number of the first “somebody” should be matched to person and number of the predicate, and number of the second “somebody” can be independently modified, that is the default behaviour for subject and objects. In the Ukrainian expression e_3 the first term should be in nominativus and should be matched in number, gender and person to the predicate. The third term should be in dativus and its number and gender can be freely modified.

5. LANGUAGE FOR DESCRIPTION OF GRAMMATICALLY AUGMENTED ONTOLOGY

The creation and use of the GAO requires the development of special means for its representation. The approach based on domain specific language (DSL) was chosen due to its good extensibility, portability and verificability [28]. The term DSL indicates a language, that is used to solve specific problems using terminology that is as close to the subject area as possible.

The DSL named GAODL was created to facilitate uniform editing and processing of grammatically augmented ontologies. These ontologies could be created for specific subject areas and lately merged to obtain upper ontologies. The GAODL language contains means for definition of new grammatical attributes, synsets, relations on synsets, predicates and expressions.

The notion ***grammatical_attribute <name of category> [=description]*** was used to introduce new grammatical attribute. For example basic attributes for Ukrainian spoken and sign language were introduced using the following code:

grammatical_attribute noun_nom = noun in the nominative case
grammatical_attribute noun_gen = noun in the genitive case
grammatical_attribute noun_dat = noun in the dative case
grammatical_attribute noun_acc = noun in the accusative case
grammatical_attribute noun_loc = noun in the ablative case
grammatical_attribute noun_voc = noun in the vocative case
grammatical_attribute v_inf = verb (infinitive)
grammatical_attribute v_sign = verb (sign)
grammatical_attribute noun_sign = noun (sign)

Special attributes were added to distinguish expressions in Sign Language (***v_sign, noun_sign***). This approach was helpful to keep spoken and sign expressions in the same file.

Noun synsets were introduced using expression ***synset <name of synset> [=description]***. Every synset presents certain language concept. Synsets can be considered as a set of words or expressions that express the same concept. All nouns, verbs, adjectives and adverbs of Ukrainian spoken and Ukrainian sign language create sets of synonyms (synsets), each one is presenting one semantic concepts. For example:

synset knowledge_container
synset contains_knowledge
synset read_understand
synset read_recite
synset listen_understand
synset obtain_knowledge
synset entity
synset human_person
synset can_learn = any entity that can learn something
synset can_teach = any entity that can teach someone
synset object

Verb synsets with associated expressions were defined by expression ***synset <name of synset> [=description]*** (<newline> expression)* (<newline> description of domains)*.

synset teach = pass knowledge
teach 1.noun 2.v_inf
teach 1.noun 2.noun
explain 1.noun to 2.noun
0: can_teach
1: can_learn
2: knowledge_domain

Numbers were used to link expression terms to predicate variables. Number 0 was reserved for the subject. In the example provided above synset “teach” corresponds to some predicate $teach(a,b,c)$ were a is someone who teaches, b is an entity that obtains knowledge and c is some piece of knowledge.

The main relation that was used for sentence parsing was a hypernymy relation on synsets. This relation was defined using expression ***hypernym(<synset1>) = <synset2>***. For example:

hypernym(book) = contains_knowledge

There was no special keyword for hyponymy relation because it is the opposite relation to hypernymy. Besides hypernym/hyponym relation we found useful to use relation of association and meronymy(whole/part) for WSD tasks. These relations are defined by the following expressions:

*parts(<synset1>)=<synset2> [,<synsetN>]**
*optional_parts(<synset1>)=<synset2> [,<synsetN>]**
*associations(<synset1>)=<synset2> [,<synsetN>]**
*optional_associations(<synset1>)=<synset2> [,<synsetN>]**

These relations were used to increase the probability of word meanings that were associated or were in the meronymy relationship with neighbor words.

parts(book) = page
optional_parts(page) = page_number
associations(student) = university
optional_associations(teacher) = school

GAODL language was implemented using Xtext framework for Eclipse IDE. The Xtext framework provides a set of tools for development, editing and verify-cation of domain specific languages. It includes the language code analyzer, code formatting tool, compiler, code editor etc. A parser and an editor for the GAODL language were automatically generated when its grammar was declared in Xtext. The screenshot of text editor for GAODL is depicted in Fig. 1.

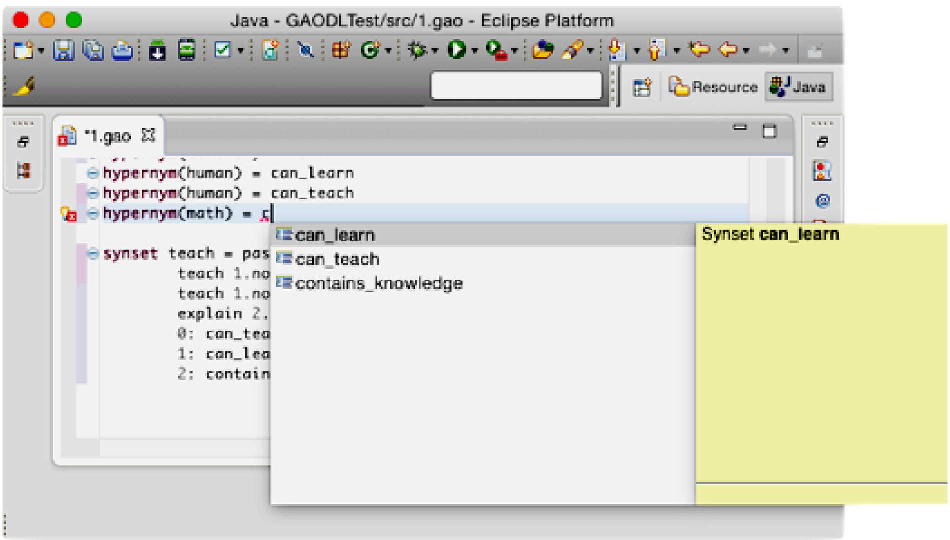

Fig. 1. The editor of GAODL files based on Eclipse IDE [source: own study]

6. THE RESULTS OF USING GAO FOR PARSING SENTENCES

The developed GAO was used for parsing sentences in Ukrainian Spoken Language and Ukrainian Sign Language. UKL sentences were represented as glosses.

Grammatically augmented ontology for "Education", "Nature", "Journey", "State", "Family", "Production", "Profession", "Army", "Theatre", "Culture", and "Hospital" subject areas were built. For this purpose, 1200 words were collected from these subject areas and the meaning of each word was verified using the Ukrainian glossary [29]. The meaning of UKL signs was clarified with teachers of Lviv Maria Pokrova Secondary Residential School for Deaf Children because there are no glossaries for UKL yet. GAO description was built using the collected words as synsets. Expressions in UKR and UKL were added for all verb synsets.

Affix probabilistic context free grammar (APCFG) parser UkrParser [30] was used for parsing sentences. All experiments were conducted for Ukrainian language and examples below are English equivalents of them.

The algorithm for parsing a sentence comprises the following steps:

1. Look up all possible meanings of every word from the sentence.
2. Add base forms for every word and detect its grammatical attributes.
3. Add hypernyms for every meaning of the words.
4. Add all expressions for every verb in the sentence.
5. Parse the sentence using UkrParser.

Consider parsing sentences "Professor teaches math to students" and "Professor teaches math to the car". The parsing starts by adding all possible meanings of all words from the sentences, their base forms and all possible hypernyms (steps 1–3 of the algorithm). This process is outlined in table 1. GAO relation "hypernym" is not limited to be a simple tree structure. It can be used to define different groups of words that share some common property. In the example provided property "can_learn" is common for all individuals ("person_individual"). It is shown by relation person_individual→can_learn.

Tab. 1. Possible meaning of words from the example and their hypernyms [source: own study]

Word	Grammatical attributes	Meaning	Hypernyms
Professor	Noun, person3, singular	Someone who is a member of the faculty at a college or university	Professor → faculty_member → educator→ professional → adult → person_individual → organism_being → living_thing → whole_unit → physical_object → physical entity → entity
Teaches (teach)	Verb, present-simple, person3, singular	Impart skills or knowledge to	Teach → inform → intercommunicate → interact → act
Math	Noun, person3, uncountable	A science (or group of related sciences) dealing with the logic of quantity and shape and arrangement	Math → science → discipline_subject → knowledge_domain → content → noesis→ psychological_feature → abstraction
To	Preposition		–
	Part of infinitive		–
Student	Noun, person3, singular	A learner who is enrolled in an educational institution	Student → enrollee → person_individual → organism_being → living_thing → whole_unit → physical_object → physical_entity → entity. person_individual → can_learn
The	Definite article	Definite article	–
	Adverb	Used to modify an adjective or adverb in the comparative degree	–
Car	Noun, person3, singular	A motor vehicle with four wheels (automobile)	Car → motor_vehicle → self-propelled_vehicle → wheeled_vehicle → vehicle → transport → instrumentality → artifact → whole_uni t→ physical_object → physical_entity → entity
		A wheeled vehicle adapted to the rails of railroad (railcar)	Car → wheeled_vehicle → vehicle → transport → instrumentality → artifact→ whole_unit → physical_object → physical_entity → entity
		Elevator car where passengers ride up and down	Car → compartment → room → area → structure_construction → artifact → whole_unit → physical_object → physical_entity → entity

The next step is to add expressions for these words. Only verb "teach" contains an associated expressions, so it is added to the set of APCFG rules:

VP → teach <knowledge_domain>[NP] to <can_learn>[NP] (1.1)

VP → teach <can_learn>[NP] <skill>[VP, GERUND] (1.1)

where VP means verb phrase, NP means noun phrase and the numbers in braces mean multiplicative weight of the rules. In the conducted experiment all grammatical rules were weighted 1.0 and the weight of all expression rules was set to 1.1. This helped the parser to prefer expressions over the grammatical rules where it was possible.

The result of parsing the sample sentences is depicted in Fig. 2. An expression "teach" was used when the first sentence was parsed, thus the weight of the result is 1.1. In the second sentence expression "teach" could not be used because "the car" does not belong to the group of entities who "can_learn". Thus, the second sentence was parsed using only grammatical rules.

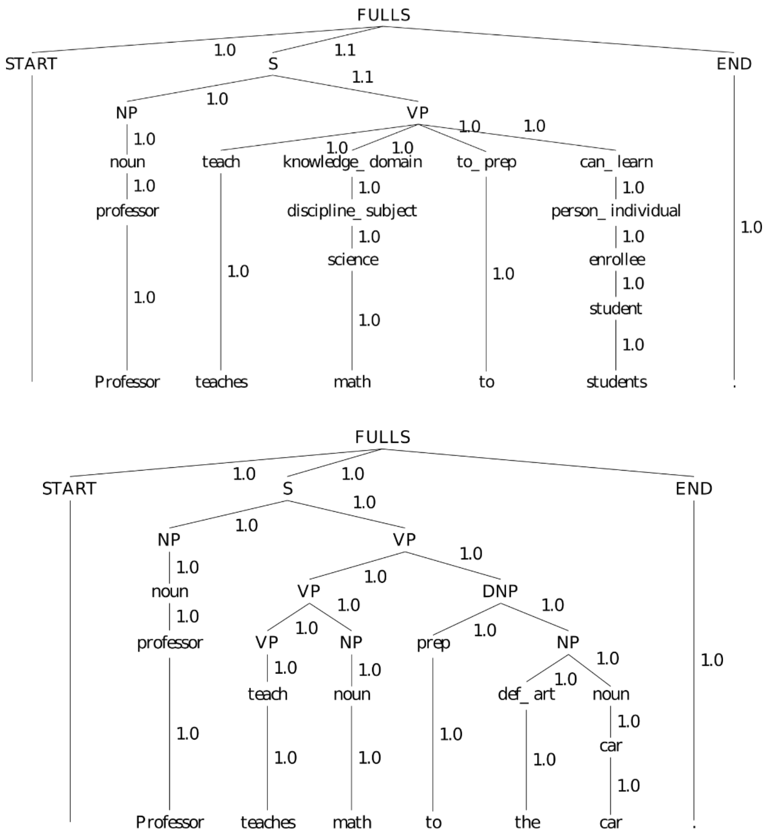

Fig. 2. The result of parsing sentences "Professor teaches math to students" and "Professor teaches math to the car". FULLS stands for "full sentence", S – a part with major clause, VP – verb phrase, NP – noun phrase, DNP – object or complement [source: own study]

The results of the experiment with parsing 200 test sentences in UKL and UKR language are given in table 2. The percentage of correctly parsed sentences was low when only the grammatical rules were used. This percentage is small especially for spoken language. It was due to the fact that Ukrainian spoken language grammar has flexible word order and word order in sign language is fixed in most expressions.

Tab. 2. Percentage of correctly parsed UKL and UKR sentences

Rule set	Ukrainian Sign Language	Ukrainian Spoken Language
Grammatical rules only	72%	65%
Grammatical rules + rules generated from GAO	91%	90%

7. CONCLUSIONS

The mathematical model and GAODL language for description of grammatically augmented ontology was developed. The model provides the possibility of integrating expressions into ontologies and supports the means for description of grammatical attributes.

The use of the developed grammatically augmented ontology for parsing sentences in Ukrainian Spoken and Ukrainian Sign Languages improved the performance of APCFG parser. The major increase in percentage of correctly parsed sentences was achieved for Ukrainian Sign Language.

GAODL language and the environment for editing grammatically augmented ontologies was developed using Xtext framework for Eclipse. This approach lets to use Eclipse environment with intelligent code completion for editing ontology files.

The language can be easily extended to incorporate more relations between concepts. Such relations can be relations like “role”, “instrument”, “locations” and others.

However, we faced challenges of verification ontology files from different sources, automatization of the process of building GAO ontologies from other known ontologies and large text corpuses. Besides that optimal weights for rules generated from GAO expressions and grammatical rules should be determined to achieve better performance of APCFG parser. These challenges would be a subject of further research.

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thin-walled elements, FEM analysis, carrying capacity, buckling

Katarzyna FALKOWICZ, Mirosław FERDYNUS*,
Paweł WYSMULSKI**

FEM ANALYSIS OF CRITICAL LOADS PLATE WITH CUT-OUT

Abstract

The work presents the original conception of thin-walled plate element with the cut-out of irregular shape for use as a elastic or bearer element. The influence of geometrical parameters and the shape of the cut-out on the value of the critical load of the structure was researched. To discrete model and to perform numerical calculations used commercial program ABAQUS. Numerical calculations constitued own solution problem of compression structure and are the initial stage of research on work construction in elastic postcritical field with forced torsional-bending form of loss of stability was performed.

1. INTRODUCTION

The uniform, thin plates belong to the group of structural elements relatively cheap to manufacture, but due to the low flexural stiffness can move relatively small loads [1]. When they are compressed, the loss of stability occurs at low load and has a flexural buckling character [2–6]. Known common methods for improving the plate carrying capacity through the use of stiffeners or ribbing, lead to the significant changes in the design, thereby to increase the weight of the thin-walled construction.

However, there is a way to significantly improve the carrying capacity of this type construction, through the execution of the central cut-out and by forcing the work construction according the higher (bending-torsional) form of buckling.

Accordingly, to the basic problems we can include the carrying capacity of this type elements in particular working conditions of structure, and the impact of the size and type of cut-out on the carrying capacity. As a significant contribution in this field we can distinguish the works [7,8], where was considered the limit load capacity of this type elements.

* Lublin University of Technology, St. Nadbystrzycka 36, 20-618 Lublin, Poland
+48 (81) 538 42 00, e-mail: k.falkowicz@pollub.pl, m.ferdynus@pollub.pl, p.wysmulski@pollub.pl

However, there not found studies where was researched plate elements with cut-out and in which attempted to force deformation of element by a higher bending-torsional form.

The study addresses the concept of suitably shaped the geometric parameters of thin-walled plate element with cut-out, without change of its overall dimensions, in order to obtain the effect of improving the carrying capacity.

The influence of geometrical parameters and the shape of the cut-outs on the characteristics of the construction work in the field of operational loads was researched and the corresponding form of the loss of stability was determined.

The studies included linear numerical analysis of structures by using the finite element method (FEM) in ABAQUS software [9].

2. SUBJECT AND RESEARCH METHODOLOGY

The calculations assume a structural plate model made of an isotropic material. The research object is a rectangular plate with a central cut-out with different shapes and with variable geometric parameters of cut-out. The plate geometric parameters are shown in Fig. 1.

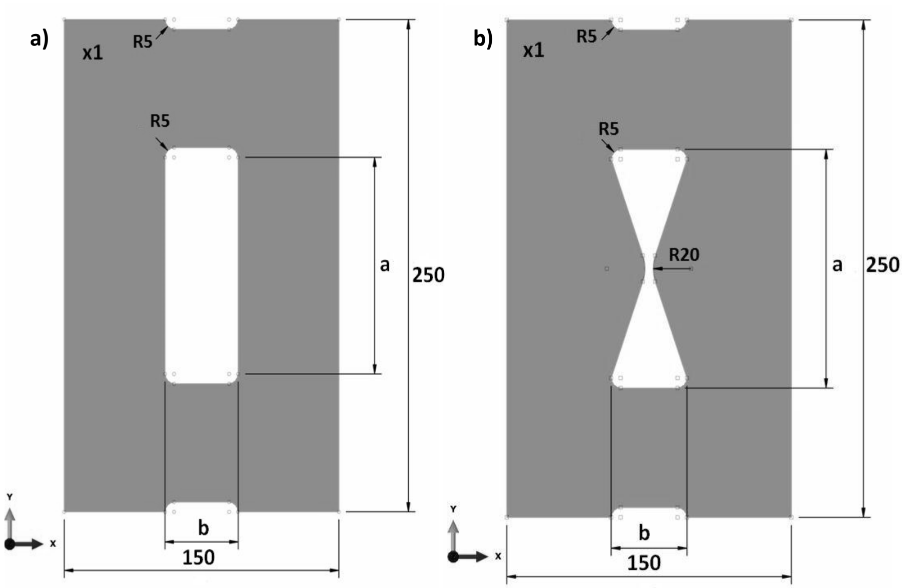


Fig. 1. Rectangular plates with cut-outs a) cut-out with rectangular shape, b) cut-out with hourglass shape [source: own study]

Analyzed plates had a symmetrical cut-out in the middle of the plate, which dimensions constituted geometrical parameters of the structure having a decisive effect on the characteristics of configuration in the loaded condition.

The range of cut-out geometric parameters was respectively: *a* = 80 ÷ 200 mm and *b* = 10 ÷ 50 mm.

As a plate material was adopted spring steel 50 HS which properties indicated in Table 1.

Tab. 1. Materials properties for spring steel 50 HS

Young Modulus in Tension E [MPa]	Poisson Ratio v [-]	Yield Strenght Re [MPa]	Tensile Strenght Rm [MPa]
210000	0.3	1180	1320

In case of elastic elements made of material with elastic-plastic characteristics, level of the yield strength determines the limits of construction parameters, while providing a significant limitation in design of this type configurations.

3. NUMERICAL ANALYSIS

To performed the discrete plate model and to carried out numerical analysis used ABAQUS program.

The plate was articulately supported and loaded by a compressive force distributed evenly over the top of edge. Boundary conditions mappers articulately support of plate was defined by blocking the kinematic degrees of freedom of nodes on the top and bottom edges of the element. Discrete plate model is shown in Fig.2.

Numerical calculations concerned the linear stability analysis and included a critical state analysis of rectangular plates with cut-outs. Solution to the eigenvalue problem concerned the determination of critical load values and the corresponding it form of the loss of stability. In each case, were determined 3 the lowest form of buckling, what allowed on determination of a higher, bending-torsional form, providing the staid nature of structure work after buckling (Fig. 3).

As we can see, in the case of the bending-torsional form in compression plate we can identify vertical stripes subjected to bending and horizontal stripes subjected to bending and torsion.

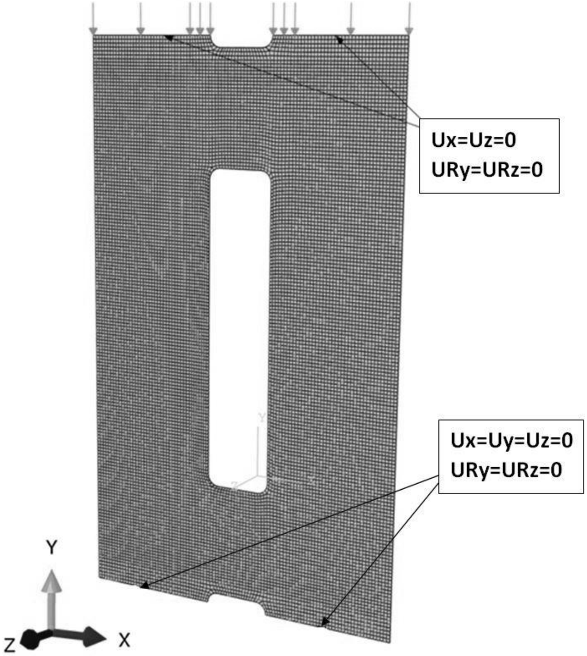


Fig. 2. Discrete model plate [source: own study]

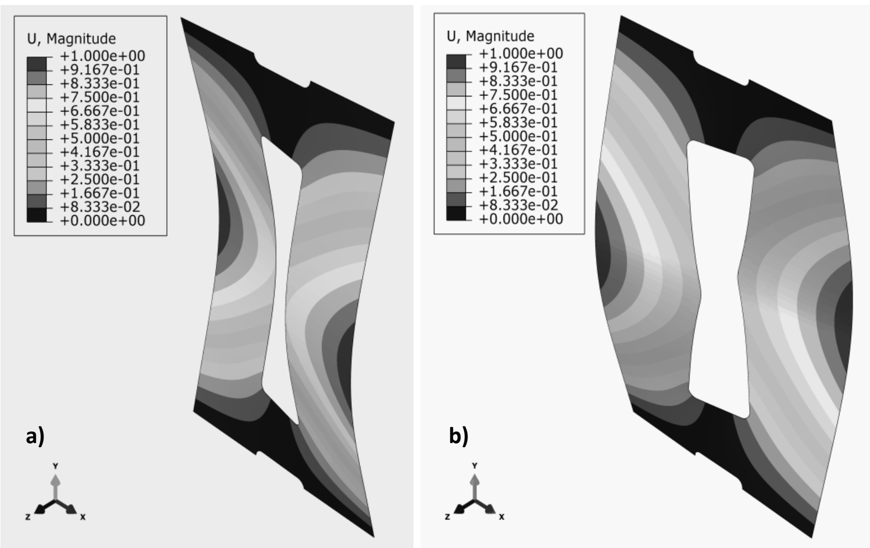
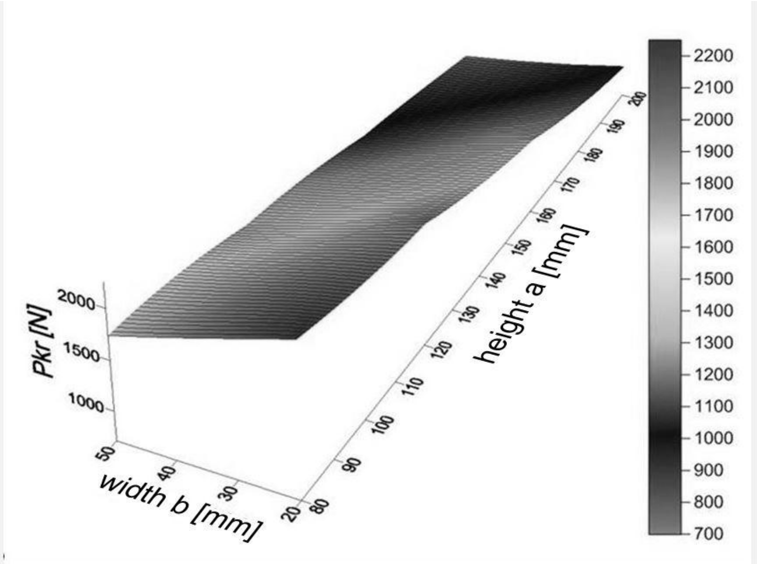


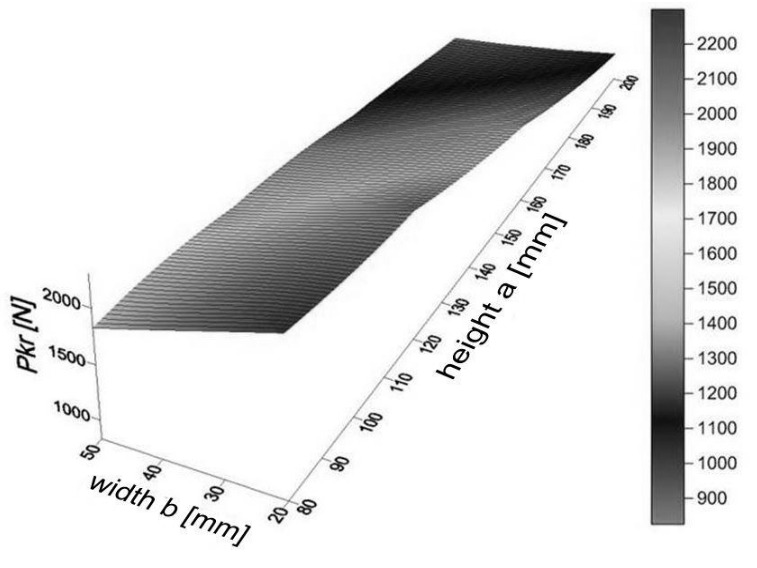
Fig. 3. Examples of buckling form plates with cut-out in ABAQUS program
a) higher buckling form: bending-torsional form of plate with rectangular cut-out
b) higher buckling form: bending-torsional form of plate with hourglass cut-out
[source: own study]

4. RESULTS

The performed numerical calculations were basis to determine a critical force in analyzed system, in depends on cut-out geometric parameters – height *a* and width *b*, and cut-out shape (Fig.4 and Fig.5).



a)



b)

Fig. 4. Critical force depends on geometrical parameters of cut-out *a* and *b* for: a) plate with rectangular cut-out b) plate with hourglass cut-out [source: own study]

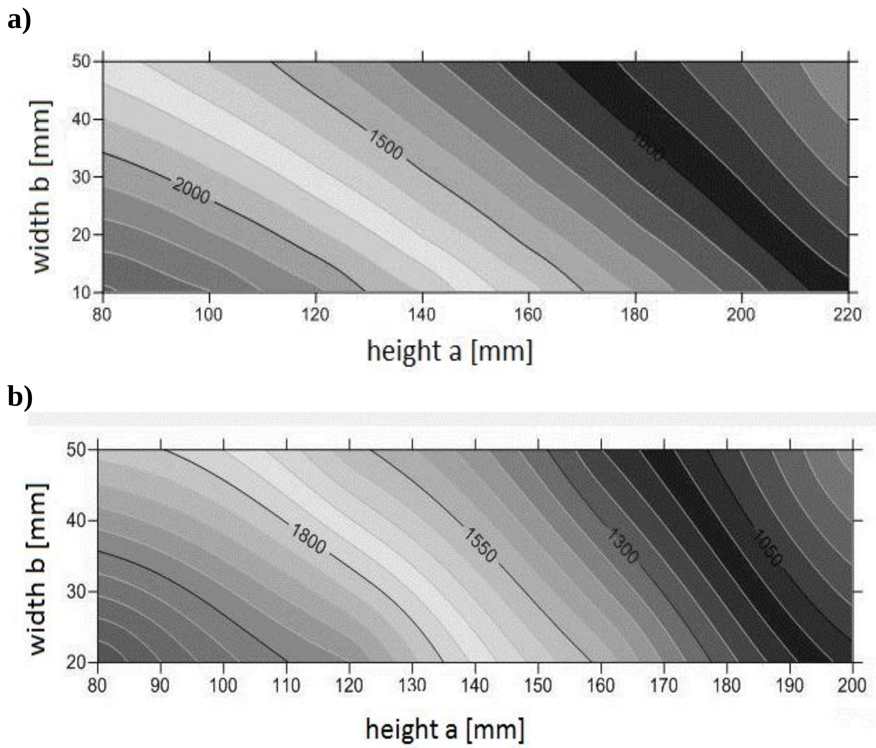


Fig. 5. Critical force in depends on cut-out geometrical parameters in contour form for a) plate with rectangular cut-out, b) plate with hourglass cut-out [source: own study]

On the basis of Fig. 4 and Fig.5 we can see that by changing the dimensions defining the cut-out in plate we can affect on the size of the critical force. The best mechanical properties with regard to the critical load, have a plates with small cut-out width *b* and a relatively small amount of cut-out heigh *a*.

Based on these results, we can see that with the increase of the parameter *a* decreases the value of the critical load. A similar situation occurs with increasing cut-out width *b*.

Wherein, the change of the shape of the cut-out does not have a significant impact on the size of the critical force.

Results of critical force calculations show that by changing the geometric parameters of the cut-out we can affect on its capacity.

The results confirm the possibility of determining stiffness parameters the tested elements in a fairly wide range, while keeping constant the overall dimensions of the structure.

5. CONCLUSIONS

In the work was presented a numerical analysis of linear stability the compression plates with cut-out. The research was conducted in the range of numerical FEM analysis of the critical state for different geometrical parameters of the cut-out, by changing the height *a* and width *b* of the cut-out while maintaining the same overall dimensions of the plate and for different cut-outs shapes.

The results showed a fairly significant impact of cut-out dimensions on the value of the critical load. This concerns in particular the height of cut-out for which the maximum difference in critical load at a constant width cut-out was in the range of 698.59–22497 N in the case of plates with rectangular cut-out shapes and 825.92–2299 N for plates with cut-out shape similar to the hourglass. Wherein, the same shape of cut-outs does not have such a big influence on the critical load value.

This numerical analysis is a preliminary stage to research concerned with the work of construction in elastic postcritical field with forced bending-torsional form of loss of stability.

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ÖNDER AYER[*]

FEM SIMULATION OF COMBINED EXTRUSION METHOD (ECAE/DIRECT EXTRUSION)

Abstract

Equal Channel Angular Extrusion (ECAE) is known as a severe plastic deformation process and material is deformed without any geometrical change. It is widely used for obtaining high mechanical properties from the product. Direct Extrusion is another plastic deformation process in which a workpiece is reduced in cross-section by forcing it through the die opening of a small cross-sectional area than that of the original billet. In this study, these two processes are combined together via using DEFORM 3D which is a very specialized software for metal forming operations. Lead is used as workpiece material to simulate hot forming conditions and also process parameters (die angle and die land length) were investigated. The forming load and strain components were calculated from the FEM results obtained from DEFORM 3D software.

1. INTRODUCTION

Equal Channel Angular Pressing (ECAP) which is known as one of the most promising material processing techniques involves severe plastic deformation. In contrast to rolling, drawing, forging the main purpose of ECAP is to accumulate deformation in material without any reduction in workpiece cross-section. The process gives uniform grain structure because of shear stress effect on the product. The grain size can be smaller in the range of in the range of hundreds of nanometers applying multiple ECAP passes. Methods that employ severe plastic deformation (SPD) to produce nanostructured materials are more suitable for bulk production of fully dense materials. During the ECAP process, the grain refinement occurs together with significant dislocation hardening, enhances considerably mechanical properties for many engineering materials. Parshikov et.al. [1] the influence of die geometry

[*] Trakya University, Department of Mechanical Engineering, Ahmet Karadeniz Yerleşkesi, 22030 Edirne, Turkey, onderayer@trakya.edu.tr

and friction condition on irregularity of shear strain field in the cross section of the billet and therefore on mechanical properties distribution was studied. Balasundar [2] made a series of experiments using plasticine and tin have been used to validate the numerical modeling results and to gain further insight in to the process. Balasundar [2] and et al. also used FEM method to simulate the ECAP process and concluded the importance of corner angle and fillet radius at the inner channel surface to process a variety of materials has been realized. Basavaraj et.al. [3] carried out for different combinations of channel angle, inner and outer corner radii and realized that there exists an optimum outer corner for which strain inhomogeneity is minimum, which depends on the channel angle. Inner corner alone has no influence on the strain inhomogeneity but its interaction with channel angle has some influence. Figueiredo [4] proposed a FEA of a two pass ECAP processing of copper following route C. This processing route involves the shearing of the material in the same plane as in the first pass, but in a reversed shear direction. They concluded that the consideration of the strain path effects changed the final strain distribution in the material and led to a lower punch force in the second pass, in comparison with the results from the analysis considering a single stress–strain curve for all passes.

Direct extrusion is a plastic deformation process in which a workpiece is reduced in cross-section by forcing it through the die opening of a small cross-sectional area than that of the original billet. The direct extrusion of rods and solid shapes is the simplest production method in use for high production rate and accuracy. One-third of the annual world aluminum production of 20 million tons is delivered as extruded sections. Therefore extrusion method is a famous and effective method for among of all metal forming processes so many researchers studied on the direct extrusion. Azad-Noorani et al. [5] studied on the optimal die profile by using finite element method (FEM) analysis and experimental results with the comparison of the conical and curved die profiles. Many of the studies have been performed to investigate the effect of the die profile on the deformation load and the product quality. Reggiani et.al [6] used FEM method to predict the charge weld in hollow sections and validated their results with experiments. Karami [7] developed a new kinematically admissible velocity field for the forward extrusion of a square section from a round billet and compared the upper bound results with FEM and experimental results. Qamar et al. [8] analyzed the effect of the shape complexity on the dead metal zone and metal flow through the flat-faced dies by experimental and numerical methods using Ansys-LS-Dyna. Altinbalik and Ayer [9] studied theoretical and experimental study for forward extrusion of clover sections. Chandra et. al. [10] demonstrated how the extrusion ratio and ram speed affect the temperature evolution of the workpiece during extrusion of the AA6061 alloy by using the rigid-viscoplastic formulation of a 3D FEM program. They evaluated the results for selecting the process parameters to avoid extrusion defects and minimize the temperature variations along the extrudate and on its cross section. Ulysse [11], built a numerical model which uses the 3D finite element method combined with techniques of mathematical programming to design traditional die flow correctors used in flat-faced aluminum extrusion dies.the author showed that die design depends, among other factors, on process parameters such as ram speed and product parameters such as the type of alloy used. Peng and Sheppard [12] used a commercial FEM code FORGE to study the influence of the number and the distribution of die holes on extrusion parameters. They obtained the flow pattern, pressure requirements, and temperature histories developed are established and they reported that FEM simulations agree well with obtained experimental results.

Lately, researchers paid attention to combine two severe plastic forming methods which are Equal Channel Angular Pressure and Forward Extrusion in a single die and used for powder compaction. Mani and Paydar [13] applied hot forward extrusion and ECAP process together for consolidation of Al-SiCp premixed particles. They presented that products produced by FE-ECAP combined process have better mechanical properties in contrast with forward extrusion products. Addition to this, Paydar et.al. [14] investigated the possibility of performing Forward extrusion and ECAP in a single die and producing long bar samples with full density from particles. their results show that the FE-ECAP process is a promising method for producing bulk materials from particles with full density and excellent mechanical properties. Also they concluded from experimental results that FE-ECAP sample is because that the average grain size is about 4 μm which is finer than that of the FE sample 30 μm. In another study Paydar et.al. [15] aimed to produce fully dense bulk material with a good bonding properties by using single FE-ECAP die. They found that comparison of the properties of ECAP–FE samples with that of FE samples indicates that the percent elongation of the ECAP–FE sample (12.8%) is higher than that of the FE sample (5.8%). Nagasekhar et.al. [16] invtestigated in their research the deformation flow, strain homogeneity, and load requirements of FE and ECAP combined processes of FE+ECAP and ECAP+FE are numerically investigated and compared with those values in individual FE and ECAP processes by using DEFORM software.

In this study combined ECAP and Forward extrusion method was used as a metal forming process and it was simulated by using FEM based metal forming software DEFORM. Lead was chosen as prototype material because of its hot forming characteristics at room temperature. Three different extrusion ratios which is 2, 4 and 4 and three different die angle (15°, 20°, 25°) for each E.R. (Extrusion Ratio) were selected for die assembly. Maximum forming load values and strain distributions were investigated.

2. THEORY

The model was built in commercial CAD software and then exported to the FEM based metal forming software DEFORM which was selected for the simulations. The geometrical view of the die design is given in Fig. 1.

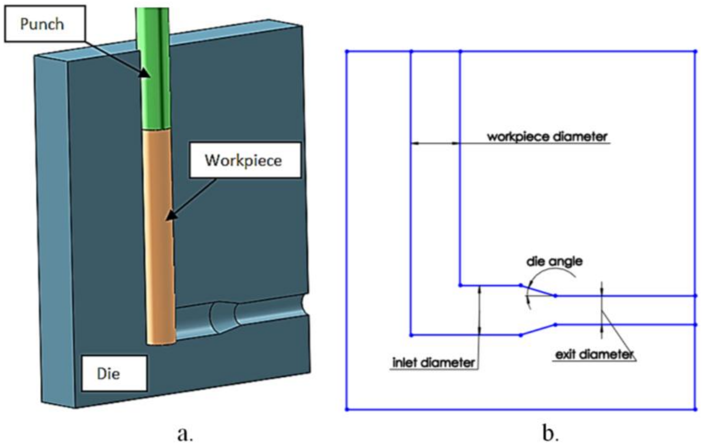

Fig.1. a) schematical view of die setup, b) die parameters [source: own study]

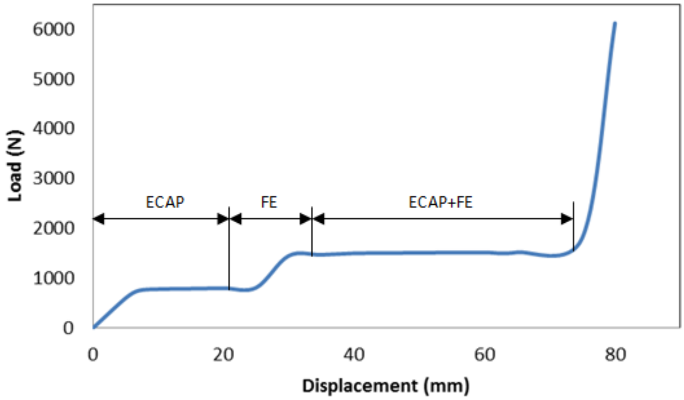

Fig. 2. A typical load-displacement curve for ECAP+FE process [source: own study]

The sample diameter was 12 mm. as it is same as container diameter and exit diameters were 10, 8 and 4 mm respectively. The die angles were 15°, 20°, 25° for each extrusion ratio. Since the model has a cylindrical workpiece, two dimensional analysis method was applied for the study. 2500 tetragonal element was chosen for meshing. Friction coefficient was 0.4 for all contact surfaces between die and sample, punch velocity was 5 mm/sec and all simulations were assumed to be performed at room temperature.

The forming load of combined ECAP+FE process was investigated in this study to obtain the optimum die design. Since strain distribution affects material flow and that leads to change in the forming load, it was also investigated. Fig. 2. shows a typical load-displacement diagram and it can be clearly seen the sections of the combined method. At the beginning of the process the workpiece is forced to flow in the die and material is forced and compressed and then material flow 90° degree angles. After a while the extrusion process behavior is active and the forming load is similar with the extrusion process forming. The two forming method is effective rest of the process.

3. RESULTS AND DISCUSSION

Fig. 3. shows the maximum forming load values of all processes according to extrusion ratio and die angle. It is clearly seen that forming load increases with higher E.R. as expected. Die angle is another important parameter which affects the load value. Load change is significant for the higher extrusion ratios as expected. The maximum forming load decreases with the increasing die angle. The load is about 5 kN for extrusion ratio of 2 and the load value doubles when extrusion ratio is 9 for the 15° die angle. The load value decreases from 5.1 kN to 4.7 kN when die angle becomes 15° for the extrusion ratio of 2 and this change is much more significant for higher extrusion ratio value of 9. The forming load of E.R. 9 decreases 600N for the bigger die angle. The state of change of the forming load looks similar for extrusion ratio of 2 and 4 but for E.R. 9 the drop of the forming load is so remarkable.

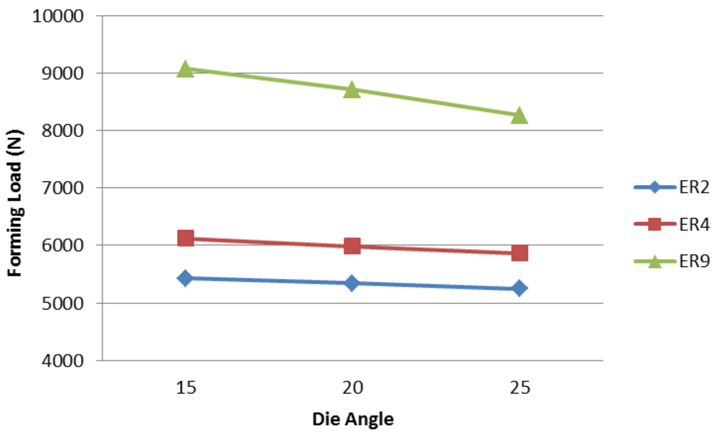

Fig. 3. Maximum Forming Load Values [source: own study]

The efficient strain value is important parameter not only material flow but also forming load. The better material flow results lower forming load for metal forming processes and for this study the effective strain diagrams were investigated in Fig. 4-12. which were given below.

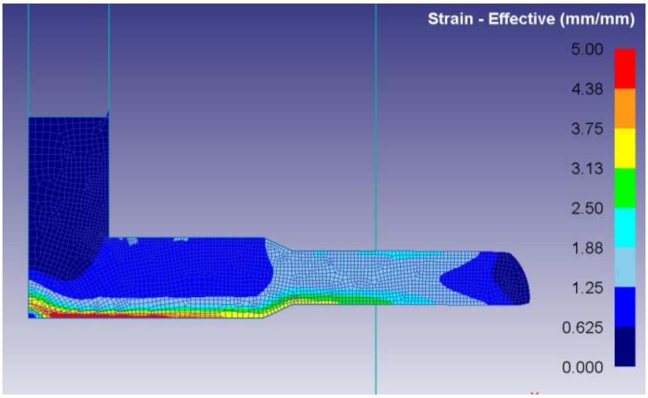

Fig. 4. Strain diagram for E.R.: 2 die angle: 15 [source: own study]

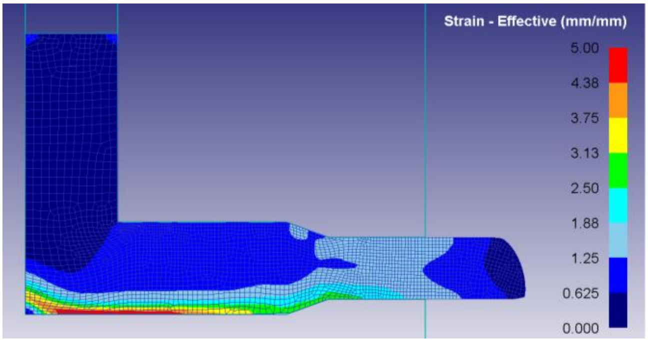

Fig. 5. Strain diagram for E.R.: 2 die angle: 20 [source: own study]

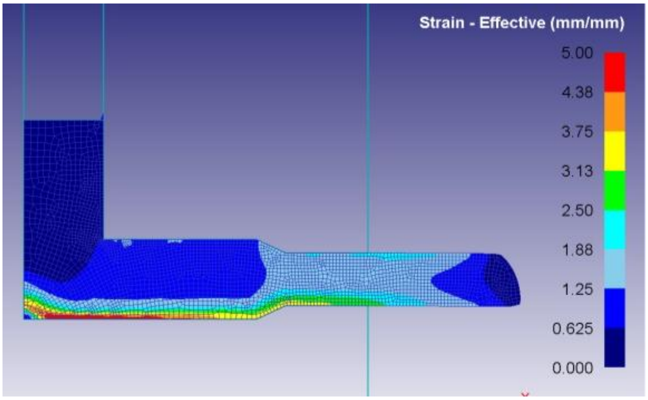

Fig. 6. Strain diagram for E.R.: 2 die angle: 25 [source: own study]

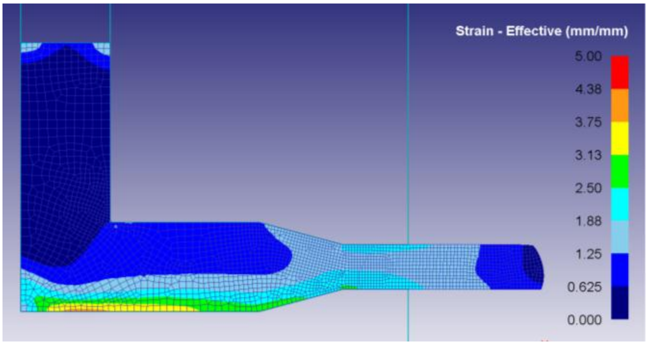

Fig. 7. Strain diagram for E.R.: 4 die angle: 15 [source: own study]

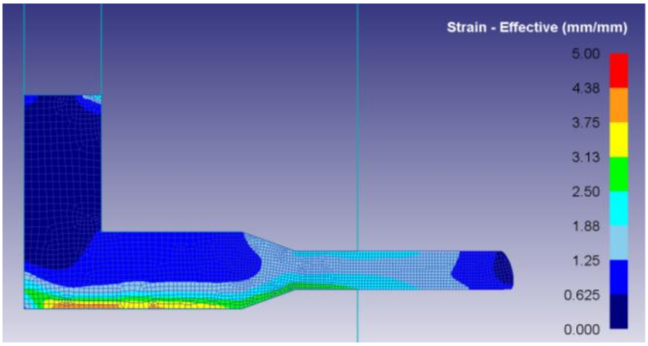

Fig. 8. Strain diagram for E.R.: 4 die angle: 20 [source: own study]

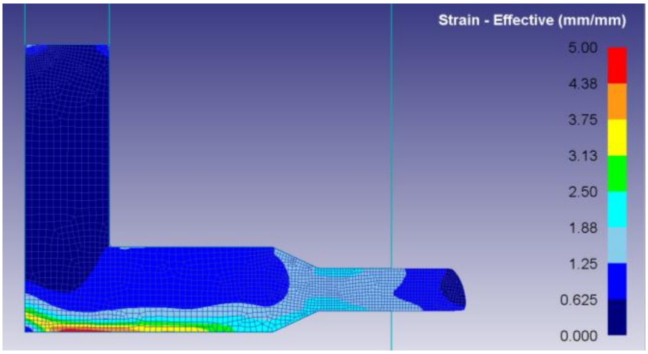

Fig. 9. Strain diagram for E.R.: 4 die angle: 25 [source: own study]

Forming load was investigated regarding to strain values and material flow of the ECAP and FE combined processes. The results were analyzed using the finite element simulations. When the diagrams analyzed together, the effective strain value which is selected as a main parameter of the study since its relationship of both material flow and forming load and it was not observed significant change which lead to the decrease in the forming load when the die angle increases for the same extrusion ratio of each die setup.

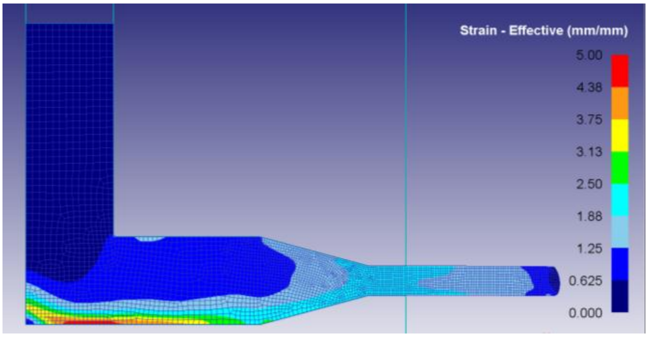

Fig. 10. Strain diagram for E.R.: 9 die angle: 15 [source: own study]

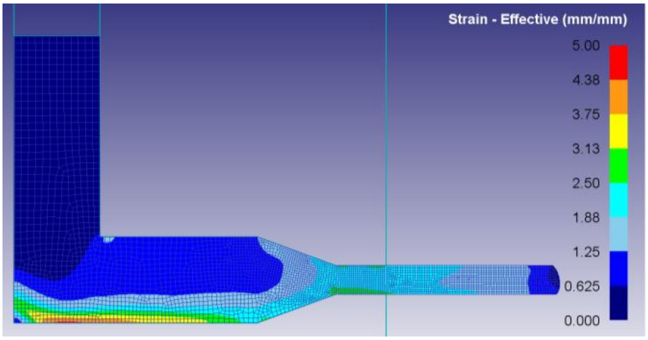

Fig. 11. Strain diagram for E.R.: 9 die angle: 20 [source: own study]

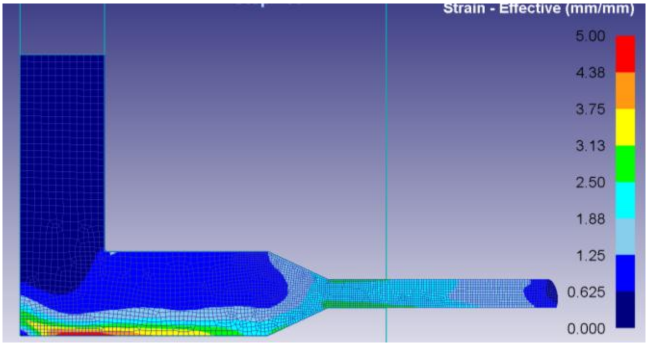

Fig. 12. Strain diagram for E.R.: 9 die angle: 25 [source: own study]

The friction factor (m) was selected relatively high both dry conditions and lead material characteristics were considered in the simulations and it can be conclude that for the lower die angles the contact surface between die and the workpiece is higher than that of the dies which have higher die angles. The frictional surface calculated from the geometry and it is seen that the frictional surface for die angle 15^o is 17% and 26% higher than that of the die angle 20^o and 25^o respectively for E.R. 9. The frictional surface change is about

16% between die angle 15º and 25º, when the E.R. is 2. The selected simulation conditions lead to dominant friction characteristics on the forming load results. Frictional behavior is more significant for the higher extrusion ratios and lower die angles. In this study, forming load is 8.9kN for highest extrusion ratio (9) and lower die angle (15º) but the load decreases with the increasing the die angle to 8.3 kN because of the smaller contact surface and less friction forces. When the extrusion ratio is 4, die angle 15º gives 6.1 kN maximum load value and for die angle 25º load value becomes 5.8 kN. The load is calculated as 5.4 kN for the lowest die angle and for the highest angle value (25º) the load decreases to 5.25 kN. It can be clearly observed that friction highly effects the maximum forming load of the ECAP+FE combined process for higher friction conditions.

4. CONCLUSIONS

The combined Equal Channel Angular Extrusion Method + Forward Extrusion method was investigated in terms of forming load results and the effect of die angle on the forming load. The three die angle was selected for three different extrusion ratios. Because of the material is lead the friction factor was m = 0.4 and the results were obtained from the DEFORM software.

It can be concluded from the results that the forming load is effected highly from the frictional conditions and the die with higher die angles gives lower forming load since the die which has lower die angle has bigger contact surface. The research can be expanded with experimental study and different die and process parameters.

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FEM, numerical analysis, crack propagation, Abaqus, ABS

Patryk RÓŻYŁO, Łukasz WÓJCIK***

COMPARISON OF NUMERICAL AND EXPERIMENTAL ANALYSIS OF THE CRACK PROPAGATION PROCESS

Abstract

Nowadays numerical methods are a powerful tool to simulate real processes. Polymer materials are increasingly used in engineering solutions. ABS is a common material used interchangeably with respect to traditional materials. Process for the production of components for research on 3D printers is becoming more widespread and accessible to ordinary users. Crack propagation process was carried out at the same time to compare results through experiments performed on the testing machine and numerical study. Cracking process was carried out by finite element method, implemented on the basis of simulations xFEM. This method allows to conduct research related to the separation of the material nodes, in places of highest stress levels that exceed the limits of plasticity and strength of the material. The analysis involved comparison of the shape of the resulting cracks through experimental and numerical way.

1. INTRODUCTION

One of the key aspects of machine design is to provide a sufficiently high level of safety, to long-term operation of the equipment. A common problem arising both from structural defects or sometimes with the phenomenon of fatigue cracking. Cracking phenomenon is an irreversible process that occurs when stresses exceed the border limits of the material.

Modern research methods such as complex experimental analysis and computer simulations, a significant effect on reducing unwanted cases of damage mechanisms during long-term operation. Finite element method is a technique that allows to conduct research numerical analysis mechanism designed of components, before final production. By properly prepared model and to define the numerical process, there is a confirmation of the research through experiments on real objects of research.

* Politechnika Lubelska, Nadbystrzycka 36, 20-618 Lublin, +48 603 359 217, p.rozylo@pollub.pl
** Politechnika Lubelska, Nadbystrzycka 36, 20-618 Lublin, +48 785 221 354, l.wojcik@pollub.pl

The research sample was made on a 3D printer uPrint SE of ABS material. The object of the research was thin-walled plate which was subjected to a stretching process on testing machine Instron 3369.

The work was carried out numerical analysis of fracture at a critical point the object of study, in order to confront with the result obtained by experimenting. The tool, which was used for the preparation of the numerical process was Abaqus 6.14 environment. The main objective of the research was to compare the obtained path of crack propagation and numerical experiments.

In the cited references [4, 5, 11, 12], the authors presents the introduction of the program Abaqus, indicated the approach used in the design of the basic components of simple geometry in static analysis.

In the papers [1, 2, 6–10], the authors deal with the presentation of a general approach to the problem of propagation of cracks occurring in the material. The authors of these works present experimental results obtained on the basis of the characteristics of the process of fracture of polymeric materials.

In [3] the author takes up the subject describe a general approach to a point of the process of fracture mechanics of materials.

Currently, there is a possibility to use substitutes made of polymeric materials instead of traditional materials consumer.

2. MATERIALS AND METHODS

The research part was a copolymer made of ABS materials. The sample for the study has been to design in Solid Edge ST4 environment and printed on a 3D printer uPrint SE. The dimensions of the element are designed according with the following drawing.

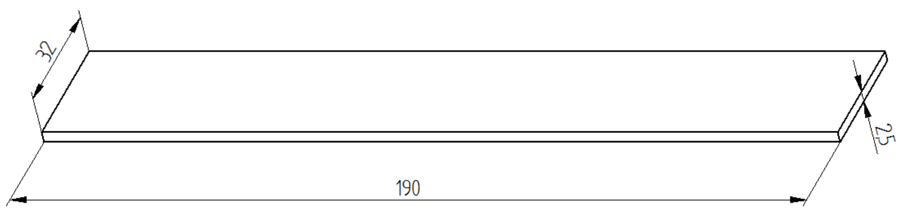


Fig. 1. The dimensions of the element [source: own research]

Model prepared in advance in Solid Edge ST4 software has been imported into the corporate environment uPrint SE 3D printer.

3D printing as opposed to commonly used methods is a method of incremental processing means that the element is produced by the application of successive layers of material. The sample was made on a 3D printer through the use of ABS polymer incremental method. Method of application building material held in by the method of FDM (fused deposition modeling) – modeling liquid thermoplastic.

Initially, this method for the worktable are applied adhesive layer, which is intended to facilitate the finished remove from the printing plate. The next step is to incorporate the constituent material and the support layer. The support layer is used in the created model complex geometry and is inclined with respect to the printing plate at an angle without giving damage effect to the geometry of the performed element. The finished model after the printing process still needs some finishing operations. These include the removal of the selected support material by special detergents and then in a further step is necessary to the working of the outer portion of the object in order to obtain the desired surface quality.

The object of research was characterized by a consistent material properties for the data ABS material. Characteristics of the material necessary to carry out the numerical process based on data spring. Any characteristics of the material shown in the table below.

Tab. 1. Data material of ABS [14]

ABS material	
Young's Modulus [MPa]	1700
Poisson's Ratio	0.38
Yield Strength [MPa]	31
Tensile Strength at Break [MPa]	70

Research station to implement the prepared sample tensile testing machine was Instron 3369. Dual Column Testing Systems is able to perform the processes of compression and tensile test with a maximum force of 50 kN.

The sample was mounted in the jaws of the tensile, symmetrically at a distance of 40 mm from the both ends. The same study was based on a static tensile member, to break the sample. The process led to permanent stretching of separations between the fibers of the material.

Progressive separation of the fibers has consistently led to the destruction of the test piece. The shape of the resulting cracks had stepped characteristics. Area cracking was observed in the area of the mounting location of the sample. Testing machine at work was equipped with a jaw for the stretching process.

Test stand with instrumentation and 3D printer on which the sample was prepared, shown in Figure 2.

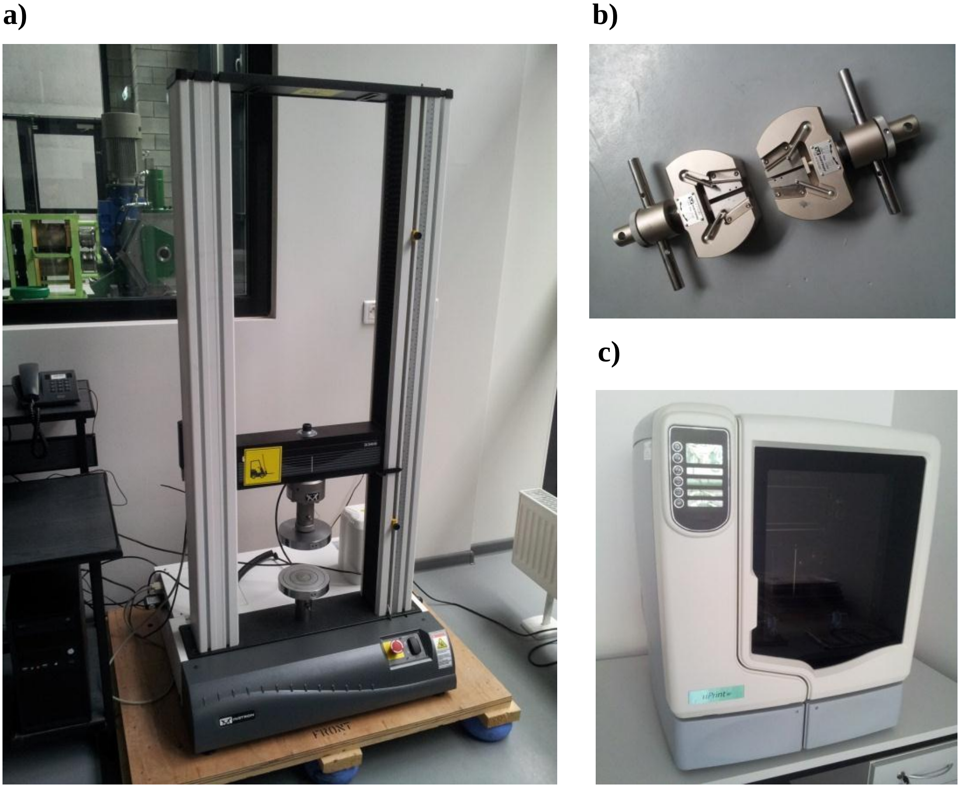
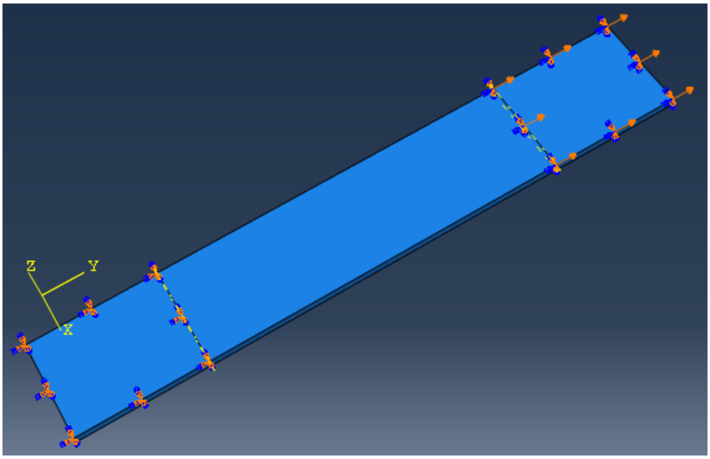


Fig. 2. Test stand: a) Machine Instron 3369, b) Manual jaws Instron 50 kN, c) 3D printer uPrint SE [source: own research]

The next stage of the research was carried out numerical analysis using the finite element method. For this purpose a number of test environment Abaqus 6.14. The program was prepared as part of the rigid body, according to the data in the material element made on a 3D printer. Element had well-defined boundary conditions (fully mapping the actual mounting material in testing machine). One piece of component was fully fixed and the second suffered forced displacement of 1 mm in the direction of Y axis.

The FEM model of type C3D8R tetrahedral elements with a reduced number of integration points. Reduced integration is a technique for removing the impact of the blocking effect of finite elements (reduction of false forms of shape distortion) [13]. Boundary conditions and FEM mesh is shown in Figure 3.

a)



b)

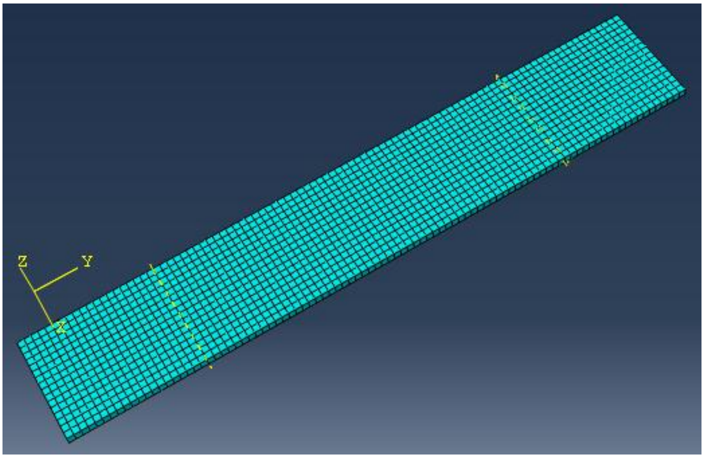


Fig. 3. Numerical model: a) Boundary conditions, b) Mesh [source: own research]

The total number of elements in the mesh was over 1500, with the amount equal to 3264 nodes.

The correctness of the course to simulate real phenomena using numerical methods is dependent on the correct definition of the boundary conditions, the knowledge required for the process material properties and the ability to test the application of the interaction between objects.

The process of crack prepared according to the method xFEM. This method allows for the implementation of crack propagation.

3. RESULTS

FEM analysis allowed us to obtain the stress distribution in the test mechanism. As part of an experiment performed on a testing machine test result was obtained in the form of a broken element.

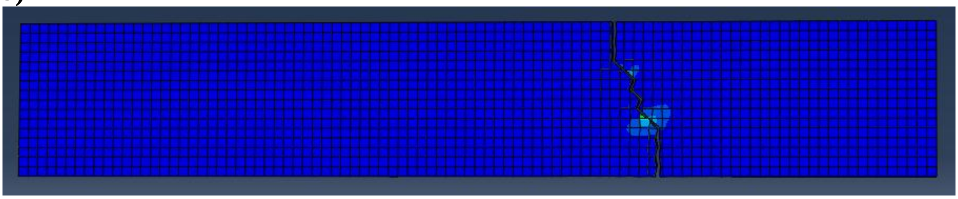
Comparative destruction of the element by numerical experiments and tests made it possible to observe a similar process of crack propagation in both cases.

Computer simulation of yield showed a more than tenfold, with respect to the base value of R_e = 31 MPa, at which the material permanently burst [14].

Progressive process of permanent separation of the fiber material obtained through simulation studies constantly confronted with the result of progressive cracking on the road made the experiment. The test results of material damage are shown in Figure 4.

a)

b)



c)

d)

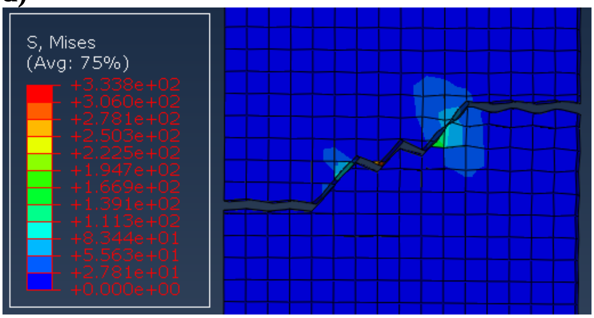


Fig. 4. The comparative results of numerical analysis and experimental study: a) real model after fracture, b) numerical model after analyzing xFEM element, c) the shape of the crack obtained through experience, d) the shape of the crack obtained through FEM [source: own research]

Simulation initiate the process of stretching the sample allowed to obtain form the shape of cracks similar to the one which resulted from previously conducted experiments. The reduced stresses, which have been fixed by separation of all material of the fibers was less than 334 MPa. In almost five times exceeded destructive stress of the material, which amount to 70 MPa there was a total destruction of the sample.

Obtained through computer simulation visualization of material separation, an idealized case of actual rupture results obtained after the stretching process on a laboratory.

4. CONCLUSIONS

With respect to the research it is possible to draw the following conclusions:

- FEM analysis results showed exceeded both the yield strength and the strength of the material, leading to a permanent separation of fibers,
- the shape of cracks obtained by computer analysis is similar to that obtained by the experimental,
- may rupture characteristics obtained stepped mirror symmetrically relative to the axis of the test object,
- analysis of the occurring stress levels appeared sensitive area of the sample in the process of separating material in the form of real-time crack propagation.

Application of FEM to destructive testing in the elements subjected to tensile loading, allows for visualization of the state of effort and permanent separation of fibers prepared numerical models, which nowadays is indispensable in engineering applications.

Observation of crack propagation behavior in relation to the load exerted on the element during operation, allows the proper selection of the material from which it is to be made for future use. Numerical methods allow to predict crack propagation process, thanks to which without prior preparation elements may be beneficial for improving the structural properties.

Observation of the shape of the crack obtained material, in a similar type of analysis gives opportunities to prevent cracking processes by the proper preparation of the sample.

A wide range of research opportunities through experience and performed numerical simulations greatly improves operating conditions studied objects. Computer simulations of physical processes have the potential to future-proof machine optimization methods.

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commercial content, information resource, business-process, content management system, content lifecycle, electronic content commerce system

Victoria VYSOTSKA [*], *Lyubomyr CHYRUN* [**]

METHODS AND MEANS OF PROCESSING INFORMATION RESOURCES IN ELECTRONIC CONTENT COMMERCE SYSTEMS

Abstract

This paper presents the development of unified methods and software tools for processing information resources in the electronic content commerce systems. A model of electronic content commerce systems is proposed. The models of information resource processing in electronic content commerce systems are proposed.

1. INFORMATION

Rapid development of the Internet contributes to the increase of needs for the efficient data of the production / strategic nature and implementation of new forms of information services through modern information technologies (IT) of e-commerce [1–3]. Documented information prepared in accordance with users needs is a *commercial content.* Today e-commerce is a reality and a promising business process. Internet is the business environment, and commercial content is a commodity with the highest demand and selling rate. It is also the main object of the processes of electronic content commerce. Commercial content can be immediately ordered, paid and got on-line as a commodity. The entire spectrum of commercial content is sold via the Internet – scientific and publicist articles, music, books, movies, pictures, software etc. Well-known corporations that implement electronic content commerce are Google through Google Play Market, Apple – Apple Store, Amazon – Amazon.com. Most of the decisions and researches are conducted at the level of specific projects. The electronic content commerce systems (ECCS) are built on the closed principle as non-recurrent projects. Modern ECCS is focused on the realization of commercial

[*] Information Systems and Networks Department, Lviv Polytechnic National University, S. Bandery Str., 12, Lviv, 79013, UKRAINE, +38 (032) 258-26-38, victana@bk.ru

[**] Software Department, Lviv Polytechnic National University, S. Bandery Str., 12, Lviv, 79013, UKRAINE, +38 (032) 258-25-78, chyrunlv@mail.ru

content that is made outside of the system. Design, development, implementtation and maintenance of ECCS are impossible without the use of modern methods and information technologies of formation, management and support of commercial content [1–13].

2. RECENT RESEARCH AND PUBLICATIONS ANALYSIS

Development of the technology of information resources processing is important in view of such factors as lack of theoretical grounding of methods of study of commercial content flows and the need for unification of software processing methods of information resources in ECCS. A practical factor of the processing of information resources in ECCS is related with the solution of problems of formation, management and support of growing volumes of commercial content in the Internet, rapid development of e-business, widely spreader availability of the Internet, the expansion of the set of information products and services, and increasing of a demand for commercial content. Principles and IT of electronic content commerce are used while creating on-line stores (selling of e-Books, Software, video, music, movies, picture), on-line systems (newspapers, magazines, distance education, publishing) and off-line selling of content (copywriting services, Marketing Services Shop, RSS Subscription Extension), cloud storage and cloud computing. The world's leading producers of means of processing of information resources as Apple, Google, Intel, Microsoft, and Amazon are working in this area.

A theoretical factor of information resources processing in ECCS is connected with the development of IT processing of commercial content. In scientific studies of D. Lande, V. Furasheva, S. Braychevskoho, A. Grigoriev mathematical models of electronic processing of information flows are investigated and developed [1–3]. G. Zipf proposed an empirical law of distribution of word frequencies in natural language text content for its analysis. In the works of B. Boiko, S. McKeever, A. Rockley models of the life cycle of content are developed [4–13]. The methodology of content analysis for processing textual data sets was initiated and developed by M. Weber, J. Kaiser, B. Glaser, A. Strauss, H. Lasswell, O. Holsti, Ivanov, M. Soroka, and A. Fedorchuk. In the works of V. Korneev, A. F. Gareev, S. V. Vasyutina, V. V. Reich were proposed methods of intellectual processing of text information. EMC, IBM, Microsoft Alfresco, Open Text, Oracle and SAP have developed specification of Content Management Interoperability Services based on Web-services interface to ensure interoperability of electronic content commerce system management. From the scientific point of view, this segment of IT is not investigated enough. Each individual project is implemented almost from the very beginning, in fact, based on the personal ideas and solutions. In literature, very few significant theoretical studies, research findings, recommendations for the design of ECCS and processing of information results in such systems are highlighted. Appeared a need to analyze, to generalize and to justify existing approaches to implementation of e-commerce and ECCS building are proposed. The actual problem of the creation of technological products complex is based on the theoretical study of methods, models and principles of processing information resources in ECCS, based on the principle of open systems that allow managing the process of increase in sales of commercial content. Analysis of the factors enables us to infer the existence of a contradiction between the active development and extension of IT and ECCS on the one hand, and the relatively small amount of research on this subject and their locality on the other. This contradiction raises the problem of containment of innovation development in the segment of electronic content commerce through creation and introduction of appropriate new advanced IT that affects negatively the growth of this market. Within this problem there is an urgent task of developing scientifically based methods of processing information resources of electronic content commerce, and building process on the basis of software for the creation, dissemination and sustainability of ECCS. In this paper a study to identify patterns, characteristics and dependencies in the processing of information resources in ECCS was carried out. This paper detailed analysis of the system's control of the content and prospects for implementation of ECCS are proposed. Analysis of business processes, the torrent of content, tools, and models of the systems' control of the content had been made. The methods and the means of the control of commercial content, their preferences and drawbacks had been described. The basic terms and concepts had been defined and concretized. The following of them had been used in the work.

The content is the totality of all data (commercial, service, extra, etc.) that implement a certain set of meta-models (a model that describes the structure and principles of a particular model) and the models of copies concentrated among information system [14–16]. The commercial content is a part of the general content, which is the subject of the purchase, the user's use and owner's profit; textual, visual or audio content as part of the user's experience according to the information resources (text, images, audio, video and software). The content control is control functions for receiving, analyzing, saving, searching and spreading of the content [14–16]. The information product is documented information prepared and designed to meet the needs of users. The information resource is an object of the means' action and information technology; set of documents in the information systems (libraries, archives, data banks, etc.) [1–3].

The e-commerce is a field of digital economy and of e-business, including all financial and commercial transactions over computer networks and business processes associated with conducting these transactions. E-commerce content is a field of e-commerce, where the commercial content is an object of financial and commercial transactions and business processes. The e-commerce content system is a system of processing of commercial content and related information, human, technical, organizational and financial resources, to support and distribute commercial content. The content lifecycle is- a multi-complex process that takes place in the content control via the various stages/phases of the publication with a set of properties such as collaboration, records' control, digital asset and versions that are supported by various technologies [4–13].

Large torrents and volumes of different content are in ECCS. Most of these content's torrents are made up of easily formalized and automated procedures and commercial content. But there is no general approach to the process of modeling, design, development and implementation of ECCS.

The formal description of the e-commerce content is presented as

$$Y = \langle X, Q, C, V, H, Z, T, \delta \rangle, \tag{1}$$

where: $X = \{x_1, x_2 \ldots, x_{n_X}\}$ – a set of content from various sources (information re-resources, authors, moderators, editors, visitors, journalists, users, administrators, analysts) (Fig. 1) [17–18],

$Q = \{q_1, q_2 \ldots, q_{n_Q}\}$ – set of users' information requests,

$C = \{c_1, c_2 \ldots, c_{n_C}\}$ – a set of commercial content,

$V = \{v_1, v_2 \ldots, v_{n_V}\}$ – a set of conditions content maintenance and external influences on the system environment,

$H = \{h_1, h_2 \ldots, h_{n_H}\}$ – a set of processing content's conditions,

$Z = \{z_1, z_2 \ldots, z_{n_Z}\}$ – set of information resource's components,

$T = \{t_1, t_2 \ldots, t_{n_T}\}$ – time of transaction processing content,

$Y = \{y_1, y_2 \ldots y_{n_Y}\}$ – an outgoing characteristics' totality of system,

δ – an operator which form the statistics' analysis of ECCS's functioning [17–18].

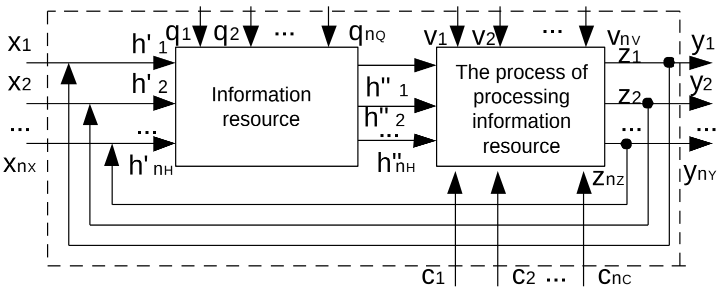

Fig. 1. Diagram of the process of e-commerce content [17–18]

The process which works up information resources (1) is described by

$$y_j(t_{p+1}) = \delta(x_i, q_d, c_r, v_l, h_k, t_p, z_w)\,. \tag{2}$$

The value $y_j = \{y_{1j}, y_{2j}, ..., y_{gj}\}$ is a totality of data over a specified period of time, where y_1 is number of visits, y_2 is average time of information resource's attendance (min: c), y_3 is a rate of refusals (%), y_4 is an achieved goal of a search, y_5 is content's dynamic (%), y_6 is the total number of viewed pages, y_7 is number of viewed pages per visit, y_8 are new visits, y_9 are absolute unique visitors, y_{10} is a traffic's source in % and so on.

The impact of the values x_i, q_d, c_r, v_l, h_k on the values z_w and y_j as a result of the e-commerce's content are unknown and unexplored. Connections between the input data, content, input data and the processing of information resources in the system are undisclosed. This justifies a goal, an actuality, expediency and a research's areas.

3. RESEARCH RESULTS ANALYSIS

The general design principles of ECCS's patterns make it possible to automate processing of resources to reduce production cycle, saving time and capacity of doing e-commerce. The main stages of the process of information resources' elaboration in ECCS are formation, control and maintenance of commercial content, with the following links: *content → content's formation → database → content's control→ informational resource or user's request → content's control→ informational resource → content's maintenance → database.* Then from (2) $\delta : X \to Y$ conveyed functions' superposition

$$\delta = \gamma \circ \beta \circ \alpha\,, \tag{3}$$

where: α – an operator of commercial content's formation,
β – an operator of commercial content's control,
γ – an operator of commercial content's maintenance.

The e-commerce content's system is presented as

$$Y = \langle X, Q, H, C, V, Z, T, \alpha, \beta, \gamma \rangle\,. \tag{4}$$

The operator of commercial content's formation α is a content's reflection c_r into new state c_{r+1}, that differs from the previous due to emergence of a new piece of content Δc which complements the previous state $c_{r+1} = c_r + \Delta c$, then

$$\alpha : (c_r, t_p, X, u_f) \rightarrow (c_{r+1}, t_{p+1}), \qquad (5)$$

where $u_f = \{u_{1f}, u_{2f}, \ldots, u_{n_U f}\}$ is set of conditions of content's formation c_r.

Commercial content c_r is presented as

$$c_r = \left\{ \bigcup_i^{n_X} x_i \middle| \begin{array}{l} \forall x_i \in X_{u_f}, x_i \notin X_{\overline{u_f}}, \exists u_f \in U_{x_i}, u_f \notin U_{\overline{x_i}}, \\ X = X_{u_f} \cup X_{\overline{u_f}}, U = U_{x_i} \cup U_{\overline{x_i}}, f = \overline{1, n_U} \end{array} \right\}, \qquad (6)$$

where the set of conditions u_f commercial content's formation c_r is defined as

$$u_f = \left\{ \bigcup_j^{k} u_{jf} \middle| \begin{array}{l} \forall u_{jf} \in U_{x_i}, \exists x_i \in X_{u_f}, u_{jf} \notin U_{\overline{x_i}}, \\ U = U_{x_i} \cup U_{\overline{x_i}}, X_{u_f} \subseteq X, f = \overline{1, n_U}, i = \overline{1, m} \end{array} \right\}. \qquad (7)$$

The operator of commercial content's control β is a reflection of commercial content c_r into new state c'_r, which is different from the previous state due to values of the defining parameters $h_k \rightarrow h'_k$ (actuality, completeness, relevance, authenticity, trustworthiness) that satisfy predefined requirements

$$\beta : (q_d, z_w, c_r, h_k, u_M, t_p) \rightarrow (c'_r, h'_k, z_{w+1}, t_{p+1}), \qquad (8)$$

where $q_d \in Q$, $h_k \in H$, $h_k = \{h_{1k}(c_r, q_d), \ldots, h_{n_H k}(c_r, q_d)\}$ is set of conditions of commercial content's control, with it is presented as

$$z_w = \left\{ \bigcup_{r=1}^{n_C} c_r \middle| \begin{array}{l} \forall c_r \in C_{q_d}, \exists q_d \in Q, \exists h_k \in H_{c_r}, c_r \notin C_{\overline{q_d}}, h_k \notin H_{\overline{c_r}}, \\ C = C_{q_d} \cup C_{\overline{q_d}}, H = H_{c_r} \cup H_{\overline{c_r}}, d = \overline{1, n_Q}, k = \overline{1, n_H} \end{array} \right\}, \qquad (9)$$

where the set of defining parameters' values form as $h'_k = h_k + \Delta h$.

The operator of commercial content's maintenance γ is a commercial content reflection c_r in the collection of values y_i, which is formed as result of the analysis, monitoring, evaluation of user's interaction, searching engines and other information resources that are the basis for making decisions about development and commercial content's control

$$\gamma : (c_r, q_d, v_l, h_k, z_w, u_S, t_p) \to y_i, \tag{10}$$

where $v_l = \{v_{1l}(q_i, h_k, c_r, z_w, t_p), \ldots, v_{n_V l}(q_i, h_k, c_r, z_w, t_p)\}$ is set of conditions of content's maintenance and impact of the environment on the system. Outgoing data is implemented in

$$y_j = \left\{ \bigcup_{l}^{n_V} v_l \left| \begin{array}{l} \forall v_l \in V_{q_d} \cup V_{z_w}, \exists q_d \in Q, \exists z_w \in Z, \exists h_k \in H_{c_r}, \\ v_l \notin V_{\overline{q_d}}, v_l \notin V_{\overline{z_w}}, V_{q_d} \subset V, V_{z_w} \subset V, d = \overline{1, n_Q}, \\ w = \overline{1, n_Z}, r = \overline{1, n_C}, k = \overline{1, n_H} \end{array} \right. \right\}. \tag{11}$$

4. METHOD OF COMMERCIAL CONTENT FORMATION

The process of content's formation for an information resource provides a mapping of the input data from different sources to the set of formed commercial content and saved in an appropriate database in the electronic commerce content

$$S(x_i) \to x_i \to X \to \alpha(u_f, x_i, t_p) \to c_r \to C \to D(C), \tag{12}$$

where $S(x_i)$ is a data source, $D(C)$ is database of commercial content.

The process of commercial content's formation is presented as

$$\alpha = \left\langle X, T, U, C, \alpha_0, \alpha_1, \alpha_2, \alpha_3, \alpha_4, \alpha_5, \alpha_6, \alpha_7 \right\rangle, \tag{13}$$

where $\alpha : X \to C$ is presented by superposition of functions

$$\alpha = \alpha_7 \circ \alpha_6 \circ \alpha_5 \circ \alpha_4 \circ \alpha_3 \circ \alpha_2 \circ \alpha_0, \text{ or } \alpha = \alpha_7 \circ \alpha_6 \circ \alpha_5 \circ \alpha_4 \circ \alpha_3 \circ \alpha_2 \circ \alpha_1. \tag{14}$$

The set $\{\alpha_0, \alpha_1, \alpha_2, \alpha_3, \alpha_4, \alpha_5, \alpha_6, \alpha_7\}$ is adequate in the content formation.

1. The operator of the commercial content's establishment is mapping of input data from various sources of information into content that is different from the previous state of the content due to its actuality.

$$\alpha_0 : (X, U_C, T) \rightarrow C_0. \quad (15)$$

2. The operator of the content's collecting is reflection of input data from the authors or systems' moderators in content that is different from the previous state of the content due to its trustworthiness and actuality.

$$\alpha_1 : (X, U_G, T) \rightarrow C_0. \quad (16)$$

3. The operator which identifies commercial content's duplication is a reflection of a commercial content into a new state that is different from the previous state according to its uniqueness.

$$\alpha_2 : (C_0, T, U_B) \rightarrow C_1. \quad (17)$$

4. The operator of content's formatting is display it's in a new state that is different from the previous state according to its format of presentation.

$$\alpha_3 : (C_1, U_{FR}, T) \rightarrow C_2. \quad (18)$$

5. The operator which identifies content's keywords is a content's reflection into a new state that is different from the previous state due to the presence of the set of keywords that describe the general content.

$$\alpha_4 : (C_2, U_K, T) \rightarrow C_3. \quad (19)$$

6. The operator which categorizes commercial content is content's reflection into a new state due to its validation, which is different from previous state due to it's belonging to the set of thematic content.

$$\alpha_5 : (C_3, U_{CT}, T) \rightarrow C_4. \quad (20)$$

7. The operator which forms content's digests is a content's reflection into a new state that is different from the previous state due to the emergence of a new piece of content as a summary of its complement previous state.

$$\alpha_6 : (C_4, U_D, T) \rightarrow C_5. \quad (21)$$

8. The operator of commercial content's selective distribution is a commercial content's reflection into a new state that is different from the previous state due to its purpose and spread among the target audience.

$$\alpha_7 : (C_5, U_{Ds}, T) \rightarrow C_6 . \quad (22)$$

It is a complex of measures of providing data control from different sources to create commercial content with a set of additional values (relevance, credibility, uniqueness, completeness, accuracy etc.). The creation of commercial content is described by the operator $C_0 = \alpha_0 (X, U_C, T)$, where U_C is a set of the conditions for creation of commercial content. The task of gathering information from the sources is described by the operator $C_0 = \alpha_1 (X, U_G, T)$, where U_G is the set of conditions of data collection from various sources . The task of identifying of doubling commercial content matter is described by the operator α_2 in form $C_1 = \alpha_2(\alpha_0(X, U_C, T), U_B)$ and $C_1 = \alpha_2(\alpha_1(X, U_G, T), U_B)$, or $C_1 = \alpha_2(C_0, U_B)$, where U_B is the set of conditions of identifying and doubling matter of commercial content.

Identifying of duplicate commercial content by content in ECCS is made with help of linguistic-statistical methods of finding common terms, lines of which form a verbal signature of commercial content (the text is unique in the factor of uniqueness $\geq 80\,\%$).

The task of scanning the commercial content and the conversion to a common format in XML is described by the operator α_3 in form

$$C_2 = \alpha_3(\alpha_2(C_0, U_B), U_{FR}) , \quad (23)$$

where U_{FR} is the set of conditions of content formatting. Processing of the content set C_2 to identify relevant keywords in meaning (terms) is based on the Zipf law and is reduced to the choice of words with an average frequency of occurrence (the most used words are ignored by using stop-dictionary, and rare words are not taken to account from text messages. Identifying keywords and concepts with the use of dictionaries is determined by the operator $\alpha_4(C_2, U_K)$ in form $C_3 = \alpha_4(\alpha_3(\alpha_2(C_0, U_B), U_{FR}), U_K)$ when $U_K = \{U_{K1}, U_{K2}, U_{K3}, U_{K4}\}$, where U_K is the collection of conditions to identify keywords and concepts in the text, U_{K1} is the set of all terms (a term is basis of the noun, noun, word combinations of the nouns or an adjective with a noun), U_{K2} is the set of frequencies of term use in the text of commercial content, U_{K3} is the set of coefficients of terms use that is based on the number of symbols without space

(2000–3000 symbols the frequency of keywords is in the range of 4–6%, up to 2000 symbols – 6–8%,more than 3000 symbols – 2–4%), U_{K4} is the set of terms which comply with the conditions of belonging to the keywords and concepts.

The set of digests C_5 is formed depending on $C_5 = \alpha_6(C_4, U_D)$, where U_D is the set of conditions of formation commercial content digests, that is $C_5 = \alpha_6(\alpha_5(\alpha_4(C_2, U_K), U_{CT}), U_D)$. Relevant content is sent to a user and loaded into the database. The sampling distribution of the content is described like $C_6 = \alpha_7(C_5, U_{DS})$, where U_{DS} is the set of conditions of the sampling distribution of content. Selective distribution of commercial content list $C_7 = \max(C_6)$ depends on the level of demand for this content. Associative rule of formation content list consists of original content list C_6 and the content list which is selected from original and derived list C_7, in other words $C_6 \to C_7$. The formation of associative rule is a formation of content list that was formed through the merger of the original and derived lists. Associative rule of the appearance of the content from the original list along with the content from the list in the database is the following operator

$$P = \varphi(C_6, C_7) = \frac{\max(C_7 \cup C_6)}{\max(C_6)}, \tag{24}$$

where $d_s = \max(C_6)$ is the maximum of the set of content C_6 when $\forall c_{6i} \in C_6 \Rightarrow c_{6i} \le d_s$; $d = \max(C_7 \cup C_6)$ is the maximum $C = C_6 \cup C_7$ with $\forall c_i \in C = (C_6 \cup C_7) \Rightarrow c_i \le d$, then

$$d_s = \max(C_6) \Leftrightarrow d_s \in D_{C_6} \wedge \forall c_{faset} \in D_{C_6} : d_s \le c_{faset}, \tag{25}$$

$$d = \max(C_6 \cup C_7) \Leftrightarrow d \in D_{C_6 \cup C_7} \wedge \forall c_{faset} \in D_{C_6 \cup C_7} : d \le c_{faset}, \tag{26}$$

where $D_{C_6} = \{c_{faset} \in C_{faset} | \forall c_{6i} \in C_6 : c_6 \le c_{faset}\}$ is the set of maxima values for C_6 at values of cardinalities set $\rho_{faset} = |C_{faset}|$, $\rho_6 = |C_6|$, $\rho_{faset} \ge \rho_6$; $D_{C_6 \cup C_7} = \{c_{faset} \in C_{faset} | \forall c_i \in (C_6 \cup C_7) : c_i \le c_{faset}\}$ is the set of maxima for $C_6 \cup C_7$ with $C_{faset} \ge (C_6 \cup C_7)$.

Indicators of profitability and growth of demand for commercial content are used to determine its relevance and calculate respectively as

$$I_p = \kappa(C_7, P) = P\frac{\max(C_6 \to C_7)}{\max(C_7)}, \tag{27}$$

$$I_g = \chi(C_7, P) = \frac{\max(C_6 \to C_7) - \max(C_7)}{\max(C_6 \to C_7)[1 - P]}. \tag{28}$$

Derived list of rules determines the moderator. The list, the formation of which exceeds the minimum level is the most used content list. Even if this condition is formed by a large number of lists of frequently used content in accordance with requests. The result is limited when the sample by operators

$$I_r = \psi(C_6, C_7, P) = \min(\forall C_6' \subset C_6, P - P'), \tag{29}$$

$$I_r = \min(\forall C_6' \subset C_6, \varphi(C_6, C_7) - \varphi(C_6', C_7)). \tag{30}$$

5. METHOD OF COMMERCIAL CONTENT MANAGEMENT

The process of content control is presented by the following scheme of links:

$$User(q_d) \to q_d \to Q \to H(c_r, q_d) \to \beta(q_d, c_r, h_k, t_p) \to z_w \to User(z_w), \tag{31}$$

where $User(q_d)$ is a formation of user's request; $User(z_w)$ is browsing by user's answers to a request q_d. The operator of commercial content's control $\beta : C \to Z$ is presented as superposition of functions

$$\beta = \beta_4 \circ \beta_3 \circ \beta_2 \circ \beta_1. \tag{32}$$

The management process of commercial content is presented as

$$\beta = \langle C, Q, H, U, T, Z, \beta_1, \beta_2, \beta_3, \beta_4 \rangle. \tag{33}$$

1. The operator of the editing and modification of commercial content

$$\beta_1 : (c_r, h_k, u_l, t_p) \to c_r'. \tag{34}$$

2. The determination operator of the block weight and formation the base search images of commercial content

$$\beta_2\ (c'_r, y_j, u_l, t_p) \to c''_r\,. \tag{35}$$

3. The operator of the determinant meanings control parameters formation

$$\beta_3 : (c''_r, h_k, u_l, t_p) \to h'_k\,. \tag{36}$$

4. The operator of information resource page formation and presentation

$$\beta_4\ (c''_r, h'_k, z_w, q_d, t_p) \to z_{w+1}, \tag{37}$$

where $h_k \in H$, $h_k, = \{h_{1k}, h_{2k}, ..., h_{mk}\}$ is the set of process parameters that control commercial traditional content (h_{1k} – actuality, h_{2k} – relevance, h_{3k} – completeness, h_{4k} – authenticity, h_{5k} – authenticity of commercial content); $u_l \in U$, $u_l = \{u_{1l}, u_{2l}, ..., u_{nl}\}$ is multiple criteria process to control commercial content (u_{1l} – the coefficient of the block location in the commercial content, u_{2l} – the coefficient of keywords in the block, u_{3l} – coefficient of the key words statistical importance, u_{4l} – the coefficient of keywords from the user request, the coefficient of the keywords volume from the request). It is a support measures for determining parameters of commercial content (actuality, completeness, relevance, authenticity, reliability) in accordance with certain requirements by the set of criteria for the management of commercial content.

Processes classification of commercial content management.

1. The management of commercial content to generate pages on demand of the user of the electronic content is commerce is field as

$$\beta_Q = \langle C, Q, H, U, T, Z, \beta_1, \beta_2, \beta_3, \beta_4 \rangle\,. \tag{38}$$

The stage of editing and modification of commercial content is served by the operator $c_j(t_{r+1}) = \beta_1(c_j, t_r, h_k, u_l)$ where $c_j(t_{r+1}) \in C$. The stage of development of pages set is described by the operator, where

$$z_i = \left\{ \bigcup_{j=1}^{m} c_j(q_i, t_r) \left| \begin{array}{l} \forall c_j \in C_q, c_j \notin C_{\bar{q}}, C_q = \beta_3(\beta_2(C_q)), \exists q_i \in Q_c, \\ \exists h_k \in H_c, h_k \notin H_{\bar{c}}, C = C_q \cup C_{\bar{q}}, Q_c \subset Q, \\ H = H_c \cup H_{\bar{c}}, k = \overline{1, n_H}, i = \overline{1, n}, r = \overline{1, w} \end{array} \right. \right\}. \quad (39)$$

The block weight is defined as the sum of the coefficients of the scales of commercial content:

$$\omega = \|C\| = \beta_2(C, \omega_1, \omega_2, \omega_3, \omega_4, \omega_5), \quad (40)$$

where: $\omega_1(c_j)$ – the coefficient of the block location in the content,
$\omega_2(c_j)$ – the coefficient of keywords in the block,
$\omega_3(c_j)$ – the coefficient of statistical significance of terms,
$\omega_4(c_j)$ – the coefficient of the availability of additional terms,
$\omega_5(c_j)$ – the coefficient of the volume of terms from the user request.

2. Management of commercial content with pages generation during editing information resource by moderator is presented as

$$\beta_E = \langle C, H, T, Z, \beta_1, \beta_2, \beta_3 \rangle. \quad (41)$$

Stage of pages set forming is described by operator: $Z(t_r) = \beta_3(C, H, t_r, \beta_1, \beta_2)$.

3. Mixed type of management of commercial content is presented as

$$\beta_M = \langle C, Q, H, T, Z, W, \beta_1, \beta_2, \beta_3, \beta_4, \beta_5 \rangle, \quad (42)$$

where: W – the set of commercial cached content,
β_5 – the operator of formation of the set of cached commercial content or information blocks when $W = \beta_5(C, \beta_3(\beta_2(\beta_1(C, t_r, H, U)), t_{r+1})$ or $W = \beta_5(Z, \beta_3(\beta_2(\beta_1(C, t_r, H, U)), t_{r+1})$,

$$w_l = \left\{ \bigcup_{i=1}^{n} c_i \middle| \forall c_i \in C_Q, C_Q \subset C, C_Q = \beta_3(\beta_2(C)) \right\}, \quad (43)$$

$$w_l = \left\{ \bigcup_{j=1}^{m} z_j \middle| \begin{array}{l} z_j \in Z_c, \forall c_j \in C_z, \exists c_j \in Z_c, \forall c_j \in z_j, \\ C_z = \beta_3(\beta_2(C)), C_z \subset C, Z_c \subseteq Z, i = \overline{1,n} \end{array} \right\}. \quad (44)$$

6. METHOD OF COMMERCIAL CONTENT SUPPORT

The process of commercial content support is presented as scheme of links $User(q_d, z_w) \to q_d \to z_w \to V(q_d, z_w, t_p) \to \gamma(v_l, h_{k,} c_r, z_w, t_p) \to y_j \to User(y_j)$.

The process of commercial content engineering support is presented as

$$\gamma = \langle Q, C, H, V, T, Z, Y, \gamma_1, \gamma_2, \gamma_3, \gamma_4, \gamma_5, \gamma_6, \gamma_7, \gamma_8 \rangle . \quad (45)$$

Content support $\gamma : Z \to Y$ is represented by a superposition of functions

$$\gamma = \gamma_8 \circ \gamma_6 \circ \gamma_5 \circ \gamma_3 \circ \gamma_1, \text{ or } \gamma = \gamma_8 \circ \gamma_7 \circ \gamma_5 \circ \gamma_4 \circ \gamma_2. \quad (46)$$

1. The operator of formation digital flows portraits of commercial content is a mapping of the set of relevant commercial content in a variety of settings, which describe the thematic needs of the target audience according to certain criteria that is defined by the moderators.

$$\gamma_1 : (V_{Pc}, C, H, Q, T) \to Y_{Pc} . \quad (47)$$

2. The operator of formation portraits of regular users is the mapping of the relevant commercial content set in a variety of settings which describe the thematic needs of the target audience according to certain criteria that is defined by the moderators.

$$\gamma_2 : (V_{Pq}, Q, H, Z, T) \to Y_{Pq} . \quad (48)$$

3. The operator of identification of thematic subjects in the plural of new content which is mapping of new commercial content set from a variety of sources of information in the set of keywords for new rubric of commercial content which describe a topic sentence of these reliable sources according to certain criteria that is defined by the moderators.

$$\gamma_3 : (C, H, X, V_T, T) \to Y_T . \quad (49)$$

4. The operator of content thematic subjects identification with a set of user requests is the mapping of multiple user requests to the set of keywords for the new content rubric which describe thematic needs of registered users according to certain criteria that is defined by moderators.

$$\gamma_4 : (C, H, Q, V_T, T) \to Y_T . \quad (50)$$

5. The operator of tabulation of the commercial content relations by keywords and frequency of visits is the mapping of commercial content in a new state, which is different from the previous large number of links content based on criteria such as thematic, the relevance factor rating, sequence and frequency of viewing, popularity, actuality, authorship.

$$\gamma_5 : (C, V_c, T) \to Y_C . \quad (51)$$

6. The operator of calculating the ratings of commercial content is the mapping of content to a new state which is different from the previous state of commercial content by the emergence of new content in the form of ratings on certain criteria that complements the previous state.

$$\gamma_6 : (C, Q, H, Y_C, V_{Rc}, T, \theta, \vartheta) \to Y_{Rc} . \quad (52)$$

7. The operator of calculating the ratings of regular users is the mapping of the set permanent portraits of classified users in a new state, which is different from the previous condition of commercial content by the emergence of a new part of the characteristics of these users in the form of ratings on certain criteria that complements the previous state.

$$\gamma_7 : (C, Q, H, Y_C, V_{Rm}, T) \to Y_{Rm} . \quad (53)$$

8. The operator of the statistical analysis of system functioning is the mapping of statistic system functioning in a collection of values, which create as result of analysis, monitoring, evaluation of user interaction, search engines and other information resources, which is the basis of making decisions regarding to the creation and management the content.

$$\gamma_8 : (Y_P, Y_T, Y_C, Y_R, Z, H, V, T) \to Y . \quad (54)$$

A analysis result of the S e-business system functioning and C commercial Web content support is formed set $Y=\{Y_P,Y_T,Y_C,Y_R\}$ under the conditions $V=\{V_P,V_T,V_C,V_R\}$, where $Y_P=Y_{Pc}\cup Y_{Pq}$ is a subset of the information portraits of Y_{Pc} content and Y_{Pq} users, Y_T is a subset of thematic storyline of content, Y_C is subset of content relationship tables, $Y_R=Y_{Rc}\cup Y_{Rm}$ is a subset of the rating content Y_{Rc} and moderators Y_{Rm}, $V_P=V_{Pc}\cup V_{Pq}$ is the conditions set of information portraits formation, V_T is a conditions set for thematic storyline identification, V_C is the conditions set of the content relationship construct tables, V_R is the parameters set of the content ratings calculation. The information portraits set of content is presented as $Y_{Pc}=\gamma_1(V_{Pc},C,H,Q,T)$, and set of the users` portraits are given as $Y_{Pq}=\gamma_2(V_{Pq},Q,H,Z,T)$.

The thematic storyline set for the content is presented as $Y_T=Y_{TC}\cup Y_{TQ}$, where $Y_{TC}=\gamma_3(C,H,X,V_T,T)$ is condition set for content storyline identification in the of new commercial content and $Y_{TQ}=\gamma_4(C,H,Q,V_T,T)$ is thematic storyline definition. The set of relationship content tables is presented as $Y_C=\gamma_5(C,V_c,T)$. The set of the content rating is presented as $Y_{Rc}=\gamma_6(C,Q,H,Y_C,V_{Rc},T,\theta,\xi)$, and a set of a moderators ratings Y_{Pq} is presented as $Y_{Rm}=\gamma_7(C,Q,H,Y_C,V_{Rm},T)$, where $V_R=V_{Rc}\cup V_{Rm}$ is the parameters set for the content ratings calculation, $\theta(Q^+,Q^0,Q^-,T,H)$ is the tonality criteria for commercial content, $\xi(Q,T)$ is operator of comments filtering definition. The Y set of output statistical data is presented as

$$Y=\{Y_P,Y_T,Y_C,Y_R\}=\gamma(V_P,V_T,V_C,V_R,C,Q,H,Z,T). \qquad (55)$$

Commercial Web content management subsystem is implemented through caching (representation module generates a page once; then it is several times faster loaded from the cache, which is updated automatically after a certain period of time or when making changes to specific sections of an information resource, or manually by administrator command) or information blocks formation (blocks conservation in the information resources editing stage and page collection from these blocks at the user request of the relevant page).

Web content support subsystem provides information portraits formation, thematic storyline identification in content flows, the content relationship tables building, content rankings calculation, new events identification in their content flows, their tracking and clustering. Analysis of commercial support content helps identify causes of the formation of the target audience for a set of characteristics of functioning of e-commerce content.

The subsystems presence of commercial Web content creation, management and support in an e-commerce content increases sales volume of commercial content to the permanent user at 9%, active involvement of unique visitors, prospective users and expand the limits of the target and regional audience by 11%, viewed pages by 12% , visiting time and information resources by 7%.

7. CONCLUSIONS

The paper is solved the actual scientific problem of methods and means research and development for commercial Web content processing in e-business systems by using the developed mathematical software for the appropriate systems creation, which made it possible maintain the life cycle of commercial content on the level of developer (the time and costs reducing for development, quality improvement through the use of proven solutions).

Software tools for content creation, management and support are developed. Design and implementation methods of electronic content commerce systems are based on online newspapers, which reflect the results of theoretical research, are developed. From the perspective of a systemic approach, the principles of applying information resources processing in electronic content commerce systems for content lifecycle implementation made the development of methods for the commercial content formation, management and support possible. An integrated method of commercial content formation for the time and resources reduction of content production is developed. This makes it possible to create a means of information resources processing and implement subsystem of automatically generated content. A method of commercial content management for the time and resources reduction of content sales was created, which makes it possible to implement commercial content management subsystem. A method of commercial content support for the time and resource reduction of the target audience analysis in electronic content commerce systems is implemented, which makes it possible to develop a commercial content support subsystem.

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CNC machine tool, diagnostic systems, positioning errors

Jerzy JÓZWIK, Przemysław MAZUREK**,*
*Marcin WIECZOREK***, Marek CZWARNOWSKI****

LINEAR POSITIONING ERRORS OF 3-AXIS MACHINE TOOL

Abstract

This paper presents results of 3-axis CNC machine tool diagnostics performed with XL-80 laser interferometer and XC-80 environmental compensation unit, including pressure, humidity and temperature sensors. Furthermore, the paper includes the methodology and results of conducted measurements of linear positioning errors, which supplied data for further analysis. The conclusion section presents important results of conducted experiments. Measurement results were presented in figures, charts and tables.

1. INTRODUCTION

Machining and machine tool technology has been developing very dynamically for many years. This results from increasing requirements for the performed parts. The development of CNC machines is focused on finding new solutions and improving existing ones. Despite great advances in machine precision (motors, spindles, gears, measurement and control systems, etc.) the need for compensation of linear and angular positioning errors has not been thus far eliminated [1, 2]. The errors enabling assessment of technical condition of the machine include linear and angular error motions, their repeatability and backlash.

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* Lublin University of Technology Mechanical Engineering Faculty,
Department of Production Engineering, 36 Nadbystrzycka Street, 20-816 Lublin, Poland,
+ 48 81 5384230, j.jozwik@pollub.pl
** The State Higher School of Vocational Education of Szymona Szymonowica in Zamość,
Institute of Natural Science and Technology, 22-400 Zamość, 64 Zamoyskiego Street,
+48 84 6380940, przemekmazurek1992@gmail.com
*** The State School of Higher Education in Chełm, Institute of Technical Sciences and Aviation,
Department of Mechanical Engineering, 54 Pocztowa Street, 22-100 Chełm,
55 Depułtycze Królewskie, +48 608120010 wew. 106, mczwarnowski@pwsz.chelm.pl;
mwieczorek@pwsz.chelm.pl

These values are affected by many external and internal factors, inter alia, geometry and kinematics of machine tools, thermal factors, drive, controller and measurement system errors, or machining-induced errors. Errors generated by the machine tool can be divided into systematic and random [1–4].

All systematic errors regardless of their type (geometric, kinematic, thermal) can be compensated with accuracy dependent mainly on the accuracy of their identification and the rate of change [5–7]. It is difficult to compensate for the dynamic errors [8–11]. Errors that occur regularly, predictably and with little dynamics can be compensated with high accuracy provided that the nature of their changes is known. Temperature changes of machine tool systems are generally slowly variable processes of inertial first-order member characteristics, relatively easy to compensate by *e.g.* linear extension of the rolling screws of a machine tool [12–14]. The main source of thermal changes are all systems which generate heat in the machine tool, such as engine, bearings, pump and the cutting process itself [1]. All systems that generate heat should be placed on the outside of the body in order to limit the effect of heat on the machine frame. These activities are designed to prevent inducing thermal deformation of the machine frame. The purpose of these procedures is to avoid the shift of shaft axes and spindles [13].

The second group of errors are stochastic problems. The errors belonging to this group are much more difficult to compensate, owing to the lack of functional equations describing their occurrence. It is during the planning stage that active vibration reduction systems are designed and applied to limit the occurrence of such errors. Factors which contribute to random errors are predominantly vibrations induced while cutting, the weight of the machine and the heat from the production hall [11, 12].

2. THE MEASUREMENT SYSTEM AND TESTING METHODOLOGY

Experimental tests were conducted at Engineering Studies Center of The State School of Higher Education in Chełm. The accuracy and repeatability of positioning tests were performed on a vertical machining centre DMU 635 with Heidenhain TNC 620 (Fig. 1a). The measurement was performed with a portable laser measurement system XL-80 with a dedicated software driver [5, 6] (Fig. 1b), which employs the light of a known wavelength as a measure of length.

a) **b)**

Fig. 1. Diagnostic stand during tests: a) vertical machining center DMC 635, b) laser interferometer XL-80 [5]

The measurement consists in counting the wavelength of the light incident on the optical detector. This allows high precision positioning measurements [3–5]. According to the manufacturer of the interferometer, the accuracy of the measurement of linear displacement with no thermal expansion compensation is MPE = ± 0.5 ppm. Detailed analysis of the uncertainty of this measurement allows accuracy at a 95% confidence level ($k = 2$), at a level of about 6 microns per meter length of the axis and at a temperature difference of 5° C of normal temperature. Temperature, pressure and humidity conditions during the measurements necessitated the compensation of laser wavelength, which significantly increased measurement accuracy [13].

The system is based on a set of laser sensors, compensator and tripods with a table. The measurement points for each axis were programmed at 50 mm intervals, including the zero point, to the farthest point of the machine at a predetermined pitch. The measurement range of the X-axis is 635 mm, of the Y-axis is 510 mm and in the case of the Z-axis up to 460 mm [3–7]. Programmed measurement points for each axis are presented in Table 1.

Tab. 1. Programmed measurement points for each axis [source: own study]

Axis	**Programmed measurement points Pi [mm]**												
X	0	50	100	150	200	250	300	350	400	450	500	550	600
Y	0	50	100	150	200	250	300	350	400	450	500	-	-
Z	0	50	100	150	200	250	300	350	400	450	-	-	-

Tab. 2. Positioning tolerances of axes up to 800 mm [10]

Tolerance		Axis measurement range [mm]	
		≤500	>500 ≤800
Bi-directional positioning accuracy of an axis	A	0.022	0.025
Unidirectional positioning accuracy of an axis	A↑ and A↓	0.016	0.020
Bi-directional repeatability of an axis	R	0.012	0.015
Unidirectional repeatability of an axis	R↑ and R↓	0.006	0.008
Reversal value of an axis	B	0.010	0.010
Mean reversal value of an axis	$\bar{B}$	0.006	0.006
Bi-directional positioning systematic error of an axis	E	0.015	0.018
Unidirectional positioning systematic error of an axis	E↑ and E↓	0.010	0.012
Mean bi-directional positioning error of an axis	M	0.010	0.012

The tests employed a bi-directional alternate strategy. The number of passes for the X-axis and Z is 3, and the Y-axis is 4. In order to diagnose the precision of machine tools the tolerance table for machining centers with normal accuracy contained in the standard ISO 10791-4: 2001 was employed (Table 2). The obtained results were subsequently processed according to the standard ISO 230-2 with the use of XCal-View 2.2 software [11].

3. RESULTS AND ANALYSIS

Conducted measurements produced a positioning accuracy waveform changes as a function of length of measured axis. The tests were repeated bi-directionally with double precision for each axis.

Fig. 2 shows the results of the X-axis accuracy according to the standard ISO 10791-4:2001. Figs. 2 and 3 show that the maximum error is 10.5 µm at the measurement point of 500 mm. Fig. 2 shows that the bi-directional positioning accuracy is 12.5 µm and the mean error is 0.2 µm. The trend observed in X-axis measurement is degressive (decreasing). The absolute value of deviation equals 10.5 µm.

Fig. 3 presents the results of the Y-axis measurements developed in accordance with the standard PN-ISO 10791-4: 2001. Y-axis exhibited highest bi-directional positioning accuracy of 4.6 µm. The analysis of the error changes leads to the conclusion that the test of Y does not represent any growing trend. The resulting values do not exceed 2 µm with the exception of the last measurement point, where the value of 2 µm was by 0.7 µm.

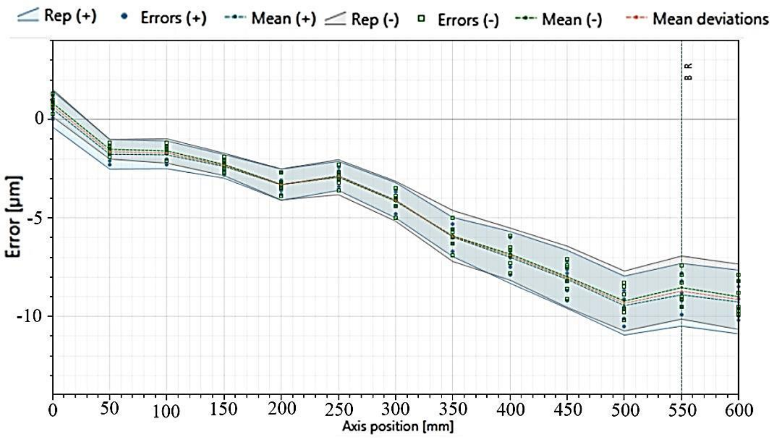

Fig. 2. Bi-directional positioning accuracy of X-axis of 3-axis milling machine DMU 635 eco as function of measurement point position [source: own study]

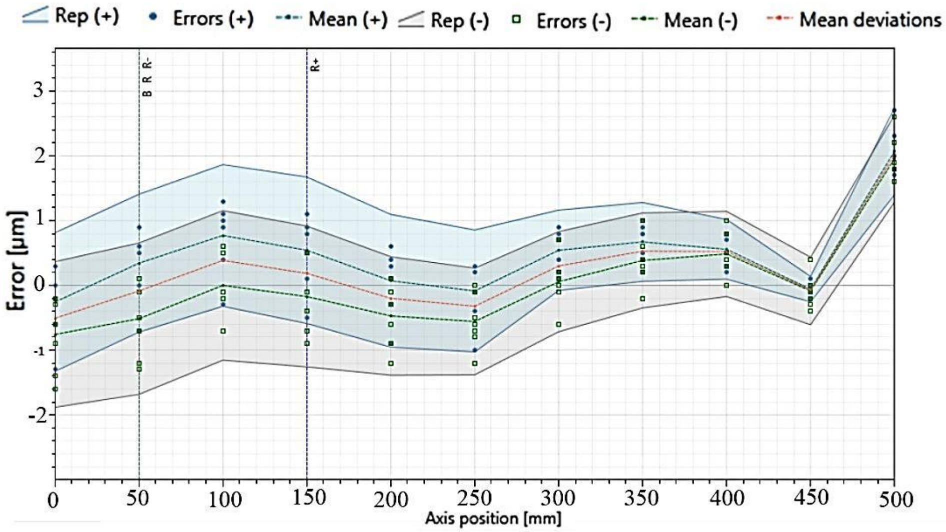

Fig. 3. Bi-directional positioning accuracy of Y-axis of 3-axis milling machine DMU 635 eco as function of measurement point position [source: own study]

Fig. 4 presents the tests results of the Z-axis. The results were prepared in accordance with the standard ISO 10791-4: 2001. Fig. 4 presents error values amounting to 23.7 microns occurring at the last measurement position of the axis, 450 mm. The value obtained at the position of 450 mm exceeds the tolerance for bi-directional positioning error. The changes indicate growth of inaccuracy in the positive direction.

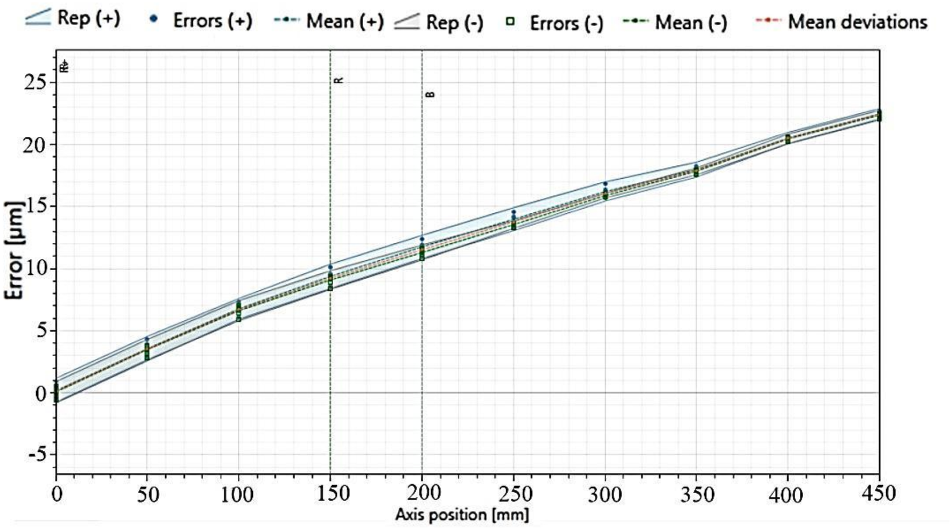

Fig. 4. Bi-directional positioning accuracy of Z-axis of 3-axis milling machine DMU 635 eco as function of measurement point position [source: own study]

Fig. 5 shows experimental results of linear positioning of a 3-axis machining center DMC 635 in all analysed axes. The graph shows that the lowest error values were observed in the Y-axis.

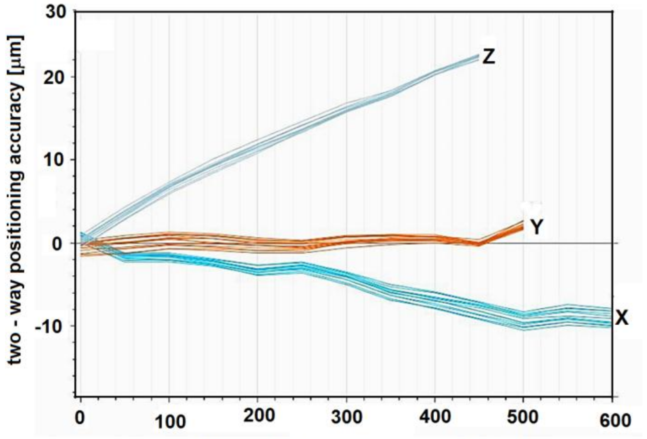

Fig. 5. Bi-directional positioning accuracy of X, Y, Z-axis of 3-axis milling machine DMU 635 eco as function of measurement point position [source: own study]

Table 3 shows a comparison of obtained accuracy parameters with the standard tolerances described in the norm ISO 10791-4: 2001. Green bars denote compliance with the standard, whereas red indicate the lack of compliance (marked as "-" in Table 3) as they exceed the tolerances presented in the standard (Table 3).

Tab. 3. Comparison of the received parameters of table positioning accuracy tolerance [source: own study]

Tolerance		measurement range of axis [mm]		measurement results of errors [μm]					
		≤500	>500 ≤800	X		Y		Z	
Bi-directional positioning accuracy of an axis	A	22.0	25.0	12.5	✓	4.6	✓	23.7	-
Unidirectional positioning accuracy of an axis	A↑ and A↓	16.0	20.0	12.3	✓	4.5	✓	23.7	-
Bi-directional repeatability of an axis	R	12.0	15.0	3.6	✓	3.1	✓	2.0	✓
Unidirectional repeatability of an axis	R↑ and R↓	6.0	8.0	3.3	✓	2.3	✓	2.0	✓
Reversal value of an axis	B	10.0	10.0	0.4	✓	0.9	✓	0.5	✓
Mean reversal value of an axis	$\bar{B}$	6.0	6.0	0.2	✓	0.4	✓	0.2	✓
Bi-directional positioning systematic error of an axis	E	15.0	18.0	10.3	✓	2.8	✓	22.4	-
Unidirectional positioning systematic error of an axis	E↑ and E↓	10.0	12.0	10.1	✓	2.7	✓	22.3	-
Mean bi-directional positioning error of an axis	M	10.0	12.0	10.0	✓	2.5	✓	22.3	-

For the X-axis tolerances are specified for the measurement range from 501 to 800 mm. Y and Z are compared with measurement tolerances of up to 500 mm. In the Z-axis unidirectional and bi-directional positioning accuracy exceeded the tolerances of the standard ISO 10791-4: 2001. Unidirectional and bi-directional positioning systematic error, mean deviation bi-directional positioning also exceeded the prescribed tolerances. The tolerances for the X and Y are within the range of values allowed by ISO 10791-4: 2001.

Table 3 and Fig. 6 show that the Y-axis achieved the highest accuracy. Best values for the Y-axis were obtained for bi-directional positioning accuracy and for bi-directional systematic positioning error, mean bi-directional positioning error produced the best results in the case of this axis, in comparison to the X-axis and Z. Only the positioning repeatability is slightly worse than for the Z-axis.

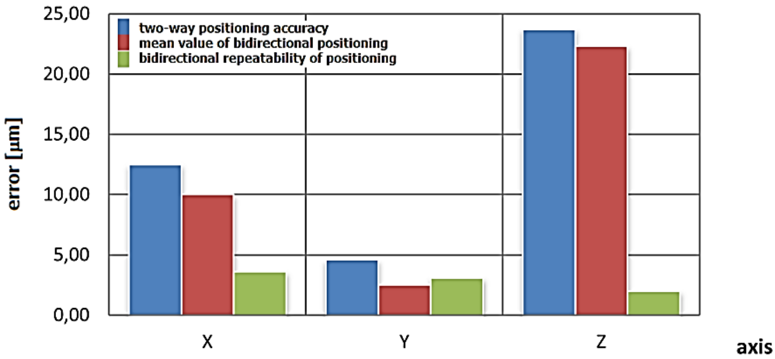

Fig. 6. Bi-directional positioning accuracy, mean bi-directional positioning error, bi-directional repeatability in micrometers [source: own study]

Table 4 presents the values inserted into the machine control system to compensate the Z-axis errors.

Tab. 4. Table of error compensation in Z-axis [source: own study]

Table of error compensation in Z-axis					
Rate	Location [mm]	Connectedly [µm]	Rate	Location [mm]	Connectedly [µm]
1	0	0	6	250	-3
2	50	-3	7	300	-2
3	100	-4	8	350	-2
4	150	-2	9	400	-2
5	200	-2	10	450	-2

Table 4 was generated automatically by software XCal-View based on the results shown in Fig. 5.

4. SUMMARY AND CONCLUSIONS

Vertical machining center DMC 635 shows high accuracy in X and Y-axis. The results of the X and Y-axis compared with Table 3 demonstrate excellent performance accuracy. In the X-axis a characteristic decrease of the positioning accuracy is noticeable. Z-axis exceeds 5 of 9 deviations contained in the PN-ISO 10791-4: 2001, as presented in Table 3. The overrun of the tolerances of bi-directional positioning accuracy is noticeable in Fig. 5. Error compensation table for the Z-axis is shown in Table 4. The Z-axis demonstrates an increasing positioning error trend with the increase of distance from the first measurement point, in the positive direction.

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Introduction

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