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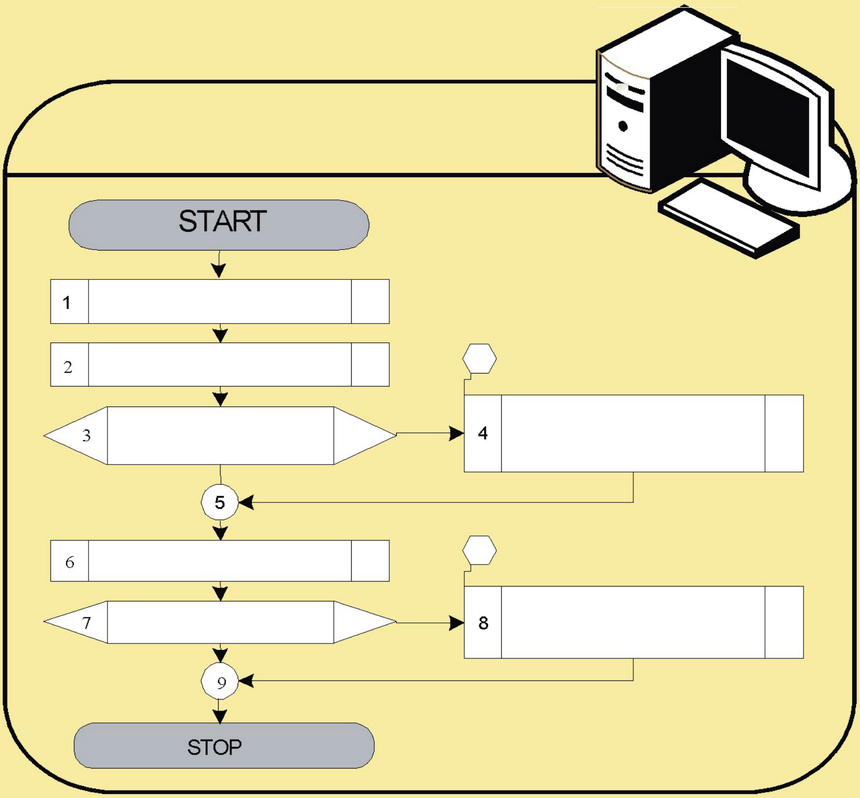

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APPLIED COMPUTER SCIENCE

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CONTENTS

commercial content, information resource, content analysis, content search, content monitoring, content lifecycle, electronic content commerce system

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SET-THEORETIC MODELS AND UNIFIED METHODS OF INFORMATION RESOURCES PROCESSING IN E-BUSINESS SYSTEMS

Abstract

In the given article is functional logistic model of commercial content processing as the content life cycle stage in electronic commerce systems proposed. The model of commercial content processing describes the information resources forming in electronic content commerce systems and automation technology simplifies the commercial content management. In the given article the main problems of electronic content commerce and functional services of commercial content processing are analyzed. The proposed model gives an opportunity to create an instrument of information resources processing in electronic commerce systems and to implement the subsystem of commercial content formation, management and support.

1. INFORMATION

The Internet active development promotes the needs growth in production/strategic data and new forms of information services implementation [1-5, 7-9]. Documented information is an informational product or commercial content, if it is prepared in accordance with user needs and intended to meet them [2, 13-23]. Electronic content commerce systems development and implementation is one of the e-business development strategic directions. A characteristic feature of such systems is the automatic information resources processing to increase content sales of permanent user, for potential users active involvement and expanding the target audience boundaries [5]. Specialists in designing, implementation and deployment of electronic content commerce

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systems (ECCS) deal with the information resources processing at various levels. They contribute to the goal to increase sales volumes of content a regular user, the active involvement of potential users and the boundaries expansion of the target audience [1, 2, 5, 9]. The special feature of ECCS is as follows [1-12]: open – access for all companies and users; global – access from anywhere in the world; unlimited in time – available at any time of the day/week/year; frankness – a low barrier to market entry; direct interaction with the user – reducing the channels of distribution and elimination of intermediaries production; information products and information services testing and implementation; automatic processing requests; automatically track information about users; reducing costs for the business operation; providing more information in online [2]. The modern market is characterized by an increase in demand for commercial content and growth proposals in public enterprises and public institutions [1-2]. Using commercial content helps optimize the management, trade and economic strategy and long-term development programs for production. It is associated with an increase in the complexity of management and implementation of systems using the predictive content of character. Specialized information resources are most type's users of commercial content, e.g., online newspapers, online magazines, online publishing, etc.

2. METHODOLOGY OF COMMERCIAL CONTENT PROCESSING

The actual problem in the electronic content commerce systems design, development, implementation and maintenance is to the research active development in the e-business. An important problem is the lack of theoretical justification, standardized methods and software for information resources processing in such systems. There are new approaches and solutions to this problem. But the important issue is the discrepancy between the known methods and software of information resources processing and the electronic content commerce systems construction principles. There is no common approach of electronic content commerce systems creation and standardized methods of information resources processing in these systems. One of the modernity main features is the constant growth rate of content production. This process is objective and positive. But there is one big problem. Progress in the content leads production to a decrease in the general awareness level of the potential user. Increased content leads to the impossibility of his immediate processing and its spread speed. In addition there was also a specific problems number [2, 7-9, 12-23]. The initial information in ECCS operation process is evidence of appointment and conditions of the system. They define the main purpose simulation ECCS. They also make it possible to formulate the requirements for systems S and content processing subsystems [2]. ECCS model is

$S = \langle X, C, V, H, Function, T, Y \rangle$, which X – entrance effects on the system; C – the content impact on the system; Q – the users impact on the system; V – the external environment; H – the internal parameters of the system; Z – information resources components of system; T – time transaction of the content processing; Y – output characteristics of the system [10]. The quantities x_i, c_r, v_l, h_k, y_j are the elements of disjoint subsets. They contain deterministic and stochastic components [10]. The process of ECCS S operation described by the function $y_j(t_i + \Delta t) = Function(x_i, c_r, v_l, h_k, t_i)$ [2, 10], where x_i – the requests for information of visitors/users to ECCS. According to Google Analytics from [5] y_j – the number of visits per time period Δt; the average time on site (min: c); rate of failures (%); achieved goal; dynamics (%); the number of all browsing; the number of page views for each visit; new visits (%); absolute unique visitors; traffic sources in %. Effects for c_r, v_l, h_k values on y_j to ECCS is unknown and unexplored [2].

3. SET-THEORETIC MODELS OF INFORMATION RESOURCES PROCESSING IN E-BUSINESS SYSTEMS

The main subsystems of information resources processing in ECCS are the content formation, management and support, the circuit connections which is as follows [2]: *content formation → content management → content support.* Model of electronic content commerce systems presented as:

$$S = \langle X, Q, Formation, H, C, V, Management, Support, Z, T, Y \rangle, \tag{1}$$

where: $X = \{x_1, x_2 \ldots, x_{n_X}\}$ – set of input data $x_i \in X$ from different sources at $i = \overline{1, n_X}$,

$Q = \{q_1, q_2 \ldots, q_{n_Q}\}$ – set of user queries $q_d \in Q$ while $d = \overline{1, n_Q}$,

$Formation$ – the operator of content formation,

$H = \{h_1, h_2 \ldots, h_{n_Y}\}$ – set of internal parameters $h_k \in H$ of the system S when $k = \overline{1, n_H}$,

$C = \{c_1, c_2 \ldots, c_{n_C}\}$ – set of commercial content $c_r \in C$ at $r = \overline{1, n_C}$,

$V = \{v_1, v_2 \ldots, v_{n_V}\}$ – set of the influence parameters $v_l \in V$ of the environment on the system S at $l = \overline{1, n_V}$,

$Management$ – the operator of content management,

$Support$ – operator of commercial content support,

$Z = \{z_1, z_2 \ldots, z_{n_Z}\}$ – set of information resource pages $z_w \in Z$ of in the system S at $w = \overline{1, n_Z}$,

$T = \{t_1, t_2 \ldots, t_{n_T}\}$ – time $t_p \in T$ transaction of information resource processing in the system S when $p = \overline{1, n_T}$,

$Y = \{y_1, y_2 \ldots y_{n_Y}\}$ – set of statistical data $y_j \in Y$ in system at $j = \overline{1, n_Y}$.

4. CONTENT FORMATION METHOD

The commercial content formation for information resource provides a link between the input data from different sources set and the commercial content set into the appropriate database in electronic content commerce systems that can be presented as $Sourse(x_i) \rightarrow x_i \rightarrow X \rightarrow Formation(u_f, x_i, t_p) \rightarrow c_r \rightarrow C \rightarrow DataBase(C)$, where $Sourse(x_i)$ – content source, x_i – matched content from the source, X – the relevant sources data set, $Formation(u_f, x_i, t_p)$ – content formation operator in a fixed time t_p under u_f appropriate conditions, c_r – formed content under u_f conditions, C – generated content set, $DataBase(C)$ – commercial content prevailing database. Content formation model in electronic content commerce systems can be showed as

$$Formation = \left\langle \begin{matrix} X, Gathering, Formatting, KeyWords, Backup, \\ Caterization, BuDigest, Dissemination, T, C \end{matrix} \right\rangle, \qquad (2)$$

where: $X = \{x_1, x_2 \ldots, x_{n_X}\}$ – input data set $x_i \in X$ from different information resources or the moderators at $i = \overline{1, n_X}$,

$Gathering$ – content collecting/creating operator from various sources;

$Formatting$ – content formatting operator,

$KeyWords$ – the content key words and concepts identify operator;

$Categorization$ – content categorization operator,

$Backup$ – the content duplicate detect operator,

$BuDigest$ – content digest formation operator,

$Dissemination$ – content selective distribution operator; $T = \{t_1, t_2 \ldots, t_{n_T}\}$ – the content forming transaction time $t_p \in T$ while $p = \overline{1, n_T}$, $C = \{c_1, c_2 \ldots, c_{n_C}\}$ – a content set $c_r \in C$ with $r = \overline{1, n_C}$.

The content formation is described by the form $c_r = Formation(u_f, x_i, t_p)$ operator, where u_f – the content formation conditions set, i.e. $u_f = \{u_1(x_i), \ldots, u_{n_U}(x_i)\}$. Commercial content submitted as follows:

$$c_r = \left\{ \bigcup_f u_f \middle| (x_i \in X) \wedge (\exists u_f \in U), U = U_{x_i} \vee U_{\overline{x_i}}, i = \overline{1,m}, f = \overline{1,n} \right\} \tag{3}$$

that the data set convert following steps passing in a relevant, formatted, classified and validated content set:

$$x_i \in X \rightarrow Gathering(u_f, x_i, t_p) \rightarrow Backup(c_r, u_b, t_p) \rightarrow Formatting(c_r, t_p) \rightarrow$$
$$KeyWords(c_r, t_p) \rightarrow Categorization(c_r, t_p) \rightarrow BuDigest(c_r, t_p) \rightarrow$$
$$Dissemination(c_r, t_p) \rightarrow c_r \in C.$$

Decisions that can help to navigate in the dynamic input information from different sources, provide the data syndication $C = Gathering(X, U_G, T)$, i.e. information gathering from sources and its fragments for further distribution according to user needs, where X – content set from data different sources, U_G – data collecting conditions set from various sources, $Gathering$ – the content collecting/creating operator, T – the content collection/creation time.

Content duplicate detecting marked by the operator as

$$C = Backup\big(Gathering(X, U_G, T), U_B\big), \tag{4}$$

where: X – content set from data different sources,

U_B – text content duplication identify conditions set,

$Backup$ – the text content duplication identify operator,

C – content set. Content duplicate identifying in text is based on the linguistic statistical methods for general terms detecting, which a content form the verbal signature chain.

Content syndication technology contains data collect programs learning process with the individual sources structural characteristics (of information resources, from moderators, users, visitors, journalists and editors), content direct scanning and bringing the total:

$$C = Formatting\big(Backup\big(Gathering(X, U_G, T), U_B\big), U_{FR}\big), \tag{5}$$

where: $Formatting$ – content formatting operator,

U_G – data collecting conditions set from various sources,

$Gathering$ – the content collecting/creating operator,

U_{FR} – information formatting conditions set,

T – the content collection time.

A content set C developing to keywords identify is built on the keywords finding principle in content (terms), based on the Zipf's law and reduced to the words choice with an occurrence average frequency (the words most used ignored by stop-dictionary, and rare words from messages text do not into account). Keywords and concepts identify defined by the operator $KeyWords(C)$ and the operator described the form:

$$C = KeyWords(Formatting(Backup(Gathering(X, U_G, T), U_B), U_{FR}), U_K) \tag{6}$$

,

where $KeyWords$ – the content keywords and concepts identify operator that is implemented as a processes set, using the presented chart in Fig. 1; $Formatting$ – content formatted operator; U_G – data collecting conditions set from various sources; $Gathering$ – the content collecting/creating operator; U_{FR} – conditions data formatting set; T – the content collection time; U_K – keywords and concepts identify conditions set.

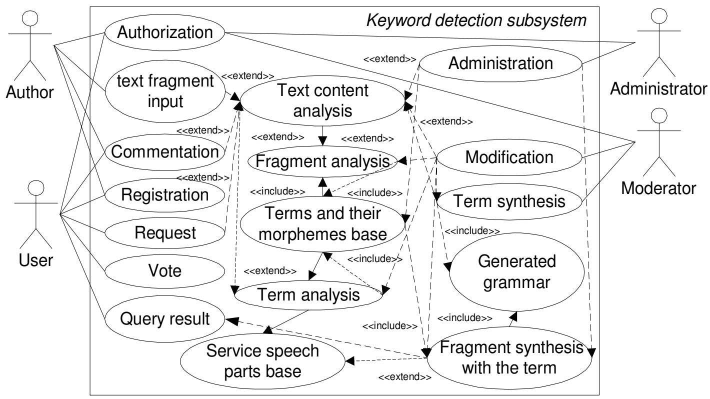

Fig. 1. Use case diagram for the content keywords identifying process [source: own study]

Content analysis for compliance thematic requests to $C_{Ct} = Categorization(KeyWords(C, U_K), U_{Ct})$, where $KeyWords(C, U_K)$ – the key-words identify operator, $Categorization$ –content categorize operator according to the keywords identified, U_K – keywords identify conditions set, U_{Ct} – categorization conditions set, C_{Ct} – rubrics relevant content set. Digest set formed by such dependence as $C_D = BuDigest(C_{Ct}, U_D)$, where $BuDigest$ – digests forming operator, U_D – conditions set for the digests formation, C_{Ct} – rubrics relevant content set, i.e.

$$C_D = BuDigest(Categorization(KeyWords(C, U_K), U_{Ct}), U_D). \tag{10}$$

Content sent by users and uploaded into thematic database. Content selective distribution described as $C_{Ds} = Dissemination(C_D, U_{Ds})$, where C_{Ds} – content selectively distributed set, U_{Ds} – content selective distribution conditions set, $Dissemination$ – the content selective distribution operator.

Terms searching is defined using terms/morphemes database, speech service part database and text analysis rules. Based on the generated grammar rules perform correction term according to its use in context. Classification and content distribution means is an information retrieval system for content selective distribution (Content Router).

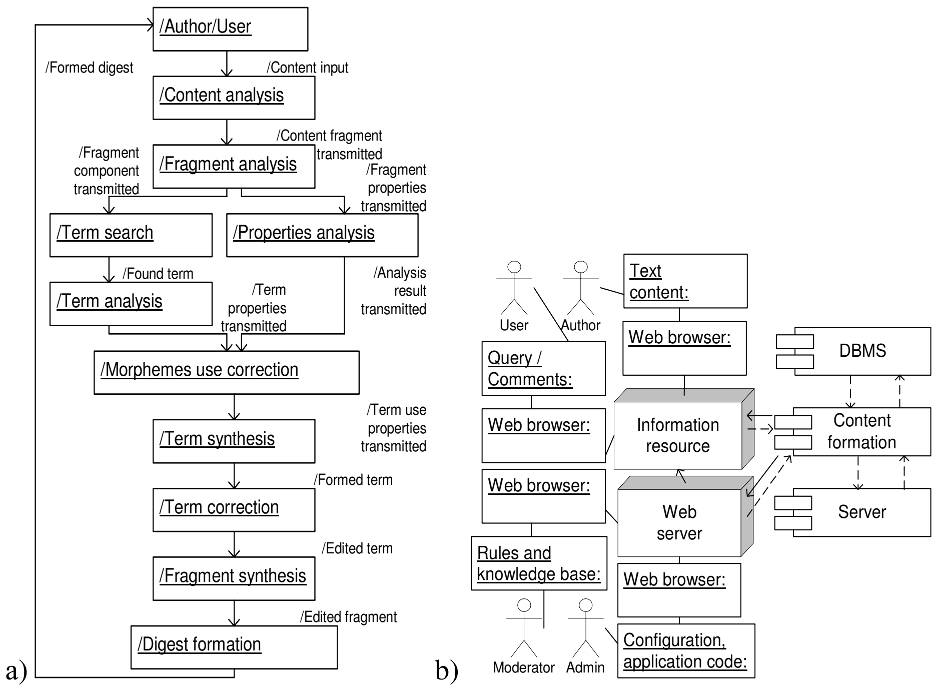

Fig. 2. a) Cooperation diagram and b) components diagram for the process to content subject keywords find [source: own study]

In Fig. 2, a submitted cooperation diagram for content subject keywords identifying process. The text lexical-grammatical and semantic-pragmatic construction analysis used in the content automatic categorization, whose main task is to find text in the content flow through the content analysis that best matches the content topics and user needs. After text fragment and term analysing is the new term synthesis as a content topic keyword. In Fig. 2, b submitted component diagram for content topic keyword process. The keywords detecting principle by content (terms) is based on the Zipf law. Process reduced to the words choice with use average frequency (the most-used words ignored by the dictionary, and rare words in the text do not include) using terms and their morphemes database. In Fig. 3 activity diagram for the content subject keywords identifying process is showed. The present method next step in the content forming is the content categorization.

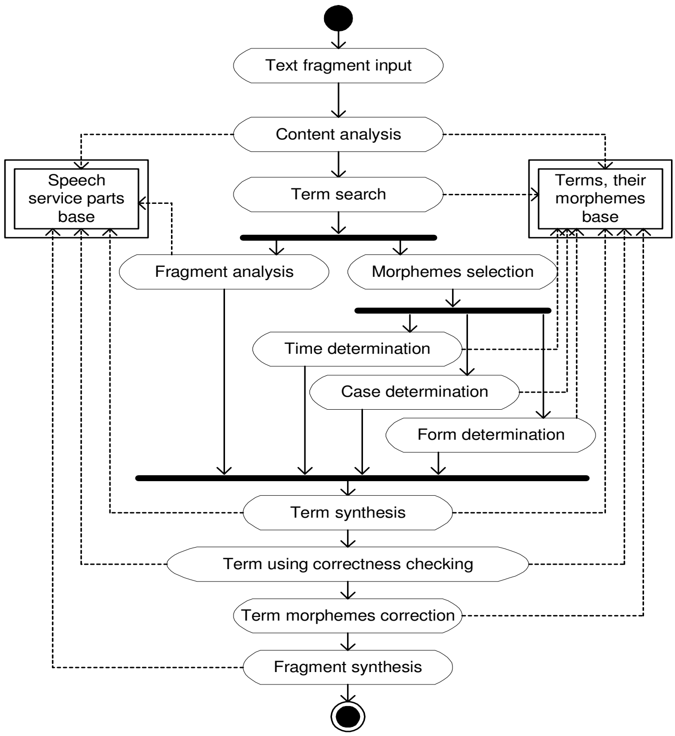

Fig. 3. Activity diagram for the content subject keywords identifying process [source: own study]

5. CONTENT MANAGEMENT METHOD

The commercial content life cycle presented in the form next major processes communication as *source → content formation → database → content management → user → content implementation → database.* ECCS model $S = \langle X, Formation, C, Management, Realization, Y \rangle$, where $X = \{x_1, x_2, \ldots, x_{n_X}\}$ – input data set, $Formation$ – content formation operator, $C = \{c_1, c_2, \ldots, c_{n_C}\}$ – content set, $Management$ – content management operator, $Realization$ – content implementation operator, $Y = \{y_1, y_2, \ldots, y_{n_Y}\}$ – output data set. Below is the content management models classification.

1. Pages generate per request is submitted in the form of the following main stages connection *Content → content editing → Database → content presentation → informational resource.* Pages generate model on demand as $Management_Q = \langle X, C, Q, R, Edit, Y \rangle$, where X – input data set, C – content set, Y – pages generated set, Q – query set, R – pages formulation and submission function, $Edit$ – content editing and updating function.
2. Pages generate model while editing is presented as the next major stage of communication *Content → content editing → database → informational resource.* When making changes to the site content creates a static *pages* set. Not is taken into account interactivity site between visitors and content. Pages generation system model while editing as $Management_E = \langle C, Edit, Y \rangle$, where C – content set, Y – static pages set, $Edit$ – content editing function. The pages formation described function as $\vec{y}(t) = Edit(\vec{c}, Weight, t)$.
3. Pages generate mixed model combines the advantages of the first two types and is presented as a communications major stages *Content → content editing → Database → content analysis → blocks collection → content presentation → informational resource.* Mixed type model is as $Management_M = \langle X, C, Q, R, Edit, Caching, Y \rangle$, where X – input data set, C – content set, Y – pages generated set, Q – query set, R – pages formu-lation and submission function, $Edit$ – content editing and updating function, $Caching$ – cache formulation function. Cache is update automatically (after a certain period or when amending certain site sections) or manually (team administrator). Another approach is to maintain information blocks on the editing site stage. Then the pages collected from these units when requesting user. The process is implementing caching. The module generates submission page once. Then it is several times faster downloading from the cache.

User queries content analysis allows to qualitatively assess the content flow in the system. This facilitates the subsequent decisions by the moderator as follows: the problem situation description and study purpose search; precise definition of the study object and subject; the object preliminary analysis; concepts substantial clarification and empirical interpretation; the procedures description for the properties and phenomena registration; the overall study plan determining; the definition of the sample type, sources collection and so on. Qualitative content analysis is intended to provide the necessary means moderator for results analysis (Table 1). With their help identify the content properties and test them on the general content stream. Then apply the content stream general properties on its specific thematic part.

Tab. 1. Qualitative content analysis stages

Stage name	Stage characteristics
Text wrapping on blocks	Integrated content units are formation for encoding and processing.
Content stream reconstruction	The values, thoughts, views systems and arguments are reconstruction of each source text.
Conclusions forming	Generalizations are withdrawal by comparing individual system values.

Quantitative content analysis consists of the stages presented in Table 2. Main task for content management process are the following items: a database create and access to it; the operational and retrospective databases forming; databases rotation; users work personalization; personal needs and sources protection; work statistics keeping; search ensuring in database; output forms generation; interaction with databases of other subsystems. In Table 3 presents the content management key stages in the electronic content commerce systems.

Tab. 2. Quantitative content analysis stages

Stage name	Stage characteristics
The analysis unit selecting	Linguistic unit convert in the form for processing.
Units frequency counting	Relationships are identifying between linguistic units.
Categorization	Categories finite and excess aggregate are determining to obtain quantitative data of their appearance. Categories irregular sequence is clustering (into groups and classes division). And on the basis of new generalized categories is received.
Data Mining	New knowledge is identifying in the content flow through multiple quantitative evaluations. Next qualify them as categories.
Results interpretation	Content and semantically-filled results are getting. For this purpose use various statistical mathematical methods and semantic formalisms.

Tab. 3. Content management stages

Stage name	Process name	Process features
Content editing	content themes definition	creating goal, the content and structure formation;
	form definition of content presentation	graphic information; the text (article, news release, job descriptions); HTML templates; back-end code, etc.;
	management tools selection	HTML editors, processors word; visual tools for creating objects;
Content analysis	rights access assignment	full or limited access to content;
	process identifying	standard processes of new information content creation/ publishing;
	content saving	in a database or repository;
	processes logging	creation, transmission and storage processes;
	information interactive	information about the next performer content;
	events audit	content versions save;
	text content analysis	quantitative or qualitative;
	versions access	support the possibility of users appealing to previous content versions;
	business process analysis	objectives, roles and tasks definition; roles default to user groups; business processes development for all content;
Content presentation	static	without any logic behavior;
	dynamic	personalization (rules/filters), globalization, localization.

As information technology basis considered annotated database in search engines. It contains an index, inverse, dictionary tables, etc. In content management systems creates a database search primary content pattern (PCP). They used clustering technology (automatic forming groups with similar content on the criteria PCP). In content management systems formed database annotations for used in the search process. Clusters database each record is corresponding cluster definitions and containing its description. Database record is performing automatic abstracting methods (digest is formation of text statistical analysis methods). These methods are used to create the PCP and descriptions of available users (Fig. 4). Personalization based rules is the content provision to specific users or users groups of conventional business logic using. For example, using a rule where all those interested in children's books fall into the group that focused advertising children's clothing. Rules developed on the content basis that type users in a registration card. In content management systems use algorithms categorization with personalization using filters (intelligent agents). Also, algorithms use based on the content analysis of user behaviour. In particular, he analyses the content to which the user accesses, the sites visited and more. That is constantly conducted analysed registered user and user's group history with priorities an overwhelming number for interest.

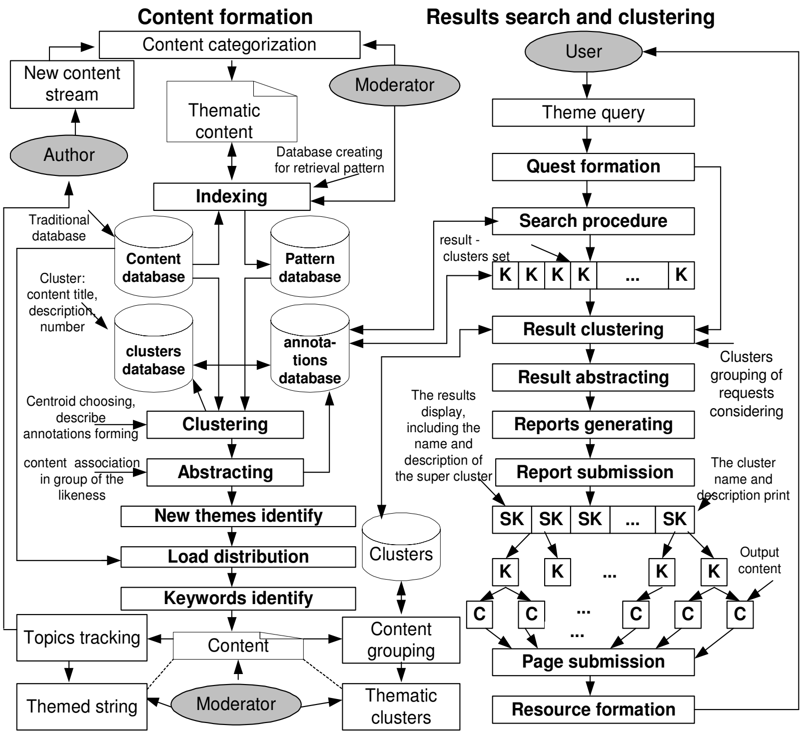

Fig. 4. Scheme of the electronic content commerce systems functioning from annotated database [source: own study]

The full-text search problem in large content arrays is ineffective. The annotated content search solves the problem exactly: instead of the full content searching to search on annotations (search content pattern). Digest remotely similar content and often not perceived by person. But as the search content pattern with weighted keywords and phrases it leads to adequate results with full-text search. Digest constructed from content fragments with the largest weight values. Content analysis is used for digests automatic generation, the concepts (categories) relationship automatic detection, relationships automatic clustering to the most important identify, the relationships automatic detection (e.g., positive and negative). One of the most important tasks in content analysis is the categorization process. It sets the conceptual grid. In its terms is the content flow analysing and new categories generate.

6. CONTENT SUPPORT METHOD

Content support method provides information portraits formation; digests formation; thematic content identification; concepts relationship tables' construction; concepts ratings calculation; new developments identification, their tracking and clustering. The fully functional ECCS is characterized complex system of interrelated operations, methods, techniques. The annotations database creating is a search images database creating of original content and their clustering (to the content group formation with close on some criteria of search images). Annotation base (search pattern of clusters used in the search process) is associated with the cluster base. Each entry corresponds to its specified cluster and description containing. This description is made of automatic abstracting methods.

Content analysis of textual information allows determine the signs prevalence of researched content in ECCS. It is important not as an absolute, but the relative importance of attributes, i.e. characteristics of the place (shares) among other features. For example, this is the percentage of forum users discussion of economic Issues concerning political or the percentage of positive comments on articles regarding the negative and in respect of all comments on this category of articles in online newspapers. The degree of correlation between the features in the texts provides empirical data to understand of the functional links between elements reflected in the texts reality e.g. the audience mood determination of online newspaper about the economic or political situation in the country and/or world. If there are texts that have chronological sequence received number fixed in time portraits of the investigated reality (change in demand for a content category according to the season, such as winter read more fiction and detective stories – summer) or the target audience portraits (change in demand for a content category according to the article, for example, demand for political articles before the election). This allows to put forward hypotheses of the prognostic character about the system functioning.

In digest formation using content analysis with regard to frequency weights of words from the concepts dictionary generated. The digest formation consists of algorithms of the concepts dictionary forming (alg. 1), of the content duplicate definition (alg. 2) and of the digest create (alg. 3).

<u>Algorithm 1. Concepts thematic dictionary formation.</u>

Stage 1. Concepts alphabetical-frequency vocabulary formation.

Step 1. Sequential selection of all words in the input content stream.

Step 2. The alphabetical-frequency vocabulary construction based on content categories.

Step 3. Words normalization through automatic morphological analysis.

Step 4. The alphabetical-frequency vocabulary modification.

Step 5. Words assign of weight w (use frequency).

Step 6. Insignificant words deleting from the alphabetical-frequency vocabulary ($W \le k$, where k – threshold value of word extracting).

Stage 2. The thematic dictionary choice as requested.

Stage 3. Words weight adjustment of alphabetical-frequency vocabulary dictionary based on thematic dictionary.

Stage 4. Words choosing at $N = n$ are with more weight w of alphabetical-frequency vocabulary, which $n = const$ is given by the moderator.

Algorithm 2. Duplicate content determination.

Stage 1. The initial data formation.

Step 1. The moderator introduced of words in a string $m = const$.

Step 2. The moderator input strings unique coefficient ie $U = const$.

Step 3. Coefficient limits formation $K = [a_1, a_2]$ of keywords use, where $a_1 = const$, $a_2 = const$.

Step 4. Content partitioning on n chains of m words.

Step 5. Frequency calculation of k_i keywords use.

Stage 2. Content duplicates determination.

Step 1. Words strings comparison for all content.

Step 2. Chains uniqueness coefficients calculation u_i .

Step 3. Chains uniqueness coefficients comparison u_i with U . At $\frac{1}{n}\sum_i^n u_i < U$ mark the content as unsuitable.

Step 4. The frequency comparison k_i with coefficient K . If $k_i < a_1$ or $k_i > a_{21}$ then a content mark as unsuitable.

Algorithm 3. A digest create.

Stage 1. Content Select based on its weight.

Step 1. Digest size C input.

Step 2. The algorithm 1 implementation.

Step 3. Weight consistent determine of each content as $W = \sum w_i$ sum of its individual words.

Step 4. The input content stream sort from the weights values.

Step 5. Meaningful content duplicates definition for statistical criterion of text uniqueness $U \geq 0{,}9$ (alg. 2).

Step 6. Content filter of unsuitable for digests building (when $W \leq l$, where l – Content removal threshold value by the self-education rules of content structuring and moderating) and statistically substantial duplicates.

Step 7. Choice of $V = q$ content with greater weight where $q = const$ and the moderator given.

Stage 2. Digest text construction of selected content.

Step 1. Dictionary construction of selected content (alg. 1).

Step 2. Content analysis application to the text (Table 4).

Step 3. Sentences filtration that do not meet semantic rules of content structuring and moderating.

Step 4. Hypertext presentation formation of digest, its contents and a link to the original source.

Stage 3. Generated text edit of digest.

Step 1. The check amount of generated content c_i . If $c_i < C$, then step 2, otherwise stage 4.

Step 2. Content delete from the input stream that is used to the digest formation.

Step 3. Steps 1-2 implementation.

Step 4. Resulting append to the pre-formed digest and move to step 1.

Stage 4. Digest text formation as a separate content and its maintaining in the database with reference on the source.

Tab. 4. Content analysis stages of textual information

Stage	Stage characteristics of content analysis
Total sources or content determination	Using a set of defined criteria which corresponds to each content: given type of source; one type of content; given the parties which involved in the communication process; message size matched (minimum / length); messages appearance frequency; messages distributing method; messages distribution space; messages appearance time, etc.
Content analysis selection	The selected set of content is formed on the criteria a limited sampling from a larger array of information. It's forming using the procedure from a set of precisely defined actions for processing without any changes of all objects study.
Linguistic units identifying	Compliance with strict requirements concerning the linguistic units choice for content analysis: large enough to interpret meaning; small enough not to interpret the many meanings; easily identified; units number is large enough for sampling. When taking of the themes analysis unit take into account that its size does not go beyond a paragraph; new theme arises with the new characteristics appearance of units.
Computation units finding and classifier formation	Computing units may coincide with semantic units, or have specific characteristics. In the first case, the analysis procedure is to the frequency calculate of the selected content unit use. Otherwise, the researcher proposes computation unit (physical length of the texts; text area, filled with informative units; the number of rows, paragraphs, characters, columns in text; the file size / type; pictures number with a certain content and story) based on the analysed material and research purposes.
Calculating	Standard techniques for classification of selected groups of mathematical statistics and probability theory formulas.
Results interpretation	This includes all extracted text fragments. When forming conclusions do not take into account of the some results, without exception all. Here are identified and measured the text characteristics. They allow drawing conclusions about that wanted to emphasize or hide its author. Or they predict changes in demand for content based statistical set of calculated coefficients for the time period of specified category.

Topical stories identification in content stream. Content with new themes is the new group's basis of interdependent content in thematic stories identifying with the following procedures: control within the system – level destination of user access to different content; content integration – content moving to a new decision; content support of various types – content storage and sorting in a central repository; detailed documentation and context-intelligent help support; rating system of site articles evaluation; template changes – general formatting changes to the content of the part site reflects the entire site; workflow support – automated business processes create for specific content; content marking – new categories and markers adding to content before / after saving; version control –new versions creating, view and return to the previous versions of content; content analysis of text streams in the system; visual administration tool – easy authors management of content, without resorting to programming, typically implemented using HTML-forms; concepts relationship tables construction.

The concepts ratings calculation is based on procedure for results calculating of content analysis, taking into account the ratio coefficient c of positive and negative (for the selected item) estimates, opinions, arguments, as described in the user comments on the content ECCS.

7. ANALYSIS OF DATA

Based on the developed method content forming subsystems at various stages are implemented in Internet projects “Fotoghalereja Vysocjkykh” (FGV, fotoghalereja-vysocjkykh.com), “Tatyana” (T, tatjana.in.ua), “AutoChip” (autochip.vn.ua), “Vgolos” (vgolos.com.ua), “PressTime” (presstime.com.ua), “Exchange rates” (ER, kursyvalyut.com), “Good morning, accountant!” (GM, dobryjranok.com). Table 5 presents the developed systems comparative characteristics derived from Google Analytics.

Tab. 5. The system work comparative characteristics for the time period 10.2012-11.2012

Systems characte rization	FGV	Vgolos	T	PressTime	Auto Chip	ER	GM
Formation	+/-	+	-	+/-	+	+	+/-
Managment	+	+	-	+	+	+/-	+
Support	+/-	+	-	+	+/-	+/-	+
Visiting	73	326940	49	167 856	406	103	58
Unique visitors	62	217719	21	123 756	326	42	7
Pages browse	136	562455	142	345 234	863	237	226
Pages/Visit	1,86	1,72	2,90	1,45	2,13	1,67	3,90
Visits average duration	00:47	01:45	04:38	01:09	01:08	00:37	09:35
Fault indicator	71,23	76,92	46,94	79,56	56,90	61,23	48,28
New Visits	80,82	51,83	36,43	45,65	77,59	90,87	12,07
Returning Visitor	82,19	48,15	63,27	54,35	77,59	62,79	87,93
New Visitor	17,81	51,85	36,43	45,65	22,41	37,21	12,07
Ukraine	87,67	89,81	71,43	92,33	73,89	97,07	55,17
Russia	2,74	2,55	24,49	6,27	17,00	1,05	43,10
USA	1,37	0,58	0,07	0,06	0,05	0,61	1,72
Search traffic	69,86	36,03	73,47	60,05	88,67	59,03	43,10
Traffic Conversion	12,33	54,62	0	34,65	3,45	35,65	6,90
Direct traffic	17,82	9,21	26,53	5,25	7,88	5,32	50,00
Traffic campaigns	0	0,14	0	0,05	0	0	0

The commercial content formation model implement in the form of content-monitoring complexes to content collection from data various sources and provide a content database according to the users information needs. As a result, content harvesting and primary processing its lead to a single format, classified according to the Categories and he is credited tags with keywords. This facilitates the commercial content management process implementation. In text analyzing explore its layered structure: the source text as a characters linear sequence; morphological structure linear sequence, statements linear sequence, related unity net. The text preliminary study provides for the text division into individual tokens that carry out the finite automata method. Entry information is text in natural language text as a characters sequence, and output information – analysed text partition, sentences and tokens table. There is the following relationship: the more unique content in the ECCS, the more the visitor’s information resource in its system. Google Analytics provides advanced data analysis and allows us to estimate the content traffic and marketing activities effectiveness, such as the newspaper “Vgolos” (Fig. 5).

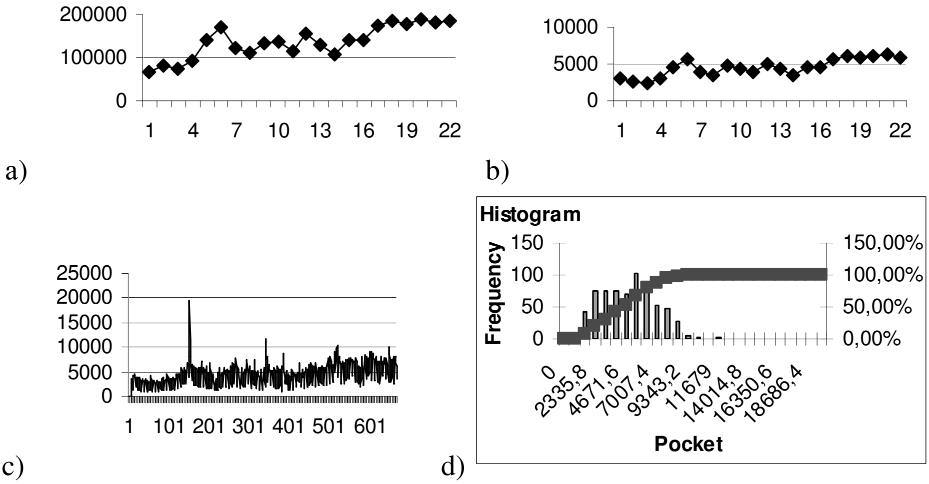

Fig. 5. Visitors distribution of a) total, b) medium, c) daily, d) monthly number in 2010-2012 [source: own study]

8. CONCLUSIONS

In the given paper is functional logistic model of commercial content processing in e-business systems developed. The model is based on the layered structure of processes. This model involves the division of the overall process into the following stages: content collection/creation from different sources; content formatting; key words and concepts identifying; content categorization; content duplicate detection; digests formation; selective distribution of content between moderators and users of ECCS. The model is based on the principles of content analysis. It automates the various steps of information product creating of this type without loss of content and lower quality. The method effectiveness confirms the results of its application in developing a number of commercial content projects. Developed automation commercial content processing allows speeding up the content formation, management and maintenance process. It also contributes to the rating increase of generated by their use with commercial information resources.

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electro-mechanically coupling, activator, piezoelectric, bimorph, natural frequencies

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AN INFLUENCE OF THE d_{311} EFFECT ON THE BEHAVIOR OF THE CANTILEVER BEAM-SHAPED PIEZOELECTRIC ACTIVATOR MADE OF TWO LAYERS OF PVDF WITH INVERSE POLARITY

Abstract

In the present work an example of the numerical modeling of electro-mechanical coupling of the activator in the form of cantilever beam made of two layers PVDF subjected to an inverse polarity is described. Calculations were done for static deflections at the selected voltage levels and for modal analysis with an included and excluded piezoelectric effect. The effect of active material on the behavior of the beam was examined. In order to validate the model, results of the static calculation were compared with the strict analytical solution and the results presented by other authors.

1. INTRODUCTION

Activators are very important parts of many micro-electromechanical systems (MEMS). Starting from 1980 many solutions were presented of the activators, which used different effects, for example electrostatic, electromagnetic, piezoelectric, shape memory alloy (SMA). Activators with the piezoelectric effect are most popular, they have wide application - among others, in electrical fans, microphones, printers, engines, pumps, control systems and injectors [1,2]. A characteristic feature of piezoelectric actuators is their high potency and very

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small displacements they can trigger in a system. Force and displacement are dependent on the applied voltage. In many research a piezoelectric polymer polyvinylidene fluoride (PVDF) is used because it is easy to be formed and gives a possibility of constructing very small activators. Additional advantage of the PVDF polymer is that the material is particularly examined and data are available to describe the mechanical and electric properties. In addition, in the literature you can find results of experimental, analytical or numerical research for elements made from this material [1,2]. The literature addressed to cantilever beams made from the polymer PVDF type beams like bimorph are very extensive [[3]-[9]].

The aim of this paper is to describe influence of an electromechanical coupling of static and dynamic behavior of the activator in the form of cantilever beam made of two layers of polymeric piezoelectric polyvinylidene fluoride (PVDF) with inverse polarity. In order to achieve the peak, effect of electro-mechanical combination of both layers must be rigid. For this purpose, numerical simulations were performed with the Finite Element Method (FEM). The results of static calculations were validated with those published by other authors [8-9] and received from the linear analytical model. The choice of 'benchmarks' yielded from the completeness of data available, what was necessary for numerical simulations. In the second stage the validated model was used to determine natural frequencies and modes for bimorph-like beams with piezoelectric effect (open system) and without the piezoelectric effect (closed system).

In addition, natural frequencies and mode shapes determined for the open system were compared with the results for the beam made of the material having mechanical properties the same as PVDF, but without the piezoelectric effect.

2. ELECTRO-MECHANICALL COUPLING EFFECT/ PIEZOELECTRIC TRANSDUCERS

The PZT activators use the piezoelectric effect, which consists in the phenomenon that the piezoelectric element located in electric field undergoes deformation, while under mechanical load acting on its surface the active material generates electrical charge.

According to the above described properties of the PZT, one can write the following constitutive relation [1]:

$$\{\varepsilon\} = [S]\{\sigma\}+[d]\{E\} \tag{1}$$

where: $\{\varepsilon\}$ – the strain vector,
$\{\sigma\}$ – the stress vector,

$\{E\}$ – components of the electric field strength,
$[S]$ – the compliance matrix,
$[d]$ – the matrix of piezoelectric coefficients.

Further it was assumed that the intensity of the electric field E_3 acts only along the x_3 axis (Fig. 1). Its value can be determined for a specified voltage U applied on upper and lower surfaces of beam from dependencies:

$$E_3 = U/h \tag{2}$$

where: U – voltage applied to the system,
h – thickness of the element.

Figure 1 shows piezoelectric effect d_{311}, when examined strain or stress in axis direction x_1 induced by E_3.

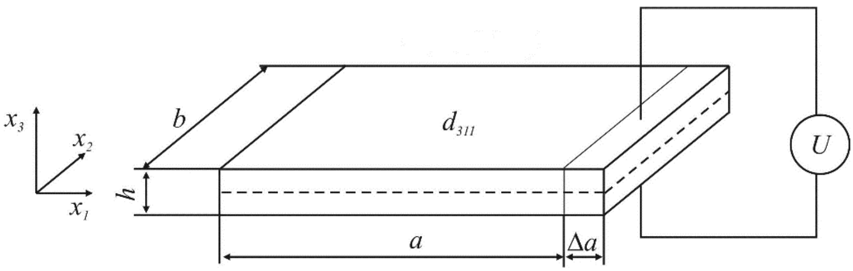


Fig. 1. The d_{311} effect for piezoelectric material [source: own study]

In this case the extension Δa in axis directions x_1 is:

$$\Delta a = d_{311} E_3 a = d_{311} U a/h \tag{3}$$

where: d_{311} – the electromechanical coupling coefficients in directions 1,
a – length of the element.

The ε_{11} strain component and the σ_{11} stress component in the direction x_1 are:

$$\varepsilon_{11} = d_{311} U/h$$
$$\sigma_{11} = d_{311} U E_{11}/h = e_{311} U/h \tag{4}$$

respectively; here:
E_{11} – Young's modulus,
e_{311} – the piezoelectric coefficients in the directions 1.

3. RESEARCH OBJECT

Object of analysis was an activator of the "bimorph" type having the form of cantilever beam. It was further assumed that the material of the beam was isotropic. A schematic diagram and dimensions of the examined system are shown in Fig. 2.

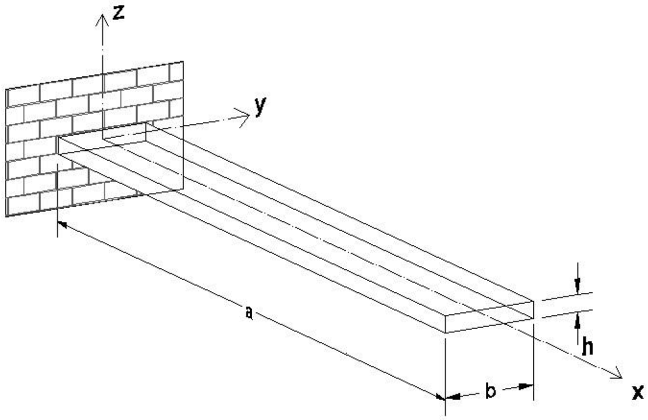


Fig. 2. The activator in the form isotropic cantilever beam [source: own study]

The activator was composed of two combined beams of piezoelectric material PVDF inversely polarized.

The accepted geometrical dimensions of the beam were as follows (Figure 2): *a* – the length of the beam was 100 mm, *b* – beam width – 5 mm *h* – beam thickness – 1 mm (each piezoelectric layer had a thickness of 0.5 mm). The density of the PVDF polymer was ρ = 1600 kg/m^3. Other material data of the active elements are given in Table 1. Beam dimensions were the same as in the works [[7]-[8]].

Table 1. The PVDF's mechanical and piezoelectric properties [[8]-[10]]

Mechanical properties				
Young's modulus $E_{11}=E_{22}=E_{33}$		Shear modulus $G_{12}=G_{13}=G_{23}$		Poisson's ratio $\nu_{12}=\nu_{13}=\nu_{23}$
2GPa		1GPa		0
Piezoelectronic propetries				
Piezoelectric constant				Electric permittivity
$e_{311}=e_{322}$	e_{333}	$d_{311}=d_{322}$	d_{333}	$\chi_{11}=\chi_{22}=\chi_{33}$
0.046 C/m2	0	0.023 nm/V	0	0.1062 nF/m

4. NUMERICAL MODEL OF THE ACTIVATOR

The numerical (FEA) model of the cantilever beam was constructed by using the C3D20RE type solid elements. They were 20-node 2nd order (with a square shape function) elements, having three translational degrees of freedom at each node and one extra degree of freedom associated with the piezoelectric properties.

All elements used a reduced integration method (elements with full integration caused over rigidity of the structure in test simulations). The simulations were performed using a commercial package Abaqus [[11]].

The mechanical boundary conditions of the numerical model were realized by restraining the nodes located on one end of the beam all the translational degrees of freedom and modeling this way the beam's restraint. Density of the mesh was right.

The combination of the PVDF layers was realized by defining interactions as "TIE", what resulted in linking the degrees of freedom of nodes in contact on the appropriate surfaces of the model. The developed FEM numerical model of the "bimorph" beam is shown in Figure 3.

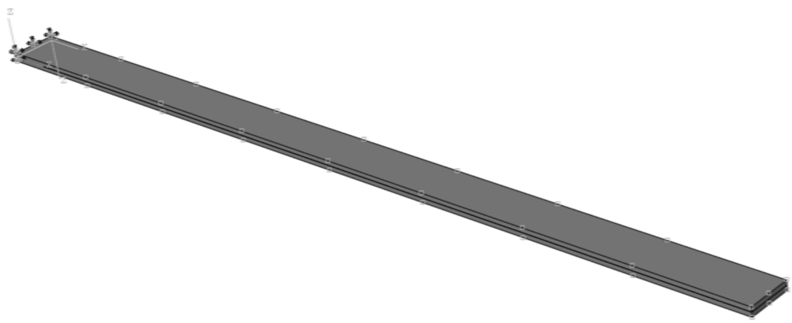


Fig. 3. The FEM model of the "bimorph" beam [source: own study]

In the numerical model, the electric field as the beam's load was introduced through boundary conditions by defining the value of the electrical potential both on the upper and the lower surface of the beam. In subsequent simulations the potential equal zero was applied on the bottom surface. On the upper surface of the beam a target value of the potential was applied (expressed in volts). For the examined system the load-like electric field applied in the direction 3 resulted in a dimension change in the direction 1; this was the examination of the d_{311} effect. Note, that the two parts of the activator were inversely polarized, so one part extending, while the second one shrank, and the resulting moment caused the beam's bending. This allowed the deflection measurement of the beam in static regime. In dynamic research two cases were considered: an open and a closed system. The open system was the case in which the bottom surface was treated with 0V and on the upper surface no voltage was applied. The closed system had a short circuit across the two surfaces.

5. STATIC TESTS

In order to validate the FEA model calculations of the beam's center line were performed at 1V voltage on the upper surface, while on the lower surface the voltage equaled 0V. The solution to this problem is a very popular benchmark known from the literature [[3]-[9]]. Figure 4 shows the deflection of the beam under the applied electrical load.

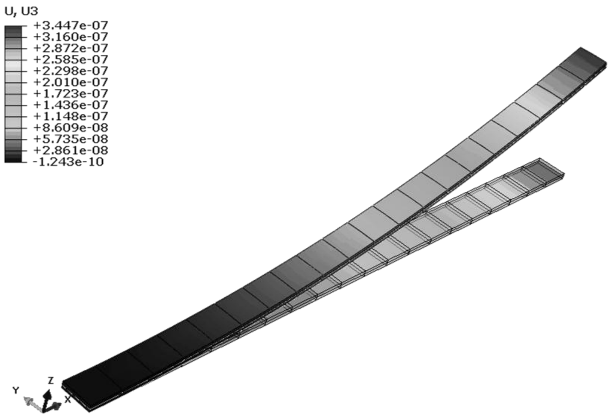


Fig. 4. Deflection of the beam under 1V voltage [source: own study]

In addition, by solving a linear equation of deflection line with analytical method, the center line deflection was determined. The resulting solution is correct for small deflections. The equation of the beam's center line deflection can be written as [[12]]:

$$E_{11} J_{x_2} \frac{d^2 u_3}{dx_1^2} = M_{x_2} \tag{5}$$

where: J_{x2} – second moment of area for the beam's cross-section,
u_3 – deflection in the direction 3,
M_{x2} – bending moment.

For the analyzed present case the bending moment created when the voltage *U* was applied between the upper and the bottom surface of the beam, which caused the expansion of one part and shortening of the second part, in accordance with the equation (4) is equal:

$$M_{x_2} = \sigma_{11} b \left(\frac{h}{2}\right)^2 = \frac{d_{311} U E_{11}}{4} bh = \frac{e_{311} U}{4} bh \qquad (6)$$

Substituting the bending moment (6) into equation (5) gives:

$$u_3 = \frac{3}{2} d_{311} U \left(\frac{x_1}{h}\right)^2 = \frac{3}{2} \frac{e_{311}}{E_{11}} U \left(\frac{x_1}{h}\right)^2 \qquad (7)$$

where: x_1 – distance from the fixed end.

All the results are presented in Table 2.

Tab. 2. The static deflection of the PVDF beam u3 [µm] for voltage equal 1V

x_1 [mm]	Theory according to (7)	Abaqus C3D20RE	Pablo et al [[8]]	Jiang et al [[9]]
20	0.0138	0.0140505	0.0137	0.0136
40	0.0552	0.0553451	0.0549	0.0545
60	0.1242	0.1241730	0.1235	0.1226
80	0.2208	0.2205330	0.2197	0.2180
100	0.3450	0.3444270	0.3433	0.3410

The results of the FEM numerical simulations differ by about 0.2% as compared with the results obtained with analytical calculations (according to the formula (7)) and about 0.5% with respect to the results presented in the papers [[8]-[9]]. This shows a very good compatibility of the obtained results with those available in the literature.

In the second stage, the FEM simulations for voltages from 50 to 200V were performed. The deflections obtained numerically were compared with the results of analytical calculations and shown in Figure 5. The results in the whole voltage range are similar.

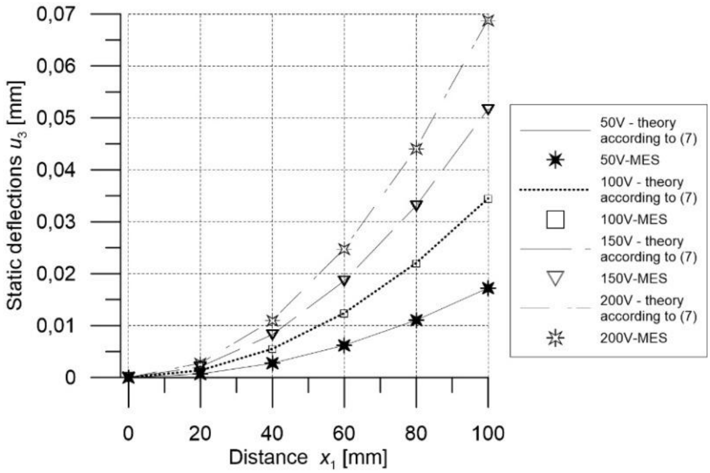


Fig. 5. Comparison of static deflections obtained with the FEM simulations and analytical solutions from equation (7) [source: own study]

6. MODAL ANALYSIS

In order to determine the d_{311} effect on dynamic behavior of the activator a numerical modal analyzes were performed. In the FEM simulations the Lanczos method was used [[11],[13]] in order to determine the natural frequencies and mode shapes of free vibrations for three load cases. The first one was an open system, where on the upper and the bottom surface had no applied voltage potential (Case 1). The next was a closed system, where on both surfaces of the PVDF beam the applied potential equaled 0V (Case 2). The third case was a system made of material with identical mechanical properties as the beam made of PVDF, but with deactivated piezoelectric properties. Modal analysis' results are shown in table 3, where in the case No. 3 the natural frequencies were determined from the formula (8) [[14]]. The determined mode shapes are shown in Figures 6, 7.

$$f_i = \frac{1}{2\pi}\left(\frac{\lambda_i}{a}\right)^2 \sqrt{\frac{EJ}{\rho A}} \tag{8}$$

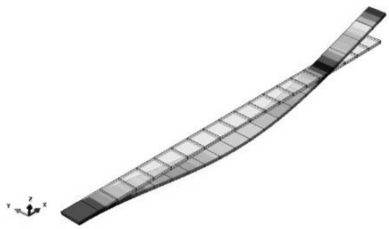
where : f_i – natural frequencies of free vibrations [Hz],
λ_i – constants: λ_1=1,875, λ_2=4,694, $\lambda_n = \pi n/(2n\text{-}1)$ dla n>2 [14],
ρ – mass density of the material,
A – the cross-sectional area of the beam,
EJ – bending stiffness: for the compliant direction $E_{11}J_{x1}$, for the rigid direction $E_{22}J_{x2}$.

Tab. 3. Natural frequencies of the PVDF beam [Hz]

Mode	Case 1	Case 2	Case 3
	Direction susceptible (plane: x_3-x_1)		
1	17.21	17.14	17.12
2	107.79	107.40	107.26
3	301.64	300.54	300.17
	Direction rigid (plane: x_2-x_1)		
4	85.92	-	85.50
5	533.81	-	531.23

a) Mode 1

b) Mode 2



c) Mode 3

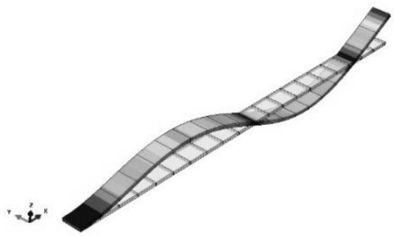
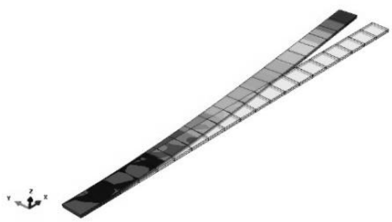


Fig. 6. The bending natural mode shapes of the beam in the compliant direction (plane: x_3-x_1)

a) Mode 4



b) Mode 5

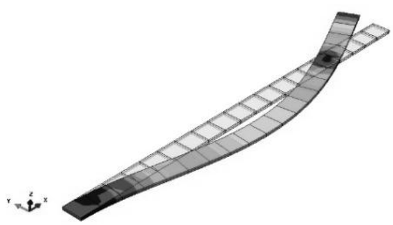


Fig. 7. The bending natural mode shapes of the beam in the rigid direction (plane: x_2-x_1)

Comparison of the results showed that for the compact system (case 2) and the system without of piezoelectric properties (case 3) the increase in natural frequencies didn't exceed 0.15%. It can be assumed that the results are identical. In the case of the open system (case 1) the increase in natural frequencies compared to the system without piezoelectric properties (case 3) didn't exceed the 0.5%. Again, the influence of the piezoelectric effect isn't important.

7. CONCLUSION

This article deals with the influence of piezoelectric effect on static and dynamic behavior of like bimorph – beam. Numerical model FEM was built in the commercial system Abaqus. In the case of static research on deflection of the beam a good compatibility of the numerical simulations with the analytical model and results published by other authors was obtained. Numerical analyzes' results differed by about 0.2% as compared with the results of analytical calculations, but in comparison to the research presented in the literature the differences don't exceed 0,5%. Thus, in all the analyzed cases the adequacy of the FEM model was proved. In the next step modal analysis of the activator to examine the influence of the piezoelectric effect on the behavior of the system. It was found that the natural frequency of the compact system and the system without the piezoelectric properties are identical. In case of the open system the increase in the natural frequencies in relation to the system without the piezoelectric properties was irrelevant and didn't exceed 5%.

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FEM analysis, RPM, technological head, robot

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FEM ANALYSIS OF THE MODULES BODIES FOR BUILDING OF THE ROBOTS TECHNOLOGICAL HEADS

Abstract

As a part the project it was necessary to design and implement accurate reducers and actuators in various kinematic solutions of modules. These modules will be possible to stack them into desired shapes, allowing them to be deployed in production machines and robotic equipment according to the specific customer requirements, e.g. technological heads. The article deals with designing and especially FEM analysis modules – technological heads for 2 and 3 axis handling and robotic systems. Designed modules – technological heads will allow correcting inaccuracies motion manipulator or less precise robot. Solving of these modules is based on the use of smart actuators consisting of engine, precise gearbox and appropriate sensing technique. Control of the motion will be implemented on the basis of information obtained from sensors placed directly in drives the positioning module and the sensors working environment according to specific requirements for each application.

1. INTRODUCTION

The analysis of specific solutions can be concluded that technological heads are customized to the needs customer (a very small percentage of the products produced as a catalog) [1-2]. It follows that the solution of the necessary motion functions the technological head are used either catalog motion module; resp. motion axes are original solution throughout the project technological heads. This leads to the need to design appropriate dimensional series, which would be

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applicable for creating mutually compatible modules enable create a complete units. These units allow to create the final shape of the module – the technological head according to different needs, such are intelligent modules – grippers for mounting rotating, non-rotating components to manipulate objects and the like. In the case of proposal heads is important for specific application, what will technological head used, such as grinding, drilling, threading and milling. On the figure 1 is shown 3-axis technological head consisting of the modules RPM 110-70-50 [3].

Rotary axis of positioning and handling unit or rotary positioning module is autonomous, functional and construction module for rotary positioning axes. It has integration function with intelligence for mechanic and driving ability to connect with other modules into one higher function machinery systems. Rotary positioning module is node of device, which must perform driving rotary movement with required to speed and precision of positioning [4,5].

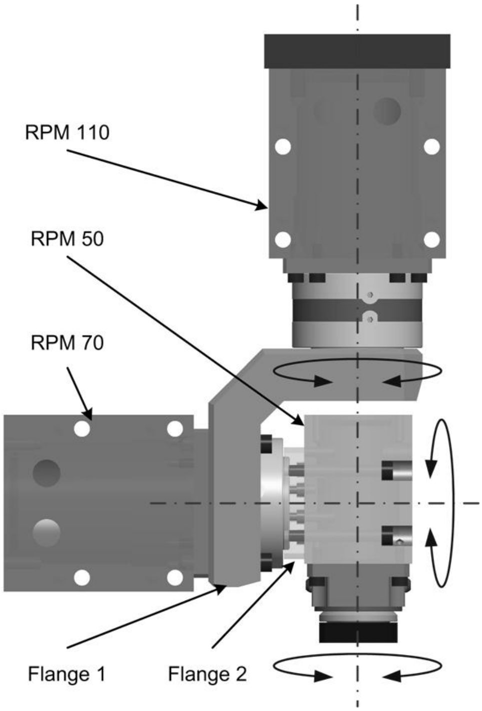

Fig. 1. Technological head (3 – axis) [source: own study]

Rotary positioning module (next RPM**)** in figure 2 is electro servomechanism for drive position (rotary angle or linear displacement) of machine. It consists from gearbox, servomotor and sensors in one construction and function compact [6].

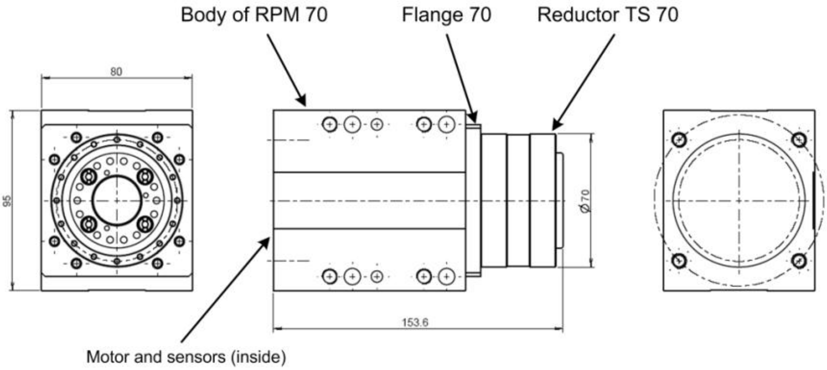

Fig. 2. Module RPM 70 [source: own study]

2. THE BASIC STRUCTURE OF RPM

Systemic *RPM* model describe conception of engine solution (drive and transform mechanism for change of kinematic motion parameters – speed of movement) and it describe internal structure of RPM module (block structure). Basic internal structure is shown on figure 3. Module marked like *IRPM* – intelligent rotary positioning module contains all components like RPM module, but it has one difference. This means that drive and control block have the intelligence which consists from adaptive drive. It allows answer to changes from working activity in real time. Changes are monitored on information base from sensors (for example sensor of revolutions, temperature, speed, acceleration, torque, forces). Quantity and kind of sensors is dependent on currently application [1,3,6].

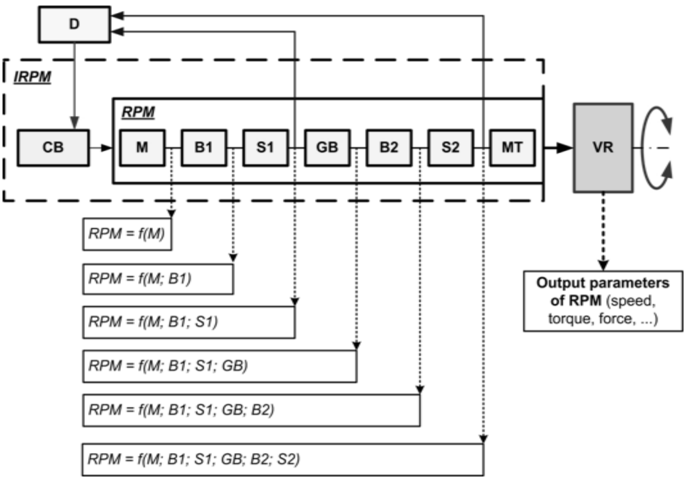

Fig. 3. Systemic RPM model – block structure [source: own study]

Legend of figure 3 Systemic RPM model:

- ***D*** – *drive* (primary energy, output of drive system),
- ***CB*** – *control block* (device for editing drive signals),
- ***M*** – *motor* (rotary servomotor; sensoring function for angular rotation, safety brake), *technical variants*: ***M_1*** without brake, ***M*** – ***B1*** with safety brake integrated,
- ***GB*** – *gearbox block* (reduction speed of motor **M**, higher torque on module output, physical transfer of rotary motion(ρ_M) from motor **M** out-put to rotary motion of module ***VR*** (ρ_2); have function for conversion of motor **M** parameters (n_M – revolutions per minute, f_M – motion frequency, P_M – performance, φ_M – path of movement/angle) to module output V_R (ρ_j).

Technical variants: GB1 gear block with classic shaft output, ***GB2*** – gear block with hollow shaft output, ***GB3*** – gear block with flange output),

- ***MT*** – *mount* (motion ensuring for direct path (circle) with one degree of freedom; system of guideways contact between moving and non-moving part of module),
- ***S1*** – *sensor* (sensor for output parameters of motor ***M*** (speed, revolutions per minute, position),
- ***S2*** – *sensor* (sensor for output parameters of module **RPM** (position)),
- ***B1*** – *safety brake* (non will brake for motor output ***M1***),
- ***B2*** – *positioning brake* (positioning brake for output of module ***VR***, fix ending rotary position of module **RPM**),

VR – *output element* (mechanical element / interface for connection **RPM** as higher functional unit).

Totally (theoretical) model of structure RPM consists from: M-B1-S1-GB-B2-S2-MT-VR.

3. BASIC DATA OF INDIVIDUAL MODULES

In conformity with the concept of solutions and objectives of the project development new series RPM to the performance and focus on parametric type series RPM module size range 50, 70 and 110. Basic data on the individual RPM modules are shown in table 1.

Tab. 1 Technical characteristic RPM 50, 70 a 110

	RPM module		Units	RPM 50	RPM 70	RPM 110
1.	Max. dimension RPM Module	b x b	[mm]	58x66	80x95	112x135
2.	Max. dimension body of reducer	ØA (a x a)	[mm]	55 x 55	Φ 70	Φ 110
3.	Length of RPM	L	[mm]	111	153,6	202
4.	Reduction ratio	**i**	--	63	57	67
5.	Rated output torque	$\mathbf{T_R}$	[Nm]	18	50	122
6.	Acceleration and braking torque	$\mathbf{T_{max}}$	[Nm]	36	100	244
7.	Rated input speed	$\mathbf{n_R}$	[rpm]	2000	2000	2000
8.	Cycle effective speed	$\mathbf{n_{ef}}$	[rpm]	3000	2500	2000
9.	Max. allowable input speed	$\mathbf{n_{max}}$	[rpm]	5000	5000	4500
10.	Lost motion	**LM**	[arcmin]	<1,5	<1,5	<1,0
11.	Average angular transmission error	**ATE**	[arcsec]	+/- 36	+/- 36	+/- 20
12.	Hysteresis	**H**	[arcmin]	<1,5	<1,5	<1,0
13.	Input inertia	**I**	[10^{-4} kgm^2]	0,006	0,061	0,16
14.	Torsional stiffness	$\mathbf{k_t}$	[Nm/arcmin]	2,5	7	22
15.	Tilting stiffness	$\mathbf{M_t}$	[Nm/arcmin]	4	35	150
16.	Max. tilting moment (a2=0)	$\mathbf{M_{c\ max}}$	[Nm]	44	142	740
17.	Max. axial force	$\mathbf{F_{a\ max}}$	[kN]	1,9	3,7	13,1
18.	Rated radial force	$\mathbf{F_{R\ max}}$	[kN]	1,44	2,6	9,3

4. FEM ANALYSIS OF BODIES RPM MODULES

FEM analysis focuses on static analysis, result of a determination of the appropriateness of the proposed use of the material for the carrier body of module RPM. Load carrier body of the module is at the maximum torque values and burdensome forces acting on exactly reducers used in the construction of modules. Based on the above structure, three were selected sized series the modules that are most to deployed for the handling and robotic applications. With regards to the modules RPM 50, 70 and 110.

FEM analysis was carried out on all three type - size series the modules RPM. In the next part of the article we focus on the medium size range of the module RPM 70. Module the RPM 70 is formed in a 3D CAD program ProEngineer 5.0/Creo and FEM analysis is the solution in module Pro/Mechanica. The material of the module body was compared according to standard EN AW 2017, which is characterized by good machinability and good strength properties. Material parameters are shown in table 2.

Tab. 2 Characteristic EN AW 2017 (AlCu4MgSi)

Material / EN	State	Rm (min.) [MPa]	Rm (max.) [MPa]	Rp 0,2 [MPa]	Ductility [%] (A 50 mm)
AlCu4MgSi EN AW 2017	O/H111		250	Max. 135	10
	T3	400		250	8
	T4	500		240	8

The proposed module body 70 RPM (2D model – sketch), figure 4 is also fitted with the connecting holes in which they is possible the install flange through bolts.

Connection holes on the body module are located on the back and bottom side of the module. Therefore, it is necessary for analysis of stress taken into account way and direction of the load as shown in figure 5.

The resulting value of the tilting moment depends on the load RPM module from constituents radial and axial forces. The formula is as follows:

$$M_C = F_R.a + F_A.b \tag{1}$$

where: M_C – tilting moment [Nm],
F_R – radial force [N],
F_A – axial force [N],
a – arm radial forces [m],
b – arm axial forces [m].

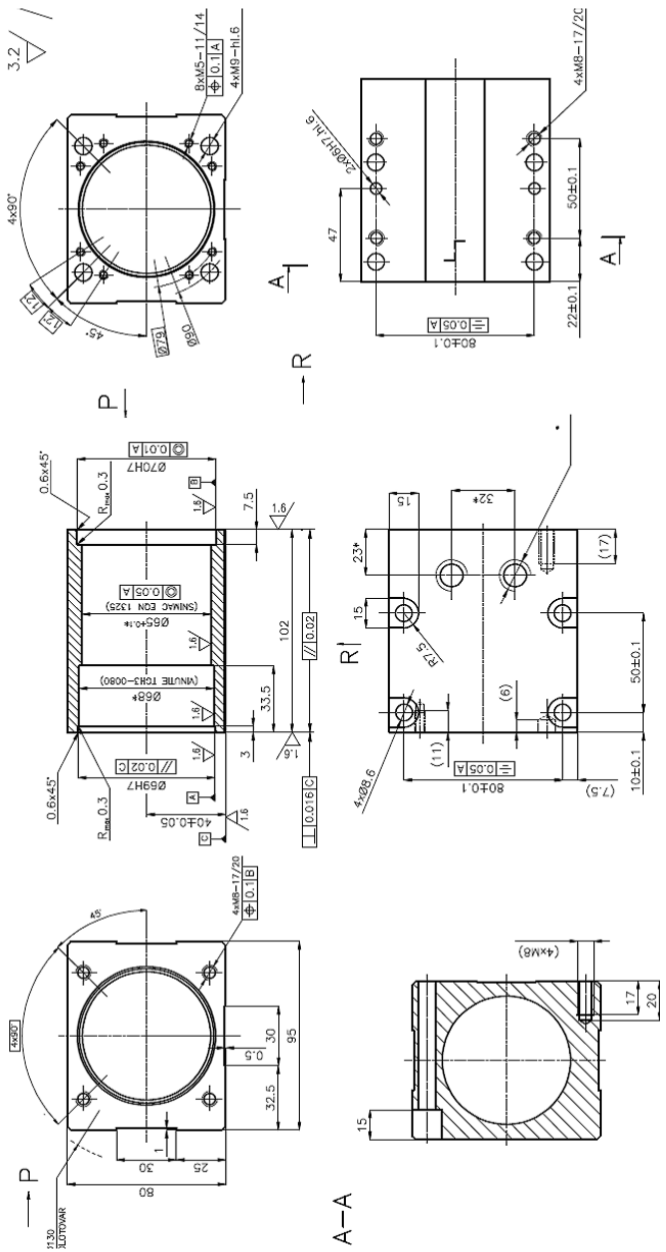

Fig. 4. Sketch of the module body RPM 70 [source: own study]

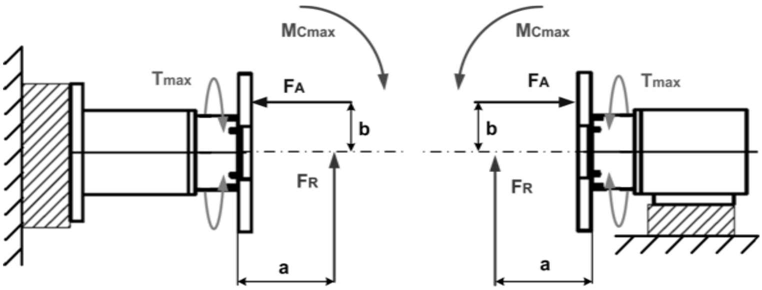

Fig. 5. Location of forces and moments [source: own study]

Creating of different configurations 2- and 3-axial technological head is dependent on the action of applied forces and character of the proposed application use of the heads. It was therefore necessary to determine the maximum value of burdensome moments and forces applied to the output flange technological heads. By maximum torque and forces acting on each RPM modules are defined their structure and composition. Specific the value of maximum loads to module RPM 110, 70 and 50 are shown in table 3, focusing on the module RPM 70.

Tab. 3 Maximum and rated load RPM modules

Maximum load output flange	**Units**	RPM 110	**RPM 70**	RPM 50
Rated output moment - T_{max}	Nm	244	**100**	36
Maximal tilting moment - M_{Cmax}	Nm	740	**142**	44
Rated radial force - F_R	kN	9,3	**2,6**	1,44
Maximal axial force - F_A	kN	13,1	**3,7**	1,9

Static analysis of stress and strain in the body of module RPM 70 - load body at a torque value of 100 Nm. The direction of load (torque) and anchorage area - constraints (fixation on the back of the body) is shown in figure 6.

For create of networking the body module RPM 70 was created 6765 elements of type Tetrahedron, figure 7. In a programme ProE / Creo Mechanica module is a most preferred element. Type elements Wedge and Brick were not used. Calculation method has type QuickCheck which do not check convergence calculation. The degree of polynomial was set to value 3.

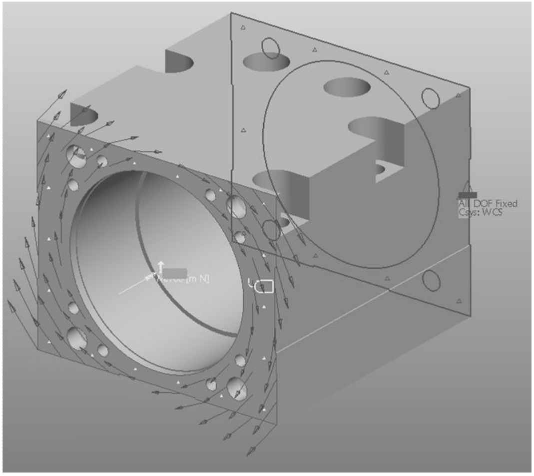

Fig. 6. Method of load and anchorage – constraints of the body for 70 RPM (back of body) [source: own study]

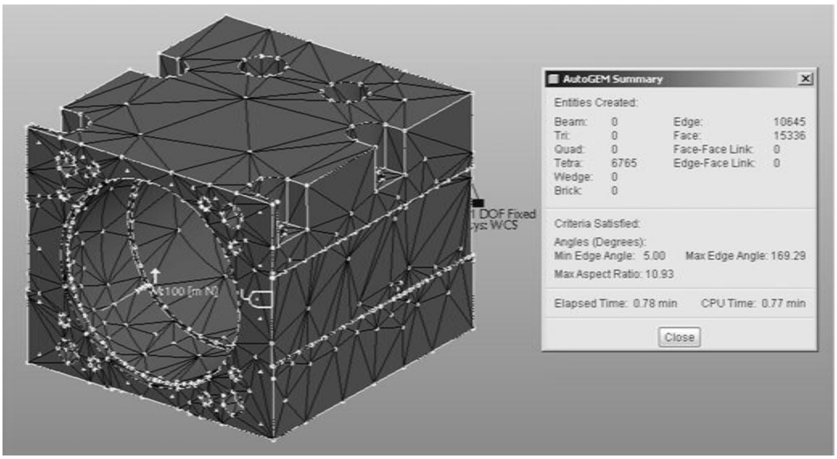

Fig. 7. Network on the module body RPM 70 [source: own study]

The findings of stress value (fixation on the back of the body) are shown in figure 8, where the value of the measured voltage has a value of 11,4 MPa. The permissible stresses for materials in accordance with EN AW 2017 have a value of 250 MPa. Comparison of the observed and the permissible stress (11.4 ≤ 250 MPa) confirms that the proposed material for a maximum torque of 100 Nm satisfies requirements. The maximum value for the deformation body module RPM 70 (fixation on the back of the body) for the load of torque Mk 100 nm is 0,0053 mm. The based on expected deployment module for the application robotics and manufacturing techniques, the value of deformation sufficient.

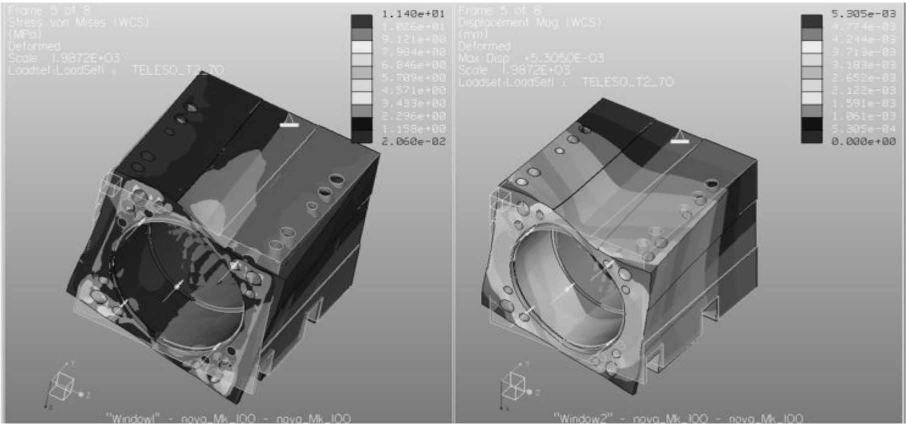

Fig. 8. Value of stress and distortion body the module RPM 70 for M_k 100 Nm (fixation on the back of the body) [source: own study]

The findings of stress value (fixation on the upper part of the body), where the value of the measured voltage has a value of 23,8 MPa. The permissible stresses for materials in accordance with EN AW 2017 have a value of 250 MPa. Comparison of the observed and the permissible stress (23,8 $\leq$ 250 MPa) confirms that the proposed material for a maximum torque of 100 Nm satisfies requirements. The maximum value for the deformation body module RPM 70 (fixation on the upper part of the body) for the load of torque Mk 100 nm is 0,00687 mm.

Static analysis of stress and strain in the body of module RPM 70 – load body at a axial force value of 37 000 N. The findings of stress value (fixation on the back of the body) are shown in figure 9, where the value of the measured voltage has a value of 26,28 MPa. Comparison of the observed and the permissible stress (26,28 $\leq$ 250 MPa) confirms that the proposed material for a maximum axis force F_A 3,7 kN satisfies requirements. The maximum value for the deformation body module RPM 70 (fixation on the back of the body) for the load of axial force F_A 3,7 kN is 0,00612 mm. The based on expected deployment module for the application robotics and manufacturing techniques, the value of deformation sufficient.

The findings of stress value (fixation on the upper part of the body) are shown in figure 9, where the value of the measured voltage has a value of 29,01 MPa. Comparison of the observed and the permissible stress (29,01 $\leq$ 250 MPa) confirms that the proposed material for a maximum axis force F_A 3,7 kN satisfies requirements. The maximum value for the deformation body module RPM 70 (fixation on the upper part of the body) for the load of axial force F_A 3,7 kN is 0,009 mm.

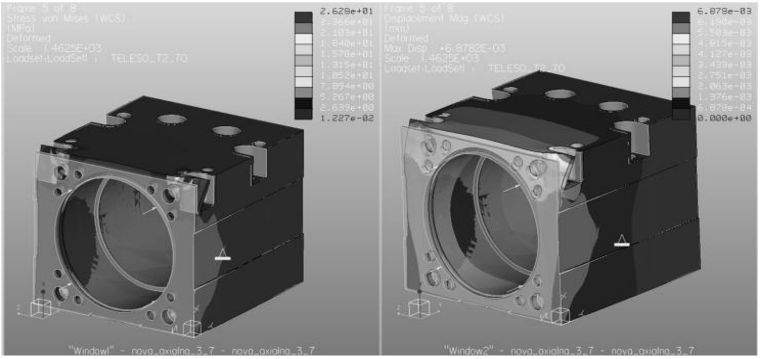

Fig. 9. Value of stress and distortion body the module RPM 70
for F_A 3,7 kN (fixation on the back of the body) [source: own study]

Static analysis of stress and strain in the body of module RPM 70 – load body at a radial force value of 26 000 N. The findings of stress value (fixation on the back of the body) are shown in figure 10, where the value of the measured voltage has a value of 14,89 MPa. Comparison of the observed and the permissible stress (14,89 $\leq$ 250 MPa) confirms that the proposed material for a maximum radial force F_R 2,6 kN satisfies requirements. The maximum value for the deformation body module RPM 70 (fixation on the back of the body) for the load of radial force F_R 2,6 kN is 0,01475 mm.

The findings of stress value (fixation on the upper part of the body), where the value of the measured voltage has a value of 44,36 MPa. Comparison of the observed and the permissible stress (44,36 $\leq$ 250 MPa) confirms that the proposed material for a maximum radial force F_R 2,6 kN satisfies requirements. The maximum value for the deformation body module RPM 70 (fixation on the upper part of the body) for the load of radial force F_R 2,6 kN is 0,0172 mm.

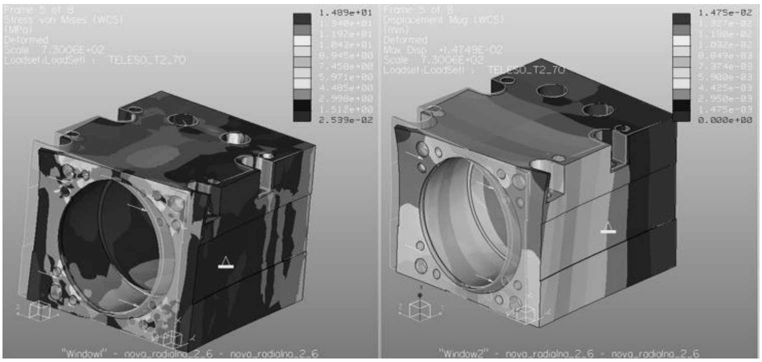

Fig. 10. Value of stress and distortion body the module RPM 70 for F_R 2,6 kN
(fixation on the back of the body) [source: own study]

In an analogous way, was the solution FEM analysis on the sized series RPM 50 and 110.

5. CONCLUSION

Development of a new RPM types allows better meet the needs constructors of automatized and robotized workstations. By deploying of precise technological head on end member of the robot can be improved resulting accuracy and repeatability of the robot in space. This leads to the reduction of the resulting rates robotized workplaces, since there is no need make it to deploy of accurate and expensive robot.

FEM analysis of the proposed modules is achieved by confirm the suitability of the use of aluminium alloys in structures RPM module. Deployment of the material was reduced by resulting of module weight while maintaining of sufficient strength and rigidity. This leads to the possibility of deployment of the proposed modules for robots and manipulators with lower load capacity.

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FMS, subsystem of objects ordering, Enterprise Dynamics, computer simulations

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A METHOD FOR MODELLING THE FLOW OF OBJECTS TO BE MACHINED IN FMS USING ENTERPRISE DYNAMICS

Abstract

Owing to the complexity of technical and organizational problems that manufacturing enterprises are faced with, there is a growing interest in methods and tools that aid design of manufacturing systems. These methods and tools can be applied both to reorganize the existing manufacturing systems and to design new ones. For this reason, computer simulations are widely used in production engineering. This paper presents the application of computer simulations when designing the subsystem known as ordering of objects in a flexible manufacturing system. The simulations were performed using the comprehensive simulation software Enterprise Dynamics.

1. INTRODUCTION

Simulations of manufacturing process allow us to examine models to be applied in practice with regard to such factors as time, cost, efficiency and resource utilization [1]. Enterprises can take advantage of a number of process modeling tools to either design a new manufacturing system or reorganize the existing one. These tools particularly allow comparison of alternative process models and – following experimental tests – selection of the best solution. Generally, experimental simulations do not include initial state estimation, so as to provide a basis for middle- and long-term analysis [15]. Also, they serve as a starting point for estimating potential of the system being tested [2,16]. This contrasts with the requirements of supporting decision-making operations which are aimed at estimating the possibility of introducing short-term changes to the process to

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enable better performance of the system in case of unforeseen circumstances [17]. The estimation of the current state of the system and history of events allows us to gain insight into short-term effects of changes introduced to the designed system [3].

Computer simulations are used to design highly complex objects, including flexible manufacturing systems (FMS) [4]. These systems – combined in various configurations – are the fastest developing form of production organization [5]. The term "flexible manufacturing system" is generally used to describe systems based on the use of so-called means of flexible automation, i.e. computer-controlled manufacturing devices that are highly universal and easy to retool. System flexibility is one of the most desired features that can be obtained in various ways, starting from product range, selection of machinery and production equipment, organizational structure, systems of production control and cooperation between employees, to establishing proper connections between the FMS and its surrounding environment [6]. The use of flexible manufacturing systems leads to higher production efficiency due to the integration of manufacturing processes, lower costs of starting a new order and shorter time of fulfilling it, less capital to be invested and – at the same time – higher turnover of this capital. The introduction of FMSs based on the use of microsystem electronics, IT and electrical engineering has therefore led to a significant technological and organizational progress. In the literature, the FMS is defined as a *computer-integrated complex of machines and technological devices characterized by high flexibility, automation and integration of its constituent elements* [7,8]. The application of numerical control in this system ensures considerable efficiency, practically no manual operation, and a short time of retooling. Another advantage of the FMS is that – given the potential of an enterprise – it can be used to produce any product depending on a demand [9].

2. DESIGN OF FMS SUBSYSTEMS

Flexible Manufacturing Systems (FMS) are highly complicated systems, which means that it is necessary to split an individual FMS into its constituent parts, or subsystems [10]. The FMS structure (Fig. 1) is made up of a network of connections (existing and observable relationships) between individual elements which help carry out the manufacturing process. Two systems can be distinguished: static (made up of a stock of machine tools and auxiliary devices) and dynamic (form of the process). When building the system, it is difficult to create a physical environment of the process, as this is either very expensive or – in many cases – simply impossible to do. To prevent this, systems are often virtually mapped, including the parameters of machinery and devices during machining and transport [11,14].

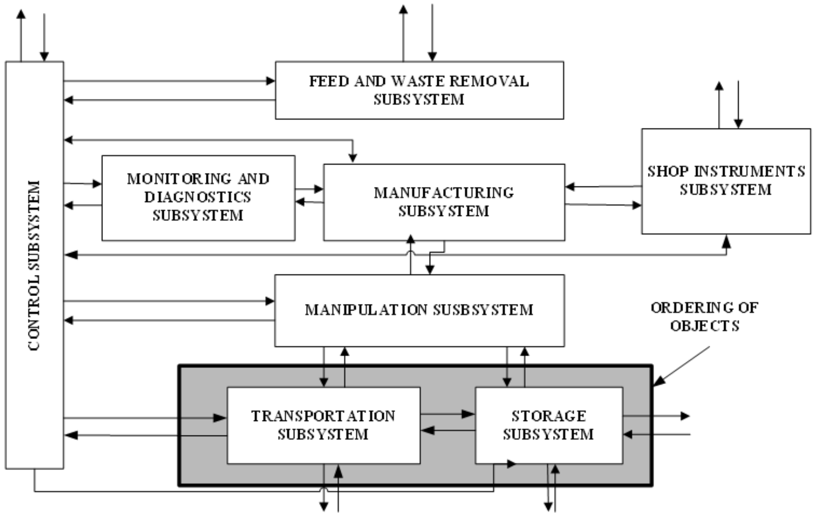

Fig. 1. FMS structure [12]

When designing flexible manufacturing systems, it is difficult to design the flow of objects in the storage and transportation subsystems [13]. The correct design of the flow of objects depends on both the financial aspect and the way in which the flow is intended to function. The design involves considering not only the size, type and arrangement of stores, but also their dimensions and capacity. The examination of individual factors according to different criteria ensures that the structure is designed correctly and, hence, it will function correctly, too.

A suitable selection of storage and transport devices responsible for the flow of materials (the subsystem known as ordering of objects) is an essential element in manufacturing system structure design, as it ensures that the manufacturing process will run smoothly. Its main task is to ensure that the machines work in an uninterrupted manner, which means that once a given operation is over another workpiece is immediately mounted on the machine tool.

3. DECISION-MAKING PROCESS AND CHARACTERISTICS OF THE FLEXIBLE MANUFACTURING SYSTEM

The complexity of modeling flexible manufacturing systems becomes clear when one examines the major aspects of designing such systems. The FMS is modeled using a closed queuing network. It is assumed that every single time a part leaves the system through the unloading station, it is immediately replaced with a new workpiece installed by the loading station. The production task is to select the parameters of material flow such that all machine tools in the system are under a uniform load.

The decision-making problem can be stated in the following way: An enterprise specializing in the machining of bodies wants to implement a flexible manufacturing system to improve both the flexibility of its manufacturing processes and its own competitiveness. First, using multi-criteria analysis methods, we selected the quantity of machine tools for the machining of the defined class of parts [18]. Then, we selected and deployed stores in the system [19]. Another stage involved enhancing the subsystem of objects ordering in such way that both the time of retooling and the queuing time are as short as possible, while load distribution is uniform.

In terms of quality and quantity, the workpieces (bodies) are sent to production at random, yet in compliance with the expected demand. The mean annual production rate of representatives of particular parts is as follows: Body_1 – 3950 pcs., Body_2 – 5435 pcs., Body_3 – 3160 pcs. These parts are machined using CNC machines selected at the stage of the flexible manufacturing system: MCX900 – 3 pcs., TOStec PRIMA – 3 pcs., MCFV1680 – 3 pcs.

The parts were machined in compliance with the process route shown in Fig. 2. The times marked in the chart with the names of machine tools denote the times of travel of parts in a given machine tool during subsequent operations (including the time of retooling).

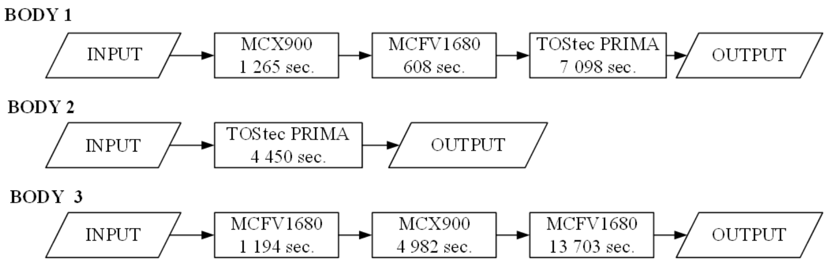

Fig. 2. Routes of parts in the manufacturing process [source: own study]

The selection of parameters and devices for the ordering of objects is aimed to improve the flow of manufactured parts by eliminating production bottlenecks and by reducing costs caused by incorrect selection of storage capacity and store types. Also, this will ensure effective management of the premises of an enterprise, hence making this enterprise more competitive.

4. MODELING OF THE MANUFACTURING PROCESS USING ENTERPRISE DYNAMICS

The model of the manufacturing system is designed using the Enteprise Dynamics simulation software manufactured by Incontrol. The designed model was used numerically simulated and the results obtained were then examined. The tested system was assumed to work 365 days a year, including 15 days for standstills due to inspections, repairs and maintenance of the devices. We allowed additional 3% of time for unexpected standstills of the system. 10% of the system operation time was assigned for conveyance operations. The work was to be conducted in a triple-shift system. Having calculated the above, we obtained the simulation time which was 7333 hours and 12 minutes – the amount of time corresponds to the annual work period of the system. The use of Enterprise Dynamics enables application of the incremental method tailored to conditions of the task with a graphical user interface; it also ensures experiment control via an interpretable language (e.g. 4DScript).

The objects flow system in the designed model (Fig. 3 and 4) consists of the following:

- 3 central stores responsible for the maintenance of the manufacturing department, additionally equipped with storage and retrieval machines located in the store,
- 7 changers, i.e. autonomous loading and unloading devices,
- 2 technical stores for ”re-routing” products according to the ”process route”; these stores do not, however, have any effect on the design process,
- conveyor belts made up of at least three layers: two protective screens (running and carrying screens) and a core, each belt having a speed of 1 m/s and a capacity of 1 piece [6].

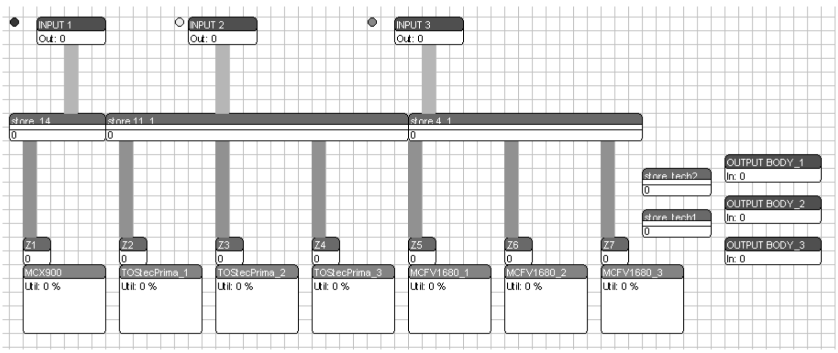

Fig. 3. FMS model [source: own study]

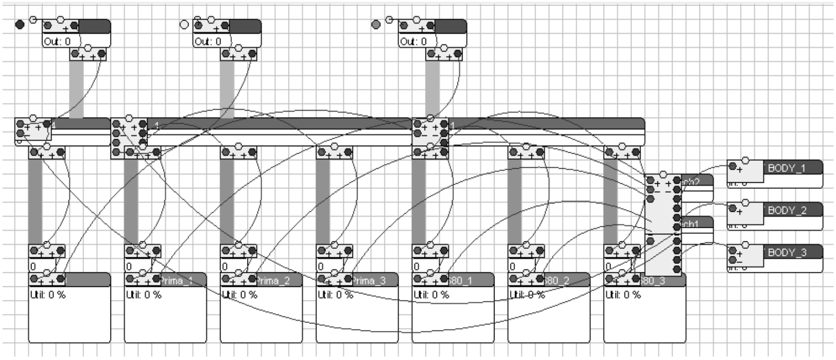

Fig. 4. FMS model showing connections between atoms [source: own study]

The tested model is used to manufacture three products: Body_1, Body_2, Body_3. Once all parts have entered the system as scheduled in the production plan, the input channel is blocked. The products are sent at random times, defined by inter arrival time. The flow of parts in the designed model is compatible with the real process route defined by a production engineer. At the end of the process, the products are sent to specified output channels (output channels are defined individually for each product). This operation is possible owing to selecting suitable parameters of the flow channel (individual atoms in the model are labeled).

The cycle time of particular operations performed on different machining stations is given in the 4DScript programming language. The application of 4DScript enabled us to create scripts that control the process according to the defined parameters of products; also, it allowed us to devise process routes showing which model of machine tool a product must be sent to as well as to transfer the finished product from one store to another. In effect, the machining of parts could be performed in accordance with the scheduled time of operation. The parts are sent in the system using the FIFO configuration. If several machine tools of the same type are occupied at the same moment, the workpiece is transmitted to the first free machine tool in the queue. If several work stations are free at a given moment, we use the following function: *Send to: A random open channel: choose a random channel from all the open output channel*, which results in sending the product to a machine tool selected at random. In the course of the simulations, we did not introduce any changes to the tested machine tools subsystem in the flexible manufacturing system for producing parts (bodies) according to the above process routes (see eg. Fig. 5).

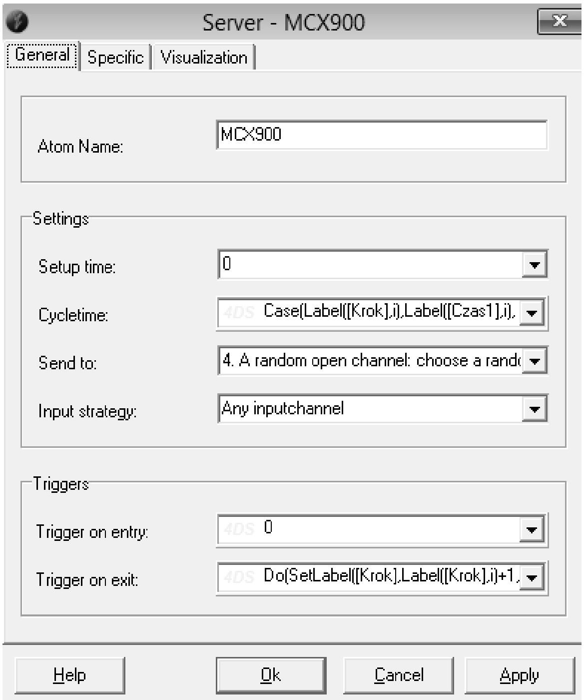

Fig. 5. Parameters MCX900 machine [source: own study]

5. COMPUTER SIMULATION AND DISCUSSION OF THE RESULTS

Based on the above assumptions, we built a model that was used in twenty simulations of the flow of objects. In the simulations, we examined the following parameters:

- mean load of the machining tool in the simulation (in %),
- maximum quantity of products stored (in pcs.),
- storage occupancy during the whole process (in %),
- mean quantity of products stored (in %),
- mean queuing time (in secs.).

The above factors were analyzed to select a suitable configuration of objects flow. The use of computer simulations both aids and ensures the building of a high quality system.

We conducted 20 simulations (Table 1), which confirmed that the stores had been selected correctly. The following had central stores: Store_14, Store4_1, Store1_1. We mounted changers at machine tools with a capacity of 2 pieces. They were located next to these machine tools and labeled as Z1, Z2, Z3, Z4, Z5, Z6, Z7. The results demonstrate that the above quantity is adequate and the mean occupancy does not exceed unity. The longest queuing time was recorded for changer Z1, which results from the fact that the changer is mounted at the MCX900 machine (Fig. 6) – the only machine of this type in the system. This machine tool is characterized by a short machining time, and the simulation results demonstrate that it was utilized in 78.564 %. The percentage is correct and it does not disturb system operation. The load applied to individual machine tools is similar (Fig. 7), which is proves that the system's random demand for specific parts was designed correctly. What is more, the entire system functions correctly, parts do not get stuck when entering the system, and the production plan is implemented. No disturbances to the system were recorded. We did not identify the occurrence of bottlenecks that could have a negative effect on flow capacity of the system.

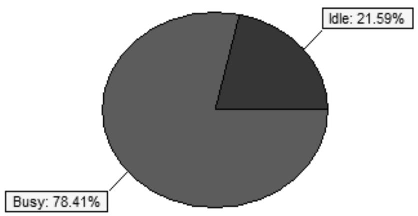

Fig. 6. Machine MCX900 usage [source: own study]

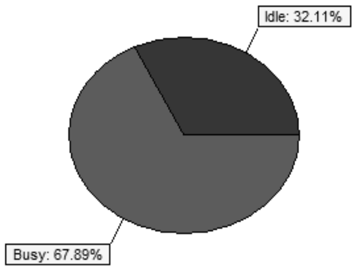

Fig. 7. Machine TOStecPrima usage [source: own study]

Table. 1. Mean results of the stores and machine tools

Storage parameters	Store_14	Store 4_1	Store 11_1	Z1	Z2	Z3	Z4	Z5	Z6	Z7
Capacity [pcs.]	10	10	10	2	2	2	2	2	2	2
Mean occupancy [pc.]	0.117	0.089	0.012	0.844	0.414	0.442	0.432	0.648	0.601	0.673
Maximum quantity in store [pc.]	4	3	3	2	2	2	2	2	2	2
Queuing time [s]	434.52	0.364	0.000	3133.2	3486.9	3735.6	3646.9	5115.0	4509.7	5214.7

Machine tools parameters	MCX900	MCFV1680_1	MCFV1680_2	MCFV1680_3	TOStec Prima_1	TOStec Prima_2	TOStec Prima_3
Mean load of machining tools [%]	78.564	62.548	62.528	62.252	66.838	66.088	65.872
Mean time of machining [s]	2916.980	4647.750	4875.945	5563.071	5586.512	5543.647	4925.809

It is estimated that a system built in compliance with the designed model will ensure a smooth flow of materials in the system. When designing a subsystem of objects ordering, we examine individual parameters that affect a given subsystem in order to arrive at the optimum solution. With the system built thereby, it is possible to save space (not only the storage space) owing to better use of both the central store and the entire system. Although the application of conveyor belts and their developed spatial structure hinders access to work stations in cases of emergency, conveyor belts (Fig. 9) are nonetheless often used in this type of system configuration. They are structures suitable for products of varying sizes.

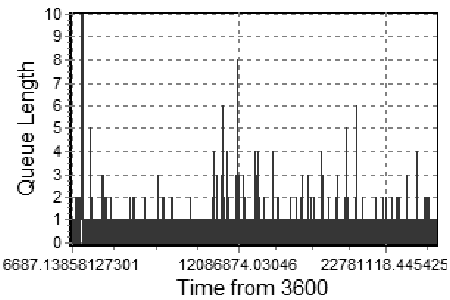

Fig. 8. Storage_14 occupancy [source: own study]

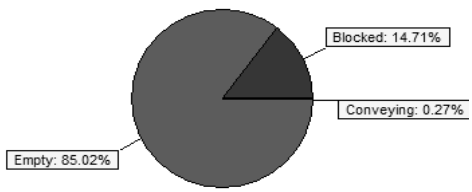

Fig. 9. Conveyor belts usage [source: own study]

In the system designed thereby, the main storage unit is defined by central store. In addition, parts can queue to be processed on conveyor belts, therefore they are not sent to the central store. The results of the performed 20 simulations show that the scheduled production plan has been implemented, even though it was burdened with uncertainty due to the random input time and random product selection when entering the system. Parts to be manufactured queue in the vicinity of the machine tools, which ensures that a workpiece is mounted on the machine tool immediately after the previous process performed by this machine tool is over.

Computer-aided simulations allow us to use manufacturing cells in a more effective way – delivery ineffectiveness can be eliminated if the flows of parts, tools and workpieces are combined. In fact, this confirms the thesis that an optimally working manufacturing cell will not ensure process continuity unless it is equipped with correctly functioning coupled subsystems.

6. CONCLUSION

Given the tendency of keeping investment outlays to the minimum while at the same time attempting to improve manufacturing efficiency and product quality, the realization of manufacturing processes involves dealing with unexpected challenges. Since the manufacturing system of an enterprise cannot function well without a well-organized internal logistics, the use of computer simulations can considerably optimize the flow of raw materials, components or finished products. Internal logistics has a significant effect on the organization of individual processes, as it ensures correct flow and transport of all components and products in successive manufacturing stages as well as the supply of fini-shed products to the store.

Due to their simple design, high reliability and relatively low energy consumption, conveyor belt systems are the basic means of transportation. Installed in an FMS, they can provide additional buffer storage. A buffer storage is used when we want to give up on large storage capacity and limit the usable area to the changers that operate the machine tools. Recently, we are witnessing a growing interest in belt conveyor systems. The only problem connected with the maintenance of conveyor belts is that after unloading plastic strain (elongation) tends to remain or they rapidly build up at the beginning of working life of new belts and set permanently after a certain period of time [2]. Nonetheless, conveyor belts are still the most widely used conveyor systems in flexible manufacturing systems.

The experimental results demonstrate that the proposed transportation system was designed correctly and the destinations of parts in the stores were set correctly, too. When using conveyors belts, however, it must be remembered that they are most suitable for circulating systems and that the route of materials flow depends on the design of a given conveyor belt. On the one hand, conveyor belts prevent easy access to work stations. On the other, the cost of mounting them is low due to a vast number of specialized transport services that are available on the market. Also, conveyor belts can be custom-designed for a specific manufacturing system. The experimental results demonstrate the potential of using computer simulations as a method for solving highly complicated problems, particularly for investigating decision-making problems that cannot be solved by traditional methods.

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Rubik's cube, Pneumatical manipulator, Service robotics, Thistletwaite45

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OPTIMIZATION AND DESIGN OF FOUR GRIPPER PNEUMATICAL RUBIK'S CUBE SOLVER

Abstract

Robotic Rubik's solver is an excellent example of science popularizing mechatronic device, since it combines knowledge of several technological fields including computer vision techniques, advanced numerical algorithms and control of industrial pneumatic components with popularity of Rubik's cube in one resulting device. First version of solver constructed by our department was equipped only by 2 lower grippers, resulting in approximately four minutes for single cube solution. Proposed paper describes not only experience gained by development of upgraded 4 gripper version but includes statistical analysis of Thistlethwait's 45 algorithm required for solving process optimization. Mechanical design, electronics, system overview, performance and limitations of upgraded 4 gripper version are explained in detail as well.

1. INTRODUCTION

Rubik's cube is famous puzzle invented by Erno Rubik in 1974. 57mm wide cube consisting of 6 center, 8 edge and 12 corner pieces, allows more than $43x10^{18}$ mutual combinations. Consequently, solving the Rubik's cube like many other problems is the NP-hard problem (see: eg. [1-5]). Since Rubik's cube introduction, its popularity has inspired many students and researchers to build robots capable of solving this 3D puzzle. Several solving mechanisms have been proposed already [6], most of them using NXT components, but some pneumatical robots have been constructed as well [7]. Considering speed, David's Gilday's Cubestormer III is the current Guinness world record holder in category Fastest Rubik's cube solving robot – time 3.253s [8].

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No matter what mechanics is used, the principle of real cube solving process remains the same including three phases: Detection of cube state, Generating solution and Realizing particular moves. Proposed paper describes mechanical construction in first section, followed by solving algorithm description, system overview, electronics specification and statistical analysis of Thistlethwait's 45 algorithm. Last section provides information from real testing including solving times and personal experience gained during several public presentations of this showpiece. The main drawback of the whole system identified during presentation phase was vision based cube detection algorithm. It's weakness is mainly caused by mechanical construction, because in order to keep clear industrial design, USB webcam is not only opposite-visitor oriented, but moreover mounted on gooseneck platform, which prevents long-term fixed position of camera with respect to handled cube. Every time the showpiece is set up, the position of the camera slightly changes. This drawback in combination with various lighting conditions during several day-long presentations requires more robust algorithm for cube detection than the one previously used. The development of robust computer vision algorithm for Rubik's Cube state detection can be found in [9].

2. MECHANICAL CONSTRUCTION

As mentioned in the beginning, our motivation was to by develop fully pneumatical Rubik's cube solver to demonstrate possibilities of pneumatical approach in precise manipulation tasks. 3D CAD design shown in Fig. 1 gives an overview of whole construction.

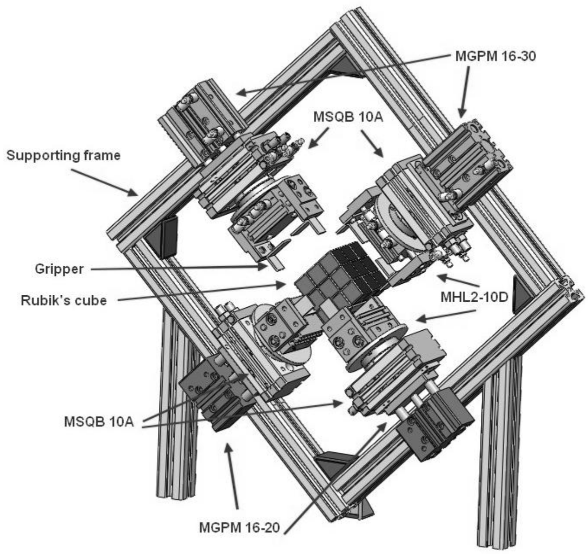

Fig. 1. Mechanical design of Rubik's solver [source: own study]

Supporting frame is assembled of aluminum mounting profiles 30x30mm and attached to wooden base providing cover for electronic part of a system. Four manipulation units consist of three air modules – compact guide cylinder, rotary table and a gripper module. For our particular construction, SMC modules were used, since they provided best price/performance ratio.

The very first component that needed to be selected in Rubik's solver mechanical design was gripper unit. SMC provides several types of components including angle, parallel or three point grippers. Considering all possible options, MHL parallel units were selected as best suitable for our task. MHL in general are double piston parallel style grippers with large holding force, which are available in several sizes.

In order to select particular type of MHL gripper module, it was necessary to compute holding force and determine holding point distance. If Rubik's cube weight is $m_{rc} = 0{,}12$ kg , safety factor $k = 10$, then required holding force is computed as follows:

$$F_u = m_{rk} \times g \times k = 11{,}8N \tag{1}$$

Considering holding force F_u , distance from grasping point R = 30 mm and Rubik's cube width L = 57 mm , MHL2-10D unit, providing opening/closing stroke range 56-76 mm was selected. As shown in diagram in Fig. 2 required holding force can be achieved already at 0.4 MPa.

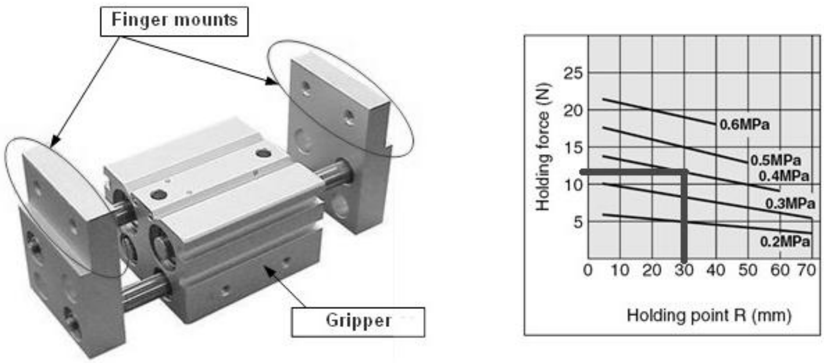

Fig. 2. MHL2-10D gripper unit and appropriate holding force graph [source: own study]

Rotation of gripper unit is handled by SMC MSQ units. MSQ is compact rotary table including load bearings, mounting face, with a rack-and-pinion style rotary acutator. Achievable rotating range of MSQ tables is 190 degrees, in case of Rubik's cube manipulation; adjustments are set to 0-90°. In order to select optimal rotary table type, two important variables - moment of inertia and time of 90° rotation must be determined. Considering weight of Rubik's cube m_{rc} = 0,12 kg , weight of gripper unit m_{GU} = 0,28 kg as well as dimensions of gripper unit, moment of inertia can be computed as follows:

$$I = (m_{rc} + m_{GU}) \times \frac{a^2 + b^2}{12} = 1{,}51 \times 10^{-4}\, kgm^2 \tag{2}$$

If duration of 90 degree rotation is set to 0.3s, MSQB-10A unit meets computed requirements as shown in diagram in Fig. 3.

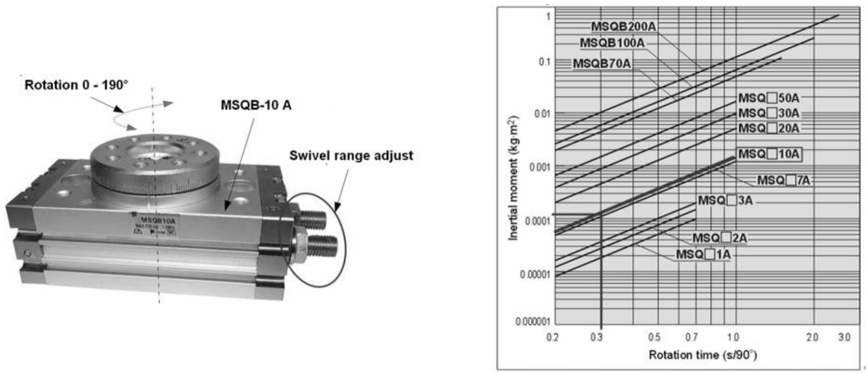

Fig. 3. MSQB-10A unit and appropriate rotation time – inertial moment selection graph [source: own study]

As mentioned above, current mechanism allows manipulating with four sides of cube directly. But solving process require clockwise and counterclockwise manipulation with all six sides of the cube, therefore it is necessary to turn the cube every time the front or back side of the cube needs to be rotated. However, turning the cube without stroking of particular units is not possible because of mutual gripper collisions. Application of compact guide cylinders eliminates this problem, by providing stroking capability for each manipulation unit. When rotating the cube, only gripper holding the cube can be ejected, remaining three must be shut to avoid collision. From all available cylinder units, MGPM class was most suitable for our construction mainly because of its flat design and rectangular mount allowing simple attachment of rotary unit.

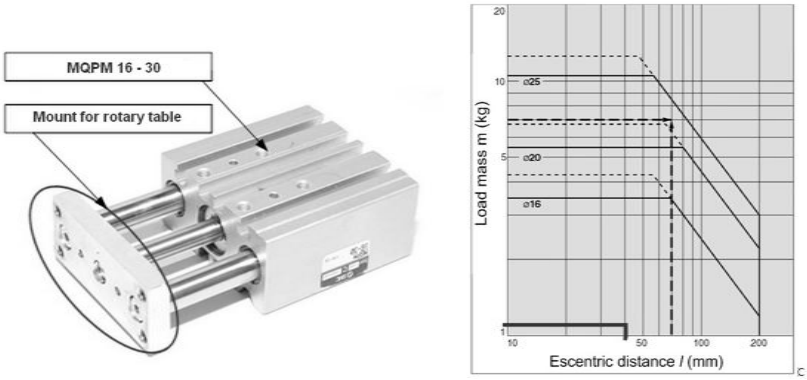

Fig. 4. MPQM 16-30 and appropriate load mass –
eccentric distance selection graph [source: own study]

MGPM in general is compact guide cylinder designed for high side load applications with available strokes within range 20 – 400 mm. Since MGPM load of single unit in our case was approximately 1kg, model size with cylinder diameter D=16 mm according to graph in Fig. 4 was selected. Lower two gripper units are equipped by 20 mm stroke, while upper grippers units use 30 mm strokes. This configuration in combination with dimensions of supporting frame results in appropriate gripper position with respect to the cube.

Comparison of prior and current version of Rubik's solver is shown in Fig. 5.

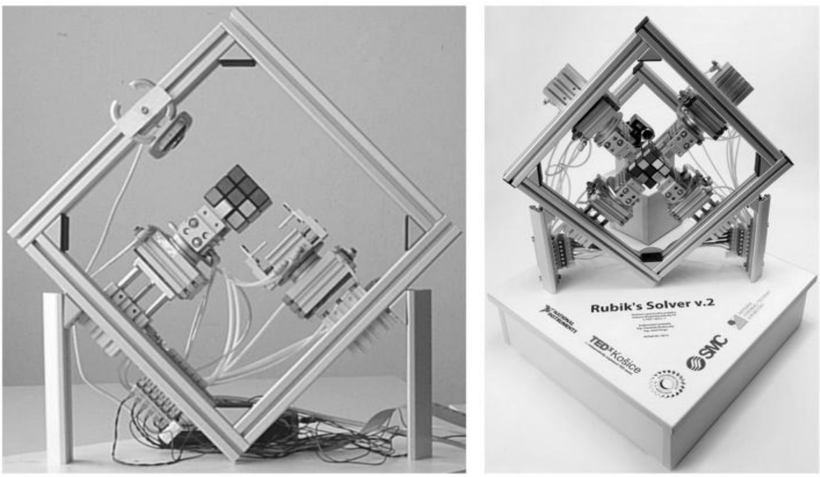

Fig. 5. Comparison of previous and current solver version [source: own study]

2. SOLVING ALGORITHM

Rubik's cube solving algorithms can be in general divided into two categories: Human algorithms & Computer algorithms.

Human algorithms are quite simply memorable but not as fast as computer's. Computer algorithms require extensive computer searching, which is not possible in human approach. First computer algorithm introduced in 1981 by Morwen Thistletwait [9] provided maximum 52 move solution of arbitrary scrambled cube. By exhaustively searching, it was later found, that the best possible number of moves is 45, resulting in so called Thistletwait45 algorithm [10]. Our solver uses Joren Heit's implementation of T45 algorithm, written in Matlab under BSD license, open source and free for public [11]. Median number of moves for T45 method is 31 – quarter of average moves required for basic human algorithm – Layer by Layer.

Thistlewait algorithm was improved by Herbert Kociemba in 1992. Using this algorithm, solutions are typically found of fewer than 21 moves, though there is no proof that it will always do so. Implementation of Kociemba algorithm will be probably the next step in future development.

3. SOFTWARE DEVELOPMENT

The whole application was programmed in Matlab, not only because the solving algorithm was written in this language, but moreover because the fact, that Matlab provides all necessary features, including vision algorithms, tools for designing graphical user interface and support of hardware input output devices via Data acquisition toolbox.

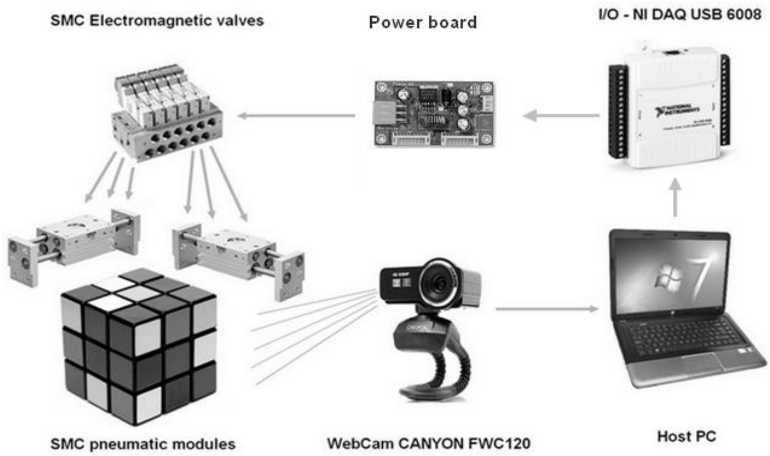

Fig. 6. System Overview [source: own study]

4. ELECTRONICS

Overview of solver control is shown in Fig. 6. The most important part of whole system is physical link between host PC and SMC electromagnetic valves. It was realized by low-cost USB DAQ 6008 from National instruments, supported by Data acquisition toolbox. This combination allows direct control of 12I/O by single line of code. The only complication was the fact, that SMC electromagnetic valves as most of industrial components require 24V for switching, but USB6008 provides only 0-5V I/O voltage levels. Hence simple power board including Darlington NPN transistors TIP122 were used to raise the voltage level up to 24V. Outputs of USB6008 are not connected to transistor base directly but via optocouplers providing galvanic isolation between control and power part of the system.

5. OPTIMIZATION

There are three ways to manipulate with single cube side:

- 90 degrees clockwise (L,R,F,B,U,D)
- 90 degrees counterclockwise (L', R', F', B', U', D')
- 180 degrees (L2, R2, F2, B2, U2, D2

Rubik's cube solution is always a combination of these 18 types of moves, what differs is its implementation in particular solvers.

Our implementation uses principle "*Basic cube orientation* --- *Move* --- *Basic cube orientation*", so cube returns to basic orientation after every single move. Since our mechanism allows us to manipulate only with 4 cube sides directly, time consuming re-grasping is required in case of manipulating with remaining two cube sides. Therefore the main question in initial stage of implementation was selecting basic cube orientation to minimize inevitable re-grasping moves.

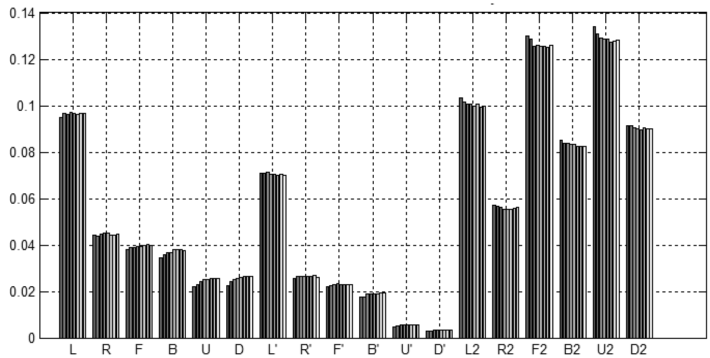

Fig. 7. Relative abundance of all possible moves for 8 different mixing values [source: own study]

In order to find pair of cube sides (L-R, U-D, F-B) least frequently manipulated in Thistlethwait's 45 algorithm, we have conducted statistical analysis on 80 000 of randomly mixed cubes. Function generating random cubes takes a number of moves used for mixing the cube as an input argument. 8 different mixing values (15, 20, 25, 30, 35, 40, 45, 50) were used, each for 10 000 cubes resulting in relative abundance of particular moves shown in Fig. 7. As one can see, U2 and F2 are most frequently used moves, while U', D' are almost not used at all in T45 algorithm. Summarization of first chart with respect only to cube sides is shown in Fig. 8.

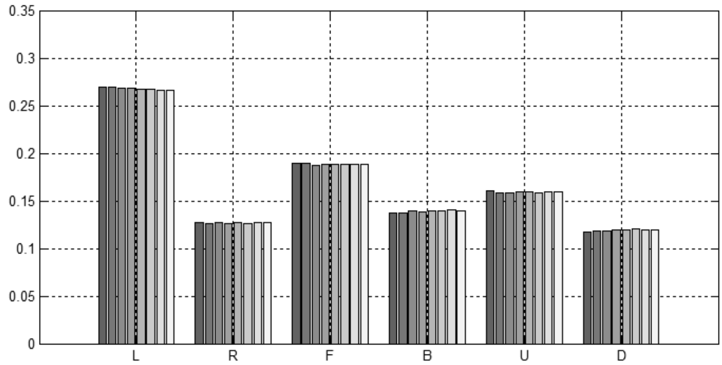

Fig.8. Relative abundance of manipulated cube sides [source: own study]

As shown in Fig. 8, left side is most frequently manipulated, in contrary with least manipulated, right cube side. It is also worth noticing, that changing number of mixing moves does not influence relative abundance markedly, values are almost the same for different settings. Combining results from Fig. 8 into opposite cube pairs yields to most important chart for optimizing of solving process shown in Fig. 9.

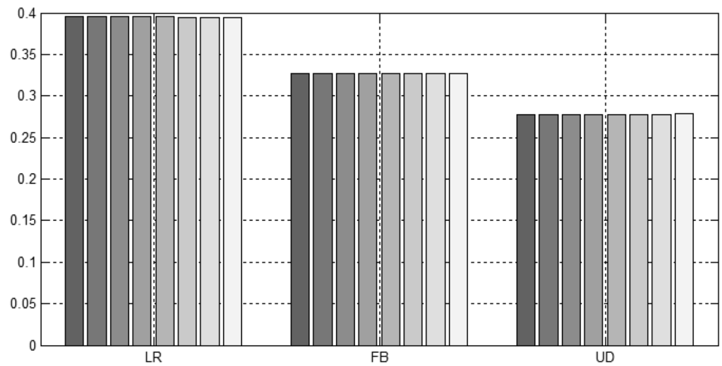

Fig. 9 Relative abundance of manipulated cube side pairs [source: own study]

It is obvious that “Up-Down” pair is statistically least manipulated, so when following general Rubik’s cube notation:

Up side – White center square	Down side – Yellow center square
Left side– Green center square	Right side – Blue center square
Front side – Red center square	Back side – Orange center square

It means that in order to minimize time-consuming re-grasping, white and yellow center sides needs to be front/back oriented with respect to the solver, while Green, Blue, Red and Orange cube sides are directly reachable by particular grippers.

Besides cube side manipulation, statistical analysis of number of solution moves has been conducted as well. Solving 80 000 sample cubes has resulted in normal Gaussian probability distribution with median value 31 as shown in Fig. 10. Maximum number of moves in our sample set was 40, but as the name of algorithm indicates, cube states requiring exactly 45 moves are known as well.

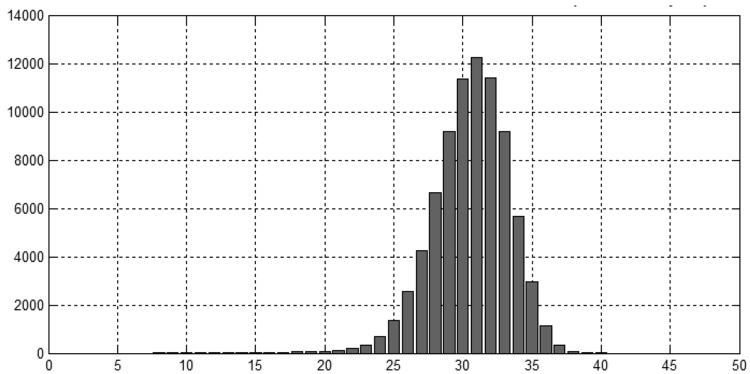

Fig. 10. Thistlethwait’s 45 - Number of solution moves (80 000 samples) [source: own study]

6. CONCLUSION

Construction of Rubik’s solver can provide a lot of useful experience, especially when studying mechatronics, since it requires combining several different subsystems into one functional mechanism. Our main motivation was to build Rubik’s cube solver using standard industrial components to demonstrate pneumatical approach for solving precise manipulation tasks. First version has proven the basic functionality, adding 2 more grippers in second version have reduced average solving time under 2 minutes.

Rotary table allowing movement only between two endpoints is the main constraint of current mechanism. In case of Rubik's solver, endpoints are mechanically set to 0 and 90 degrees. It is possible to solve the cube with such a limitation but frequent time-consuming re-grasping is required. Optimal end-points for clockwise, counterclockwise and double moves would be -90, 0, 90 and 180 degrees. Replacing current rotary units for stepper motors could rapidly reduce solving time to less than one minute, but for the price of simple pneumatical design.

Video of proposed Rubik's cube solver developed by our department is available on http://www.youtube.com/watch?v=-VhLoyQBhj8.

7. FUTURE WORK

Rubik's cube solver is the main presentation showpiece used by Faculty of Mechanical engineering during several science popularizing actions. Authors of this paper have spent hours and hours presenting this mechanism in public, while solving hundreds of cubes randomly mixed by visitors.

Mechanical construction as well as electronic part of system has proven its reliability during this period, though no further upgrades of these parts are foreseen. What is worth considering is the robot control software since new solving algorithms have been released recently. Implementation of more advanced algorithms could reduce average number of moves and thus reduce overall solving time even more.

Rubik's solver is also a great experimental platform for testing different vision algorithms. In future, we would like to try different approach to move from static image recognition to video tracking of the cube. Moreover existing dataset of positive and negative scans could be also used to train a support vector machines algorithm for cube position detection. Such an approach has the potential to bring more sophisticated solution and reduce the scan time significantly.

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computer image analysis, measurements, contact angle

Anna KRAWCZUK, Jacek DOMIŃCZUK***

THE USE OF COMPUTER IMAGE ANALYSIS IN DETERMINING ADHESION PROPERTIES

Abstract

The paper discusses the use of computer image analysis in determining adhesion properties of materials, including the work of adhesion and surface free energy components. Also, it discusses methods and operators for edge detection employed in the determining of geometrical parameters which are then used as the basis for calculations. In addition, the paper presents an example of expanding the scope of investigations through the application of new IT solutions.

1. COMPUTER IMAGE PROCESSING AND METHODS OF IMAGE PROCESSING

Computer image analysis is currently used in numerous fields of science. This is an automatic method, which allows both the processing and analysis of images saved in digital form [1]. Until recently, adhesion properties were investigated with methods based on geometrical measurements carried out manually [2].

The development of computer technology has opened up new possibilities of analyzing recorded digital images. Also, the available image processing operations applicable in the analysis allow to improve the quality of images and to fully exploit information recorded in these images.

Current studies into adhesion properties are conducted by means of computer image analysis, which enables automatic measurement of a contact angle formed by a drop that is not reactive with a solid surface (Fig. 8) [3]. This measurement is particularly important in determining the work of adhesion and surface free energy.

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The equations presented below (3, 4) show that the accuracy in determining the work of adhesion is related with precise measurement of a contact angle. The contact angle can be determined based on the measurements of geometrical dimensions of drops lying on a solid surface (Fig. 1). Having determined the dimensions of the drops, it is easy to calculate the contact angle with the formula:

$$tg\frac{\theta}{2}=\frac{k}{r} \tag{1}$$

The designations shown in Figure 1.

As for the drop shape shown in Figure 2, we can use the formula:

$$tg\frac{\theta}{2}=\frac{x}{r-h}=\sqrt{\frac{2h}{r-h}} \tag{2}$$

The designations shown in Figure 2.

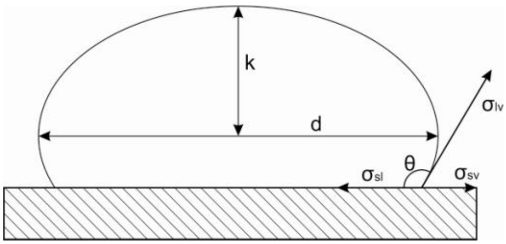

Fig. 1.Determination of the contact angle by measuring the size of a drop [source: own study]

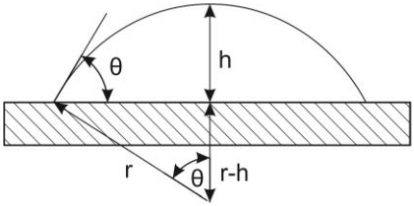

Fig. 2. Determination of the contact angle [source: own study]

Another method for determining the contact angle is to measure it directly. Performing a quantitative analysis of objects present in the images and taking geometrical measurements [2] is based on extracting elements, that is the detection of the contact angle's edges. On a monochrome image, the edge is a transition area between two levels of brightness, which is the line separating the regions of different luminance [4]. Edge detection can both reduce the amount of data to analyze by filtering out less important pieces of information, while at the same time maintaining the properties of structures found in the images. Edge detection methods can be divided into two groups. The first group of methods studies the first derivative (gradient methods), while the second group is based on the study of the second derivative.

One of the fundamental methods for edge detection uses the first derivative of a function representing the change in a grayscale image along a set straight line. Due to the difficulty in determining the derivative, local gradients are adopted on the computer image as an approximation of the derivative. Based on the information about the rate of increase in the original data, the extremities of the first derivative of luminance are studied.

The second derivative of luminance shows the rate of change in the first derivative of luminance. The first derivative has a small value for images with inconspicuous transition between different areas of gray. In such cases, the second derivative is used, which assumes the value of zero for the edge.

We can distinguish the following operators in edge detection [5]:

a) operators of the first type – the Prewitt operator, Sobel operator and Roberts operator,

b) operators of the second type – Laplacian operators.

1.1. Roberts operator

The Roberts gradient is clearly directional. The differentiation of the two-dimensional function is performed along a certain direction; as for the Roberts gradient, this direction is located at 45 degrees [6]. The mask used by the Roberts operator is shown in Figure 3. It can also be written in the minimized form as a 2x2 mask.

$$\begin{bmatrix} 0 & 0 & 0 \\ -1 & 0 & 0 \\ 0 & 1 & 0 \end{bmatrix}$$

Fig. 3. Mask used by the Roberts operator [source: own study]

Depending on the mask form used, this gradient always highlights the lines of a set orientation.

1.2. Prewitt operator

This operator is used to detect vertical and horizontal edges in images. The mask used by the Prewitt operator is shown in Figure 4.

$$\begin{bmatrix} -1 & -1 & -1 \\ 0 & 0 & 0 \\ 1 & 1 & 1 \end{bmatrix}$$

Fig. 4. Mask used by the Prewitt operator [source: own study]

1.3. Sobel operator

The Sobel mask is a weight mask and has the form as shown in Figure 5. This mask enhances the influence of the nearest pixel environment when determining the value of a pixel on the resulting image.

$$\begin{bmatrix} -1 & -2 & -1 \\ 0 & 0 & 0 \\ 1 & 2 & 1 \end{bmatrix}$$

Fig. 5. Mask used by the Sobel operator [source: own study]

This mask can be rotated around its center point, which allows performing nine different filtration.

1.4. Laplacian operators

Roberts, Prewitt and Sobel masks define the edges only in eight directions. Often, the edges in images do not follow these directions. In order to detect edges of other directions and highlight the contours of objects in images, we use other masks – the so-called Laplacians.

A Laplacian operator is a combination of second partial derivatives of the input function. The maximum of the first derivative is the zero crossing point of the second derivative of the function. This point corresponds to the fastest changes in the function. The Laplacians are used to detect edges in images with no clear transition between the levels of gray. In this case, the first derivative has a low value and the second derivative is used to detect the edge (the second derivative of the edge assumes the 0 value). The most frequently used Laplacian masks are shown in Figure 6.

$$
\begin{bmatrix} 0 & -1 & 0 \\ -1 & 4 & -1 \\ 0 & -1 & 0 \end{bmatrix}
\begin{bmatrix} 0 & -1 & 0 \\ -1 & 5 & -1 \\ 0 & -1 & 0 \end{bmatrix}
\begin{bmatrix} -1 & -1 & -1 \\ -1 & 8 & -1 \\ -1 & -1 & -1 \end{bmatrix}
$$

$$
\begin{bmatrix} 1 & -2 & 1 \\ -2 & 4 & -2 \\ 1 & -2 & 1 \end{bmatrix}
\begin{bmatrix} 1 & -2 & 1 \\ -2 & 5 & -2 \\ 1 & -2 & 1 \end{bmatrix}
\begin{bmatrix} -1 & -1 & -1 \\ -1 & 9 & -1 \\ -1 & -1 & -1 \end{bmatrix}
$$

Fig. 6. Laplacian masks [source: own study]

2. MEASUREMENT PROCEDURE

The procedure for measuring the contact angle based on the computer image analysis is performed in the following steps:

1. Image acquisition and processing to digital form.
2. Edge detection of the measured drop.
3. Determination of the contact angle.

2.1. Image acquisition and processing to digital form

A schematic diagram of the measurement channel used for measuring the surface tension and determining adhesion properties of samples of solids is given in Figure 7. The sample is placed on a horizontal measuring table (1). Using a syringe (2), a drop of the measuring liquid with known parameters (3) is placed on the sample. The measuring table with the sample and the drop is illuminated by a focused light source (4). An image of the drop is recorded by a camera (5) and transferred directly to a computer where the contact angle is automatically measured with specialist software. The contact angle results are used to calculate such parameters as the work of adhesion and surface free energy. The analysis additionally determined other geometrical parameters of the analyzed image that can be used in the analysis of properties of the surface layer (Fig. 8).

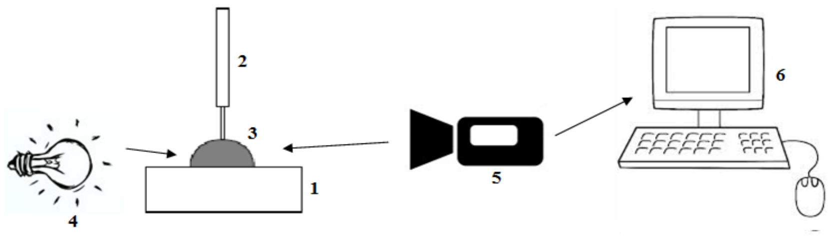

Fig. 7. Schematic diagram of the measurement channel [source: own study]

Prior to the measurements, it is necessary to prepare the device appropriately. The analysis and evaluation of a digital image considerably affects measurement precision. In order to receive an optimum image of the drop, it is necessary to adjust three image parameters: size, brightness and sharpness. An image is optimal if the drop is 2/3 width of the video image and its edges are sharp, without any interfering reflections. Also, the received mirror image of the drop must be clear. The lighting should be set such that a homogeneous lighter gray zone is above the baseline. The adjustments allow the precise determining of the baseline which is key to making measurements.

No.	Age [sec]	Theta(M)[deg]	IFT [mN/m]	Vol [ul]	Area [mm*2]	BD [mm]	System	Theta(L)[deg]	Theta(R)[deg]	WoA [mN/m]
0-0	901.552	101.1 ± 0.81		3.41	8.73	2.187	Water (Ström)	100.3	101.9	58.84 ± 1.01
0-1	938.458	114.9 ± 0.31		5.59	12.56	2.172	Water (Ström)	115.2	114.6	42.15 ± 0.36
0-2	974.244	89.8 ± 0.24		3.43	8.72	2.398	Water (Ström)	90.0	89.5	73.07 ± 0.31
0-3	1002.634	94.7 ± 0.34		3.27	8.47	2.269	Water (Ström)	94.4	95.1	66.77 ± 0.43
0-4	1014.104	105.4 ± 0.60		4.99	11.24	2.323	Water (Ström)	104.8	106.0	53.47 ± 0.74
0-5	1023.921	89.2 ± 0.18		3.37	8.64	2.393	Water (Ström)	89.3	89.0	73.86 ± 0.23
0-6	1041.138	92.7 ± 0.47		3.51	8.87	2.358	Water (Ström)	92.3	93.2	69.34 ± 0.59
0-7	1052.331	93.3 ± 0.14		3.33	8.55	2.307	Water (Ström)	93.5	93.2	68.56 ± 0.17
0-8	1062.808	95.7 ± 0.15		3.57	8.97	2.318	Water (Ström)	95.5	95.8	65.63 ± 0.19
0-9	1072.941	112.8 ± 0.16		5.43	12.19	2.255	Water (Ström)	112.9	112.6	44.63 ± 0.19
0-M		99.0 ± 9.25		3.99 ±...	9.69 ± 1.63	2.298 ± ...	Water (Ström)	98.8 ± 9.28	99.1 ± 9.24	61.63 ± 11.42
1-0	1447.388	115.2		5.91	12.91	2.298	Water (Ström)	115.3	115.2	41.77 ± 0.02
1-1	1447.895	102.6 ± 1.85		5.09	11.25	2.457	Water (Ström)	104.5	100.8	56.90 ± 2.30
1-2	1448.409	102.6 ± 1.92		5.10	11.27	2.458	Water (Ström)	104.6	100.7	56.88 ± 2.38
1-3	1448.915	102.7 ± 2.03		5.11	11.28	2.459	Water (Ström)	104.8	100.7	56.77 ± 2.51
1-4	1449.425	102.9 ± 2.09		5.12	11.29	2.459	Water (Ström)	105.0	100.8	56.57 ± 2.59
1-5	1449.925	102.6 ± 2.04		5.10	11.26	2.464	Water (Ström)	104.6	100.5	56.99 ± 2.53
1-6	1450.440	102.1 ± 1.97		5.06	11.21	2.473	Water (Ström)	104.1	100.2	57.49 ± 2.44
1-7	1450.940	102.4 ± 2.04		5.09	11.25	2.473	Water (Ström)	104.5	100.4	57.15 ± 2.53
1-8	1451.450	103.0 ± 2.14		5.15	11.33	2.470	Water (Ström)	105.1	100.8	56.47 ± 2.65
1-9	1451.956	102.9 ± 2.22		5.14	11.32	2.472	Water (Ström)	105.2	100.7	56.52 ± 2.74
1-10	1452.465	102.7 ± 2.27		5.13	11.29	2.476	Water (Ström)	104.9	100.4	56.86 ± 2.81
1-11	1452.970	103.0 ± 2.21		5.17	11.37	2.478	Water (Ström)	105.2	100.8	56.41 ± 2.74
1-12	1453.480	102.8 ± 2.22		5.15	11.33	2.485	Water (Ström)	105.0	100.6	56.68 ± 2.75
1-13	1453.980	102.9 ± 2.16		5.17	11.37	2.489	Water (Ström)	105.1	100.7	56.57 ± 2.68
1-14	1454.495	103.0 ± 2.28		5.16	11.35	2.489	Water (Ström)	105.3	100.7	56.44 ± 2.83
1-15	1454.995	103.0 ± 2.29		5.16	11.35	2.492	Water (Ström)	105.3	100.7	56.46 ± 2.84
1-16	1455.510	102.7 ± 2.29		5.14	11.32	2.497	Water (Ström)	105.0	100.4	56.85 ± 2.84
1-17	1456.011	102.7 ± 2.33		5.15	11.32	2.498	Water (Ström)	105.0	100.3	56.84 ± 2.88
1-18	1456.520	103.2 ± 2.47		5.19	11.38	2.494	Water (Ström)	105.7	100.7	56.21 ± 3.06
1-19	1457.025	103.1 ± 2.49		5.18	11.38	2.495	Water (Ström)	105.6	100.6	56.35 ± 3.08
1-20	1457.535	103.1 ± 2.52		5.18	11.37	2.495	Water (Ström)	105.6	100.6	56.29 ± 3.12
1-21	1458.035	102.6 ± 2.43		5.14	11.32	2.501	Water (Ström)	105.1	100.2	56.91 ± 3.02
1-22	1458.550	102.6 ± 2.49		5.14	11.31	2.501	Water (Ström)	105.1	100.1	56.92 ± 3.09
1-23	1459.050	102.7 ± 2.55		5.15	11.32	2.501	Water (Ström)	105.3	100.2	56.77 ± 3.16

[x , y]: GrayVal 00:01:27

Fig. 8. View of the table automatically generated by the program for the analysis of surface layer properties [source: own study]

In this stage, the image analysis is performed in order to detect the drop's contour and the line separating the solid phase from the liquid phase. To this aim, different edge detection methods can be employed, such as the Sobel, Prewitt and Roberts methods, Laplacians and the Canny method [7]. The choice of the method depends on the quality of a received image.

2.2. Determination of the contact angle

Based on the detected edge, a theoretical drop profile is determined using the above described numerical method. Figure 9 shows the example of a droplet obtained in the measurements. The horizontal line is the baseline (the line which separates the solid from the measured drop), while the green line indicates the theoretical shape of the drop.

To determine the contact angle (which was then used to determine adhesion properties), we employed a measuring method in which the shape of a droplet is determined by the equation where the derivative at the point of intersection of the baseline with the line defining material surface creates an angle of inclination at the junction of three phases (contact angle).

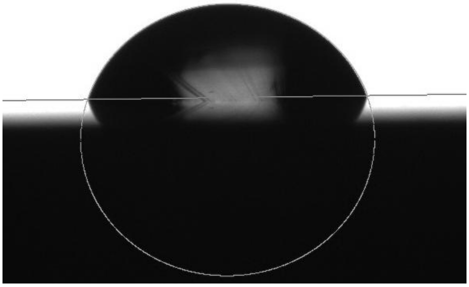

Fig. 9. Example of determining the baseline and drop contour [source: own study]

3. INVESTIGATION OF ADHESION PROPERTIES

To calculate the surface free energy using contact angle measurements Young's equation is applied. This equation has the form [8]:

$$\sigma_{SV} = \sigma_{SL} + \sigma_{LV} \cos\theta_Y \tag{3}$$

where: σ_{SV} – the surface tension of the solid in equilibrium with saturated vapor of the liquid,

σ_{SL} – the interfacial surface tension of the solid and liquid,

σ_{LV} – the surface tension of the liquid in equilibrium with saturated vapor of the liquid,

$\cos\theta_Y$ – the angle formed by the tangent to the surface of the measured drop deposited on the surface of a solid at the contact point of three phases (equilibrium contact angle; Young's angle).

This equation was developed based on the condition of equilibrium of forces and can be described as "a simple relationship between the contact angle and surface tension of the liquid, surface tension of the solid and interfacial surface tension of the solid – liquid" [8]. Using the Gibbs theory, the equation can also be presented as (4). Based on the energy balance, we derive an equation for the three-phase equilibrium point (point A in Figure 10).

$$\gamma_{SV} = \gamma_{SL} + \gamma_{LV} \cos\theta_Y \tag{4}$$

where: γ_{SV} – the surface free energy of the solid in equilibrium with saturated vapor of the liquid,

γ_{SL} – the interfacial surface free energy of the solid and liquid,

γ_{LV} – the surface free energy of the liquid in equilibrium with saturated vapor of the liquid.

Young's equation is presented graphically in Figure 10.

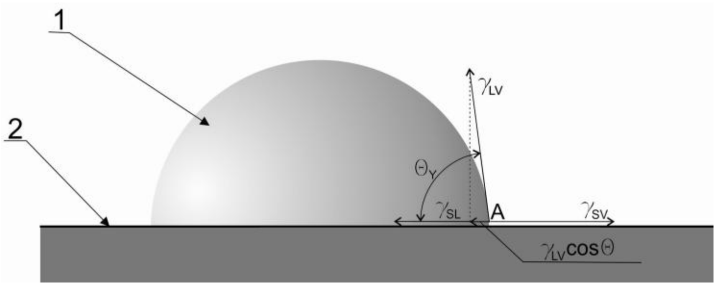

Fig. 10. Graphical presentation of Young's equation 1 – measured drop, 2 – tested material [8]

The use of Young's equation, which describes an ideal system, requires that fundamental conditions for taking measurements be observed. The surface on which measurements of the contact angle are taken should be, first, rigid enough to avoid deformation of the material under the influence of measured droplet and, second, suitably fixed to minimize drop deformation under vibration.

Another condition that must be met concerns suitable surface roughness, which is measured by an arithmetic average deviation of the roughness profile. This value should not exceed $0{,}5\mu$. The surface layer of the tested material should be free from any pollution; also it must be physically and chemically homogeneous, while the measuring liquids should be chemically neutral so as not to react with the material or material components.

As a result of the adoption of simplified assumptions, Equation (5) is obtained, which allows to determine the adhesion properties of a surface layer on the basis of the contact angle measurement results.

$$\gamma_S = \gamma_{SL} + \gamma_L \cos\theta \tag{5}$$

where: γ_S – the surface free energy of the solid,

γ_L – the surface free energy of the measuring liquid,

θ – the contact angle.

Surface free energy is often used to measure adhesive capacity of objects. The work of adhesion is defined as the work that is done against the forces of adhesion (the sum of all intermolecular interactions) during a reversible isothermal process to create a unit area of phases being in equilibrium [9]. The work of adhesion affects only intermolecular interactions. The work of adhesion for contact angles is calculated by the Dupre-Young equation. This equation has the form [8]:

$$W_a = \sigma_{LV}(1+\cos\theta) \tag{6}$$

where: W_a – the work of adhesion.

Knowledge of the contact angle also allows to determine the polar and non-polar components of surface free energy using generally known computational methods [10].

4. CONCLUSIONS

Owing to the development of computer technology with regard to image analysis, current investigations of adhesive properties of surface layers allow better investigation of the effects of factors responsible for a given energy state. The possibility of determining exact values of such parameters as the work of adhesion and surface energy opens up new possibilities for the development of adhesive techniques based on the knowledge of energetic processes occurring on the surface of bonded materials. The possibility of performing image processing in real time also enables conducting studies that have so far been difficult to perform, such as taking measurements of the advancing contact angle, receding contact angle and dynamic contact angle [11].

As can be seen in Figure 11, due to its versatility the use of computer image analysis allows us to determine the parameters and characteristics that were impossible to determine with previous methods. Computer image analysis also allows to store information in the program integrated databases.

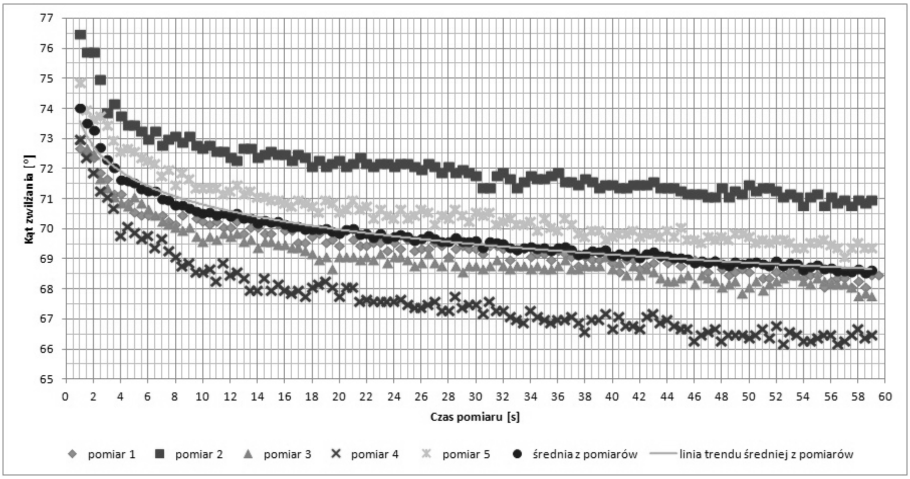

Fig. 11. Results of the dynamic contact angle measurements for polyamide PA6 after degreasing with the calculated average and indicated trend line [source: own study]

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A HIGH-LEVEL PETRI NET MODEL OF QUEUEING PRODUCTION SYSTEM

Abstract

In the paper a high-level Petri model for widespread queueing networks in production systems with many customers, several queues with independent production buffers and different service nodes is presented. Requests can be either single- or polytypic. Such parameters of system as productivity, queue length and waiting time are evaluated.

1. INTRODUCTION

The production systems with two groups of participants: customers of requests (orders, tasks) on the one hand and service nodes from the other are widely used. There can be many customers and service nodes. There can be also many types of requests, they could demand different runtime and need involvement of various profile of service nodes for their realization. This is the queueing system. Such systems are, for example, in flexible manufacturing, traffic engineering, shops, offices, banks, libraries, distributed computer nets, Internet, communication networks and in many others areas. For modeling these systems high level Petri nets that are helpful for qualitative and quantitative analysis can be used. The needs if customers concerning the waiting time are not always satisfied by service nodes' capabilities of existing systems. In this connection some customers are dissatisfied with the period of request realization. The proper modeling that would create an opportunity to predict such situations and to reduce the runtime is essential here.

Targeted opportunities to do this have timed and coloured Petri nets, which are created for simulation systems that have explicit causal relationships [1-9]. Directed bipartite graph is used to describe them. This graph has two groups of vertices: places (position, execution conditions of the event, if), represented

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by circles, and transitions (events) that are denoted by shelves (bars), as well as directed arcs, each connects only vertices of different types, i.e. place and transition or vice versa. The execution conditions are indicated by token (label) drawn as the black dot in the suitable place. The token in appropriate conditions is removed after the event is completed. Place may reflect the presence of request, material, information, etc., necessary to perform the appropriate operations. The transitions describe the different types of procedures (operations). Petri net allows us to trace the sequence of all operations that occur in the production system, to detect loops, deadlocks, resource requirements for implementation of the production system functions.

The high-level Petri nets are introduced to extend the modeling capabilities with additional options: "colours" and time. "Colours" identify the type of token that describes the properties of the resources required to perform the operation, and time determines the event's duration. It is possible to build a "tree reachability" which specifies the sequence of all possible changes in the system, to detect recurrence deadlocks in which the system may come with its imperfect design, to predict the occurrence of undesirable situations and to exclude the restructuring of the system. Coloured and timed Petri nets are used for scheduling as well as for solving many other problems that occur in production systems [10-15].

It is desirable to create the model of production systems that have many customers with different types of tasks (requests, orders), a number of service nodes with various functional properties and multiple queues. The research goal is to create a description of these types of processes, which allows estimation the service waiting time, the sequences of operations needed to determine the required composition of service nodes and other functions. Such model can be used to create the proper software for practical application.

2. PETRI NET MODEL

Let us consider the possibility of using timed coloured Petri nets to create a model of the production system of type CQS: "Customers (sources of different-type of requests, orders) – Queues – Services (a group of various profiles service nodes)" (Fig. 1). A formal definition of the CQS system is as follows:

$$\mathrm{CQS} = (C, Q, S, Stg), \tag{1}$$

where: $C = \{C1, C2, \ldots, Ck\}$ – the set of customers;
$Q = \{Q1, Q2, \ldots, Qn\}$ – the set of queues;
$S = \{S1, S2, \ldots, Sm\}$ – the set of service nodes;
Stg – Storage.

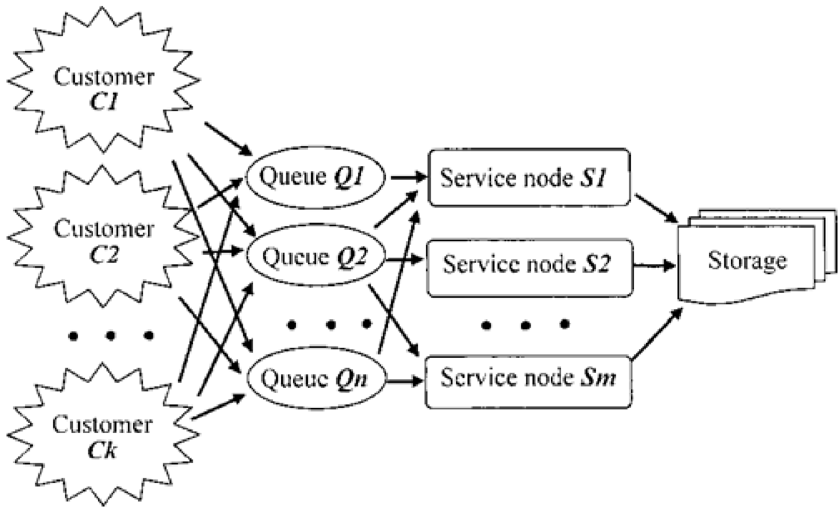

Fig. 1. Schematic representation of the CQS production system [source: own study]

The timed coloured Petri net of this system (Fig. 2) is represented by:

- $C = \{C1, C2, \ldots, Ck\}$ - the set of shelves that represent the customers.
- p_0 – the initial place that imitate the admission of rom customers.
- $T\{\{t_{11}, \ldots, t_{1w}\};\{t_{21}, \ldots, t_{2w}\}; \ldots; \{t_{n1}, \ldots, t_{nw}\}\}$ – the family transitions' sets, each of which represents one node of queue; n is the number of queues; w is the number of nodes in every queue. For simplicity, we accept that the numbers of nodes in all queues are the same. However, they can be different.
- $P\{\{p_{11}, \ldots, p_{1w}\};\{p_{21}, \ldots, p_{2w}\}; \ldots; \{p_{n1}, \ldots, p_{nw}\}\}$;
- $P^*\{\{p_{11}^*, \ldots, p_{1w}^*\};\{p_{21}^*, \ldots, p_{2w}^*\}; \ldots; \{p_n^*, \ldots, p_{nw}^*\}\}$ – the two families of sets of places each of which represents one node (independent production buffer) of the queue.
- $T\{t_{l11}, t_{l12}, t_{l13}; t_{l2}; \ldots, t_{lm1}, t_{lm2}\}$ – the set of loading transitions of service nodes as well as for simplicity the time for loading. The number of these transitions for every service node depends of the number of job types that can perform this node. For simplicity, first node in this case has tree such types, second – one and the –m^{th} – two. The number of service nodes in m.
- $T\{t_{s1}, t_{s2}, \ldots, t_{sm}\}$ – the set of direct service transitions as well as they times.
- $T\{t_{u1}, t_{u2}, \ldots, t_{um}\}$ – the set of unloading transitions as well as they times.

- $P\{\{p_{s11}, p_{s12}, p_{s1}*\};\{p_{s21}, p_{s22}, p_{s2}*\}; \ldots; \{p_{sm1}, p_{sm2}, p_{sm}*\}\}$ – the family of sets of tree places in each service node that represent acceptance of request, it completion and creation the condition for next request taking after completion unloading pre-request.
- p_{stg} represents the storage of executed requests.

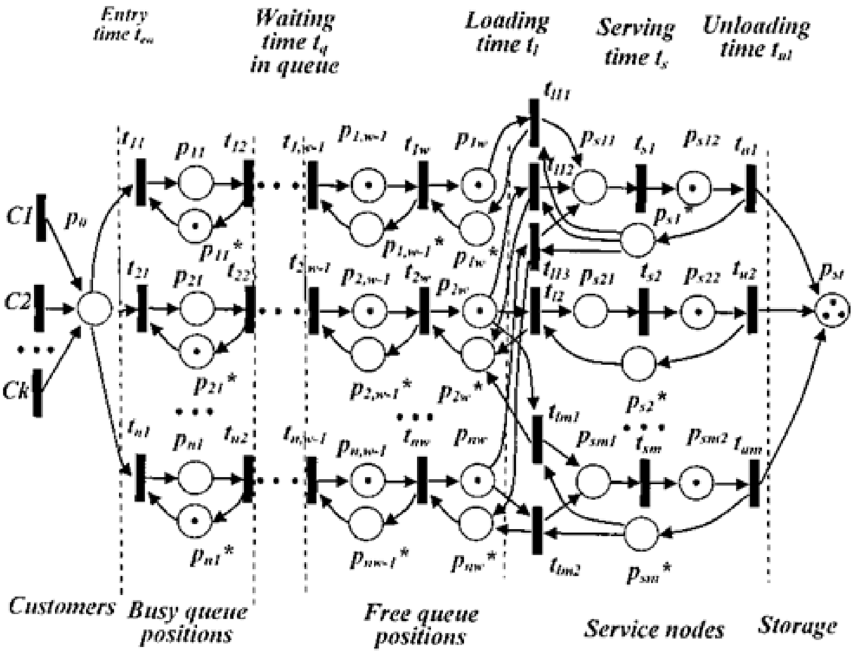

Fig. 2. The timed coloured Petri Net of CQS production system [source: own study]

Every source *C1, C2,…, Ck* generates some types of request that go to the place p_0. The requests cause the appearance of tokens. Each token has three parameters: type φ_i, time of entering the queue $t_{e,i}$ and service time $T_{srv,i}$ of going through all transactions. The first two parameters are fixed during the execution of the request. So they describe the “colour" of token. Time changes during of all transactions: waiting in the queue $t_{q,i}$, loading for serving t_l, direct serving $t_{ds,i}$ and unloading $t_{u,i}$. Every transaction has the parameter – time t_i. In addition, every first transaction in the queues $t_{11}, t_{21},\ldots, t_{n1}$ and every loading for service transaction $t_{l,ij}$ ($i=1,\ldots,m$; j is the number of job types that can perform appropriate service node) have the type ψ_j, $\psi_j = \varphi_i$.

So, the finishing moment of served request appearance in the storage (complication of the work) includes the time of appearance of request $t_{e,i}$ from customer and full service time $T_{srv,i}$:

$$T_{stg} = t_{e,i} + T_{srv,i}, \tag{2}$$

where

$$T_{srv,i} = t_{q,i} + t_{l,i} + t_{ds,i} + t_{u,i}. \tag{3}$$

Check the details of serving process. Each request from sources Ci is labelled by entering time $t_{e,i}$ and its type φ_i $(i = 1,\ldots, n)$. After formation of the request from customer it falls into the place p_o. Receipt of every request is recorded by a dot in this place. The request has the properties that are described by its token: φ_i and $t_{e,i}$. Request from each source comes in the appropriate queue that matches its type and has an attribute that contains information about the entry time. For every type of request φ_i is formed one queue. So, the number n of queues must be the same as the number of request types. Every queue has the number of nodes that are determined as a maximum possible number of requests that could be generated by the system of all customers $C1,\ldots, Ck$. This amount must be determined at the design stage. At the Figure 2 this number is the same w. Every node of queues is shown by two places p_{ij} and p_{ij}^* $(i=1,\ldots,n;\ j=1,\ldots,w)$ and one transition.

Moving in queue, the request enters the last in queue place p_{iw} and will be accepted for serving when one of the service nodes that can perform this type of request is free. Such possibility will be signalized by a token appearance in position $p_{s,j}$. The system has several various functional service nodes. Each of them takes to implement proposal from queue that match his profile. In the event of conflict the request with an earlier entering time is accepted for serving. Service nodes are depicted by tree transitions: loading with time t_l, direct serving with time t_{ds} and unloading with time t_u, as well as by two places $p_{s,ij}$ $(i=1,\ldots,m;\ j=1,2)$ and one $p_{s,i}*$ $(i=1,\ldots,m)$. The request is carried out in three steps: loading, the direct serving and unloading. After serving the result is saved in the storage p_{stg} that is reflected by appearance of the token as well as by the token in the place $p_{s,i}*$ that create condition for acceptation the new request for serving. Storage collects the results which will be taken out by the customers.

Important characteristics of production system are its productivity, service time and the length of queue. They should be determined at the design stage. Queues are formed when the total productivity of all service nodes is less than the total productivity of all sources of requests. Queues are not formed when these productivities are the same or the productivity of service nods is greater and requests have come evenly and in the same amounts. The moments of request reception can be random, irregular. Not in all cases we have such stability, and at certain intervals of time the total volume of requests can be great comparatively with the production systems possibility. Productivity of production system may also vary. For example, reducing the number of service nodes, some machines out of request etc. These will cause the creation of queues. Therefore, the requirements to designer are creating such production system that provides an efficient it functioning in the worst cases. It is necessary to properly evaluate the performance of productive resources – a number of service nodes with desired characteristics, and to prevent the formation of queues longer for the desired value.

We introduce the following notation:

- $\omega_c^{min}, \omega_c, \omega_c^{max}, i = 1,\ldots, k$ - respectively the minimum, average and maximum amounts of requests that can be produced by of *i-st* customer per unit time, i.e. it productivity;
- $\omega_{sj}^{min}, \omega_{sj}, \omega_{sj}^{max}, j= 1,\ldots,m$ - respectively the minimum, average and maximum amounts of products that can be served by *j-st* node per unit of time, i.e. it productivity.

We define the following characteristics of the production system:

- $\Omega_c^{min}, \Omega_c, \Omega_c^{max}$ – respectively the minimum, average and maximum total amounts of requests that can be produced by all sources per unit time, i.e. their total productivity where
- $\Omega_c^{min} = \sum\omega_{ci}^{min}, \Omega_c = \sum\omega_{ci}, \Omega_c^{max} = \sum\omega_{ci}^{max}, i =1,\ldots, k$;
- $\Omega_s^{min}, \Omega_s, \Omega_s^{max}$ – respectively the minimum, average and maximum total volume of products that can be served by the whole system per unit of time - it productivity, where: $\Omega_s^{min} = \sum\omega_{si}^{min}$, $\Omega_s = \sum\omega_{si}$, $\Omega_s^{max} = \sum\omega_{si}^{max}, i =1,\ldots, m.$

The conditions of absence of queue for some period of time at a constant formation of requests is $\Omega_s \geq \Omega_c$. If this condition is not satisfied at the times t_i, i.e. $\Omega_s(t_i) < \Omega_c(t_i)$, then the queue is created. The value of generated queue's length will be determined by the duration ΔT of this time.

The worst case is when the customers generate the maximum amount of requests with the performance of Ω_c^{max}, and the production system has the smallest possibility, i.e. its productivity is Ω_s^{min}. Then for interval time ΔT the amount of requests that wait for direct serving is:

$$\Delta R = (\Omega_c^{max} - \Omega_s^{min})\,\Delta T. \qquad (4)$$

The number of necessary queue nodes (independent production buffers) to avoid the accumulation of requests in customers for the *n* queues must be:

$$w_n = \Delta R / n\Delta r, \qquad (5)$$

where: Δr – average amount of one request.

Value ΔT must be defined as the maximum allowable waiting time for designing stage of the production system. For banks, cash desks, offices it should be negligible, for industrial systems – according to needs of the customers.

It is also important to determine the waiting time of the request *r* in the queue from the moment t_i of it appearance to beginning it direct serving:

$$t_q(r) = \Delta R(t) / \Omega_s(t), \tag{6}$$

where: $\Delta R(t)$ – the total amount of all requests of given type, that are waiting for serving at the moment t_i in the appropriate queue,

$\Omega_s(t)$ – the productivity of the system for waiting time which we consider as a constant.

3. CONCLUSIONS

The timed coloured Petri nets are widely used for simulating of production systems by asynchronous discrete models. Such models create conditions for the analysis of their structure, evaluated the waiting time and other characteristics that may be helpful on the stages of designing of new and reengineering of existing systems to improve their efficiency. Such nets are specifically beneficial for systems of the type "Customers – Queues – Services" that are common in various areas. Defined in the paper indicators of performance, including productivity, the waiting time and the length of queues must be considered on design stage.

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mechanical joint, adhesive joint, composite material, load transfer, FEA

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ANALYSIS OF LOAD TRANSFER INTO COMPOSITE STRUCTURE

Abstract

The paper presents advantages and disadvantages of metal foils insertion between composite layers. Composites are complex materials of anisotropic structure leading to various failure mechanisms. Mechanism of compressive load transfer into composite laminates by shear of the matrix is analysed. The method of improvement compressive strength of laminates is presented according to literature and analysed for a selected case. Simplified models of a laminate structure modified using various metal foils configurations are analysed with MSC.Marc code. Axial stress in prepreg layers and shear stress in adhesive layers are studied.

1. INTRODUCTION

The usage of different materials in aircraft structures results in the necessity of joining composite and metallic components. The never-ending attempt to obtain the lowest possible mass is the reason for using material of high specific strength in the aerospace industry. High strength titanium or aluminium alloys and composite laminates (e.g. CFRP) are the examples of such materials.

The main advantages of composite materials are: high specific strength, corrosion resistance, vibration damping ability and possibility of property tailoring for any specific case. Their main disadvantages are: anisotropy, lower deformation ability, higher notch sensitivity and higher dependence on temperature. These factors lead to difficulties in prediction of strength (load carrying capacity) of composite materials. However, the attempt to obtain the lightest

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possible structures forces constructors to search for new solutions for composite structures. Despite a large number of composite types, fibre reinforced composites in the form of laminates are commonly used in aircraft structures [1-4].

1.1. Composite material

Laminates consist of several layers (plies). Each layer is usually a unidirectional or woven fibre reinforced composite (fig. 1b). It means that it has a specific fibre orientation (angle between fibre and load direction – fig. 1a).

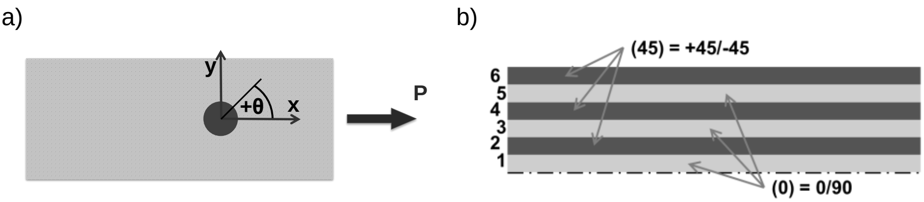

Fig. 1. Composite: a) definition of fibre orientation, b) woven laminate layers of different fibre orientation [source: own study]

A unidirectional composite layer indicates substantially different mechanical properties in all directions as its strength is mostly determined by fibre, whereas a woven ply has the same properties in two fibre directions. Strength of composite laminates is considerably influenced by laminate lay-up [1, 5].

There are five global failure modes for mechanically fastened composite laminates: tension, bearing, shear-out, cleavage and pull-through. The bearing failure mechanism is a safe progressive mechanism not leading to catastrophic failure and, therefore, is acceptable.

Material in the vicinity of the hole is compressed. Fibres compressive strength is slightly lower than the tensile one, moreover, the resin matrix has much lower strength than the fibres. Initially, the compressive load is transferred mostly by the matrix. After some matrix deformation, the load is also transferred by the fibres due to shear stress between the matrix and fibres (Fig. 2).

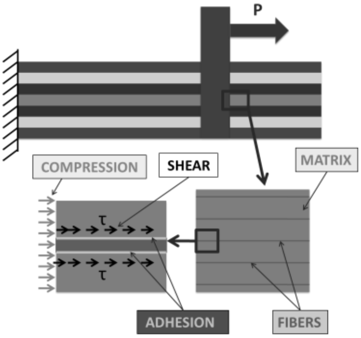

Fig. 2. Load transfer in mechanical joint of fibre reinforced composite [source: own study]

The fact that the matrix deforms more than the fibres causes adhesion failure. An unsupported fibre of a minor diameter (200 Å) has a tendency to local buckling and cracking. The whole load is transferred by the compressed matrix which fails suddenly [1, 4]. The above problems were considered by many authors [6, 7, 8].

Compression in composites can lead to damage. Taking these facts into account, the improvement of load transfer into composite panels seems to be reasonable. Exemplary methods of bearing strength improvement in composite laminates are as follows: matrix reinforcement by Al_2O_3 particles [9], fibre steering and z-pins [10] or bonding an aluminium alloy insert in the hole [11]. Another attempt to achieve this aim (one of the most promising solutions) is presented in papers [2, 3]. Sheets made of titanium alloy are bonded between composite layers in some distance from the edge of the composite panel in a way that causes gradual load transfer into the composite structure (fig. 3).

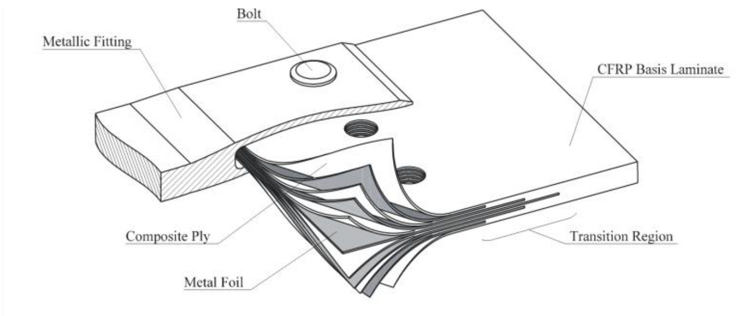

Fig. 3. Titanium foils bonded between laminate layers [2]

2. NUMERICAL SIMULATION OF LOAD TRANSFER INTO LAMINATE STRUCTURE

Selected laminate consists of twelve HTA/6376 woven prepreg layers (configuration $[(45)/(0)/(45)/(0)/(45)/(0)]_S$). A material orthotropic model of the prepreg ply is as follows: $E_1 = E_2 = 75.4$ GPa; $E_3 = 12.6$ GPa; $G_{12} = 4.55$ GPa; $v_{12} = 0.04$, $v_{13} = v_{23} = 0.46$ (based on literature data [12] and the classical lamination theory). Parameters of a resin elasto-plastic model with Mises plasticity criterion are E_a = 3.6 GPa; v_a = 0.4; R_e = 35.2 MPa; R_m = 44.9 MPa [13]. Metal foils are made of titanium alloy (isotropic model: E=115 GPa; v = 0.3).

Exemplary methods of modelling adhesive joints are presented in papers [13-15]. A simplified plane strain model of load transferring into laminate structure (between laminate layers) using metal foils is analysed with MSC.Marc code [16]. One edge of the model is fixed and the opposite one is pulled (fig. 4). The model is 6.32 mm long and 1.5 mm high (it means half a total laminate thickness). Single prepreg ply thickness is 0.25 mm (including adhesive of 0.01 mm). Prepreg and adhesive plies are described/labelled by p1-p6 and a1-a5, respectively.

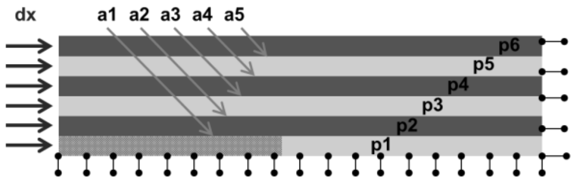

Fig. 4. Laminate model: load and boundary conditions and notation [source: own study]

One half of the laminate thickness is modelled due to plane symmetry with respect to its middle surface. Four-node, isoparametric quad elements with a bilinear interpolation function and two translational degrees of freedom at corner nodes are used. Mesh density is adapted to adhesive layer thickness (consisting of 4 finite elements) a bit further from the adhesive region element dimensions gradually increase (fig. 5).

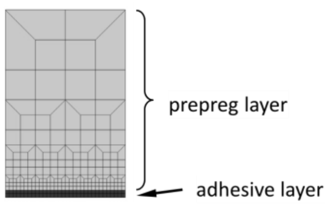

Fig. 5. Mesh density [source: own study]

Four insert configurations (where a part of selected prepreg layer is replaced with a metal foil) are taken into account (fig. 6).

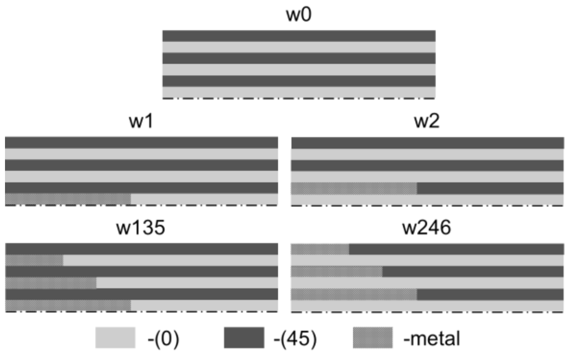

Fig. 6. Laminate configurations [source: own study]

Laminate deformation for various configurations of metal inserts are shown in fig. 7.

Selected results for cases w1 and w2 as well as w135 and w246 are presented in fig. 8-9 and fig. 10-11, respectively.

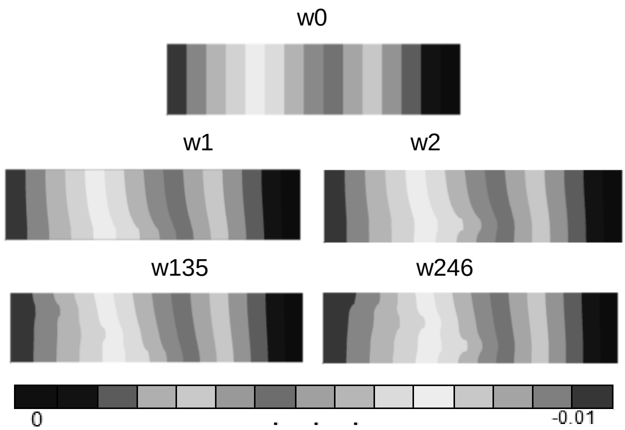

Fig. 7. Laminate deformations: X displacement component [source: own study]

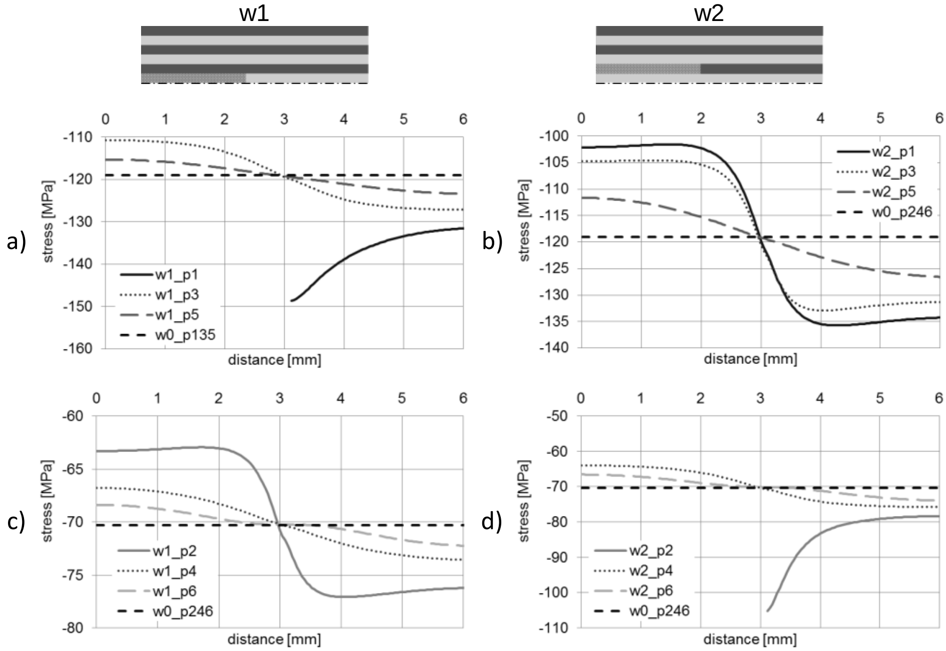

Fig. 8. Normal stress (axial component) in laminate layers – cases w1 and w2: a)-b) layers p1,p3,p5; c)-d) layers p2,p4,p6 [source: own study]

The applied load is carried into a laminate structure mainly by metal foils (fig. 7), then it is gradually transferred between the foil and the prepreg layer, due to adhesion (fig. 9 and fig. 11). Normal stresses (axial components) are larger in prepreg plies which follow the metal foils, however they are smaller at the pulled edge of the laminate (fig. 8 and fig. 10). In the insert area, stress values in prepreg layers are lower than mean stress (corresponding to model w0 – without metal inserts). Beyond this region, stress values exceed the mean ones.

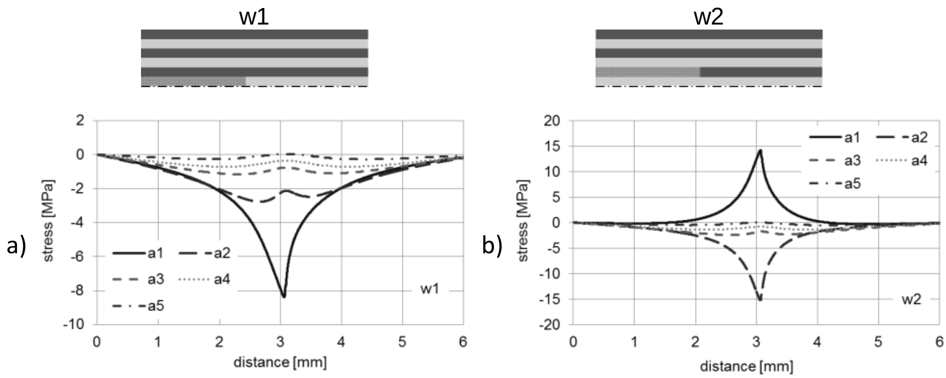

Fig. 9. Shear stress in adhesive layers – cases w1 and w2 [source: own study]

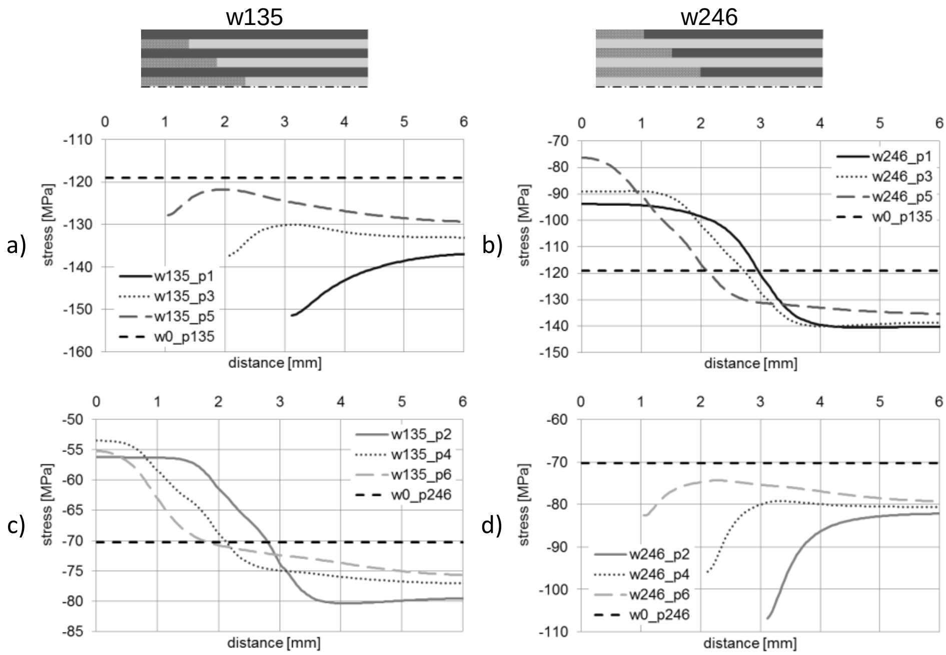

Fig. 10. Normal stress (axial component) in laminate layers – cases w135 and w246: a)-b) layers p1,p3,p5; c)-d) layers p2,p4,p6 [source: own study]

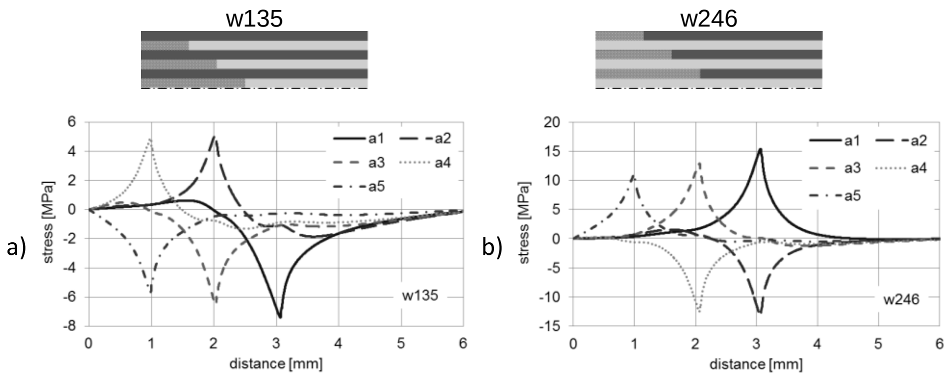

Fig. 11. Shear stress in adhesive layers – cases w135 and w246 [source: own study]

The largest axial stresses are observed in the prepreg ply which follows the longest metal insert. Those values are about 33 MPa greater than mean values regardless of insert configuration (compare fig. 8a, 8d, 10a and 10d). However, this increase in the stress value is significantly influenced by insert stiffness (twice as great as a composite one) and boundary conditions (due to a relatively short specimen). Maximum shear stress in the adhesive layers is about 7.5 MPa for cases w1 and w135 (where (0) prepreg plies are replaced with metal foils), while it is about 15 MPa for cases w2 and w246 (where (45) plies are modified). In the latter cases, the load transferred by means of shear stress is two times greater than in the former ones.

3. CONCLUSIONS AND FUTURE WORK DIRECTION

Although fibre reinforced composites have high tensile strength, the load transfer in mechanical joints of such components is limited. In this type of connection the load is transferred by bearing (local compression) determined by matrix strength. Bonding of titanium foils between laminate layers [2] is the most advantageous solution (since the load transfer becomes more gradual), however, it is the most expensive one as well.

The authors effort is concentrated on searching for an optimal solution that would create a possibility of transferring the compressive load into the composite material in a gradual way.

A proper solution of load transferring into the composite structure using shear stress in the resin matrix between metal and composite layers can improve bearing capacity of mechanically fastened joints.

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