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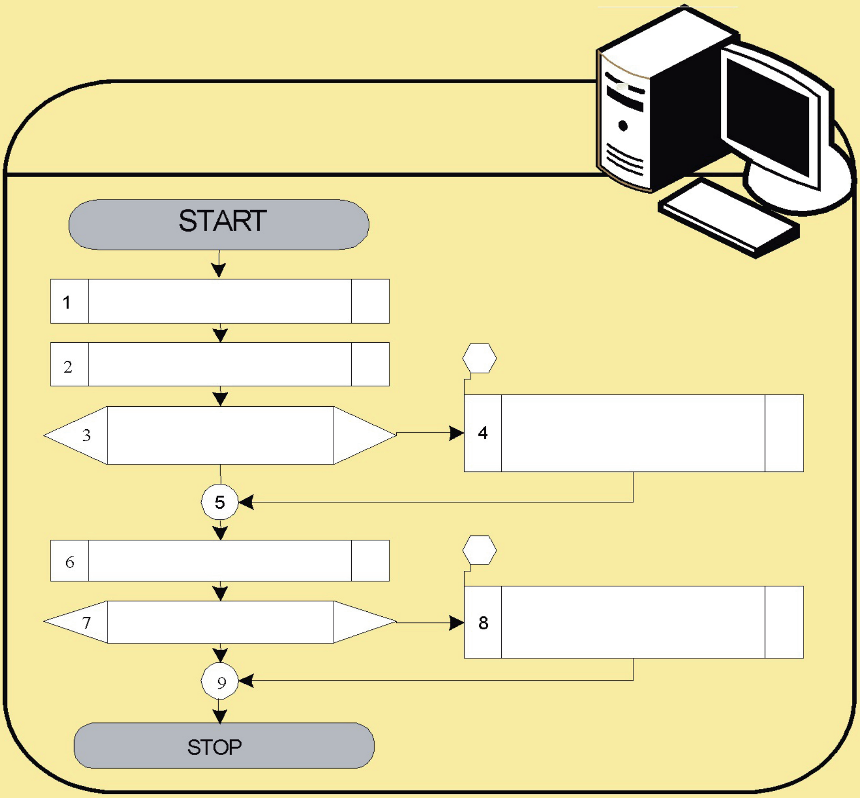

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Enrico G. CALDAROLA[*], *Marco SACCO*[**], *Walter TERKAJ*[**]

BIG DATA: THE CURRENT WAVE FRONT OF THE TSUNAMI

Abstract

In recent years, a real tsunami has flooded many human activities. Genomics, Astronomy, Particle Physics and Social Sciences are just a few examples of fields which have been intensively invaded by a massive amount of data coming from simulation, experiments or exploration. This huge pile of data requires a new way to deal with, a real paradigmatic shift respect to the past as for theories, technologies or approaches in data management. This work outlines the current wave front of Big Data, starting from a possible characterization of this new paradigm to its most compelling applications and tools, with an exploratory research of Big Data challenges in manufacturing engineering.

1. INTRODUCTION

Post or late-modern societies are going through a new revolution in these years. Current economic, social and technological trends recognize a predominant role of information and the emergence of new information-related activities, challenges and opportunities to an extent never seen before. As these new activities increase, the ICT infrastructures supporting them explode in turn. According to Hilbert and Lopez [1], in 2007, humankind was able to store 2.9×10^{20} optimally compressed bytes, communicate almost 2×10^{21} bytes, and carry out 6.4×10^{18} instructions per second on general-purpose computers. This computing capacity grew at an annual rate of 58% and the majority of our technological memory has been in digital format since the early 2000s. We are living through an age in which the generation of wealth, the exercise of power, and the creation of cultural codes depend on the societies and individuals

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attitude towards technologies [2]. The ubiquitous of ICTs in all human activities and the increasing digitalization of the world have led to a great availability of data for organizations and individuals. This has generated a real tsunami that requires a paradigmatic shift respect to the past as for theories, technologies or approaches in data management and more attention to survive it. The data explosion comes from many sources falling under the new term Big Data that is receiving a lot of buzz [3]. What does this term means is not so obvious and is still under debate. There is not a single definition encompassing all its facets and although it has become a catchy term that retains some mystique and persuasive impact in use [4], it still remains elusive. Furthermore, we can define it according to different perspectives, which emphasize some aspects more than others. From a technological point of view, Big Data "refers to data sets whose size is beyond the ability of typical database software tools to capture, store, manage and analyze" [5]. It may also refers to data, which "exceeds the reach of commonly used hardware environments and software tools to capture, manage, and process it within a tolerable elapsed time for its users" [6]. The previous definitions imply that what qualifies as big data will change over time with technology progress [3]. For this reason, VP and analyst at Gartner's Intelligence and Information Management Group Donald Feinberg stated that the "bigness" of Big Data is a "moving target" and what was Big Data historically or what is Big Data today won't be Big Data tomorrow. This is true to the extent that the term Big Data itself is going to disappear in the next years, to become just Data or Any Data [7]. Taking into account the variability of the definition over the time, Adam Jacob provided the following statement: "Big Data should be defined at any point in time as data whose size force us to look beyond the tried-and-true methods that are prevalent at that time" [8]. From a marketers point of view Big Data is an organizational and decision problem. It is not a technology problem but a business problem [3]. Finally, from a user point of view Big Data can be understood as new exciting, advanced software tools which replace the existing ones. Perspectives aside, the authors define Big Data as a new time-variant paradigm in data management whose raison d'être comes from the enormous availability of data in every human activities that needs to be acknowledged according to different points of view: technological, economic, social, scientific, etc…

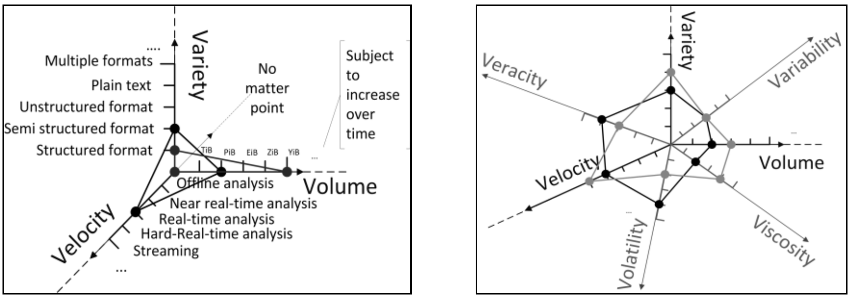
Big Data received a lot of attention in few years: a look at Google Trends shows that, starting from 2011, the term Big Data has been increasingly growing in popularity over time. This eventually demonstrates a global interest not only by research groups but also by numerous individuals with different background: managers, marketers, scientists, public or private organisms. Fields of application of Big Data are great in number: astronomy, physics, social sciences, manufacturing, e-health, genomic and a lot of others [9]. The McKinsey Global Institute [10] also specified the potential of big data in five main topics: healthcare, public sector, retail, personal location data and manufacturing.

Taking into account all the previous consideration, this work aims at reviewing the most compelling current scenarios for Big Data, highlighting the main issues to be tackle according to different dimensions, while also briefing a technological outline of its solutions.

The reminder of this paper is structured as follows. After a deep characterization of Big Data dimensions in the next section, the third section shows four case studies of Big Data in astronomy, particle physics, genomics and social science. The forth section explores the topic in advanced manufacturing and the last section presents an overview of software tools in the Big Data landscape.

2. BIG DATA DIMENSIONS

The concept of Big Data has different dimensions since the term Big not refer only to the quantity of data but also to the heterogeneity of data sources and to the velocity in analyzing data. A widely spread model to characterize Big Data is that of the 3Vs [11, 12] (Fig. 1.a), which shows the three fundamental dimensions of Big Data: Volume, Velocity and Variety.



a) 3Vs Dimensions **b) 7Vs Dimensions**

Fig. 1. Big data dimensions [source: own study]

Along the Volume axis, current scenarios involve technological solutions dealing with data sets with an order of magnitude equal to pebibyte (2^{50} bytes), exbibyte (2^{60} bytes) or higher. Along the velocity dimension, it is possible to distinguish the following typology of analysis: offline analysis (without time constraints over responses), near real-time analysis (must guarantee response within tolerant time constraints), real-time analysis (must guarantee response within strict time constraints), hard-real time (must guarantee response within very strict time constraints) and streaming that refers to data stream mining [13]. Along the Variety axis, the following data formats can be mentioned: structured formats (e.g. relational database data), semi-structured formats (XML grammars-based data, JSON-based, etc.), unstructured formats (data expressed in a no standard representation language), plain text and multiple format (which combines more data formats). Each dimensions in Fig. 1.a may have a greater or lesser weight than the others and in some cases may not exist at all, nevertheless we keep using the term Big Data. The same figure, for example, shows a scenario, marked by the red edges off, and characterized by large structured data in the order of yobibyte representing a Big Data case anyhow, even if the velocity dimension does not constitute a problem. The triangle defined by the black edges is a more complete scenario involving the need to cope with all the three challenges of Big Data. It requires technological solutions to deal with great storage capacity (PiB), real-time analytics over large data sets and mining or extracting knowledge from very heterogeneous and unstructured data. In addition to the dimensions previously described, some works in the literature provide other Vs: viscosity, variability, veracity and volatility [14, 15] (Fig. 1.b). They measure respectively the resistance to flow of data, the unpredictable rate of flow and types, the biases, noise, abnormality, and reliability in datasets and finally how long data are available and if they should be stored. The green and black irregular polygons in Fig. 1.b identify two scenarios in which different strategies are needed to face the challenges that each dimension places. Although all the seven Vs are increasing, they are not equal as well as their importance depends on the particular case studied: namely, the variety poses a great challenge for many organizations in finding economical ways of integrating newer heterogeneous data sources within existing systems. Veracity is also critical today, since the proliferation of social networks and social media requires much attention in analyzing data before decision-making, as the data can be easily manipulated.

3. BIG DATA SCENARIO

This section analyzes four well-known case studies from different fields highlighting the critical issues related to the previously described dimensions.

3.1. Data-Intensive Science

An important field of application of Big Data is Big Science and Data-Intensive Science. The availability of massive data sets from simulation, exploration or experiments has determined a new fourth paradigm for science based on data intensive computing [16]. This new paradigm has led to a new stage in history of science in which scientific discoveries happen by analyzing large sets of data in parallel computing systems instead of looking throughout telescopes. The next paragraphs describe two of the most compelling and state-of-the-art examples of intensive data science from two fascinating fields: astronomy and particle physics.

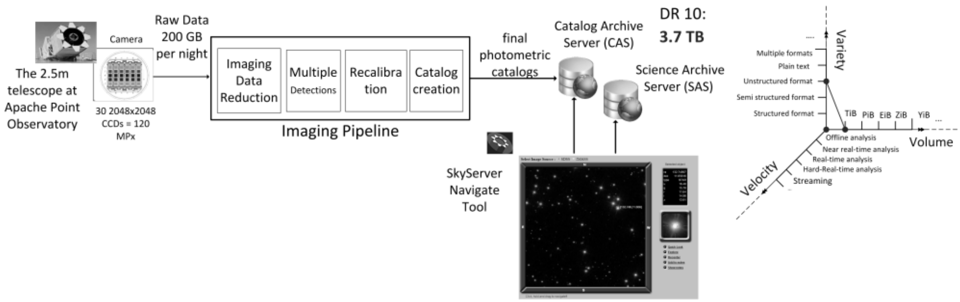


Fig. 2. SDSS overview [source: own study]

Astronomy has been among the first disciplines to undergo the paradigm shift to data intensive science. The Sloan Digital Sky Survey (SDSS) was the first example of publicly available large dataset of three-dimensional maps of the Universe and spectra for millions of astronomical objects. The telescope's camera collects photometric imaging data using an array of thirty 2048 by 2048 pixel CCDs, totaling approximately 120 Megapixels. Every night the telescope produces about 200 GB of data. These raw data pass through an imaging pipeline, which processes them acting a data reduction, a multiple data detection and a recalibration before complex algorithms perform astronomical objects recognition to produce FITS files and catalogs of imaging parameters (Fig. 2). To have an idea of the archive dimension, the photometric parameters for objects in each imaging field in the current data release (DR10) are distributed in around 938,000 fits files, each around 3.5 MB, so the total data set is about 3.7 TB. Going from pixels on the camera to robust catalog information of sky objects is a long and complicated process. Thus, the SDSS project poses important challenges not only in data volume but also along the variety and veracity dimension due the unstructured and noisy nature of raw data acquired from the CCDs. The diagram on the top right corner of Fig. 2 characterizes this scenario in the previously explained three dimensions.

A similar transformation toward data-intensive computing is happening in particle physics. The Large Hadron Collider (LHC) at CERN (Fig. 3) is set to create an integrated data system resembling the SDSS. Inside the accelerator, two high-energy particle beams travel at close to the speed of light before they are made to collide at four locations around the accelerator ring, corresponding to the positions of four particle detectors. Every second 600 millions of collisions happen inside the LHC and each of them is recognized by real-time electronic signals detectors and sent to the CERN Data Center (DC) for digital reconstruction. The DC produces about 30 PB of *collision events* every year and processes them in a distributed computing infrastructure arranged in hierarchical tiers. A part from the dimension of the data to be processed, important challenges in LHC project consist in digital reconstructing of raw electronics signals coming from particle detectors and in filtering collision events through increasingly refined processing algorithms to detect interesting events. This scenario implies big volume, big variety of data, big veracity and big velocity as shown in the right part of Fig. 3.

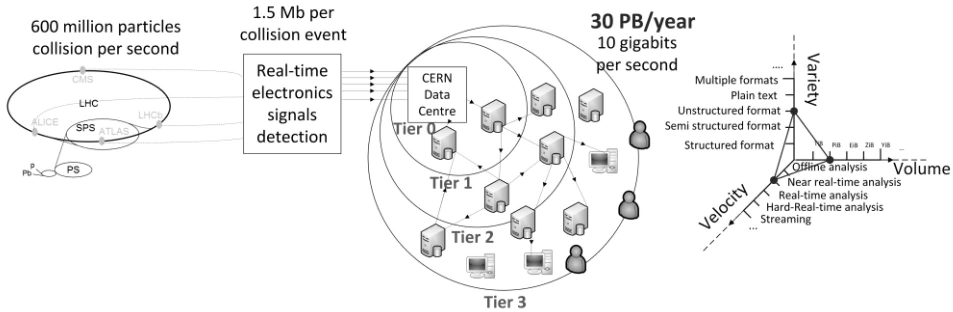


Fig. 3. LHC Overview [source: own study]

3.2 An example from Genomics: GenBank

The GenBank sequence database is an open access, annotated collection of all publicly available nucleotide sequences and their protein translations. This database is created and maintained by the National Center for Biotechnology Information (NCBI).

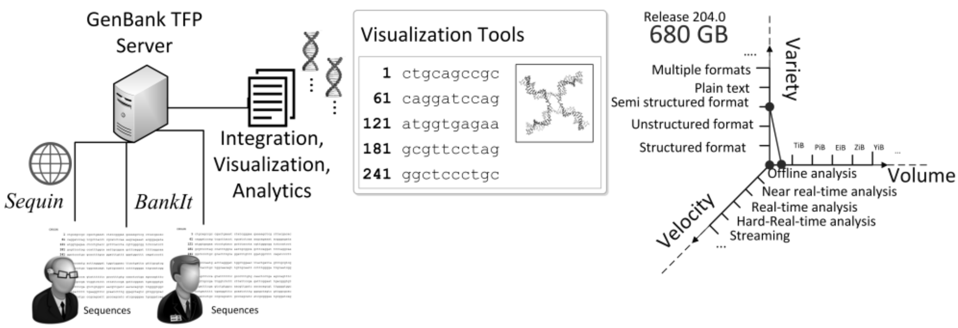


Fig. 4. GenBank Overview

The current database release (204.0) includes a set of 2216 ASCII text files most of which contain sequence data and require roughly 680 GB of disk space for the uncompressed version of them. Each file includes the nucleotide sequence and a header providing the following information: locus, definition, keywords, organism (formal scientific name of the organism and taxonomic classification levels), reference and so on. All sequences are accessible via the GenBank ftp server. This Big Data scenario is characterized by a quite data volume and highly structured data. The velocity and the veracity do not constitute a problem since GenBank rely on direct authors submission of data to ensure that they achieves its goals of completeness, accuracy, and timeliness. Generally, major challenges in bioinformatics and computational biology regards data analytics, display and integration because computational tools are quickly becoming inadequate for analyzing the amount and the heterogeneity of genomic data that can now be generated (Fig. 4).

3.3 Social Big Data: Twitter case study

With its 284 million monthly active users and 500 million tweets sent per day, Twitter it is not just a social networking service enabling users to send and read short 140-character messages, but it represents a vast array of ideas and opinions, a real global consciousness [17]. Analyzing billions of tweets can help researchers to discover new insights about public health issues and the way disease is spread, can help people during moments of crisis like natural disasters, or help in sentiment analysis form marketing researches [18]. From a Big Data perspective, Twitter poses challenges not only in volume, but also in velocity, since in some cases, e.g. epidemic and disaster prevention and control, strict time deadlines are required for a prompt intervention, and in variety due the complexity of some text analysis and computational linguistics algorithms to identify and extract subjective information from tweets.

4. BIG DATA IN ADVANCED MANUFACTURING

The globalization and the ICT revolution have made this world "flat" [19], i.e. a *level playing field*, where competitors from everywhere have equal opportunities and access to the same global market. To be competitive in this scenario, companies must continuously strive for excellence reducing the design-to-market time, providing customized products at the lowest prices and innovating products and processes. The information and communication technologies become more and more crucial to achieve these goals. In the contemporary scenario, most of the components inside the factories (machines, robots, product lines, plants, etc.) are turning into cyber-physical systems (CPSs): large scale interconnected and heterogeneous systems able to integrate computation with physical process and to communicate with each other [20]. CPSs have a virtual counterpart in the cyber-space accessible by Virtual Reality frameworks, which synchronize the real and virtual representations of the factory [21-24]. They also become great real-time data producers with the widespread presence of small smart sensors at a shop-floor level. The high availability of data collected inside factories from each component and in every product's life cycle phases makes relevant the Big Data problem inside modern factories. Real-time data produced during the manufacturing process, production planning and control data [25], the fault information data coming from machine fails, all the resource data coming from raw material information and the extra data brought by the market, policy and environmental changing contribute to increase the volume dimension (Fig. 5). Their heterogeneity also poses challenges along the variety dimension. As a matter of facts, data can be physical variable measures over time, statistics, structured or unstructured data coming from legacy or new storage systems, users' activities logs, and so on. Semantic-web oriented solutions, in this case, may help to improve the interoperability between software tools or data sources by adopting extensible and shared data models for the representation of production systems objects, resources, processes and products [21, 26]. Furthermore, discrete event simulation [27, 28] and High-Level Architecture (HLA) for distributed computer simulation systems poses challenges in the velocity dimension, as a lot of run-time data must be transmitted and synchronized between the various nodes of a network [29]. Finally, analytics over Big Data in advanced manufacturing represents a great challenge trying to mine the correlation hidden behind data that seem uncorrelated. By means of analytics tools, marketers or managers are able to find strategic factors, which can be used as guidelines in decision-making. Forecast fluctuating sales orders across a specific region, decide if buy or do not a new machinery, start or do not the production of a new product based on customer surveys, are a few examples of decision-making problems that Big Data analytics might help to resolve.

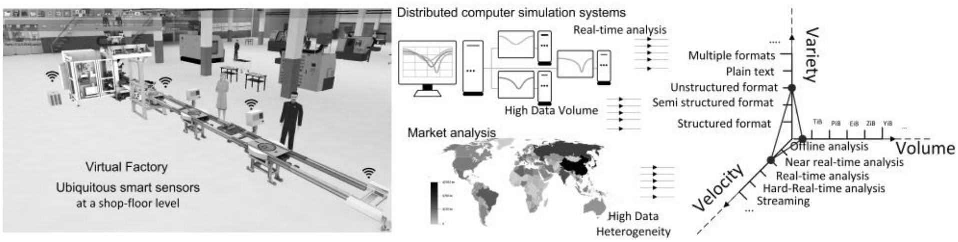


Fig. 5. Advanced Manufacturing Scenario [source: own study]

5. A TECHNOLOGICAL OVERVIEW

Most Data Base Management Systems (DBMSs) are designed for efficient transaction processing: adding, updating, searching for, and retrieving a small amount of information in a large database. Typically, these data sets grow little by little to eventually become Big Data. At this point, difficulties arise when we want to analyze large pile of accumulated data to learn something from them. In this case, relational DBMSs, Data Warehouses and OLAP (OnLine Analytical

Processing) turn out to be too slow or inadequate to face the Big Data analytics challenges [8]. This has led to a proliferation of commercial and open source tools so fare that try to overcome the traditional limitations as for data storage mechanisms or efficient and effective data analysis. As regards to data persistence, for example, No-SQL (Not Only-SQL) storage solutions such as Oracle NoSQL, Big Table, Neo4J, and MongoDB, are increasingly used in Big Data landscape. These solutions are modelled on data structures such as key-value, graph and document, which allow operations that are more efficient over large data sets than traditional databases. Form a distributed computing perspective, the Map-Reduce [30] programming paradigm remains the most used for processing and generating large data set. This paradigm was pioneered by Google and is based on two functions: Map() and Reduce() which orchestrate the data processing and generation across a cluster of machines, by providing fault tolerance and redundancy. The most used implementation of Map-Reduce paradigm is Apache Hadoop but other solutions like Couchdb, MongoDB and MapR are available. Most of Big Data solutions are increasingly available as online services. Amazon Elastic Compute Cloud (EC2) [31], for example, is a web service that provides resizable compute capacity in the cloud, while Amazon S3 provides a fully redundant data storage infrastructure for storing and retrieving great amount of data. In the analytics landscape, various tools are available: from statistical computing frameworks such as R, Matlab, etc. to machine learning algorithms GUIs like WEKA. Finally, it is possible to mention Gephi and GraphViz as data visualization tools and JSON and BSON formats for data serialization.

6. CONCLUSION

As for Big Sciences or Advanced Manufacturing, tools and strategies are needed to get insights and value from the current high availability of data. This work has provided an overview of motivations, applications and solutions in different scenario with a characterization of major challenges posed by each of them. A detailed analysis of Big Data in the Virtual Factory context will be the aim of future works. In particular, the main causes leading to an increase of data available at a shop-floor level in modern manufacturing companies will be further investigated together with the issue of heterogeneity of data sources and the need for run-time analysis in the context of distributed simulation. In addition to this, a qualitative analysis based on functional and technical characteristics of Big Data technologies will be also subject of further researches.

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sandwich construction, cylindrical shell, elastic buckling, FEM

Marek MALINOWSKI[*], Tomasz BELICA[*], Krzysztof MAGNUCKI[**]

BUCKLING OF SANDWICH CYLINDRICAL SHELL WITH CORRUGATED MAIN CORE AND THREE-LAYER FACES

Abstract

The subject of numerical research is a seven-layer cylindrical shell subjected uniformly distributed external pressure. The shell is thin-walled sandwich structure composed of main corrugated core (made of a thin metal sheet) and two three-layer faces. The cores of the faces are porous and made of isotropic metal foam. The corrugation of the main core is along longitudinal axis of the shell. The shell is simply supported at its all outer edges. Numerical FEM model of the shell is elaborated. Critical pressure for the family of these shells are calculated. Furthermore, developed a model of an equivalent single-layer shell wherein diameter, and weight are the same as the seven-layer shell. It has been shown several times higher resistance to buckling of a seven-layer shell compared to the single-layer shell.

1. INTRODUCTION

Thin-walled structures (beams, plates and shell) are heavily used in many branches of the industry. This elements are used as basic structural parts in simple and complex structural systems – structures of aircrafts and rockets, marine vehicles, tanks for liquids and gases, building structures and many others. For the construction of thin-walled components are used various materials, for example: metals, composites, polyurethanes or metal foams (used as cores for sandwich structure). Moreover, the structure of thin-walled components may be: homogeneous, sandwich, multilayered as well as inhomogeneous continuous (continuous structure with varying density). A large variety of thin-walled structures is caused by their properties and the intended use.

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Influence the choice of an appropriate structure are the following factors: the use of construction, load type of structure, load bearing capacity, vibration damping, cost of production and operation of the equipment, insulation performance, technology of production, etc. This paper focused on a sandwich structure.

Classical sandwich structure is composed of two thin metal or composite laminated faces connected with a relatively thick soft core made of foam or low strength of a suitably shaped sheet (waves, honeycomb, etc.). The main assessment criterion of the practical application efficiency of these structures, except for the economic aspect, is a high stiffness and strength with respect to low weight and the high ability of vibration damping. Due to exceptional properties, sandwich structures have been used in aircraft, marine vehicles, and other types of structures. Sandwich structures have been extensively investigated. The first theoretical models of these structure have developed C. Libove and S. B. Butdorf for sandwich plates with corrugated cores, and E. Reissner for sandwich rectangular plates in 1948 [1, 2]. In the following years, rapid growth of works describing these structures is noticeable, e.g. monographs [3, 4, 5]. In these works are presented the research of strength and stability problems of classical sandwich beams, plates, and shells with homogeneous core. These structures also nowadays are intensively developed. Analytical and numerical investigation of strength and stability of an isotropic metal foam beams, plates and shells are presented in the papers [6, 7, 8, 9, 10]. In these works, sandwich and continuous structure with varying density were analyzed. Experimental studies of the sandwich cylindrical shell with a core of the truss structure, connected to the composite facings are presented in the paper [11].

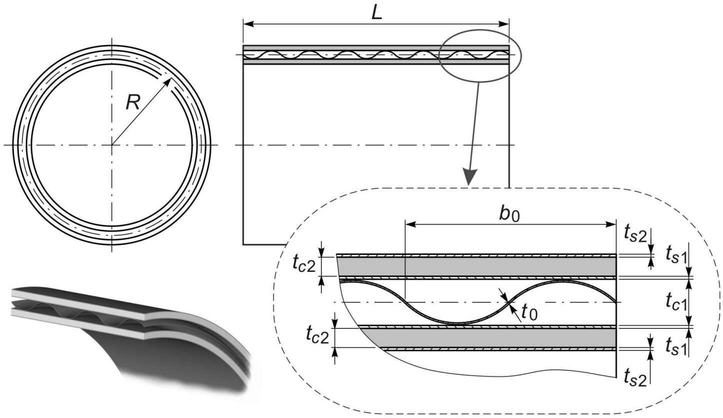

Fig. 1. The cross section of the seven-layer cylindrical shell [source: own study]

Also sandwich structures with corrugated core were studied, e.g. the three-layer beam with a crosswise and lengthwise corrugated core [12], the seven-layer circular plate with a corrugated main core and three-layer faces [13]. Presented here, are just a few of works devoted to a specific issues. A lot of research (theoretical and experimental) dedicated to thin-walled structures indicates that the issues are still relevant.

The subject of this paper is a seven-layer cylindrical shell subjected to uniformly distributed external pressure. The shell is simply supported at its all outer edges. The wall of the shell is composed of a corrugated main core – made of a thin metal sheet, and two three-layer facings with metal foam cores (Fig. 1). The numerical FEM analyses for elastic buckling of the shell are presented.

2. FEM MODEL OF THE MULTILAYERED SHELL

Stability analysis of a seven-layer cylindrical shell using the FEM is carried out with the use of ANSYS software. The edges of the shell are simply supported and closed by thin rings connecting the different layers (Fig. 2). The boundary conditions for the shell were defined on the two outer edges and the middle surface of the main core of the shell. On the outer edges, the radial and the circumferential displacements are blocked. In the middle length of the shell the longitudinal displacements were blocked. The uniformly distributed pressure was added on the outer surface (layer of a thickness t_{s2}). Rings placed on outer edges of the shell are needed for structural reasons, e.g., due to a connection of the cylindrical shell with corrugated core.

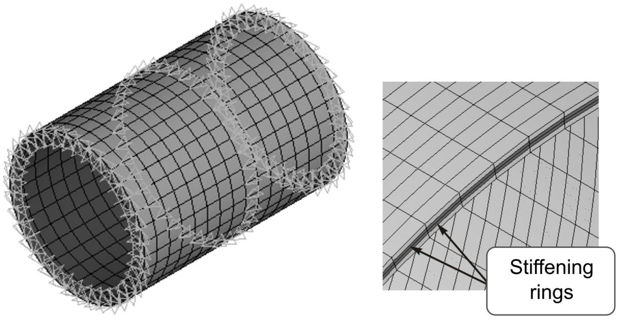

Fig. 2. Model of the shell [source: own study]

The numerical model of the shell was developed in the cylindrical coordinate system. Thin layers (sheets of thicknesses t_{s1} and t_{s2}, corrugated sheet of the core of a thickness t_0 and stiffening rings edges of the shell) were modeled thin-walled elements SHELL 181, whereas the cores of faces, made of metal foam of a thickness t_{c2}, were modeled solid elements SOLID 185. The model of the shell consisted of ca. 30 000 finite elements on 1 m length of the shell.

3. MODEL OF EQUIVALENT SINGLE-LAYER SHELL

The seven-layer shell will be compared with the single-layer shell. For this purpose, a model of the equivalent single-layer shell was developed, wherein radius of the middle surface R, and weight are the same as the seven-layer shell. The unit weight of the seven-layer shell

$$\tilde{m}_{shell}^{(7-layer)} = \left[2t_{s1} + 2t_{s2} + t_{c1,eq} + 2t_{c2} \frac{\rho_{c2}}{\rho_s} \right] \rho_s \tag{1}$$

where: $\rho_s = 7850$ kg/m^3 – mass density of the steel,
$\rho_{c2} = 0.145\rho_s$ – mass density of the metal foam [14],
$t_{c1,eq}$ – the equivalent thickness of the corrugated core,

$$t_{c1,eq} = 4\frac{t_0 R_{c1}}{b_0} \operatorname{arctg}\left[\frac{4b_0(t_{c1} - t_0)}{b_0^2 - 4(t_{c1} - t_0)^2} \right] \tag{2}$$

where: R_{c1} – the radius of the middle surface of the corrugation (Fig. 3)

$$R_{c1} = \frac{b_0^2 + 4(t_{c1} - t_0)^2}{16(t_{c1} - t_0)} \tag{3}$$

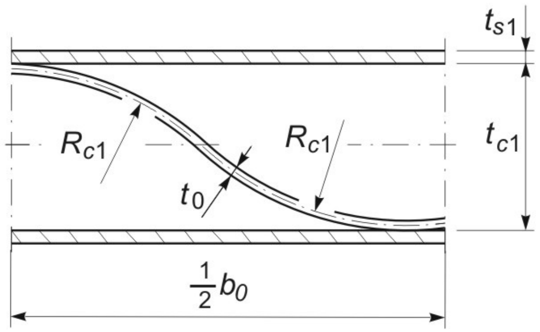

Fig. 3. The main core of the shell [source: own study]

The thickness of the equivalent single-layer shell

$$t_1 = \frac{\tilde{m}_{shell}^{(7-layer)}}{\rho_s} \tag{4}$$

4. NUMERICAL CALCULATIONS – FEM ANALYSIS

The critical pressure is calculated for the family of seven-layer cylindrical shells: material properties: $E_s = 200000$ MPa, $v_s = 0.3$ (the steel elements) and $E_{c2} = 3150$ MPa, $v_{c2} = 0.05$ (the metal foam of the cores); geometric data: $R = 2$ m, $L = 2–4$ m, $t_0 = 0.6$ mm, $t_{s1} = 0.8$ mm, $t_{s2} = 1$ mm, $t_{c1} = 20$ mm, $t_{c2} = 15$ mm, $b_0 = 100–200$ mm. The results of elastic buckling modes of selected multilayered shells and equivalent single-layer shells with the thickness t_1 (Eq. 4) are shown in Figs. 4–6. The influence of width of unit corrugation on critical pressure for seven-layer shell presents Fig. 7. The values of critical pressure of seven-layer shell indicate that the critical pressure depends on width of unit corrugation. The value of critical pressure is bigger for smaller values of b_0.

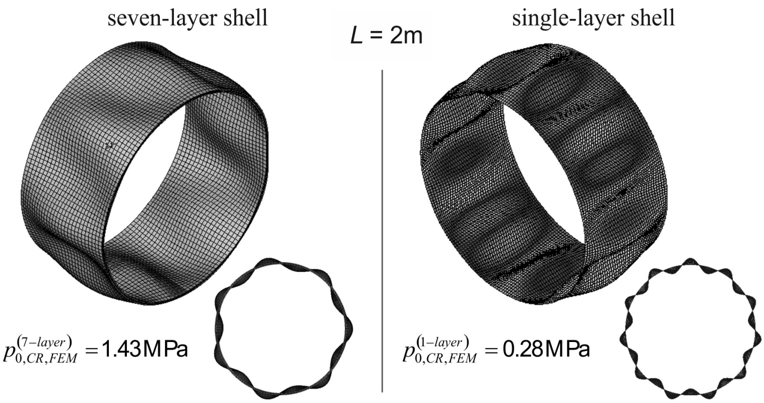

Fig. 4. Buckling mode of seven-layer and equivalent single-layer shells, L=2m, b_0=125mm [source: own study]

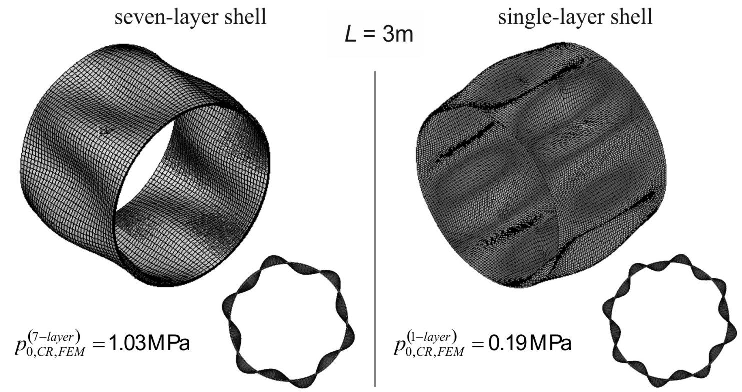

Fig. 5. Buckling mode of seven-layer and equivalent single-layer shells, L=3m, b_0=125mm [source: own study]

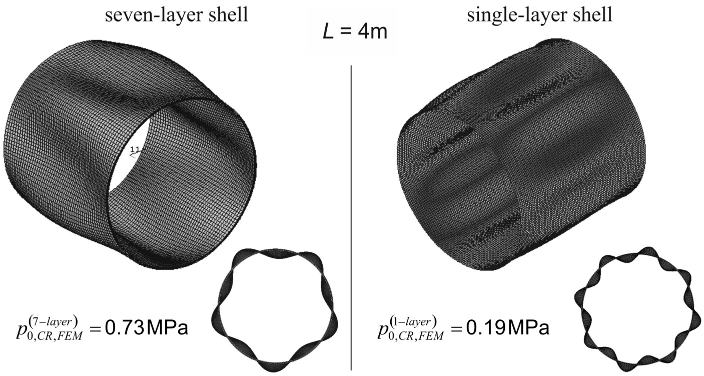

Fig. 6. Buckling mode of seven-layer and equivalent single-layer shells, L=4m, b_0=125mm [source: own study]

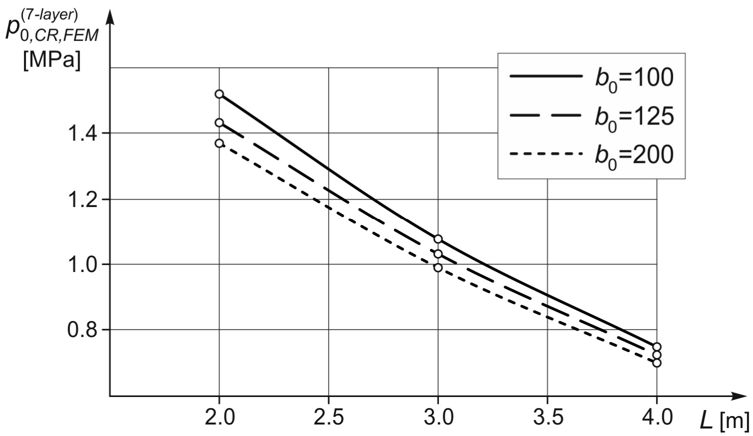

Fig. 7. The effect of the length L on critical pressure multilayered cylindrical shell. Results are plotted for three different sets of width of unit corrugation b_0 [mm] [source: own study]

These results of critical external pressure are presented in Table 1 for different values of the length L and width of unit corrugation b_0. The obtained results have been compared with one-layer shells. The seven-layer shells have smaller values of number of circumferential semi-waves compared with the one-layer shell with equivalent thickness. For example, the seven-layer shell (L = 2m, b = 100mm) has the number of circumferential semi-waves equal 12 and equivalent single-layer shell has m = 22. The seven-layer cylindrical shell is more rigid then single-layer shell of then same weight. The parameter k_p denotes the ratio of the critical pressure of the seven and single layer shells. The value of k_p is greater than one. The values of k_p ratio are in the range 4.9–6.3.

Tab. 1. Critical pressure and numbers of longitudinal and circumferential waves

L [m]	b_0 [mm]	7-layer shell			1-layer shell				k_p
		$p_{0,cr,FEM}$ [MPa]	m	n	t_1 [mm]	$p_{0,cr,FEM}$ [MPa]	m	n	
2	100	1.518	1	12	8,61	0.284	1	22	5.3
	125	1.433	1	14	8,59	0.283	1	22	5.1
	200	1.369	1	28	8,57	0.281	1	22	4.9
3	100	1.076	1	12	8,61	0.189	1	18	5.7
	125	1.033	1	12	8,59	0.188	1	18	5.5
	200	0.989	1	20	8,57	0.187	1	18	5.3
4	100	0.749	1	10	8,61	0.119	1	16	6.3
	125	0.726	1	10	8,59	0.118	1	16	6.1
	200	0.700	1	16	8,57	0.117	1	16	6.0

5. CONCLUSIONS

In the paper the numerical model of simply supported sandwich (seven-layer) cylindrical shells under external pressure are presented. Numerical calculations on a family of seven-layer shells have been performed with the use of FE method (ANSYS). Additionally for single-layer shell with equivalent thickness have been carried out. In both cases a radius of the middle surface R, and weight are the same. The values of critical pressure obtained from each sandwich shell's model is higher from 4.9 to 6.3 times then equivalent single-layer shells. As to the externally pressurised sandwich shells a influence of the width of unit corrugation b_0 on the critical pressure is observed (Fig. 7). The higher number of corrugations into main core stiffens more and shell has higher resistance to buckling, and the critical pressure increases.

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ontology, knowledge base, knowledge engineering

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METHOD OF AUTOMATED DEVELOPMENT AND EVALUATION OF ONTOLOGIES' QUALITIES OF KNOWLEDGE BASES

Abstract

The process of automated development of base ontology is considered. It has been offered to consider the concepts and elements of ontologies for increasing the effectiveness of knowledge bases, the core of which is the ontology. Methods of specifying the weights of the relevant elements and optimization the structure of knowledge base of ontologies has been elaborated. It has been offered to evaluate the quality of the ontologies based on ISO 9126.

1. INTRODUCTION

Knowledge base (KB) is the main component of intelligent systems, which is formed according to the subject area on which the functionality of operation system is oriented. Traditional knowledge of engineering (receiving knowledge from expert, data analysis, machine learning, etc.) are not based on a system of common and verified standards, that is why knowledge bases, built on this basis, eventually lose their functionality due to the low efficiency of its operation. Ontological engineering is used as the standard of knowledge engineering, applying of which results in receiving the ontology of knowledge base. Ontology – is a detailed formalization of a certain area of knowledge presented by means of a conceptual scheme. This scheme consists of a hierarchical structure of concepts, relationships between them, theorems and constraints, that are accepted in a particular subject area [1].

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Considering the foregoing, the *formal model of ontology O* determines the following:

$$O = \langle C, R, F \rangle,$$

where C – finite set of concepts notions (concepts, terms) of subject area, which ontology defines O; $R: C \to C$ – finite set of relations between concepts notions (terms, concepts) in a given subject area; F – finite set of interpretation functions (axiomatization, constraints) specified on the concepts or relations of ontology O.

Using of ontologies as a part of KB helps to solve a number of methodological and technological types of problems that arise during the development of such systems. In particular, for Ukraine, the distinctive problems consist in the lack of conceptual integrity and consistency of certain techniques and methods of knowledge engineering; the lack of qualified professionals in this field; in the stiffness of the developed software tools and their low adaptive capacity; in the complexity of intelligent systems implementation, caused by psychological aspects. All these thesis indicate and confirm the relevance of research problems of using ontologies in the process of intelligent systems development [2–4].

2. THE PROBLEM FORMULATION

In order to manually design a complete related ontology for a specific subject area it is necessary to spend a lot of time and resources. It is explained that applied ontologies must contain tens of thousands of items to be suitable for solving a wide range of problems that arise in this subject areas. Manual ontology designing – is a long routine process, which also requires a thorough knowledge of a subject area and understanding of the principles of building ontologies. Therefore, methods and algorithms of automated ontology designing are actively developing. The mathematical software implementation of the automation process of designing ontology will be suggested, or rather, its development, as it is accepted that the human expert introduced the basic terms and relations between them in the ontology manually. Such initial ontology will be called base and will be denoted as $O_{base} = \langle C_b, R_b, F_b \rangle$. That is, ontology designing starts from the moment when it has already had some data. Therefore, this process is called base designing ontology. Formally, we will write:

$$\chi : O_{base} \to O.$$

Ontology – is the language of science. The language of science, as structured scientific knowledge, sets a hierarchical multilayer formation, in which the following components are distinquished: terminological system; nomenclature; tools and rules for forming conceptual apparatus and terms. So, for designing an ontology, it is necessary to build the terminological system O_T and the nomenclature O_N. Basic ontology necessarily contains some part of terminological system, that is $O_{base} \cap O_T \neq \varnothing$. Encyclopedias, terminological and explanatory dictionaries on the basis of which terminological system of subject area is build, usually have a clear structure and consist of dictionary articles. The process of building a nomenclature is more complicated. When in dictionaries terms are singled, then in scientific texts (books, monographs, etc.) they must be allocated and the properties of concepts and relations between them should be searched. Thus, the natural language technology of processing scientific text are required.

The purpose of this article is to develop the method of automated designing base ontology and evaluating its quality [5–7].

3. MAIN PART

3.1. Structural model of ontology concepts and relations

Let the given set of names of relations $V = \{v_1, v_2, ..., v_s\}$ be suggested. Then the relation in the ontology is given as a reflection from *C* to *C*, using the element of set *V*: $R : C \xrightarrow{V} C$. That is, relation r_i – triplet form:

$$r_i = \left\langle C_{i_1}, v_{i_j}, C_{i_2} \right\rangle$$

As the ontology forms the taxonomy concepts, then, using the object-oriented approach terminology, each concept represents a class. Let's define the concept as class with this structure:

$$C = \left\langle N, R^X, R^Y, S, D, A, Ob \right\rangle, \tag{1}$$

where N – the name of the concept; R^X - set of relations in which the class *C* is domain (area of definition); R^Y – set of relations in which class *C* is the set of values; *S* – superclass *C*; *D* – subclasses *C*; *A* – axioms definition *C*, *Ob* – instances *C*.

Consequently, designing the base ontology O_{base}, it is necessary to build triplets r_i and new concepts C, which are suggested by the structure (4). This structure includes a set of axioms A, but to build such a set of axioms in an automated way is very difficult (at least author doesn't know any of such attempt). Therefore at present this process is performed manually.

Such ready parsers as Link Grammar Parser [8] for the natural language texts processing with the purpose to build an ontology have been used. Six groups of relation patterns have been developed: 1) hierarchy, 2) aggregation, 3) functional, 4) semiotic, 5) identity, 6) correlation, just as in the work [9]. The search of appropriate relations in the text is performed on the basis of these patterns [10].

3.2. Algorithm development of base ontology

The idea that underlies in the automated development of ontology is that the processed texts with the knowledge of subject area are used to obtain data to complete the existing ontology. At the same time, the intermediate ontology is used for text processing of subject area. The result is a recursive process that can be considered as self-education of the system (Fig.1). Learning can be both automated and semi-automated with the help of a teacher. In process of education of the system, the need for a teacher will disappear and the process will be completely automated. The initial ontology with the basic concepts of subject area and commonly used terms should be defined a priori.

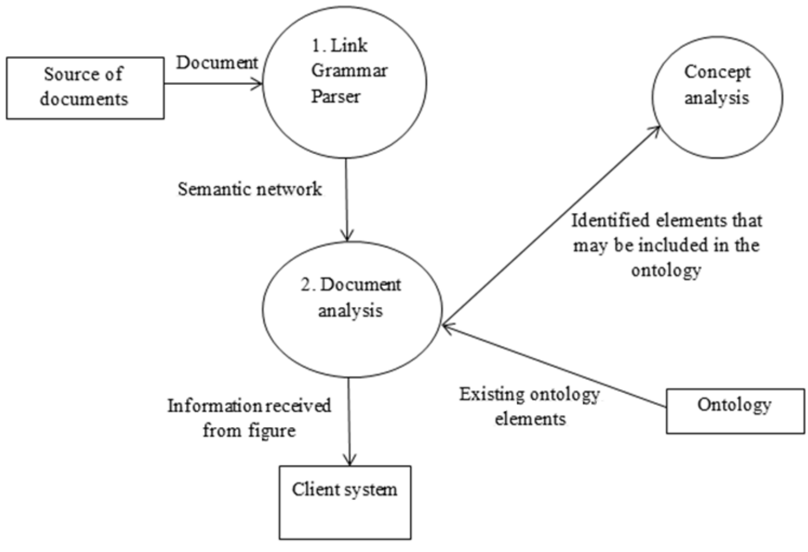

Fig. 1. Data flow diagram of automated ontology building [source: own study]

The designing of ontologies in the form of its learning based on scientific texts that are given by subject area, which are arranged in ascending order of difficulty processing will be organized. The degree of difficulty of processing text can be based on various criteria, such as the number of unknown terms that occur in the text, or the usage of the topological order of the tree of scientific papers that refer to each other.

To determine the new items that can be added to the ontology, a variety of methods that are mainly based on heuristics which take into account the existing elements in the ontology can be used. Using different methods, we obtain a set of possible modifications of ontologies among which we should choose the right ones. The choice is made by a teacher or it happens in an automated way, according to the previous studies.

Heuristics, involved in defining new elements, can be presented both as production rules, and can be based on pattern recognition algorithms, trying to supplement the areas of ontologies by the skipped items on the basis of existing templates.

The algorithm of developing base ontology on the basis of analysis of natural language text is as follows:

1) from the text the semantic units are singled out with reference to the corresponding elements in the ontology;
2) among interconnected semantic units the subset of which can form certain semantic templates which can create new elements for ontology are allocated;
3) semantic templates are added to the array in which after processing a text document a series of passes is carried out. During each pass a template can be seen to be possibly added into the ontology. If this template is allowed to be added to the policy of ontology designing, it is placed in the queue for a review performed by the administrator or added in an automated way depending on the degree of confidence of the template's type that is established by the policy of designing. Passages are carried until the new elements will be ceased to be added or a fixed number of times set by the designing policy;
4) the queue of templates is an oriented acyclic graph of proposals of the insertion of new elements in the ontology. Administrator will consider proposals from the upper level, if the proposal is declined, all proposals of lower levels will be refused in an automated way that became possible by the addition of the abolished in the queue. If the administrator has accepted a proposal, he takes the following proposals of the current level for consideration, if such proposals don't remain, it jumps to the next level. The role of administrator can run as heuristic algorithm of addition, depending on the policy of designing ontology;

5) any actions in the ontology logging in database, transactions and possibility of a change rejection are maintained, beginning from a certain point.

This process we described in details in [11, 12]. It should be noted that the line of research of automated designing of ontologies, using data bases of natural languages texts and systems based on them is actively developing. In particular, yearly The European Conference on Artificial Intelligence organizes individual sections of learning ontologies, which examines advances in the area of its automated formation.

The algorithm works with a semantic network obtained after using the Link Grammar Parser. The example of such a semantic network is shown in Fig. 2.

```
linkparser> the quick brown fox jumped over the lazy dog
++++Time                                          0.04 se
Found 2 linkages (2 had no P.P. violations)
  Linkage 1, cost vector = (UNUSED=0 DIS=0 AND=0 LEN=18)

 +---------Ds---------+             +-------Js------+
 |     +-------A------+             |   +-----Ds----+
 |     |       +---A--+---Ss--+--MVp-+   |     +--A--+
 |     |       |      |       |     |   |     |     |
the quick.a brown.a fox.n jumped.v over the lazy.a dog.n

Press RETURN for the next linkage.
```

Fig. 2. A text document after using the Link Grammar Parser [source: own study]

Let the following sentence be suggested: "The quick brown fox jumped over the lazy dog". The verb "jumped" refers to the functional relations *Fun(v,x,y,z)* (Fig. 3). Next step is to investigate whether there exist the found concepts in the ontology. Five cases and appropriate actions can be possible (see. Table. 1). In the cases 2 and 5, new concepts are added in the ontology, in other cases either ignored or put in a database for further analysis.

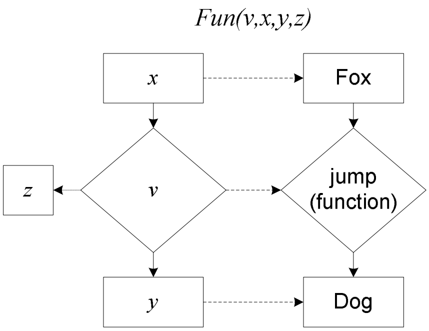

Fig. 3. Template matching [source: own study]

Table 1. Possible steps during automatic building of ontologies

№	Connection	Subject	Object	Possible action
1	+	+	+	Add into databases relations
2	+	+	–	Add an unknown concept to the ontology
3	+	–	–	Analyze
4	–	–	–	Ignore
5	+	–	+	Add an unknown concept to the ontology

Let the following sentence be suggested: "A steel has internal structure", as a result of processing of this sentence LinkParser obtains the relation "has", which belongs to the relations of hierarchical type, and it's pattern is Hier(a,x,y).

4. ADAPTATION ONTOLOGY

The effectiveness of adaptation ontologies of data bases to the subject area features determines the elements of its structure and mechanisms of its adaptation through learning during operation. One approach of the implement-tation of such mechanisms is an automated weighing of data base concepts and semantic relations between them during learning. This is the role of weight's importance of concepts and relations. Weight's importance of the concept (communication) – is a numerical measure which characterizes the importance of certain concepts (communication) in specific subject area and dynamically changes according to certain rules during system operation. It is suggested by entering into its formal description the weight's importance of concepts and relations [13, 14]. Ontology like this one is defined as:

$$\hat{O} = \left\langle \hat{C}, \hat{R}, F \right\rangle,$$

where $\hat{C} = \left\langle C, W \right\rangle$, $\hat{R} = \left\langle R, L \right\rangle$, in turn W – weight of the importance of concepts C, L – weight of the importance of relations R.

Ontology defined in this way is called adaptation ontology, that is, one that adapts to the subject area using modification of default weights importance of concepts and relations between them.

To specify the weights' importance of relations for semantic tasks the research of the Danish scientists Knappe, Bulskov and Andreasen has been used [15]. They identified the following values of weights relations: $L_1 = 0,9$; $L_2 = 0,8$; $L_3 = 0,3$; $L_4 = 0,2$. For the relation of identities it is accepted that $L_5 = 1$. The relation of the correlation occurs only in attribute problems. For attribute tasks, leave (according to the heuristics), the concepts that are lower in the hierarchy are more important because they take specific values. Based on this, we consider that $L_1 = L_2 = 1,1$, such weights are similar as for semantic tasks. The relation of correlation is a two-way communication. Its weight is the module correlation between the features: $L_6 = \left| r_{ij} \right|$.

Methods of setting the weights of importance of concepts are:

- expert evaluations;
- frequency of use of concepts in scientific texts;
- using data mining, in which intelligent decision support system operates.

The method of calculating the weights of concepts is presented in [16, 17].

The defined ontology model of data base that allows to calculate the weight of its elements in the process of its adding, removal and usage during the operation of the system, thereby implements an adaptation mechanism to a given user subject area.

Obtained weight called weights of basic concepts, the set of such weights is indicated W_B.

These weights were developed for all ontology of subject area using taxonomy of ontology concepts, relations between concepts and their interpretation. The development of weights to the whole ontology depends on the definition (axiomatization) classes, their hierarchy (vertical connections) and horizontal connections. It is suggested to use a decision tree for setting the initial weights of concepts.

Vertices (signs) of a separate branch of the decision tree are placed into k levels. Obviously, the higher the level, the more significant feature that is included on this level. In addition, (it is suggested that) these weights to be normalized in order to their sum for each class (branch of the decision tree) be equal to 1.

Weights are defined as relation of the difference (k+1) level of tree and level that contains the sign to the sum of all levels of branches, that is:

$$w_i = \frac{k+1-i}{\sum_{j=1}^{k} j} = \frac{2(k+1-i)}{(1+k)k}.$$

We propose a method for determining the weights of all concepts in the ontology. First, the weight of all signs is equal 0. For the features that take part in the decision tree for the respective class to the primary weight we add the weight derived from the tree. All others should be calculated for the ontology of the corresponding task according to the formula:

$$W_j = \sum_{R^X} L_{ij} \cdot W_i + \sum_{R^Y} W_k \big/ L_{jk} \ . \qquad (2)$$

In the general case (2) is a system of the linear algebraic equations. However, in some cases, (2) is a sequence of the linear relations.

5. OPTIMIZATION OF ONTOLOGY AND QUALITY CRITERIA OF EVALUATION

Automated ontology development leads to the appearance of some weaknesses in its structure and content, the discrepancy of its content information filling according to the needs of the user. Therefore, such systems must be «complete» by the set of optimization procedures ontology.

Criteria optimization is formed according to the quality standard ISO 9126 [18]. According to this standard the quality characteristics are:

1. *Functionality* depends on the completeness and proper construction of ontology, how accurately it describes the specifics of the subject area and the problems that occur in it. In turn, the completeness of the ontology depends on the ability to give the correct answers to its queries, and it depends on whether the system is able to evaluate the novelty of knowledge offered to be added to the ontology. A measure of the quality of functional suitability is the percentage of non-trivial (non-zero) correct answers to queries to the ontology that is $\chi_1 = \frac{N_q^p}{N_q} \cdot 100\%$. Determination of functional suitability is one of the basic characteristics of ontologies.
2. *Reliability* (or correctness) functioning of data base – is the percentage of reliably solved tasks. This is the main quality characteristic of data base. Therefore $\chi_2 = \frac{N_z^p}{N_z} \cdot 100\%$.
3. *Usability* of resources (or resource efficiency) in standards is reflected as employment of the resourses of central processor, operative, external and virtual memory, input-output channels, terminals and communication channels. For improving those characteristics the optimization problem

is considered, a criterion which is to minimize the physical memory that takes ontology. On the other hand, it is obvious that ontology takes the least amount of memory, if there is no concept. So a threshold value established on the amount of memory occupied by the ontology.

4. *Efficiency* – difficult formalized concept that defines the functional suitability and effectiveness applications for certain users. This group of indicators includes subcharacteristics that reflect different aspects of functional clarity, ease of development, system efficiency and ease of use of ontologies. This suitability is based on the integrity of the ontology, that is the absence in its core mutually denied statements and duplication, as well as on balancing subject area, which consists in the full representation of its individual units in the ontology.
5. *Maintainability is* displayed by the convenience and effectiveness of corrections, improvements or adaptation of the structure and content of ontology database depending on changes in the external environment applications, and also in requirements and functional specifications of the customer.
6. *Portability* is characterized by long and laborious installation database, adaptation and replacement in case of transfering to other hardware and operating platform. The criterion of portability is the speed which is expressed in response time to external address (reaction time to change the parameters of the environment, to which system is sensitive).

Taking into account the above-mentioned criteria, optimization method ontology provides optimization problem of its structure and contents: 1) removing parallel edges, duplication tops with the same parameters and other features of the structure of the ontology graph that may impair its integrity and reduce the effectiveness of the functioning of intelligent systems (structure optimization problem ontology); 2) optimization of semantic part of ontology in order to increase its speed and information saturation of the given limits on the system's physical memory amount. Solving these problems is spaced in time, and to preserve the integrity of ontology, at first its structural inspection should be performed, and then – semantic optimization of content part of sequential reduction of the graph to the implementation of requirements of the selected criteria through maximizing the sum of weights of tops and edges of the graph [19–20].

Into the core of the minimization of graph structure of ontology problem a typical optimization problem of graph theory for finding the minimal base, which consists in finding the base of minimal weight in a weighted graph is entrusted. The task of ensuring consistency in the structure of the graph efficiently is solved by resolutions. The problem of content optimization is reduced to the inverse problem of the backpack. Let ontology consist of n elements with a general capacity of memory M. In the role of "backpack" acts a certain given fraction of volume, for example $N = 0{,}1 \cdot M$, which should include the least valuable elements (the concepts with minimal weight of importance and maximal capacity) for their subsequent removal. Then it is necessary to maximize: $\sum_{i=1}^{n} \frac{1}{W_i} x_i \to \max$, such elements, for which $\sum_{i=1}^{n} m_i x_i \le N$, where $\begin{cases} x_i = 0, \text{ if the concept } C_i \text{ remains,} \\ x_i = 1, \text{ if the concept } C_i \text{ removes,} \end{cases}$, m_i – capacity of memory that holds the element C_i. Greedy algorithm was used for the solution of this problem. More optimization tasks of ontology are given in [7].

6. CONCLUSIONS

A method of automated development of a basic ontology using software Link Grammar Parser is considered. Classification of types of relationships is exercised. Mathematical software and algorithm for determining the type of relationships that occur in scientific texts has been elaborated. For the adaptation of the ontology knowledge base for the tasks that it can be solved by it, it is proposed to weight the ontologies' elements. The method of setting the corresponding weights of elements, which in turn makes it possible to optimize the content and structure of the ontology has been developed. It has been offered to use the standard ISO 9126 for evaluation of ontologies quality. The next step in the research will be the task of evaluation of knowledge innovation which are offered to be added to the ontology.

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vibrational diagnostics, footbridge, sensitivity analysis, rotation sensors

Anna BANAŚ, Krzysztof WILDE***

VIBRATION DIAGNOSTICS OF FOOTBRIDGE WITH USE OF ROTATION SENSOR

Abstract

The benefits of the additional measurement of rotational degrees of freedom on the performance of the vibration diagnosis of bridges are studied in this paper. The common vibrational diagnostics that uses translational degrees of freedom is extended by measurements of rotations. The study is curried out on a footbridge and the presence of damage as well as its location and size is determined with use of FEM updating procedure. The results showed that rotational degrees of freedom significantly improve the effectiveness of the vibrational method.

1. INTRODUCTION

In Poland evaluation of technical condition of new bridges with use of in situ measurements is a standard procedure. The bridge capacity tests are the last step before putting the structure into service. The evaluation always consists of static tests during which the displacements of selected points at the bridge deck, settlements of abutments and bridge piers are measured. As a dead load for testing, depending on the type of the structure, locomotives, trucks, road plates or containers filled with water are used. For all railway bridges, road bridges of span more than 20 m and most of the footbridges, dynamic tests are also conducted. The measured values are usually displacements and accelerations at the selected locations of the deck [1]. Bridge oscillations, in the case of road bridges, can by excited by trucks moving with different velocities and passing over the smooth road or over a road with obstacles. It is assumed that the moving truck should fall down from the obstacle of height of 10 cm. For footbridges, which are usually more flaccid, dynamic excitation may be generated by a group of pedestrians marching or running synchronously as well as performing squats or jumps at certain points of the deck [2]. The dynamic force can be also generated by a dynamic actuator or a set of actuators in case of large bridge structures.

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Vibrational diagnostics of engineering structures is usually performed with use of acceleration measurements of translational degrees of freedom [2–6]. Measurements are performed using accelerometers and the signals are used for identifying the natural frequency and mode shapes of the structure. One possible way to evaluate the technical condition of the bridge is to derive a Finite Element Model of the bridge and to update its parameters by using the information stored in the measured natural frequencies and mode shapes [7,8]. The updated FE model contains complete data on bridge stiffness and mass in a form of coefficients of the stiffness and mass matrices. The reduction of the stiffness in the FE element indicates the presence of the damage. Analysis of the element location in FE mesh and its stiffness changes is used to estimate the location and extend of the damage [9].

The aim of the study is to examine the effectiveness of the vibrational bridge diagnostics with use of FEM updating technique based on measurements of both translational and rotational degrees of freedom [10]. In practice, measurements of rotations are performed using gyro sensors which measure the rate of change in the angle of rotation at the specific points of the bridge deck.

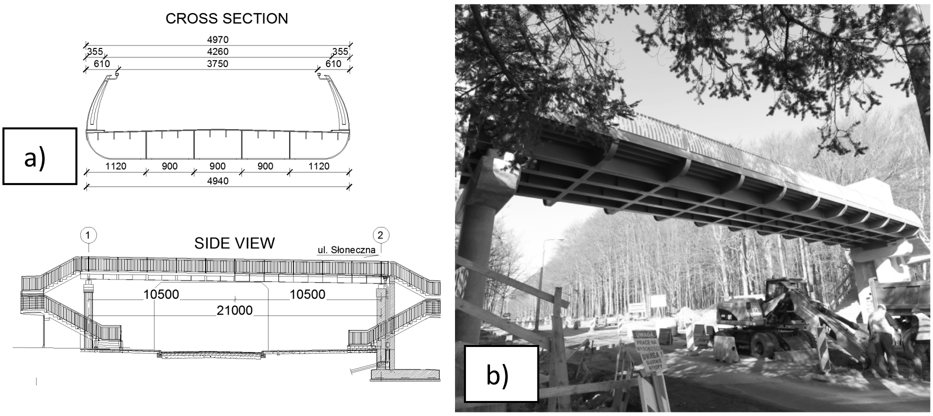

Fig. 1. a) Cross section and side view of a footbridge over the Chwarznieńska street in Gdynia b) Photography of footbridge over the Chwarznieńska street [source: own study]

It is assumed that there is only one damage zone in the bridge. The updating procedure is based on first few flexural vibration frequencies and mode shapes that can be determined in real in situ measurements. The research is carried out on an example of the existing footbridge located in Gdynia, Poland. However, due to lack of the measurement data the research is done in a form of "numerical experiment" where the "measurement data" for testing the damage detection technique is generated numerically and is modified by an added measurement noise.

2. DESCRIPTION OF FOOTBRIDGE

The footbridge is located in Gdynia city and is crossing the Chwarznieńska Street. The superstructure consists of four longitudinal girders and eleven traverses, in which the upper belt is the steel horizontal slab. The slab is additionally reinforced with open, longitudinal ribs. The bridge deck is mounted on the pillars through elastomeric bearings. Major supports are in the shape of the letter "T" with the pillar cross-section of a flattened circle. The basic geometric parameters of the footbridge superstructure are: theoretical span length L_{tp} = 21.00 m, total width of the deck B_c = 4,968 m, height of superstructure H_k = 0,530 ÷ 0,555 m (Fig. 1).

3. DESCRIPTION OF FOOTBRDIGE FEM MODEL

The analysis is carried out with use of two FE models of the footbridge superstructure developed in the commercial program SOFiSTiK. The detailed 3D beam-shell model (Fig. 2) consisted of 5551 nodes, 5632 four node shell elements and 3190 beam elements. The boundary conditions are modelled by setting to zero four vertical, one longitudinal and two transvers displacements at the nodes corresponding to the location of the bridge bearings.

The simplified model consists of only beam elements and has 81 nodes and 80 beam elements with 5 boundary constraints i.e. two vertical, one longitudinal and two transvers displacements are locked.

The first four flexural mode shapes computed by the detailed beam-shell model are shown in Fig. 4. The corresponding first four natural frequencies are respectively 2.98 Hz, 11.75 Hz, 25.56 Hz and 40.33 Hz. Due to symmetry of the bridge deck cross section (Fig. 3) there is a negligible coupling between the vertical, horizontal and torsional motions. Therefore, these four mode shapes are vertical bending modes. Since the number of the stiffening ribs is relatively large the mode shapes have no features characteristic for plate dynamics (Fig. 4).

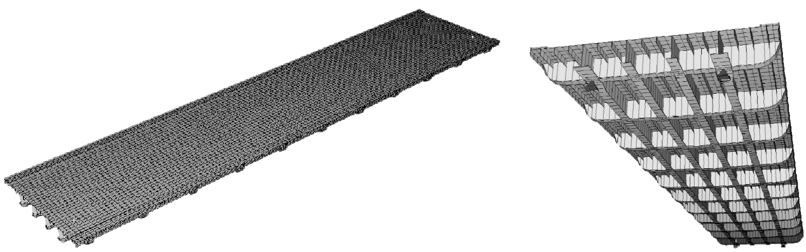

Fig. 2. Discretisation mesh of beam-shell FEM model of footbridge deck [source: own study]

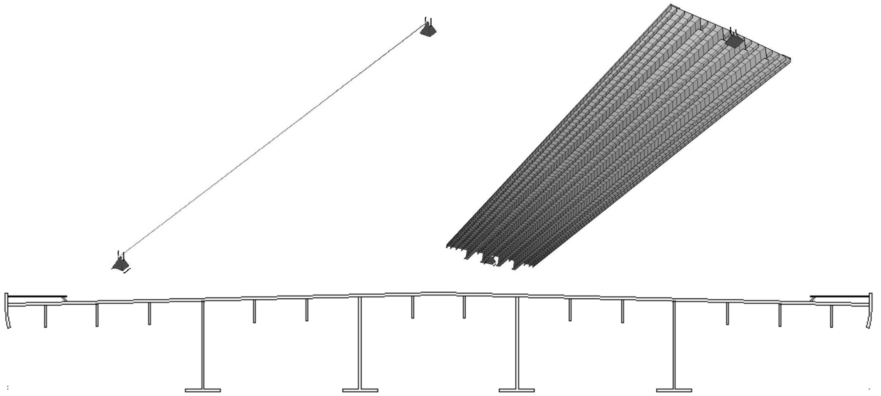

Fig. 3. Static scheme and mesh of beam FEM model and the cross-section of beam element [source: own study]

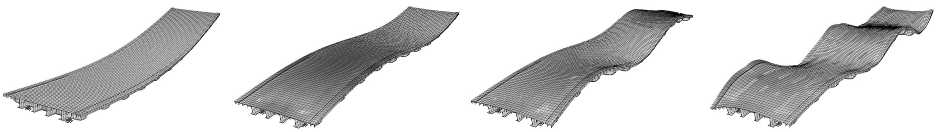

Fig. 4. First four flexural mode shapes of beam-shell model [source: own study]

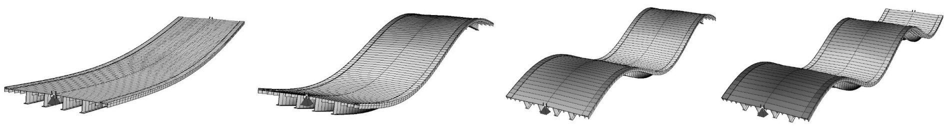

Fig. 5. First four flexural mode shapes of beam model [source: own study]

The mode shapes computed from the simple beam model (Fig. 3) are shown in Fig. 5. The corresponding natural frequencies are respectively 3.07 Hz, 11.66 Hz, 23.35 Hz and 39.71 Hz. The mode shapes form the beam model are vertical bending modes according to the classical beam theory.

The dynamic characteristics of the both FEM models are consistent. The differences in the first four frequencies are respectively 5,86%, 0,77%, 9,46% and 1,56%. The first four mode shapes computed by the detailed and simplified beam model are in a very good agreement. For the implementation of the “numerical experiment”, the required accuracy of calculations using the simplified beam model is sufficient. The simulations shown below are carried out by the simplified beam model of the footbridge.

4. ITERATIVE METHOD OF UPDATING FEM MODEL PARAMETERS

The updating procedure used in this study is an iterative optimization technique defined with use of sensitivity matrix. The design parameters $\boldsymbol{\theta}$, in step $j+1$, are updated through the sensitivity matrix $\mathbf{S}_j$ [11–13]:

$$\begin{aligned} \boldsymbol{\theta}_{j+1} &= \boldsymbol{\theta}_j + \left[\mathbf{S}_j^T \mathbf{S}_j\right]^{-1} \mathbf{S}_j^T \left(\mathbf{z}_m - \mathbf{z}_{aj}\right) \quad \text{for } N_w \geq N_\mathrm{p}, \\ \boldsymbol{\theta}_{j+1} &= \boldsymbol{\theta}_j + \mathbf{S}_j^T \left[\mathbf{S}_j \mathbf{S}_j^T\right]^{-1} \left(\mathbf{z}_m - \mathbf{z}_{aj}\right) \quad \text{for } N_w \leq N_\mathrm{p}. \end{aligned} \tag{1}$$

where N_p is a number of unknown updated parameters θ_j, N_w denotes number of measured data, $\mathbf{z}_{aj}$ is describes analytical modal pairs and $\mathbf{z}_{mj}$ denoted "measured" modal pairs obtained, in this studies, by simulations with added measurement noise.

The sensitivity matrix can be expressed as:

$$\underset{(N_\mathrm{c}\, x N_\mathrm{p})}{\mathbf{S}} = \begin{bmatrix} \dfrac{\partial \lambda_{\mathrm{a}1}}{\partial \theta_1} & \cdots & \dfrac{\partial \lambda_{\mathrm{a}1}}{\partial \theta_{N_\mathrm{p}}} \\ \dfrac{\partial \boldsymbol{\phi}_{\mathrm{a}1}}{\partial \theta_1} & \cdots & \dfrac{\partial \boldsymbol{\phi}_{\mathrm{a}1}}{\partial \theta_{N_\mathrm{p}}} \\ \vdots & & \vdots \\ \dfrac{\partial \lambda_{\mathrm{a}p}}{\partial \theta_1} & \cdots & \dfrac{\partial \lambda_{\mathrm{a}p}}{\partial \theta_{N_\mathrm{p}}} \\ \dfrac{\partial \boldsymbol{\phi}_{\mathrm{a}p}}{\partial \theta_1} & \cdots & \dfrac{\partial \boldsymbol{\phi}_{\mathrm{a}p}}{\partial \theta_{N_\mathrm{p}}} \end{bmatrix} \tag{2}$$

and its coefficients can be calculated as derivatives of natural frequencies $\lambda_{\mathrm{a}i}$ and mode shapes $\boldsymbol{\phi}_{\mathrm{a}i}$:

$$\frac{\partial \lambda_{\mathrm{a}i}}{\partial \theta_j} = \boldsymbol{\phi}_{\mathrm{a}i}^\mathrm{T} \frac{\partial \mathbf{K}}{\partial \theta_j} \boldsymbol{\phi}_{\mathrm{m}i} - \lambda_{\mathrm{m}i} \boldsymbol{\phi}_{\mathrm{a}i}^\mathrm{T} \frac{\partial \mathbf{M}}{\partial \theta_j} \boldsymbol{\phi}_{\mathrm{m}i} \tag{3}$$

$$\frac{\partial \boldsymbol{\phi}_{\mathrm{a}i}}{\partial \theta_j} = \sum_{k=1;k\neq i}^{N} \frac{\boldsymbol{\phi}_{\mathrm{a}k} \boldsymbol{\phi}_{\mathrm{a}k}^\mathrm{T}}{\lambda_{\mathrm{m}i} - \lambda_{\mathrm{a}k}} \left[\frac{\partial \mathbf{K}}{\partial \theta_j} - \lambda_{\mathrm{m}i} \frac{\partial \mathbf{M}}{\partial \theta_j}\right] \boldsymbol{\phi}_{\mathrm{m}i} - \frac{1}{2} \boldsymbol{\phi}_{\mathrm{a}i} \boldsymbol{\phi}_{\mathrm{a}i}^\mathrm{T} \frac{\partial \mathbf{M}}{\partial \theta_j} \boldsymbol{\phi}_{\mathrm{m}i} \tag{4}$$

where $\mathbf{K}$ is a stiffness matrix, $\mathbf{M}$ denotes mass matrix, $\boldsymbol{\phi}_{\mathrm{a}i}$ or $\boldsymbol{\phi}_{\mathrm{a}j}$ are i-th or j-th analytical mode shapes and $\boldsymbol{\phi}_{\mathrm{m}i}$ or $\boldsymbol{\phi}_{\mathrm{m}j}$ are i-th or j-th mode shapes obtained from the "numerical experiment".

Comparison of compliance between the measured and calculated mode shapes is made by the criterion of certainty MAC (Modal Assurance Criterion) (Eq (5)) [14,15] and by the standardized coefficient NMD (Normalized Difference Modal) (Eq (6)) [14,16].

$$\mathrm{MAC}_{ij} = \frac{\left|\boldsymbol{\phi}_{\mathrm{m}i}^{\mathrm{T}}\boldsymbol{\phi}_{\mathrm{a}j}\right|^2}{\left(\boldsymbol{\phi}_{\mathrm{a}j}^{\mathrm{T}}\boldsymbol{\phi}_{\mathrm{a}j}\right)\left(\boldsymbol{\phi}_{\mathrm{m}i}^{\mathrm{T}}\boldsymbol{\phi}_{\mathrm{m}i}\right)}. \tag{5}$$

$$\mathrm{NMD}_{ij} = \sqrt{\frac{1-\mathrm{MAC}_{ij}}{\mathrm{MAC}_{ij}}}. \tag{6}$$

Furthermore, criteria for assessing the quality of the obtained results are based on two indexes:

$$I_{k\,\mathrm{max}} = \frac{k_{dam}}{k_{\mathrm{max}\,udam}} \geq 1.5 \tag{7}$$

$$I_{k\,\mathrm{mean}} = \frac{k_{dam}}{k_{mean\,udam}} \geq 4.0 \tag{8}$$

where k_{dam} denotes the change in stiffness of the updated damaged element, $k_{\mathrm{max}\,udam}$ is the maximum change in stiffness of undamaged elements and $k_{\mathrm{mean}\,udam}$ denotes the average change in stiffness of undamaged elements.

The procedure of searching the damage location requires the following steps:

1. selection of the number of rotations and generation of an array of all possible rotation locations;
2. computation of a vector of measurement data for each combination of "measurements";
3. reduction of the $\mathbf{K}$ and $\mathbf{M}$ matrixes by the SEREP [17] method to eliminate unmeasured degrees of freedom;
4. computation of the natural frequencies and mode shapes for the reduced size matrices of the model;
5. normalization of the vector of measured mode shapes with respect to the analytical mass matrix;

6. computation of the sensitivity matrix **S**, the difference of vectors of modal pairs, selection of a matrix of weights and computation of the perturbations of design parameters;
7. minimization of the penalty function with respect to changes in designing parameters;
8. computation of the actual stiffness of the finite element model and validation of the completed calculations;
9. indication of the damage location and its extend.

5. PARAMETRIC ANALYSIS OF INFLUENCE OF ROTATION

Analysis of the effectiveness of additional measurements of the rotations for updating the stiffness of the FE model of the footbridge is conducted on a noisy numerical data. It is assumed that the damage is located in the 8th segment that consists of 4 beam elements. The FEM model of the footbridge (Fig. 6) consists of 20 segments and a total of 80 finite elements. The assumed extend of the damage is a 15% reduction in the flexural rigidity with respect to the undamaged bridge deck section. The numerical data, used instead of real "measurements", contains 5% white noise to add the characteristics of real in situ measurement errors. The vector of updating parameters is composed of flexural stiffness of 20 segments of the beam model. It is assumed that the measurements of the acceleration of translational degrees of freedom are performed in 5 locations that are equally spaced along the length of the span (Fig. 7). The parametric tests include the search for the location of damage without measuring the rotation and also assuming that one, two, three and four measurement signals of rotations are used. It is assumed that the rotation sensors can be placed in all the nodes of the footbridge featured in the FE model. The parametric studies are based on the first four flexural vibration frequencies and mode shapes.

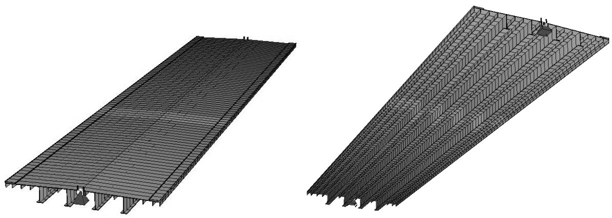

Fig. 6. Discretization mesh of beam FEM model of span with 8th element damaged [source: own study]

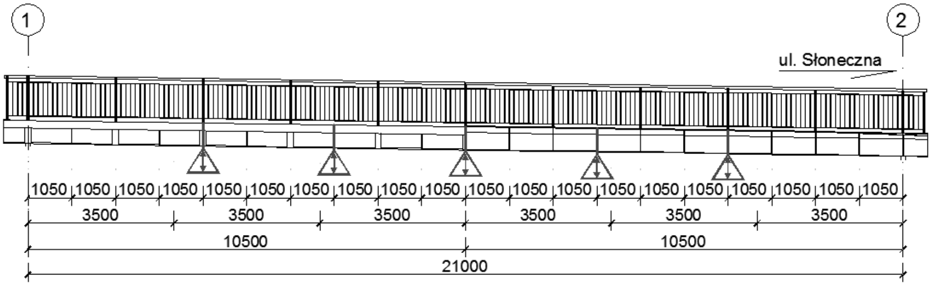

Fig. 7. Arrangement of measured accelerations points [source: own study]

The simulation results showed that updating the parameters of the FE model on data only from the translational degrees of freedom, is impossible. The results of stiffness updating of all 20 footbridge segments based only on the five acceleration signals is shown in Fig. 8. The results indicate that the damage is around the 3rd, 8th, 13th and 18th segment. The maximum change in stiffness is in the 3rd segment and should be in the 8th one.

Fig. 9–12 show results of updating procedure in case of the damage detection preformed successively on one, two, three, and four additional rotation signals. Using five translational degrees of freedom and one rotation (Fig. 9) does not allowed correct indication of the damage location. The diagram of the stiffness changes shows slight damages in several elements.

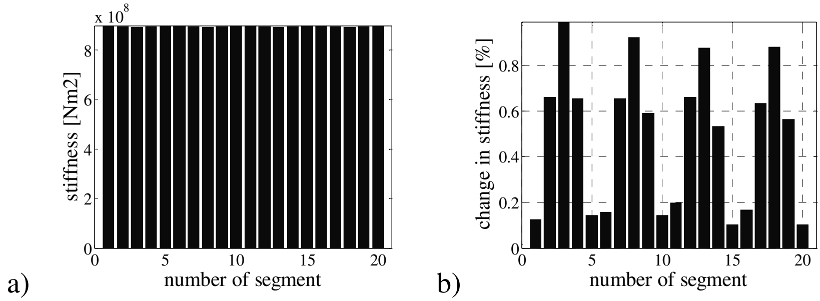

Fig. 8. Calculated change in the stiffness of the segments for the updating on 5 translations; a) change from baseline; b) the change in the stiffness in each segment [source: own study]

From the results shown in Fig. 10-12 it can be concluded that an updating on 5 translations enriched with at least two rotations allows the correct identification of the damage. The maximum value of the stiffness change occurs in segment 8 and it clearly indicates the place of the largest reduction in the beam rigidity. With two additional measurements of rotation change in stiffness of the damaged element is 21%, with three rotations 27%, and 35% with four additional rotations.

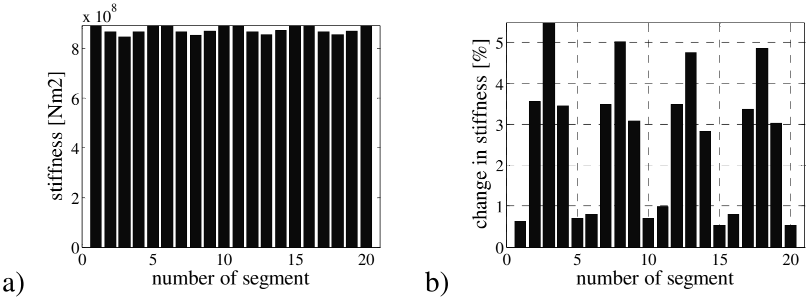

Fig. 9. Calculated change in the stiffness of the segments for an updating on the basis of: 5 translation and 1 rotation; a) change from baseline; b) the percentage change in the stiffness of the element [source: own study]

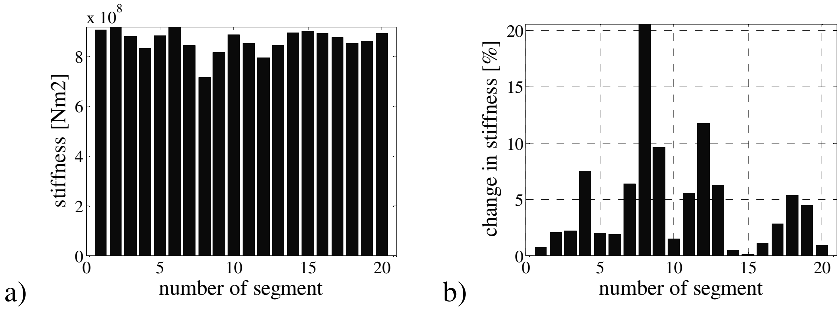

Fig. 10. Calculated change in the stiffness of the segments for an updating on the basis of: 5 translation and 2 rotations; a) change from baseline; b) the percentage change in the stiffness of the element [source: own study]

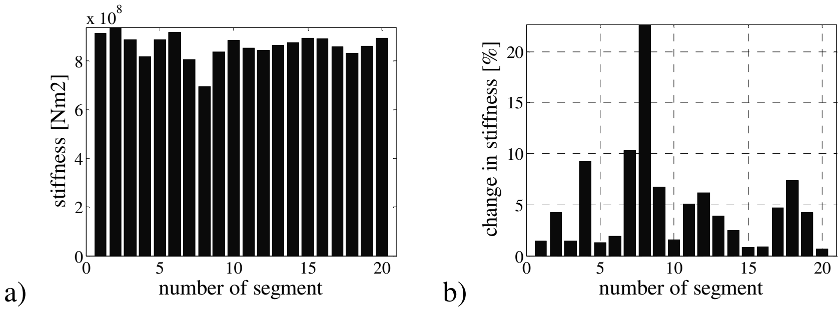

Fig. 11. Calculated change in the stiffness of the segments for an updating on the basis of: 5 translation and 3 rotations; a) change from baseline; b) the percentage change in the stiffness of the element [source: own study]

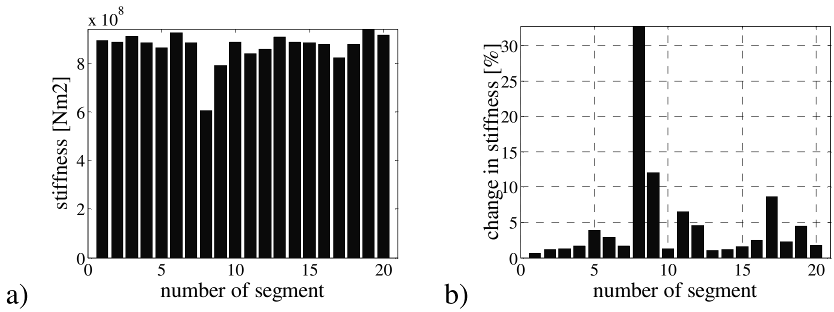

Fig. 12. Calculated change in the stiffness of the segments for an updating on the basis of: 5 translation and 4 rotations; a) change from baseline; b) the percentage change in the stiffness of the element [source: own study]

In addition, to achieve the correct updating results the rotational measurements must be performed in the precisely defined locations (Fig. 13). With two rotations only two combinations of the measurement points allow proper diagnostics. When three measurements of rotations are used only three locations of rotation sensors permits the correct detection of a damaged segment. The correct identification of the damage in the 8th segment is possible for the 24 sensor location patterns, if four measurements of the angles of rotation are available.

Table 1 summarizes the tests results with NMD criterion depending on the number of additional rotations. Table 2 lists the corresponding values of the quality indexes. In both cases, the results are presented for the most appropriate location of the rotational sensors. The results presented in Table 2 show that if only one rotation is used, the quality indexes have values of less than 1% and therefore, the procedure incorrectly indicates the defective segment. By using at least two rotation, values of quality indices increase significantly and exceeds the level of 8% for $I_{k\,\mathrm{mean}}$ and 3% for $I_{k\,\mathrm{max}}$, which allows the proper identification of the damage location.

Tab. 1 NMD criterion value depending on the number of rotations

Frequency	NMD			
	1 rotation [-]	2 rotations [-]	3 rotations [-]	4 rotations [-]
1	6.2986	4.7563	4.8451	4.3197
2	1.8096	1.5797	1.6239	1.5616
3	3.6048	1.5629	1.4888	1.6313
4	8.0029	3.2491	3.2455	3.2244

Tab. 2 Quality index values depending on the number of rotations

Index	Quality index values			
	1 rotation [-]	2 rotations [-]	3 rotations [-]	4 rotations [-]
$I_{k\,\mathrm{mean}}$	0.99539	8.2566	8.393	9.7005
$I_{k\,\max}$	0.99179	3.495	3.4561	3.385

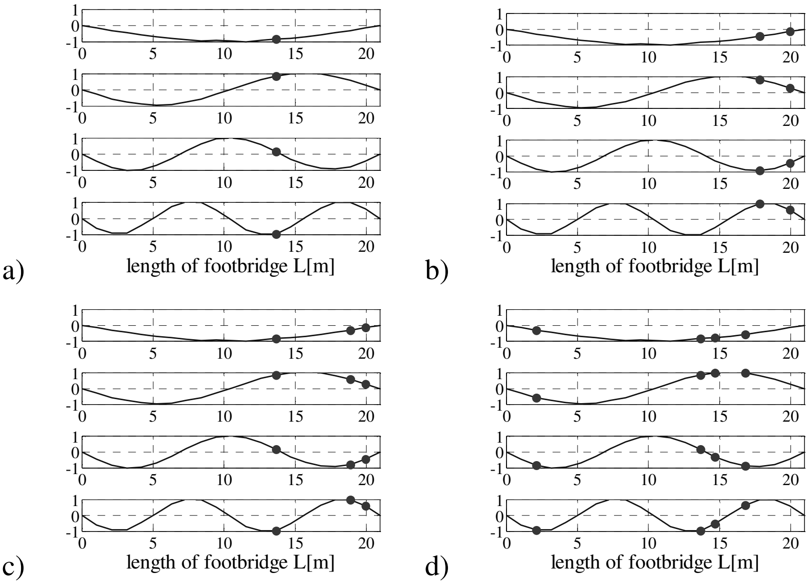

Fig. 13. Location of the best additional measurement points of rotations for a) one signal b) two signals c) three signals d) four signals [source: own study]

6. SUMMARY

The paper presents the parametric study of the vibrational damage identification method based on additional measurements of the rotational degrees of freedom. Analysis of the tests conducted on the numerical data with added noise for the steel footbridge showed that that the additional information from rotations improve the performance of the method. The correct detection of the damage for assumed damage extent corresponding to 15% stiffness reduction can be obtained if at least two additional rotations are measured. The effectiveness of the method depends also on the location of the rotation sensors. If only two sensors are used only two patterns of they locations are available. In case when five rotations are used they can by placed in 24 combinations of sensor locations.

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modular robotics, multiagent systems, metamorphic structures of robots

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MULTIAGENT SYSTEMS IN MODULAR ROBOTICS

Abstract

The article describes the use of a multi-agent system in modular robotics. Multi-agent systems originated as an extension of the field of distributed artificial intelligence which allows understanding the individual modules as independent agents. By adopting this concept, design direction, which gives the robot a new quality, which is based on the possible effective reconfigure its kinematic and functional structure, thereby taking advantage of the original robot modules generate new variants of the robot with the required new parameters and behavior.

1. INTRODUCTION

In a modular robot system (MSR), each module is usually equipped with its own independent computation, sensing, communication, and actuation capabilities and can thus be viewed as an independent agent. Each module can usually also send messages to other modules that are physically connected to it. Modular robots have three main advantages over traditional robots. They are capable of changing their configurations to become different structures or shapes based on deferent tasks. Two types of modular robots are considered in this article (Fig. 1 a,b). Chain-style modular robots, SUPERBOT (a) and Polybot (b). Each square unit is an independent module, and there is a rotary motor mounted on each module (c, d). Strut-based modular robots. Each link/node module is an independent module; each link module can perform linear actuation to elongate or contract its length [7,8].

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a **b** **c** **d**

Fig. 1. Types of modular robots [source: own study]

Most modular robots, there are distributed sensors in the whole systems because each module is equipped with a sensor. Such sensor-rich robots can potentially perform tasks more adaptively and reactively in changing environments than other robots with limited sensors. Because all modules are identical, the whole system is more robust with regard to module failures as long as we program each module in the system with an identical controller.

2. METAMORPHIC STRUCTURES OF SERVICE ROBOTS

Theoretic robotics characterizes metamorphic robots as modular systems with the ability to self-reconfigure their own kinematics and functional structure to create a „new" robot with different functional features and technical parameters flexibly [1,2,6,9].

One of the main functions of MSR is the locomotion function, i.e. mechanic relocation of MSR within some space. MSR movement is understood as the change of status in the space (position and orientation) of MSR. MSR relocation into the status B in relevant (referential) space Z is the demonstration of certain type of relation of the movement M in the space Z.

$$M(B;Z) = \vartheta \tag{1}$$

MSR movement can be described by a twelve-component vector expression (x_E, y_E, z_E) – position of the center of gravity connected with a non-mobile coordinate system (i_E, j_E, k_E); u, v, w – speed of the movement of the center of gravity connected with the body of a service robot; θ, φ, ψ – Euler angles; p, q, r – angle speed connected with a mobile coordinate system).

$$X = (x_E, y_E, z_E, u.v, w, \theta, \varphi, \psi, p, q, r) \tag{2}$$

Functional and locomotion features of MSR, in relation to the effect of the demonstration of locomotion mechanism (kinematics – locomotion chain) of the robot ML (superposition of the movements of discrete locomotion elements of the locomotion mechanism), can be described of the locomotion function FM (locomotion equations). The function expresses the relation RM of the function ML and the space Z. The above said can be also described by the values of characteristic parameters X1, X2,, ..., Xn of different elements of kinematics structures of locomotion mechanism of MSR, generated by relevant drives on the base of control instructions.

$$R_M\ (M_L; Z) = \vartheta_M = F_M\ (X_1, X_2, ..., X_n) \qquad (3)$$

System model of MSR sets that the output of locomotion mechanism ML is bound with the chassis (mobility subsystem) CH, their mutual connection is given by the relation RCH (sum of the movements of different elements of locomotion mechanism - MSR movement).

$$R_{CH}\ (CH; M_L) = \vartheta_{CH} \qquad (4)$$

Taking into account the locomotion function of MSR, the relation RB of MSR into the status B and the chassis CH is similarly defined as

$$R_B\ (B; CH) = \vartheta_B \qquad (5)$$

consequently the status B of MSR in the space Z, in relation ϑCH, ϑB (relations can be constant or variable) is a superior function φ of the kinematics function FM

$$R\ (B; Z) = \varphi\ [F_M\ ; \vartheta_{CH}\ , \vartheta_B] \qquad (6)$$

while standard MSR have constant relations ϑCH, ϑB. Generally speaking, function FM realization is given by the features of locomotion mechanism of MSR with a defined character of its mobility (principle of physical realization).

In given circumstances, MSR reconfigurability means the development of locomotion structures of MSR (MSR locomotion structures of locomotion mechanism) by the control of the variability of the relations RCH and RB within the system structure of the robot mobility subsystem, the development of increasing/decreasing the number of elements realizing the locomotion function FM, the development by increasing the share of active members (at the expense of the passive ones) on the final mobility of the kinematics chain of the locomotion mechanism [9,10].

Reconfigurable MSR (metamorphic MSR – MMSR) are based on modular structure, Fig. 2, i.e. on the set of autonomous modules AM (set of locomotion, mechanical, control, ...modules) and their mutual organization and connections.

By the change of mutual organization (serial, parallel, combined structures) and the connection of AM it is possible to construct different functional and kinematics (open, close, combined kinematics chains) of the robot configuration.

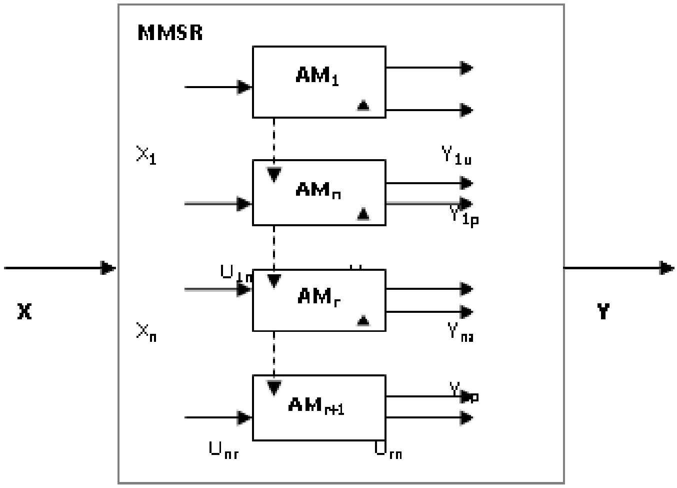

Fig. 2. System setting of modular structure [source: own study]

The inputs into the module AM_{r+1}, Fig. 3, are the following: parameters X of the task of MMSR transformed into the parameters X_{r+1} of the partial task of the module X_{r+1}, parameters of compatibility U_{rr+1} transformed as the interaction of directly connected following module AM_r in the structure of MMSR. The outputs from the module AM_{r+1} are the following: output parameters Y_{r+1u} a Y_{r+1p} of the module AM_{r+1} representing fulfilling of the partial task of the module transformed into the output parameters Y of the robot MMSR, parameters of compatibility U_{r+1r} by which the module AM_{r+1} directly influences directly connected following module AM_r in the structure of MMSR.

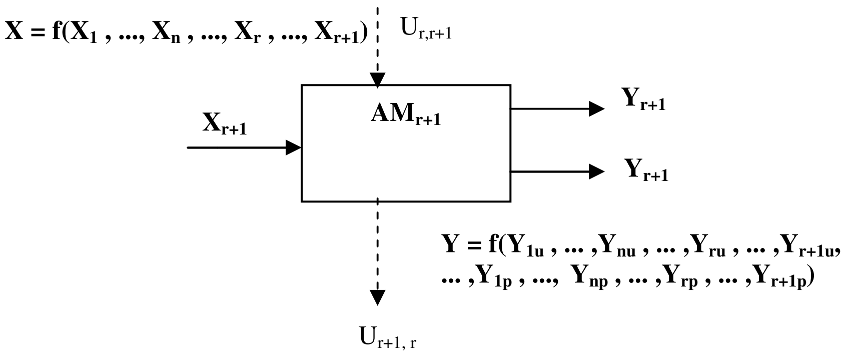

Fig. 3. Module characteristics [source: own study]

Module AM is defined as a unified structurally, functionally and construction ally independent unit (constructed from the elements E; mechanic module, servo drive, or also the source, control and communication module) with given level of function integration (main, secondary, help) and intelligence (control – integration, control and decision-making function), with the ability to connect mechanically and to control other modules into functionally superior wholes.

$$MMR_{\psi} \approx \sum_{j=1}^{a} AM_j \approx \sum_{j=1}^{a}\sum_{i=1}^{e_j} E_{i,j} \tag{7}$$

From the point of view of the application, metamorphic structures can be applied on the level of the inner structure of MMSR (by reorganizing its own modules, the robot can change its kinematics structure, functional structure and disposition setting, functional features and technical parameters), or on the level of outer structure of the application of robotic system (simple robots integrate into one, functionally higher level robot or a complicated robot disassembles into a group of simple, more active and more effective robots).

3. EXAMPLES OF THE DESIGN OF METAMORPHIC SERVICE ROBOTS

Recent practice offers several solutions to the design of MMSR (on the level of the inner structure, on the level of outer structure), from the solutions of theoretical character up to the solutions of the models for concrete technical application, Fig. 4 [3].

Use of the principles of metamorphic structures on the level of the inner structure MMSR in construction of the details of locomotion mechanism of MMSR can be presented on the design of metamorphic wheel, Fig. 5. Model EGON (designed at the workplace of the author), by the inner construction of its parts (modules) and the possibility to control the change of their arrangement it can fulfil the function of a „wheel" or a „track" [3,12,13]. The application of the model with wheeled MMSR gives the robots new driving abilities which can be adjusted to the requirements of the terrain.

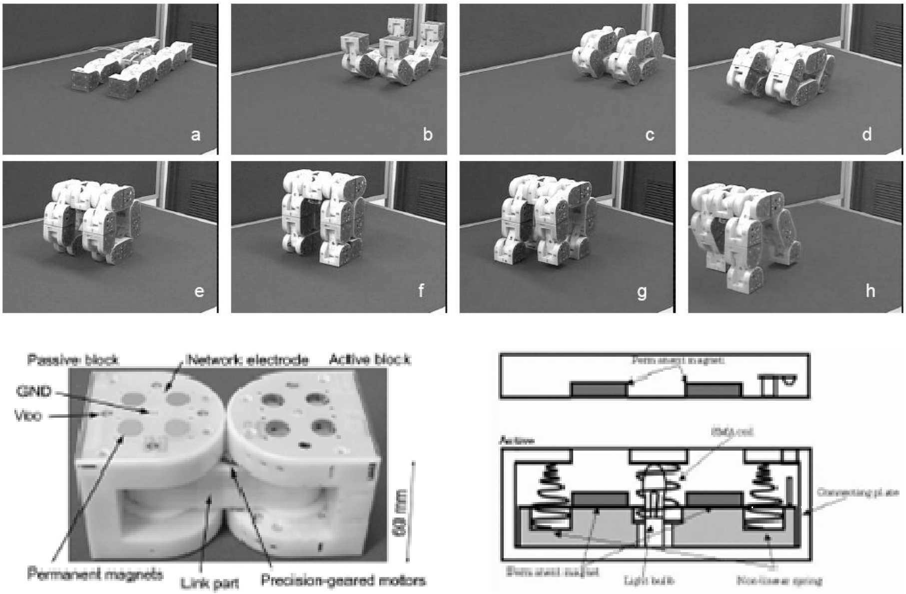

Fig. 4. Example of the possibility of reconfiguration of M-TRAN model [source: own study]

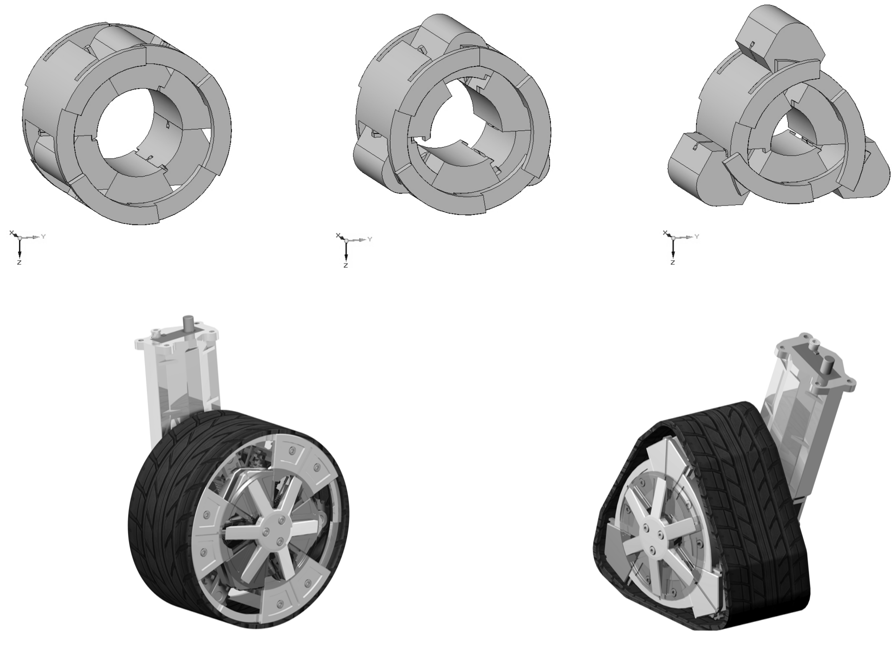

Fig. 5 Model EGON of metamorphic wheel – track system [source: own study]

Heterogeneous modular robots consist of a set of different modules with varying functionality. Typically, these modules will not work individually, but when put together, each module's functionality adds up to form a robot capable of performing a task. The modules with some sort of actuation usually integrate a motor, increasing the cost and complexity of the module. Example of this type is study of robot Thorn (Fig. 6) [4,13].

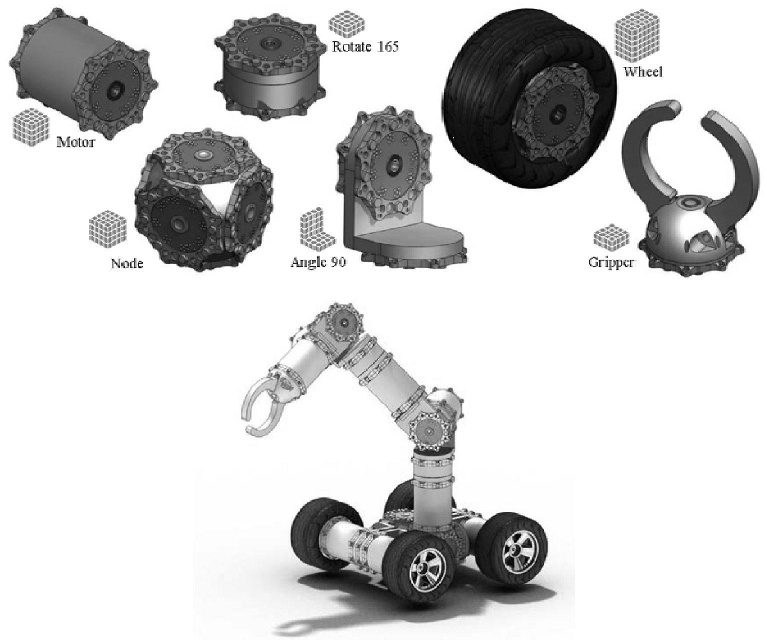

Fig. 6 Example of the possibility of reconfiguration of Thor model [source: own study]

4. CONCLUSION

The problem of the design and application of MMRS has become a highly recent topic for theoretical as well as practical robotics. It echoes the dynamics of the service robotics development and searching new technical designs of the MSR construction for the applications into non-traditional, demanding environments. The trends of the application of *metamorphic – self-regulating* structures in the design of mobility of MSR subsystem, on the base of existing results and their evaluation, have proved technical usability and suitability to design new requirements on MSR. So it can be concluded that the problem of MMSR has the reason to be solved also in our conditions.

Acknowledgements

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energy dissipation, intensive construction, hyperelastic, foam

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THE IDENTIFICATION PROPERTIES OF POROUS FOAM

Abstract

The aim of this work is to develop methods of describing the properties of such materials based on knowledge of: basic materials, technologies (gas pressure formed during foaming) using the theory of hyperplastic materials. The resulting description can be used for the applicability of hyperelastic models, and therefore in the whole range of deformation of the polymer-based composites and elastic composites of metals (not included plasticity). Thesis presents analysis methods of hyperelastic materials using Finite Elements Method. Using FEM it is possible to verify used material, define materials models and show effectiveness of designed component without performing expensive impact tests. Presented methods and applications of the characteristics of hyperelastic materials and composites with the gas phase are used to determine the proper selection of parameters (material properties), increasing the opportunities for a proper assessment of the effectiveness of safety devices.

1. INTRODUCTION

Porous polyurethane foams are widely used in the construction of motor vehicles in particular in the protective structures – systems and energy-dissipating units [5]. Used materials are foamed polypropylene, in the form of pressure, not interconnected granules. Process of static compression for the analyzed polymer foams was determined [11] with the energy absorption and energy dissipation efficiency. By using different sizes of granules elements we obtain different densities in the range of 25 g/dm³ to 220 g/dm³. The surface porosity and surface properties are dependent on the release of active ingredients and the process of formation. The analyzed foams have a high pore volume, mainly inside the macropores. Energy consuming structure is formed in the

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molding process by the blowing. The loose granules are delivered under pressure into the mold where the steam are subject the influence of the formation to yield any shapes and dimensions. Opportunities of foams are very large, in particular, is a high energy absorption and a memory shape – which occur even after multiple loadings. Absorption capacity of the analyzed structure, methods of influencing the properties depending on the external conditions are presented in the literature [6-10]. These properties are of crucial importance in the production of automotive components, which are responsible for ensuring maximum passive safety in automobiles. The products such as energy absorbers to car bumpers is one example of the wide range of applications in order to improve vehicle safety. Components for safety absorb the impact energy that is dissipated by the work done on the deformation of the structure. One factor in this regard is that the impact energy which occurs in the case of a vehicle, wherein the absorbing element is mounted element made of a foam material during the collision should be discharged or directed in such a way that the vehicle does not permanently damage. Furthermore, the vehicle can protect the bumper a pedestrian, in other words in the event of a collision with a pedestrian, the bumper should provide a high level of energy absorption with a large stroke in order to minimize deformation, thereby reducing injury to pedestrians.

The present work is devoted to the presentation of the methods of analysis and description of the properties of the foam materials used, among others, the "security elements". Verification of the properties was carried out on the basis of experimental studies and simulations performed using the Finite Element Method. The proposed method of describing the properties of foam materials are widely used primarily for the analysis of protective devices used in vehicles. At analyses included the process of foamed materials producing, wherein we define: a base material, technology (gas pressure generated during the foaming), using the theory of the material growth and temperature. Simulation analyzes were made using Abaqus system. Description of the material properties was performed using the Ogden's model and its modify-cations. The presented method of analysis of materials enables appropriate deployment model, hyperflexible and its modifications resulting in even better determination of the materials characteristics.

2. STRUCTURE AND CHARACTERISTICS OF THE MATERIAL

Foam materials are widely used, due to its thermal properties, the ability to high energy absorption [13]. The structure of materials like closed cells that can be found in two phases: a solid phase material which is formed and the gas phase, which is formed by taking a physical or chemical phenomena during the preparation steps. The relevant properties of the structure we obtain not only by the choice of how to produce, but also through appropriate selection of the materials used and the appropriate design of the structure geometry. Determination of properties of selected materials was carried out in two stages and takes into account the intended use. The first step is to conduct experimental research carried out in accordance with PN-EN ISO 604:2004, BS EN ISO 604:2006, PN-H-04320: 1957. The second step is to research the actual protection element pedestrian protection element used in VW cars. The material from which samples were made was in the form of granules unconnected filled with a gas which occupies about 97% of the volume. In the description of the material properties must therefore take into account the base material and gas [4]. The use of pellets of different sizes contributes to changes properties of the foam. For the determination of properties of the structure it was necessary to conduct a study which was carried out in the Department of Integrated Process Engineering at the Faculty of Chemical and Process Engineering, Warsaw University of Technology. The research was conducted using a scanning electron microscope Phenom G2 Pro – picture of section structure is shown in figure 1.

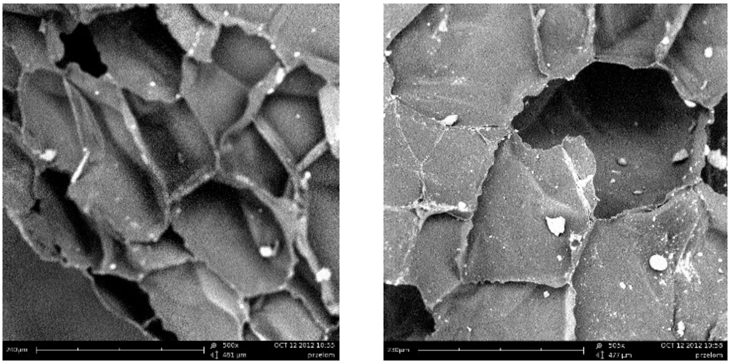

Fig. 1. SEM image of section structure – polypropylene foam [source: own study]

During the studies, there was no adhesive substances between the granules. The material has a high resistance to temperature around. 150°C, excellent thermoformability and shape memory (large ability to return to its original shape after static and dynamic loads). Given that the process of creating foam is expanding – foaming material granules such as polypropylene with water vapor and using a pressure, the granules connect to each other while increasing the volume. More than 90% of the volume of the foam produced in the process is air.

Was determined roughness of the test material:

- Average surface roughness 80–130 μm. Grains protruding above the surface to a height of 200–400 μm.
- The inhomogeneous surface of samples. The current fine grains with a diameter of 10–30 μm and a few larger – diameter of ~100 μm. Density decomposition grains ~40/μm.

3. RESEARCH METHODOLOGY

3.1. Research methodology – experimental studies

Static test for plastic compression is different due to the nature of the deformation [12]. Stress-strain characteristics of the sample obtained for the test compressive materials. The compressive strength of samples was determined using testing machines: Q-test 10 from MTS and Zwick/Roell Z005. The samples was made in the the form of cuboids. The studies of pedestrian protection element, due to the large size, compression test took place only on the first machine. The compression rate at 23°C for the first machine was 5 mm/min, for the second machine 1 mm/s. During the course of the trial were recorded according to the compression force between the piston and the piston displacement, which constituted the first part of the experimental studies. On this basis, the following of samples were made for the charts showing the dependence of the stress deformation as well as the hysteresis loops in the case of quasistatic compression tests. Example experimentally determined hysteresis loop is shown at figure 2.

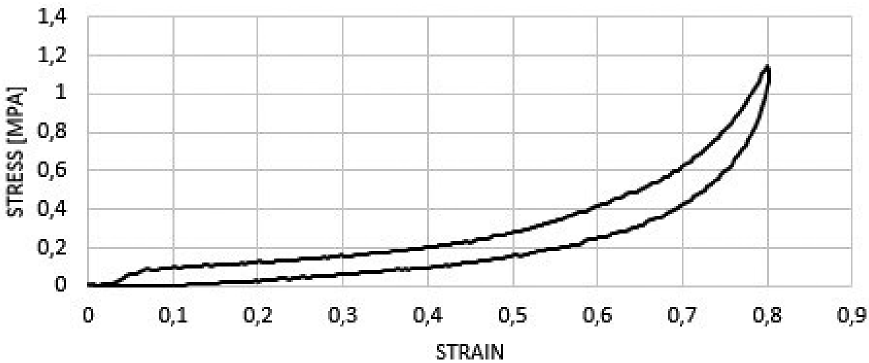

Fig. 2. Example experimentally determined hysteresis loop [source: own study]

3.2. Research methodology – simulation studies

Analysis of simulation models were made using MES (Finite Element Method) ABAQUS, which allows you to fit existing models in the database according to the theory of hyperelastic materials. Simulations were made by using the EXPLICIT module, the calculation takes into account all the necessary in this case non-linear phenomena: the theory of finite deformation by Almancy's in Euler's coordinates (referenced to the actual configuration of the body during deformation). Numerical analyzes were performed for the adequate modeled samples and security element [14]. During the simulation, the effect of friction during deformation of the foam structure – clamping a gas-filled cell. For safety component model and the model of the structure of the material was included contact issue. The evaluation of dynamic loads: stresses, accelerations and deformations occurring during the impact a pedestrian allows to determine the ability of the material to absorb energy. The adoption of the actual values of coefficients αi leads to a nonlinear model, which allows for a description of materials with much compressibility. For modeling of foams, we can modify the Ogden's model with the introduction of the actual exponent in the second part describing dependences of the volume deformations (in this case they are also dependence non-linear). The calculations using the FEM, we can choose the hyperelastic model. To select the most reflects the actual behavior of the material model, for which we perform experimental studies, should the results of both analyzes to compare (compare the results of experimental tests with the results of the numerical model). For the materials considered, a number of comparisons for different types of models. Completed studies have shown that foam materials exhibit a range exceeding 50% strain rapid increase in stresses. Description of the models of the theory of hyperelastic materials: polynomial or Ogden's is insufficient due to the adoption of linear dependencies in the component describing the volumetric strain. As a solution proposed to use a modified Ogden's model called HYPERFOAM, in which the elasticity functional is described of dependence:

$$W = \sum_{i=1}^{N} \frac{2\mu_i}{\alpha_i^2}\left[\bar{\lambda}_1^{\alpha_i} + \bar{\lambda}_2^{\alpha_i} + \bar{\lambda}_3^{\alpha_i} - 3 + \frac{1}{\beta_i}\left(\left(J^{el}\right)^{-\alpha_i\beta_i} - 1\right)\right] \tag{1}$$

in which are accepted indications**:**

volume deformations ratio $\beta_i = \dfrac{\nu_i}{1-2\nu_i}$; ν_i – Poisson's ratio, $J^{el} = \bar{\lambda}_1 \bar{\lambda}_2 \bar{\lambda}_3$ – volume , $\bar{\lambda}_i$ – extend relevant of the deviatoric parts, α_i – real exponents.

Notations in formula (1) has been adopted by monograph [1], used also the articles [2], [3]. Another alternative is to utilize material description LOW DENSITY FOAM, wherein the curve is given a description of the stress – strain separately for the compression and stretching. The studies also showed that the porous foam materials have a significant damping level. The calculation is made as a Rayleigh's model with the component of the damping matrix proportional to the inertia matrix. Impact simulation was performed with a body weight of 1000 kg (representing vehicle) moving at a speed of 11.1 m / s (40 km/h – maximum speed by the findings of the European Directive) to the impactor – the body of weight m=70kg (corresponding to the mass of human body). Model of the vehicle is equipped with a bumper made of hyperdeformable material elastic characteristics described by (1) and the attenuation by the Rayleigh's model. It was assumed that the bonds are one-sided - only compressive forces. The course forces during the impact until the rebound. In the case of a system without damping the maximum force is: 6130N. According to the findings of security organizations vehicles (e.g. EuroNCAP), the maximum force (leg) is about 8000N. The value obtained is therefore less than the limit. Is also specified allowable bending moment - 225N, the value is dependent on the value of the point of impact - bending moment is greater than the allowable. The material used in the pedestrian protection element has a high level of damping – confirmed this the hysteresis loop which was experimentally made. With regard to the level of damping of 0.25 dimensionless of impact simulation gave the force of 5694N. Damping affects a significant reduction in the speed with which the impactor is ejected after impact - it is approximately 18m/s. Example of force during the impact is shown at figure 3, speed at figure 4.

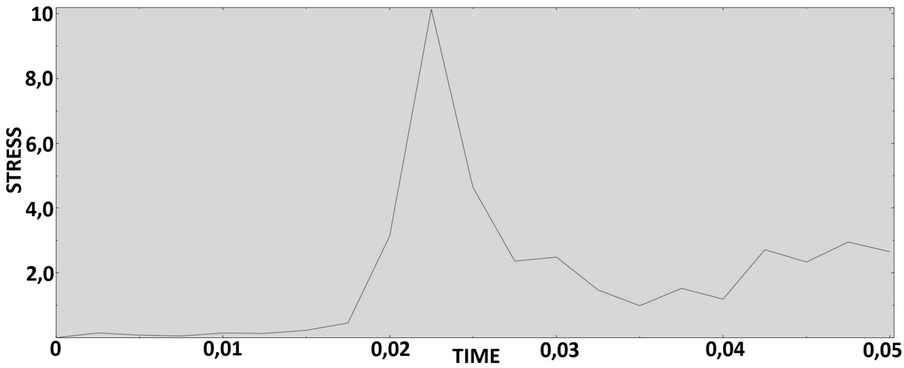

Fig. 3. Example of force during the impact [source: own study]

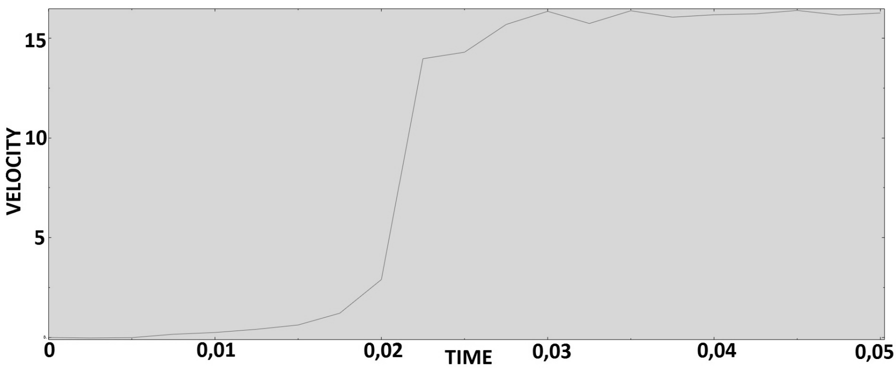

Fig. 4. Example of speed during the impact [source: own study]

4. CONCLUSIONS

The results of analyzes support the conclusion that testing methodology and simulation of reconstruction of the hysteresis loop allow to describe the properties of foam materials. Research has shown that during the trial the energy dissipation occurs through the foam material. Detailed research and analysis allow you to see what phenomena occur during compression tests. It is important to the analysis of contact problems occur at the interface between inside the surface of the material, including the gas occurring inside the structure (porous structure). Our research suggests the ability to integrate issues of engineering materials in the production of foam structures to the mechanics of materials and structural strength (evaluation of elastic and plastic properties in terms of high-speed deformation). Research and analysis allow you to see what phenomena occur during a collision in the applied material. Models foam structures take into account the phenomenon of energy dissipation. The nature of the phenomenon of energy dissipation varies with the speed of deformation. Models of materials, including modifications, can be used to assess the ability of absorbing energy and are proposed for use in describing a simulation performed using the program Abaqus. The work contributes to the development of the use of Finite Element Method to simulate the fast-changing loads - possibilities methods are not yet fully utilized. For the materials considered can determine the relationship between stress or deformations, which are dependent on properties of the material. Use of modified Ogden's model enables a description of the material and also increases the accuracy and effectiveness of the simulation conducted. For isotropic materials analyzed are considered arbitrary deformations of the body for large deformations and processes that take into account the thermal effects during manufacturing.

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Enterprise Search, Graph Knowledge, Semantic Web

Gianfranco E. MODONI[*], *Marco SACCO*[**], *Walter TERKAJ*[**]

A SEMANTIC FRAMEWORK FOR GRAPH-BASED ENTERPRISE SEARCH

Abstract

Various recent studies have shown that in many companies workers can spend near half of their time looking for information. Effective internal search tools could make their job more efficient. However, a killer application for this type of solutions is still not available. This paper introduces an envisioned architecture, which should represent the foundations of a new generation of tools for searching information within enterprises.

1. INTRODUCTION

Search engines are important productivity tools that allow users to retrieve desired information through a simple graphical interface, which embodies the one single entry point to search and explore anything related to a specific domain, i.e. within an organization. Companies of all sizes are trying to take advantage and benefit of the increased productivity the search engine technologies can provide. Following this trend, various approaches have emerged and one of the most popular is based on *Knowledge Graph* [1]. This term has been popularized thanks to Google Inc., who enhanced its web search engine results through a graph structure that understands real-world entities and their relationships, providing in this way detailed information about every examined topic in addition to a list of links to other related entities. Graph-based structure is also at the heart of social networks technologies like Facebook, whose semantic search engine, Facebook Graph Search [2], is designed to give answers to user in the form of natural language queries rather than a list of links. According to Spivack [3], such an approach marks the beginning of the third phase (Web 3.0) of the World Wide Web (Fig. 1), which is based on the idea that machines understand the meaning of the exchanged information and are able to make logical relations between them.

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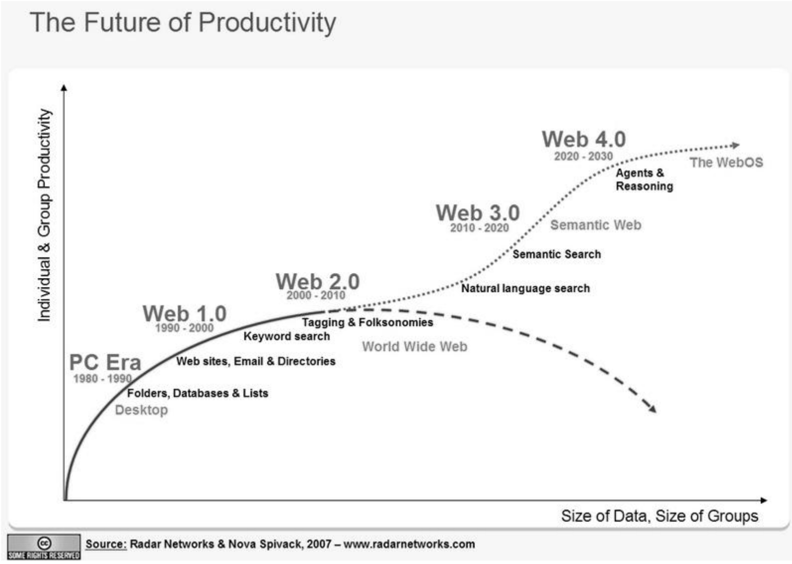

Fig. 1. The future of Productivity depending on the size of data [source: own study]

Whereas worth Internet search engines are now widely spread, valid enterprise searching tools are still a chimera; thus, the development of this type of applications remains a crucial issue to be faced. It is no coincidence that in many companies "nearly half of a knowledge worker's time is non-productive, spent gathering information, converting formats, unsuccessfully searching or recreating content that already exists" [4]. Moreover, as users are used to retrieve any information they need on the Internet through search, they expect the same behavior within an internal search tool.

Thus, more efforts have to be undertaken by researchers and developers to identify a new generation of internal tools to search, analyze and filter information within an organization [5]. The idea of the research work introduced in this paper goes in this direction, as it addresses the efforts to design the Knowledge Graph Semantic Framework (KGSF), a new interactive and explorative environment for the semantic search of the information within enterprises. Combining and adapting approaches and techniques borrowed from different fields, ranging from artificial intelligence to database management, this work assesses the role of *Knowledge Graph* paradigm to generate an integrated and aggregated view on relevant business knowledge that enhances search operations in real scenarios.

Business of the current enterprises are driven now more than ever by creation and utilization of huge information. Under these conditions, the main key factors for a worth search application are its capability to be integrated with the existing organization's infrastructure and to process large collections of heterogeneous near real-time data in order to convert them into valuable knowledge [6].

Thus, the design of KGSF has to take into account and consider this capability as a mandatory requirement for the development of the underlying architecture.

The remainder of the paper is structured as follows. Section 2 examines the recent technological trend for search engines, whereas Section 3 introduces and illustrates the proposed architecture on the basis of KGSF. Finally, Section 4 draws the conclusions, summarizing the major findings.

2. TOWARDS THE SEARCH ENGINE 3.0

Traditional technologies for search engines, based on keywords, are becoming less valid and effective as the Web increases in size (Fig. 1) [3]. Moreover, they provide a comfortable way for the user to specify information needs, but do not formally capture the explicit meaning of the user input queries [7]. Unlike these, a semantic search engine accesses to the semantics of the information and is oriented to understand the real dynamics between the entities, which represent specific concepts in a certain domain. The input is no longer a list of keywords, but a question, from which the engine will be able to extract the relevant concepts, disambiguate them if necessary and compose a set of queries to build the list of results.

The semantic search can play a crucial role to reduce the errors in the search results that are caused by polysemy (the capacity for a word to have multiple related meanings), synonymy (the capacity for a word to have the same or similar meaning of another word) and malformed queries. In fact, the paradigm shift triggered by Google Inc. towards the search of "things, not strings" [1] goes in the direction to disambiguate the input queries, aiming at understanding the difference between queries like "California" for the state of United States, "California" for the song and "California" for the sports car. This functionality allows the users to avoid wasting time looking through the possible results and also reduces the need to refine the queries. Using instead a syntactic search engine based on keywords, the results are less precise (i.e. many are not related) and incomplete (i.e. not all are relevant to the request).

Thanks to the underlying semantics, a Knowledge Graph approach also contextualizes user searches by creating logical links between the entered data; in this way, it provides the users a summary of key information about what it is looking for and a selection of in-depth details. In this regard, a significant example is represented by the above mentioned search of state "California" that can be defined by its connections to its governor, time zones, population, and so on.

In view of the advantages provided by the use of a semantic-based engine, such an approach has been exploited to design the herein presented KGSF, an interactive and explorative environment for the search of the information within enterprises. An overview of the KGSF architecture is presented in the next section.

3. THE KGSF ARCHITECTURE

The KGSF aims in the first instance at enhancing the semantic integration between the involved heterogeneous sources of data, which contributes in turn to improve the quality of search results. Compared to the state of the art, this solution is expected to provide improvements that can be summarized into four basic points:

- mashup and integration of the corporate knowledge for enabling search within structured data;
- accurate searches through the ability to disambiguate the user input queries;
- presentation of the key facts summaries related to what the end-user is looking for;
- explorative suggestions which allow users to navigate the search space while formulating their queries.

The envisioned architecture on the basis of the proposed KGSF consists of four pillars: (I) Common data model, (II) Backend, (III) Semantic Repository and (IV) Frontend (Fig. 2). This latter (Pillar IV) represents the one single graphical gateway for the search of the information within enterprises. It provides an integrated view on high-quality data derived through an automated analysis process managed by Backend (Pillar II), which plays the role of integrator, transforming and combining structured and unstructured legacy data into valuable information according to the Common data model (Pillar I). After this conversion process, the extracted information are also persisted and stored in the Semantic Repository (Pillar III). The pillars are discussed in details in the following subsections.

3.1. Common data model

In business contexts data come from several sources and can be expressed in a variety of forms. This makes it complex and tricky to find the right information, setting the stage for the first challenge to realize the KGSF: overcoming the problems deriving from the lack of integration between the involved heterogeneous sources of data, thus enhancing their semantic interoperability [8]. In this research work the definition of a common reference model, which embodies a representation of all the organization objects, is proposed as a solution to harmonize data from different sources, providing in this way a systematic manner to classify and integrate the knowledge of the organization. A common data model aggregates and unifies all the information, improving significantly the potential of a search application.

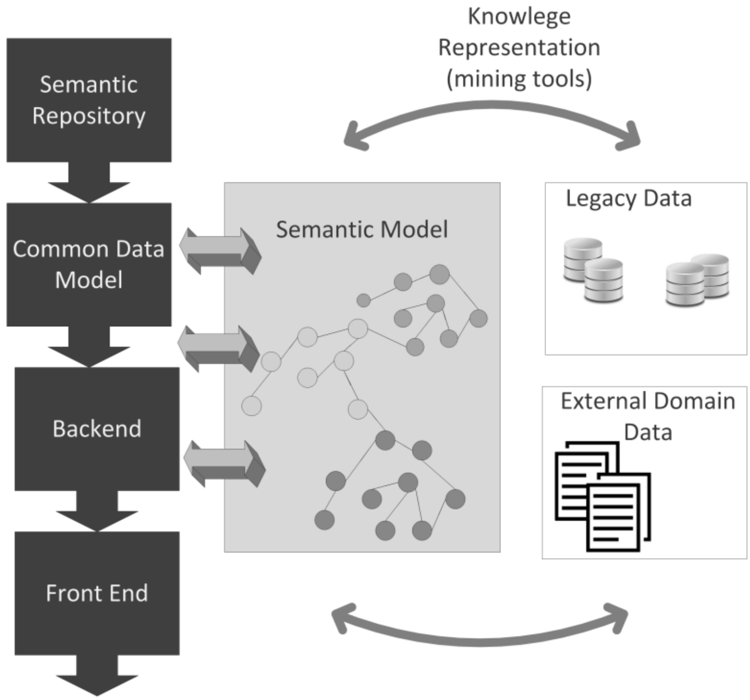

Fig. 2. THE KGSF pillars [source: own study]

Following the approach of recent researches within the factory domain (e.g. the project LinkedDesign [9], the project Virtual Factory Framework [10] and the related Virtual Factory Data Model [11], etc.), the reference model is represented through a set of ontologies by adopting the Semantic Web Technologies [12], which offers the possibility to represent formal semantics. Ontologies can be used in various ways to enhance the effectiveness of search engines. This topic has been deepened in the context of Information Retrieval, where for years researchers have experimented semantic indexing and knowledge representation tools such as thesauri and controlled vocabularies. In comparison to the latter, ontologies can lead to further benefits since they are richer and more formal. Firstly, ontologies allow to compose controlled queries and indexing vocabularies [13]. Secondly, they provide a rich axiomatization of the application domain and can be used to improve the accuracy of traditional search engines. Moreover, thanks to the expressiveness of the underlying semantic languages such as Resource Description Framework (RDF) [14] and Ontology Web Language (OWL) [15], the ontologies are expected to support properly the flexible and schema-less structure of the proposed graph-centric approach.

Finally, it is possible to re-use already existing tools to automatically infer and reason over the available data, thus deriving new knowledge about the concepts and their relationships, in addition to those already asserted and visualized in the graph.

3.2. Backend

Research in the field of information retrieval has traditionally focused more on refining information access rather than analyzing information to discover knowledge [16]. Information access aims at finding the right information for the right users at the right time with less attention on processing or transforming text data. This is the main goal of the data mining which in fact represents "the nontrivial process of identifying valid, novel, potentially useful, and ultimately understandable patterns in data" [17] through the application of specific algorithms for extracting hidden patterns (models) from data.
The overall process is interactive and involves various steps [18]:

- Understanding the domain.
- Collecting the raw data.
- Data pre-processing, which includes data cleaning in order to remove noise, and data transformation.
- Choosing the functions of data mining (clustering, prediction, classification, association, summarization, etc.) needed to be performed to derive the models.
- Storage of discovered knowledge for further reuse and integration in to the existing enterprise system.

In the KGSF the function of data mining is played by the Backend which has the goal to continuously process data streams, in order to extract and derive as much knowledge as possible through specific tools (Fig. 2), that combine and transform large amount of structured and unstructured legacy data [19] into semantic data that are then stored in the Semantic Repository. An information processing algorithm have to be implemented in order to extract large collections of candidate interrelated facts, that include a set of entities, their attributes, and their relations. Unfortunately, converting these candidate facts into useful knowledge represents an arduous challenge that requires to delve into research topics focusing on the problem of knowledge extraction from different sources, including named entity recognition, relation extraction and semantic role labeling.

3.3. Semantic Repository

The RDF is the standard model for data interchange on and off the Web and provides a general method to express data as lists of statements in the form of triples composed of subject-predicate-object. One of its strengths is that, in this format, any type of information can be virtually expressed. As the flip side, this expressivity implies the need to revise some classical data management problems, including efficient storage and query optimization. This is the reason why, as the request of semantic applications in real scenarios are continuously growing, the need to efficiently store and retrieve RDF data is getting more and more relevant [20]. This need has posed significant technological challenges for researchers and developers in terms of efficient and scalable semantic repositories. Several store solutions are currently available (e.g. Virtuoso, AllegroGraph, Stardog, etc.) and each of them may be more suitable in specific cases, depending on the requirements of the scenario.

Thus, a significant study during the plan of the KGSF regards the identification of a valid semantic repository capable to manage and reason on huge amount of Semantic data (also in the form of Big Data [21]) and capable to realize the analyses of intensive data in real-time. In fact this allows to collect and gather billions of real-time bytes of data on the organization resources, that are then processed instantaneously to optimize their utilization. A survey carried out by Modoni et al. [20] has shown how existing semantic repositories only partially support the mentioned capabilities in an effective way. These functionalities are particularly important in order to implement a scalable architecture and their lack represents a relevant technological gap to be addressed during the development of the KGSF.

3.4. Frontend

As thinking in terms of graphs opens new opportunities to allow users to visually navigate their data, another challenging aspect to be faced during the development of the KGSF consists in providing a usable Graphical User Interface (GUI) for exploring and editing the data in the knowledge graph in a natural and comfortable way. Its design, leveraged and driven by underlying ontology, has to be implemented to help users to formulate queries and express constraints for finding resources of the enterprise. The language SPARQL [22] can be used to compose structural queries on the semantic data. This approach may be feasible for experienced users, but are not practicable for users that are not familiar with Semantic Web technologies. To overcome this limitation, more intuitive ways of composing queries and showing results are needed.

A popular visualization of semantic data is based on the Big Fat Graph, which is useful for analyzing clouds of data, also evaluating their shape and density, but are not suitable for formulating flexible queries [23]. The approach on the basis of the KGSF Frontend exploits the technique of the Facets [24], which provides a specific classification of the information, allowing users to navigate a collection of information by applying multiple filters. In fact, a faceted system classifies each element along multiple explicit dimensions (facets), enabling the available items to be accessed in multiple ways rather than in a single and pre-determined order. Through the faceted GUI, the KGSF exposes both the implicit and the explicit interactions between graph entities, allowing knowledge path navigation and enabling the effective involvement of all the stakeholders across the enterprise value chain. Moreover, the proposed framework can provide explorative search suggestion helping users to create and develop new ideas and also discover serendipitous connections.

4. CONCLUSIONS

This paper has introduced a new interactive and explorative architecture for the search of the information within enterprises. Thanks to a semantic graph-based approach, the proposed solution is expected to offer several advantages regarding the quality of results and the usability to formulate the queries. However, the presented work is only a first step of a larger research agenda aiming at realizing a reference model of search engine, based on the Semantic Web technologies.

Future developments will address two main goals. First of all, the identification of a valid solution of repository is needed in order to store and handle large-scale of data processed by the KGSF. In this regard, an analysis of the performance of a set of the most widespread semantic repositories is currently under study, which will be followed by a proof of concept of the selected solution. The second goal will regard the choice of an appropriate data mining algorithm, which aims at extracting hidden knowledge from various sources of data. As many data mining algorithms have been proposed in literature, a survey of these will be conducted in order to select the most appropriate for the implementation of KGSF.

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heat transfer, technical storages, physical modeling, control process

Marian Marek JANCZAREK[*]

ANALYSES OF HEAT TRANSFER THROUGH WALLS OF THERMAL TECHNICAL SPACES WITH COMPUTER HELPING

Abstract

The paper describes research work on methods concerning heat transfers through walls of thermal technical chambers. This paper is focused on the new concept of thermal analysis derived from harmonic character of temperature changes in building environment with aspect on conductive heat transfers through walls.. The paper presents exemplary measurement results taken in Lublin region during various periods throughout a year. The purpose for the research is to point out areas subjected to the highest energy losses caused by building's construction and geographical orientation of walls in the aspect of daily atmospheric temperature changes emerging on chamber exterior.

1. INTRODUCTION

Conduction take place when a temperature gradient exists in a solid (or stationary fluid) medium. Energy is transferred from the more energetic to the less energetic molecules when neighboring molecules collide. Conductive heat flow occur in the direction of decreasing temperature because higher temperature is associated with higher molecular energy. The equation used to express heat transfer by conduction is known as Fourier's Law. The article presents the physical model of heat transfer through chamber walls by means of a mathematical model suitable for sine waveform of internal temperature changes.

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2. MODELS OF HEAT TRANSFER THROUGH WALL

The purpose of this paper is to describe the design of control systems of cooling and air conditioning systems in storage spaces. For a control systems its necessary to use only three elements: sensor, controller and controlled device. The main of those elements is temperature sensor which shows the picture of thermal decomposition in cold store. The very important are also devices, which provide control of humidity and cyclic potential motion of air in space. It must be noted, that all the control actions depend mainly on measurement of a controlled variable. It is, therefore, necessary to analyze very carefully what is actually being measured, how it may vary with time and which degree of accuracy is necessary in the measurement. Mostly, the temperature of the surfaces on which the sensors are mounted is different from the air temperature. Observations of the ambient air temperature in Lublin are showing that the variations of the temperature from the heat by day to the cold by night and yearly changes from the cold of winter to the heat of summer may vary harmonically – figures 1-4. These variations of external temperature have influence upon the internal temperature, which depending upon the conductive heat transfer through walls of thermal technical spaces. By the suitable construction of the enclosure walls composed of several slabs of different thickness and conductivities we can obtain phase angle displacement (when the time lag attains twelve hours it is the best situation), which reduce the amplitude of internal temperature inside buildings.

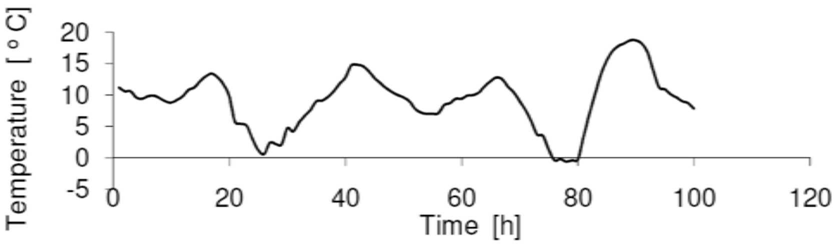

Fig.1. Diagram of atmospherics temperature in the four days of April [source: own study]

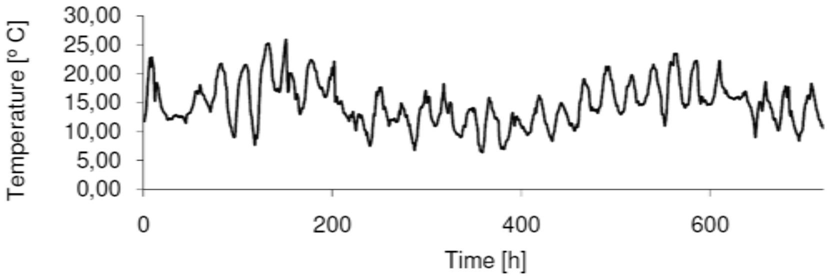

Fig. 2. Diagram of atmospherics temperature in the month of June [source: own study]

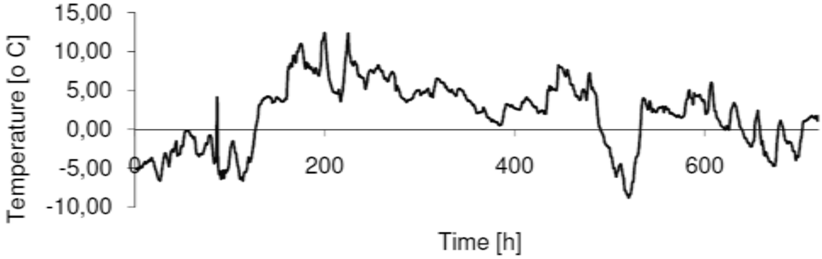

Fig. 3. Diagram of atmospherics temperature in the month of December [source: own study]

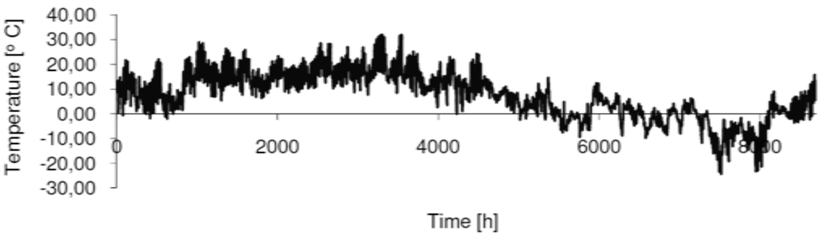

Fig. 4. Diagram of atmospherics temperature of the year in Lublin [source: own study]

The analysis has been performed on the basis of original numerical algorithms. They take into consideration hourly changes of ambient temperature in the central – eastern region of Poland. The accepted methodology of performance takes advantage of temperature dynamics which is necessary to solve physical and mathematical problems related to heat transfer processes occurring in chambers.

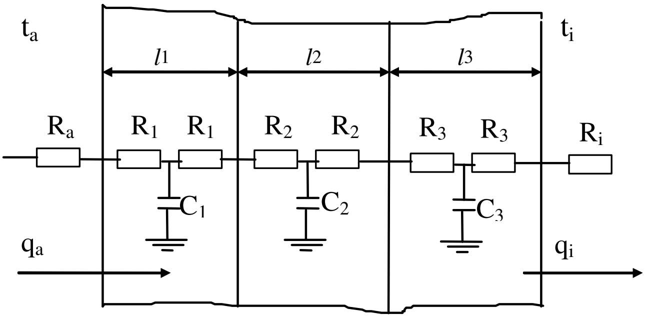

Fig. 5. Model of wall composed of three layers in electrical analogy [source: own study]

From it we can get matrix notation (eventually for n – layers of wall) and the final result of this calculation is a pair of linear relations between the temperature and fluxes at the two surfaces of the composite slabs.

$$[\Delta t_i(p), \Delta q_i(p)] =$$

$$[\Delta t_a(p); \Delta q_a(p)] \begin{bmatrix} 1 & 0 \\ -R_1 & 1 \end{bmatrix} \begin{bmatrix} 1 & -pC_1 \\ 0 & 1 \end{bmatrix} \cdots \begin{bmatrix} 1 & -pC_n \\ 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} 1 & 0 \\ -R_{n+1} & 1 \end{bmatrix} \quad (1)$$

The relation is precisely analogous to Ohm's law for the steady flow of electric current: the flux corresponds to the electric current and the drop of temperature to the drop of potential. Thus R may be called the thermal resistance of the slab (Figure 5). Next suppose we have a composite wall composed of n slabs of different thickness and conductivities. If the slabs are in perfect thermal contact mat their surfaces of separation, the fall of temperature over the whole wall will be the sum of the falls over the component slabs and since the flux is the same at every point, this sum is evidently.

This is equivalent to the statement that the thermal resistance of a composite wall is the sum of the thermal resistance's of the separate layers, assuming perfect thermal contact between them. Finally, consider a composite wall as before, but with contact resistances between the layers such that the flux of heat between the surfaces of consecutive layers is H times the temperature difference between these surfaces. The differential equation to be solved is Fourier's equation. These models we can confront with computer program Modelica, which allow to construct the walls of technical chambers. The diagram of the process of heat transfer through the wall under the program Modelica is shown in Figures 6 and 7.

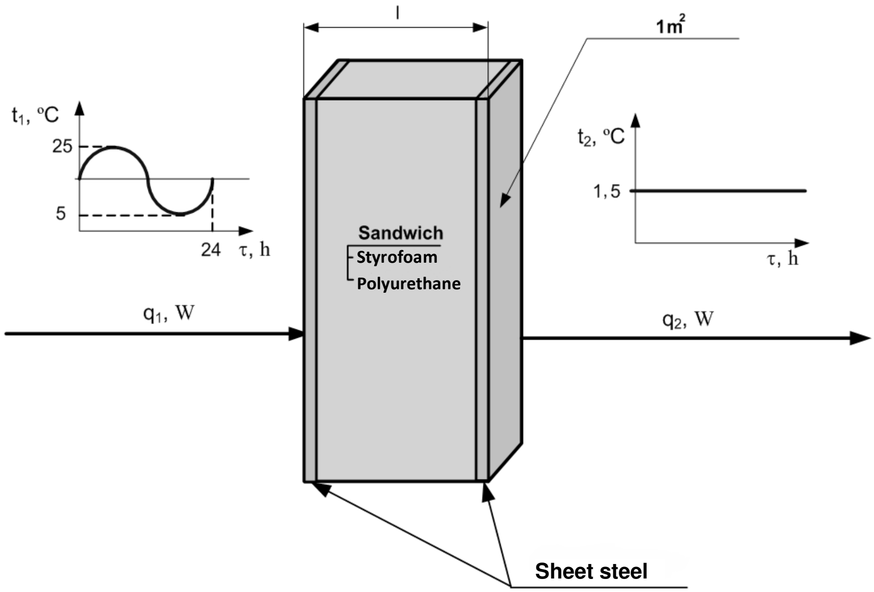

Fig. 6. Ideal model of wall [source: own study]

Below shows a universal electric scheme uses an analogy to Ohm's law for three layers wall.

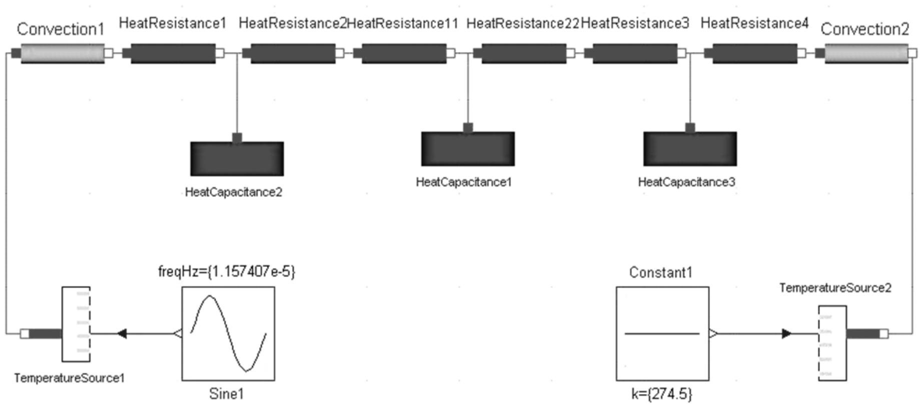

Fig. 7. Block schema using electrical analogue [source: own study]

By this modeling, we can simulate any temperature regime and heat flow both inside and outside of the chamber, for example in Figure 8 we can see periodically temperature signal on the outside surface of the wall. In Figure 9 we can obtain suppressed the course of the internal temperature.

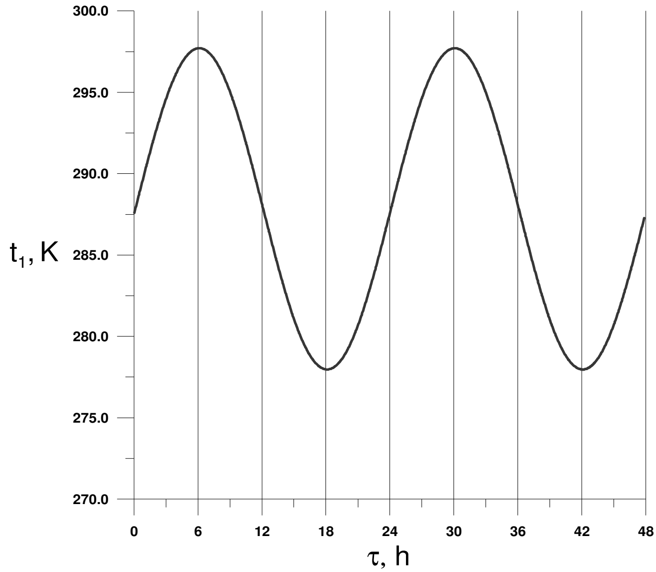

Fig. 8. Periodically temperature signal on the wall – t_1 [source: own study]

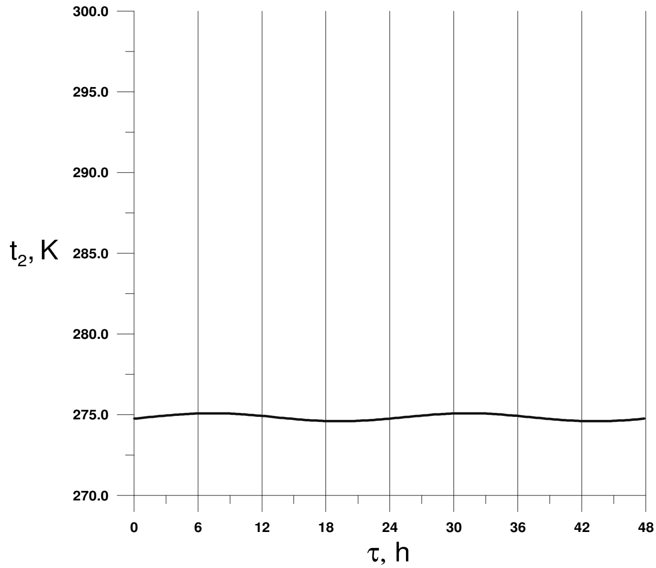

Fig. 9. Periodically temperature signal on the wall – t_2 [source: own study]

Below shows a universal electric scheme uses an analogy to Ohm's law for three layers wall.

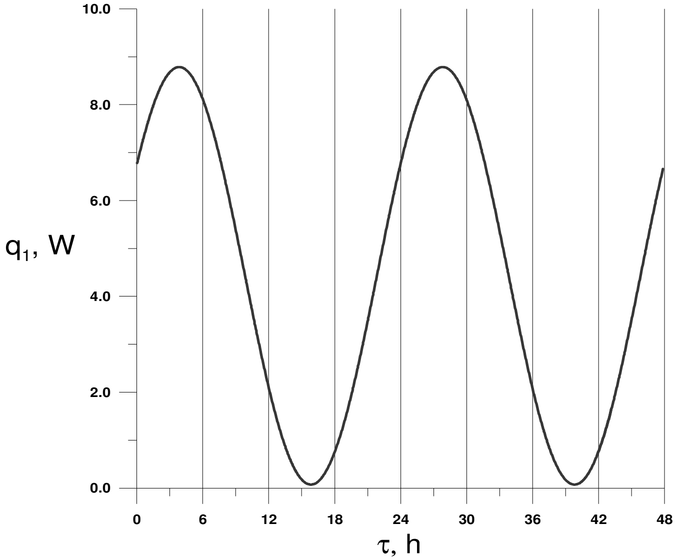

Fig. 10. Periodically heat flux flow signal on the wall – q_1 [source: own study]

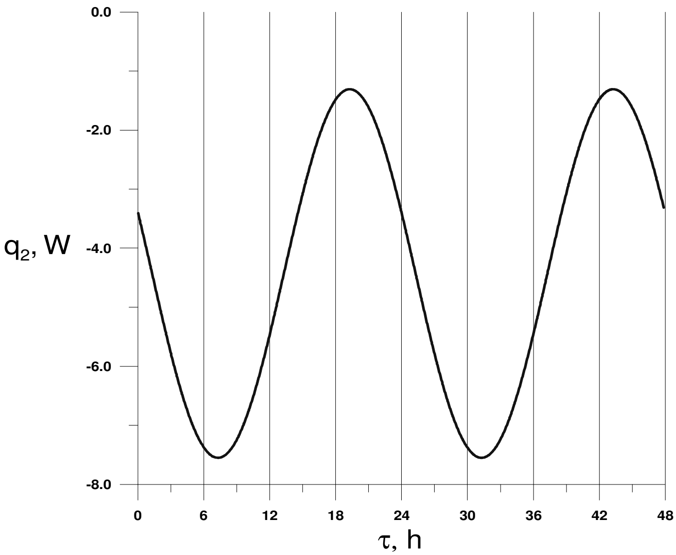

Fig. 11. Periodically thermal flow signal on the wall – q_2 [source: own study]

Analogous of the temperature process we can get the course of the heat flux (Figure 10 and 11) on the both surfaces of the wall.

3. CONCLUSION

The paper describes atmospheric temperature analysis and their variability in time in aspect of their influence upon the thermal technical chambers with the with the help of computer program Modelica. This analysis shows the periodic variability of outside temperature, changing in periods of each day and also in the year with maximum value in the afternoon or in summer and minimum value in the night or winter time. The influence of this periodically changing temperature on the inside storages climate is depending on thermal inertia of technical spaces. It is also show the periodically thermal flow signal on the wall and its influence to the inside of object. The proper construction of an object with prescribed thermo-stability characteristic can use the phase difference between internal and external temperature and allow to lower costs of energy, necessary for cooling or heating the technical spaces. By the suitable construction of the enclosure walls composed of several slabs of different thicknesses and conductivities, we can obtain phase shift, which reduce the amplitude of internal temperature inside technical chamber and in consequence, give equivalent of using energy. The influence of this periodically changing weather temperature upon the inside storages climate is depending on the material of walls and inertial property of thermal technical spaces.

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