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Address
ul. Jana Heweliusza 14
10-718 Olsztyn-Kortowo, Poland
tel.: +48 89 523 36 61
fax: +48 89 523 34 38
e-mail: wydawca@uwm.edu.pl

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CORRELATIONS BETWEEN BASIC PHYSICAL PARAMETERS OF NUTS AND THE WEIGHT OF COMMON BEECH (*FAGUS SYLVATICA* L.) SEEDS

***Zdzisław Kaliniewicz*[1], *Paweł Tylek*[2], *Andrzej Anders*[1], *Piotr Markowski*[1], *Tadeusz Rawa*[1], *Kamil Andros*[1]**

[1] Department of Heavy Duty Machines and Research Methodology, University of Warmia and Mazury in Olsztyn
[2] Department of Forest Work Mechanization, University of Agriculture in Kraków

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Key words: nuts, seeds, physical properties, variation, correlation.

Abstract

Selected physical attributes of common beech nuts harvested from four tree stands in northern Poland were determined. Seeds were manually extracted from every nut. Seeds and nuts were weighed, and the results were used to determine the ratio of seed weight to nut weight, which described the degree of nut filling. Physical parameters and the calculated coefficients were compared by the t-test for independent samples, analysis of variance, correlation analysis and linear regression analysis. The following ranges of variation were reported in the physical attributes of nuts and the coefficients of common beech seeds: critical transport velocity of nuts – from 6.33 to 11.28 m s^{-1}, nut thickness – from 4.76 to 9.86 mm, nut width – from 6.46 to 13.54 mm, nut length – from 12.63 to 21.62 mm, angle of sliding friction of nuts – from 15.67 to 26.67°, nut weight – from 93.0 to 513.7 mg, coefficient of sliding friction of nuts – from 0.28 to 0.50, seed weight – from 11.0 to 374.8 mg, and ratio of seed weight to nut weight – from 0.08 to 0.88. The majority of nuts contained one seed (average weight of 195.36 mg), and only 2.3% of nuts contained two seeds (average weight of 103.11 mg). The attribute that was most highly correlated with the ratio of seed weight to nut weight was seed weight (0.685), followed by critical transport velocity (0.527) and weight of nuts (0.493). The results indicate that common beech seeds would be processed most effectively in vibration-pneumatic separators or, alternatively, in pneumatic separators where nut fractions obtained with the use of mesh screens can be sorted separately.

Symbols:
k_m – ratio of seed weight to nut weight,
m – nut weight, mg,
m_s – seed weight, mg,
SD – standard deviation of trait,
T, W, L – nut thickness, width and length, mm,

Correspondence: Zdzisław Kaliniewicz, Katedra Maszyn Roboczych i Metodologii Badań, Uniwersytet Warmińsko-Mazurski, ul. Oczapowskiego 11/B112, 10-719 Olsztyn, phone: +48 89 5233934, e-mail: zdzislaw.kaliniewicz@uwm.edu.pl

v – critical transport velocity of nuts, m s^{-1},
V_s – coefficient of trait variation, %,
x – average value of trait,
$x_{\max}$, $x_{\min}$ – maximum and minimum value of trait,
γ – angle of static friction on steel,
μ – coefficient of static friction on steel.

Introduction

The common beech (*Fagus sylvatica* L.) is a deciduous tree that reaches up to 45 m in height and 2.2 m in diameter at breast height (SUSZKA et al. 2000). The species thrives in a temperate marine climate, and its geographic range covers all of Central and Western Europe (DITTMAR et al. 2003, OHEIMB et al. 2005, BOLTE et al. 2007, MAGRI 2008, JAWORSKI 2011, BRUS et al. 2012). The common beech is a shade tolerant species with a preference for habitats characterized by high humidity and high soil moisture levels, but it avoids excessively wet and dry soils. In most Polish habitats, the common beech is a predominant tree species or it is encountered in mixed-tree stands (JAWORSKI 2011).

The common beech is a relatively slow-growing species that begins to produce seeds (nuts) at the age of 60–80 years in dense stands or 40–50 years in open stands. The fruit are small triangular nuts covered by a brown, relatively thin and flexible coat. Most nuts contain one, sometimes two seeds with an outer seed coat (SUSZKA et al. 2000, JAWORSKI 2011). Nuts mature in September and October. They are produced at irregular intervals, generally every 5–10 years (SUSZKA et al. 2000, DITTMAR et al. 2003, HILTON, PACKHAM 2003, ÖVERGAARD et al. 2007). This reproduction strategy prevents an excessive increase in populations of animals that feed on beech nuts, and it increases the number of seeds that are stored by animals in various locations (RUSCOE et al. 2005, BOGDZIEWICZ, WRÓBEL 2012). In a good year, approximately four tons of beech nuts can be harvested per hectare, and nuts are produced by trees as old as 200 years (SUSZKA et al. 2000, DITTMAR et al. 2003, HILTON, PACKHAM 2003, ÖVERGAARD et al. 2007). Nut yield is correlated with nut vitality, and the greater the yield, the higher the quality of the resulting seed material (BODYŁ, SUŁKOWSKA 2007).

Trees of the same species can produce variously-sized seeds. Both large and small seeds play an important role in the preservation of genetic diversity (FALLERI, PACELLA 1997). TYLEK (2010) reported a significant correlation between the weight and germination capacity of nuts, which can be attributed to a high percentage of heavy and well-developed nuts. Therefore, it can be presumed that the germination energy and germination capacity of common beech nuts is determined by the ratio of seed weight to nut weight.

The objective of this study was to determine correlations between the physical parameters of common beech nuts and the ratio of seed weight to nut weight for the needs of seed separation processes.

Materials and Methods

The experimental material comprised four batches of common beech nuts from a seed extraction plant in Jedwabno. Nuts were harvested in 2011 from variously-aged tree stands in two forest regions of northern Poland. The analyzed batches were harvested from the following tree stands:

a) registration No. MP/1/10732/05, category of seed propagation material – from an identified source, region of origin – 251, municipality – Biskupiec, geographic location – 53.56°N, 20.59°E, forest habitat – fresh forest, age – 114 years (symbol: B-1),

b) registration No. MP/1/2590/05, category of seed propagation material – from an identified source, region of origin – 157, municipality – Prabuty, geographic location – 53.50°N, 19.11°E, forest habitat – fresh mixed forest, age – 125 years (symbol: B-2),

c) registration No. MP/2/31347/05, category of seed propagation material – qualified, region of origin – 103, municipality – Godkowo, geographic location – 54.06°N, 19.54°E, forest habitat – fresh forest, age – 134 years (symbol: B-3),

d) registration No. MP/1/43654/05, category of seed propagation material – from an identified source, region of origin – 106, municipality – Grunwald, geographic location – 53.37°N, 20.07°E, forest habitat – fresh mixed forest, age – 145 years (symbol: B-4).

Nut batches were divided by halving (*Nasiennictwo leśnych drzew*... 1995). The analyzed batches were halved, and one half was randomly selected for successive halving. The above procedure was repeated to produce samples of around 100 nuts each. The resulting nut samples had the following size: B-1 – 118, B-2 – 120, B-3 – 116, B-4 – 115.

Critical transport velocity of common beech seeds was determined in the Petkus K-293 pneumatic classifier (VEB PETKUS Wutha/Thur, Germany). Seed dimensions were determined with the use of the MWM 2325 workshop microscope (PZO Warszawa, Poland) (length and width) and a thickness gauge. The angle of sliding friction was measured on a horizontal plane with an adjustable angle of inclination equipped with a steel friction plate (GPS – $R_a =$ $= 0.42$ μm). The angle of sliding friction was determined as the average angle produced by three nut arrangement patterns: with the longitudinal axis perpendicular and parallel to the direction of inclination, and with the tip directed towards the top and the bottom of the friction plane. Nut weight was determined on the WAA 100/C/2 laboratory scale (RADWAG Radom, Polska). Seeds were extracted manually from nuts and weighed on the above laboratory scale. All measurements were performed according to the methods previously described by KALINIEWICZ et al. (2011) and KALINIEWICZ and POZNAŃSKI (2013).

The coefficient of sliding friction was determined for every nut based on the following equation:

$$\mu = \tan\gamma \tag{1}$$

The ratio of seed weight to nut weight was calculated with the use of the below formula:

$$k_m = \frac{m_s}{m} \tag{2}$$

Nuts were divided into two groups based on the ratio of seed weight to nut weight: poorly filled nuts (k_m<0.6) and well-filled nuts (k_m≥0.6).

The results were processed with the use of Statistica PL v. 10 application based on general statistical procedures, including t-test for independent samples, one-way ANOVA, correlation analysis and linear regression analysis (RABIEJ 2012). Statistical calculations were performed at the significance level of 0.05.

Results and Discussion

The lowest average values of critical transport velocity, nut thickness, nut width and nut weight were noted in batch B-3 (Table 1). B-3 nuts were least plump, and they were also characterized by the highest average angle of sliding friction. The thickest and the widest nuts were reported in batch B-4, the longest nuts – in batch B-2, and the heaviest nuts – in batch B-1. In a comparison of physical parameters (Table 1), significant differences between batches were noted only in the values of the angle of sliding friction. The remaining attributes differed only locally, and the most pronounced differences were noted in nut length.

The statistical distribution of the physical attributes of all four nut batches and the calculated coefficients is given in Table 2. Critical transport velocity ranged from 6.33 to 11.28 m s^{-1}, and its average value was similar to that noted by KALINIEWICZ et al. (2014) and around 7% lower than that reported by TYLEK (2011). The analyzed nuts were classified as plump based on their average dimensions and weight. They were approximately 25% heavier, 5% longer and 7% wider than the nuts harvested from 120-year-old trees in Młynary (region

Table 1

Variations in the physical attributes of beech nuts with an indication of significant differences

Physical attribute	Nut batch			
	B-1 x±SD	B-2 x±SD	B-3 x±SD	B-4 x±SD
v	9.40±0.99^{a}	9.33±0.87^{ab}	9.09±1.08^{b}	9.17±0.89^{ab}
T	7.32±0.91^{ab}	7.28±0.80^{b}	7.19±0.70^{b}	7.53±0.94^{a}
W	9.67±0.94^{ab}	9.61±0.90^{b}	9.16±1.10^{c}	9.88±0.90^{a}
L	16.75±1.54^{b}	17.17±1.56^{a}	16.99±1.50^{ab}	16.70±1.47^{b}
γ	21.64±0.95^{b}	20.47±1.52^{d}	22.05±2.15^{a}	21.19±1.15^{c}
m	306.23±76.53^{a}	299.82±65.24^{a}	276.03±64.65^{b}	292.80±62.87^{ab}

$^{a, b, c, d}$ – different letters denote significant differences in the evaluated attribute between batches.

of origin – 103) and evaluated by BODYŁ and SUŁKOWSKA (2007). No significant differences were reported between the analyzed nuts and the material examined by TYLEK (2010) and KALINIEWICZ et al. (2014). The length and width of beech nuts were similar to those determined in the seeds of *Cucurbita moschata* Duch. (JACOBO-VALENZUELA et al. 2011). The average length of beech nuts was comparable to that of pumpkin seeds (JOSHI et al. 1993) and kidney beans (ALTUNTAS, DEMIRTOLA 2007).

Table 2

Statistical distribution of physical attributes and coefficients

Physical attribute/ coefficient	x_{min}	x_{max}	x	SD	V_s
v	6.33	11.28	9.25	0.97	10.47
T	4.76	9.86	7.32	0.84	11.42
W	6.46	13.54	9.58	0.99	10.29
L	12.63	21.62	16.91	1.53	9.03
γ	15.67	26.67	21.34	1.62	7.58
m	93.0	513.7	293.80	68.18	23.20
μ	0.28	0.50	0.39	0.03	8.38
m_s	11.0	374.8	195.44	55.38	28.33
k_m	0.08	0.88	0.66	0.08	12.17

The angle of sliding friction of a steel friction plate ranged from 0.28 to 0.50, with an average of 0.39. The average value was approximately 24% lower than that reported by TYLEK (2006, 2010) and approximately 11% lower than that presented by KALINIEWICZ et al. (2014). The above differences can be probably attributed to variations in the porosity of friction plates. KALINIEWICZ et al. (2014) used a steel plate with the porosity of R_a = 0.48 μm, whereas in this study, plate porosity was R_a = 0.42 μm. The average coefficient of sliding friction of the analyzed beech nuts resembled that noted on a similar friction plate for pumpkin seeds (JOSHI et al. 1993), ackee seeds (OMOBUWAJO et al.

2000), chick peas (KONAK et al. 2002), lentils (AMIN et al. 2004), fenugreek seeds (ALTUNTAŞ et al. 2005), okra seeds (ÇALIŞIR et al. 2005) and psyllium seeds (AHMADI et al. 2012).

Approximately 2.3% of the analyzed nuts contained two seeds. The significance of differences in physical attributes between nuts containing one and two seeds is presented in Table 3. Nuts with two seeds were characterized by somewhat higher weight and higher critical transport velocity than nuts containing one seed, but no significant differences were observed between those two groups of nuts. Differences were reported in the weight of seeds from both types of nuts, and they can be attributed to the availability of free space inside nuts containing one and two seeds. Despite somewhat higher average combined weight of seeds in dual-seed nuts (206.22 mg) than in single-seed nuts (195.18 mg), no significant differences were observed between those groups. Nuts containing two seeds cannot be separated from the analyzed material with the use of conventional separators. The above poses a disadvantage for tree nurseries because a dual-seed nut can give rise to two weaker seedlings, one of which will have to be removed with time.

Table 3

Significance of differences in physical attributes between two types of nuts

Physical attribute/ coefficient	Nuts	
	with one seed x±SD	with two seeds x±SD
v	9.24±0.96^a	9.53±1.15^a
T	7.32±0.84^a	7.32±0.84^a
W	9.57±0.99^a	9.88±1.01^a
L	16.92±1.53^a	16.66±1.45^a
γ	21.33±1.62^a	21.79±1.48^a
m	293.58±68.56^a	303.17±51.27^a
μ	0.39±0.03^a	0.40±0.04^a
m_s	195.18±55.74^a	103.11±26.74^b
k_m	0.66±0.08^a	0.68±0.04^a

$^{a,\,b}$ – different letters denote significant differences in the evaluated attribute between nuts with one and two seeds.

The analyzed material comprised 10.1% poorly filled nuts (k_m<0.6) and 89.9% well-filled nuts (k_m≥0.6). An analysis of linear correlations between the physical attributes of nuts and the ratio of seed weight to nut weight (Table 4) revealed that angle of sliding friction and coefficient of sliding friction were least correlated with the remaining parameters. The above results validate the observation made by TYLEK (2006) that the frictional properties of common beech nuts cannot be regarded as the major separating criterion in the process of improving nut germination capacity and separating plump nuts. Significant correlations were noted between thickness and width and between weight and critical transport velocity vs. dimensions of beech nuts. The above results corroborate the findings of TYLEK (2010) and KALINIEWICZ et al. (2014). Nut weight was most highly correlated with seed weight (0.963). Significantly high (above 0.5) and comparable values of the correlation coefficient were noted between seed weight vs. the critical transport velocity of nuts, nut thickness and nut width. As expected, seed weight was most highly correlated with the ratio of seed weight to nut weight (0.685). Critical transport velocity of nuts was also strongly correlated with the ratio of seed weight to nut weight (0.527). The above results corroborate the observation made by TYLEK (2011) that critical transport velocity should not be used as a separation criterion in beech seeds. Nut dimensions (excluding, to a limited degree, nut width) did not influence the ratio of seed weight to nut weight, therefore, screen separators should be only used to calibrate seeds, which increases the efficiency of other separation processes, in particular pneumatic separation (*Nasiennictwo leśnych drzew...* 1995, TYLEK 2010). In view of very strong correlations between the ratio of seed weight to nut weight vs. nut weight and critical transport velocity, the use of vibration-pneumatic separators, which sort seeds based on differences in their density and critical transport velocity, could significantly improve the separation efficiency of common beech nuts (GROCHOWICZ 1994).

Table 4

Coefficients of linear correlation between the physical attributes of beech nuts

Physical attribute	T	W	L	γ	m	μ	m_s	k_m
v	**0.099**	**0.162**	-0.003	**-0.154**	**0.465**	**-0.157**	**0.527**	**0.527**
T	1	**0.531**	**0.315**	**-0.145**	**0.624**	**-0.147**	**0.527**	0.049
W		1	**0.337**	-0.033	**0.635**	-0.034	**0.562**	**0.118**
L			1	-0.055	**0.520**	-0.055	**0.423**	-0.017
γ				1	**-0.149**	**0.999**	**-0.157**	**-0.159**
m					1	**-0.151**	**0.963**	**0.493**
μ						1	**-0.159**	**-0.162**
m_s							1	**0.685**

Values in bold indicate that the correlation coefficient has exceeded the critical value.

Significant correlations between the ratio of seed weight to nut weight vs. the critical transport velocity and weight of beech nuts are presented in Figure 1. In regression equations, the coefficient of determination reached 0.278 in the first comparison and 0.244 in the second comparison. The noted results are satisfactory for biological materials and in view of the number of analyzed measurements. The presented equations can be used to plan separation processes and calibrate sorting devices. The separating threshold of a pneumatic separator should be theoretically set at approximately 8.1 m s^{-1} to obtain well-filled nuts (k_m≥0.6), whereas separators with a weight detection option should support the separation of nuts weighing up to 200 mg. A certain number of well-filled nuts would be removed from the separated material, which implies that a certain percentage of poorly filled nuts would remain in the material (around 7% of well-filled nuts and 45% of weakly-filled nuts, if a pneumatic separator is used).

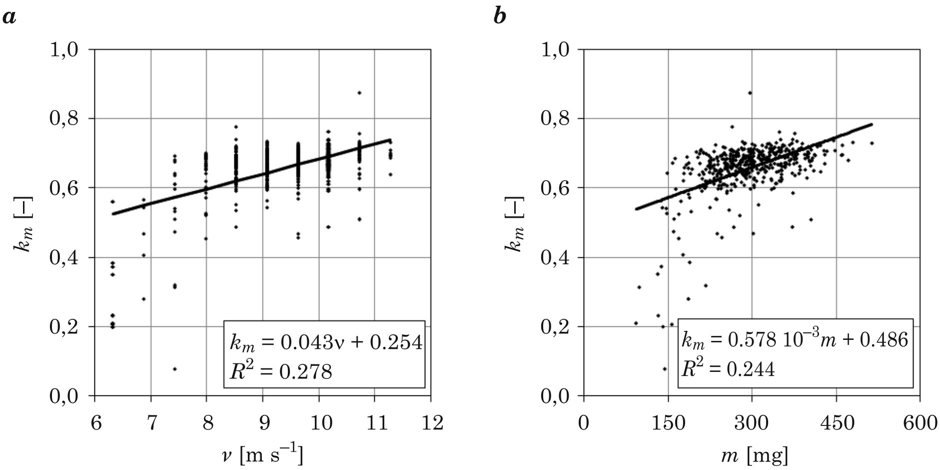

Fig. 1. Correlations between the ratio of seed weight to nut weight vs. the critical transport velocity (*a*) and weight of beech nuts (*b*)

Conclusions

1. Common beech nuts contain one or two seeds. Nuts with two seeds (around 2.3% of the analyzed nuts) were somewhat heavier and wider, but they did not differ significantly from the remaining nuts, therefore, they could not be separated with the use of conventional seed separators. In nuts containing two seeds, the average weight of each seed was nearly half that of seeds from nuts containing a single seed.

2. The weight of common beech seeds was most highly correlated with the weight of nuts (correlation coefficient of 0.963). In the group of the remaining physical attributes, seed weight was most highly correlated with nut width (0.562) and least correlated with the angle of sliding friction of nuts (-0.157).

3. Common beech nuts could be effectively separated with the use of vibration-pneumatic separators due to strong correlations between the ratio of seed weight to nut weight vs. the critical transport velocity and weight of nuts. Pneumatic separators can also be applied, and the use of screen separators for preliminary sorting could be considered.

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MARKETING SYSTEM OF CONSTRUCTION PRODUCTS IN POLAND AFTER THE ENTRY INTO FORCE REGULATION (EU) No 305/2011

Jolanta Harasymiuk

Department of Engineering Materials and Building Processes
University of Warmia and Mazury in Olsztyn

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Key words: Regulation (EU) No 305/2011, marketing system of construction products.

Abstract

System of marketing of construction products in Poland is a complex system that allows to control the initial facilitation of construction materials process on the market. The system is complex from the structural and internal relations points of view what still cause numerous issues among building material producers. The manufacturers' position has been much more complicated by the Regulation (EU) No 305/2011 of The European Parliament and of The Council that has taken effect in Poland since the 1st of July 2013 and constitutes harmonised conditions for introducing such products to trading. It is a legal act of higher rank than the overridden with its resolutions directive 89/106/EEC concerning construction products. Its regulations must be applied in each EU country identically. The EU regulation forced significant changes in the European system of marketing of construction products and further on to a domestic market in order to ensure its consistency with European solutions.

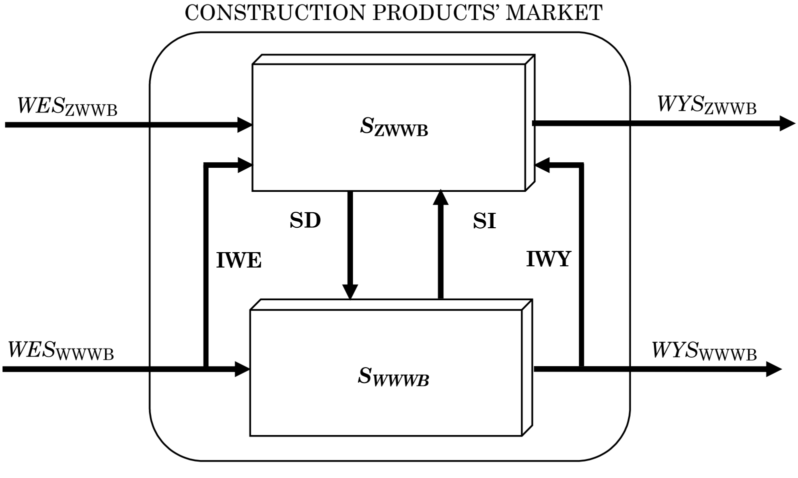
The purpose of this article is to present general model of the system and chosen algorisms of manufacturers that introduce new construction products with CE marking to the market according to the Regulation (EU) No 305/2011.

General model of the system of marketing of construction products

Analysed system can be categorised among the real-life systems, acting, with the intended actions. It consists of two compositional sub-systems – S_{ZWWB} and S_{WWWB}, and each of them can be considered as a complex system. Scheme of a general model of the system is presented on the Figure 1.

Correspondence: Jolanta Harasymiuk, Zakład Inżynierii Materiałów i Procesów Budowlanych, Uniwersytet Warmińsko-Mazurski, ul. J. Heweliusza 4, 10-724 Olsztyn, phone: 48 89 523 47 27, e-mail: jolanta.harasymiuk@uwm.edu.pl

S_{ZWWB} sub-system in the relation with the S_{WWWB} system executes management functions within: planning, organizing, controlling, assessment and the conditions for introduction building material to trading. The structure of S_{ZWWB} sub-system is based on elements and relations (functional, technical and informational) among them. Structural elements of S_{ZWWB} subjects with the financial means, realising its functions and managing tasks. Key subjects of S_{ZWWB} sub-system are: Ministry of Infrastructure and Development, Technical Assessment Body (TAB), bodies mentioned in the Regulation (EU) No 305/2011, Polish Centre for Accreditation (PCA), certification, inspection and testing bodies accredited to work within the domestic system of conformity attestation, legal branches licensed to controlling and conducting administrative dealing within the field of introduction construction products to the market.



Denotations:
S_{ZWWB} – management system of marketing of construction products,
S_{WWWB} – the system managed in the aspect of marketing of construction products,
SD – decisive couplings within the planning, organizing, managing, controlling and upgrading the system of introducing construction products to the market,
SI – informative couplings within the assessment of effectiveness of S_{ZWWB}, entrance into the S_{ZWWB},
$\mathrm{WES}_{\mathrm{ZWWB}}$ – entrance into the S_{ZWWB},
$\mathrm{WYS}_{\mathrm{ZWWB}}$ – exit from the S_{ZWWB},
$\mathrm{WES}_{\mathrm{WWWB}}$ – entrance into the S_{WWWB},
$\mathrm{WYS}_{\mathrm{WWWB}}$ – exit from the S_{WWWB},
IWE – information about the entrance's into the S_{ZWWB} quality,
IWY – information about the exit's from the S_{ZWWB} quality.

Fig. 1. General model of system of marketing of construction products in Poland
Source: The author's own study

Regulation No 305/2011 (Regulation of the European Parliament and of the Council (EU) No 305/2011...) imposed a duty on emerging new subjects in the current sub-systems that manage the introduction of new construction products to the market – Technical Assessment Bodies (TABs). They can include research institutions – accredited for independent opinions, considering the validity of European Technical Assessment (ETA) for construction products[1] (in the past, when the directive 89/106/EWG (Council Directive 89/106/EEC...) was in force there was an EC acceptance required), and compiling European Assessment Documents (EAD) as a basis for ETA acceptance. As a result of such broad eligibility, European ordinance precisely describes the requirements accompanying the assigning and assessing the TAB. All the TABs function within the Technical Assessment Organization (TAO), which tasks are i.a. compiling, receiving EADs (documents harmonising scope, ways and methods of researches as well as the assessment of the construction products) and ensuring that accepted EAD and references to issued ETA were commonly available.

Till now in Poland there were numerous TAB designated: Building Research Institute (ITB), Road and Bridge Research Institute (IBDiM), Institute of Mechanised Construction and Mining Rock (IMBIGS) and Institute of Ceramics and Building Materials (ICiMB). For example ITB's scope of activity includes 33 (among 35) construction products groups pointed in the appendix IV of Regulation 305/2011, IBDiM – 23rd group (materials for building roads), while ICiMB – the 1st group (precast manufactures made of regular/light/autoclaved and aerified concrete), and 4th group (thermal insulation materials, complex sets/systems of insulation). Nowadays there is no detailed catalogue of products categorised to particular group, which have been described sweepingly what makes things awkward for producers to establish the obligation for the construction products with the CE marking. MIiR is responsible for JOT designation.

Bodies notified in Regulation No 305/2011 (Regulation of the European Parliament and of the Council (EU) No 305/2011...) are the subjects legislated to do so called „the third side's" tasks in all (apart from 4th system) assessment procedures and verification of the constancy of the construction product performance. The list of the authorised bodies is available at KE NANDO

[1] European Technical Assessment (ETA) – a document prepared by Technical Assessment Body (TAB) on the manufacturer's request, stating the construction product performances in the reference to its basic characteristics described in European Assessment Document (EAD). The equivalent of European Technical Approval (ETA), that can be issued when the manufacturer on purpose modifies particular properties of the material or fill them with new properties not included in the harmonized standards (in this group there are innovative products that have not been applied yet).

website (European Commission...) and includes hundreds of institutions, including 19 Polish ones, that are not fully covered by the previous version of the list of institutions designated for the construction products' assessment according to Directive 89/106/EEC (Council Directive 89/106 / EEC...).

Compiling and updating the list of notified institutions covered by Regulation No 305/2011 on the domestic ground is confided to MIiR. The list is available on the ministry official website (List of Polish, notified institutions under the Regulation of the European Parliament and of the Council (EU) No 305/2011 of 9 March 2011...). New task confined to notified institutions is also verification of technical documentation prepared by the producers who apply simplified procedures (*Analiza potrzeb zmian legislacyjnych*... 2012).

One of the PKN's duties is transposition of European harmonised standards concerning construction products into the set of Polish standards. By virtue of the transitional agreement, the set of Polish standards harmonised with published on 28.06.2013 the „construction" directive, became at the same time a register of standards harmonised with the regulation. The document ted with the standards published in the second half of 2013. It is available in the EU Gazette No C259 from 08.08.2014 (Commission communication in the framework of the Regulation...).

PCA is responsible for the technical competences assessment of domestic institutions that assess conformity of construction products, surveillance over accredited institutions and creating their open to public lists. What is more, their tasks are also the assessment and monitoring the notified institutions.

Polish bodies, specialised in the construction products' control are The General Office of Building Control (GINB) and The Provincial Office of Building Control (WINB). Their competences are determined in the Act on construction products (Act of 16 April 2004 on construction products...).

The sub-system that is managed in the aspect of introducing new construction product to the market, is the executive sub-system S_{WWWB}. Its structure is based on elementary S_{WWWBi} systems, which basic, legal task is to release the producers on the market or introduce the construction product to the consumer. Regulation No 305/2011 (Regulation of the European Parliament and of the Council (EU) No 305/2011...) introduced changes in the process of allowance the CE marked products into the market. What is significant from their functionality correctness is precisely defined range of executive duties required after the analysed document take effect in life.

Legal basis of the system of marketing of construction products

The framework of introducing construction products to the market in Poland is defined by expanded set of legal acts. This set is based on the record taken from the Regulation No 305/2011 (Regulation of the European Parliament and of the Council (EU)...) (so-called European system) or amended Act on construction products (The Act of 16 April 2004 on construction products...) and executive acts to it (so-called Polish system).

The Regulation introduced significant changes in the range of allowing to the market products covered by European technical specifications repealing at the same time statements of the Directive 89/106/EEC (Council Directive 89/106/EEC...). The changes between the directive and the European regulation are presented in table 1.

For all other construction products' categories intended to use in Poland, the decree allowed an opportunity for applying the domestic system. It did not change the rules of making available on the Polish market construction products lawfully marketed in another member state of the EU.

In spite of a short period of Regulation No 305/2011 being in force, it has been already novelised twice. One of them concerns the declaration of performances – the document that replaced previous declaration of conformity for products with the CE marking. There were introduced changes in the declaration's pattern – the appendix No III for EU regulation, due to the entrepreneurs' problems concerning its correct fulfilment. For instance, the responsibility of identification of the product by its serial number, type or batch's number was abandoned. The information that the producer puts directly on the product are sufficient and do not have to be included in the declaration. Another significant change is resigning from presenting the notified body and its certificates' numbers and research results that can be several. It is sufficient to present the institution data that make it possible to recognise the institution that takes part in the product's assessment. The changes were introduced with the Regulation No 574/2014 (Commission Delegated Regulation (EU) No 574/2014...), that was put into practice on the third day after its publishing (which is 28th on May 2014). Although the changes did not forced modification of previously prepared declaration of the performance made by the producer (if they were prepared accordingly to the initial pattern), they obviously disorganized its functioning for some time.

Table 1

Basic changes introduced by the Regulation No 305/2011in relations to the Directive 89/106/EEC within introducing new construction products to the market

Directive 89/106/EEC (repealed)	Regulation No 305/2011
Was introduced into Polish law with the use of 3 acts: Construction Products Act, Building Law Act and The System of Conformity Attestation Act along with the decree to it.	Is in force directly for all EU member countries as shown in EU journal with no need for transposition into the domestic law.
Formed general purpose for ensuring construction products safety.	Departs from defining the requirements for construction products that would ensure its safety in favour of assurance that the construction products come with reliable information concerning its performances.
Mentions two types of European technical specification: harmonised standards (for traditional products), and European Technical Assessment (for innovative products).	Defines two types of harmonised technical specifications: harmonised European standards (for traditional products), and European Assessment Document (for products not covered or not fully covered by harmonised standard or innovative products).
Introduced 6 systems of conformity attestation for construction products with European technical specification: 1, 1+, 2, 2+, 3, 4	Resigns from the usage of the notion of product's declaration of conformity with technical specification, introducing 5 systems of assessment and verification of constancy of performance for construction products: 1+, 1, 2+, 3, 4
Allowed possibility of building marking of products covered by harmonised standards.	Reverse characteristics
Did not include strict criteria for institutions responsible for technical assessment of the construction product, which could be only one (ITB).	Describes strict criteria for the subject dealing with the assessment and verification of the construction products (TAB), which can be several (such as. ITB, IM).
Required the declaration of conformity to be prepared by the manufacturer before the construction product is introduced to the market. Unitary document's pattern has not been established yet. The declaration of conformity did not have to be made accessible to the consumers.	Requires manufacturer to prepare the declaration of performance when he wants to introduce a product covered by the harmonised standard or consistent with European Technical Assessment issued for the product. The declaration pattern is described in a delegated decree EU Commission No 574/2014. A copy of the declaration can be delivered to a user in a written form (if he requested), by e-mail or can be made available on the producer's official website.
Did not include any conveniences for micro-entrepreneurs.	Introduces conveniences for micro-entrepreneurs.

Source: The author's own study on the basis of Council Directive 89/106 / EEC of 21 December 1988..., MROCZKO (2012).

The manufacturers' responsibilities concerning marketing of construction products accordingly to the Regulation No 305/2011

Regulation No 305/2011 did not lessen the responsibilities laid on the manufacturers concerning introduction of new construction product to the market. The manufacturer is obliged to: determining the product type to ensure its identification, conducting initial researches of the representative sample of the product, introducing factory production control (fpc), establishing the notified body that will be engaged with the process of the attestation of conformity of his product, preparing the technical documentation and declaration of the performances as well as putting the CE marking on the product. Laxity of the manufacturer's responsibilities' description stated in the regulation ended up with unnecessary issues with its initial recognition in the beginning of appliance. In the appendix V, stating that the manufacturers' and the notified bodies; responsibilities in systems: 1, 1+ and 3 of assessment and verification of constancy of performance, the determination of the product type was entrusted to the notified body, whereas the regulation states that the manufacturer is responsible for the determination of the product's type for each product that he plans to introduce to the market.

Notified bodies were bounded with the responsibility of the assessment of the performances of the construction products which constancy can be the matter for certification. The analysed incohesion of the rule was eliminated by the delegated Regulation (EU) No 568/2014 (Commission Delegated Regulation (EU) No 568/2014...).

Dependently on the type of the reference document for the product (a harmonised standard, European Technical Assessment), the moment of making it public on the market (first or another one to the seller or the user) and the manufacturer's status, the realisation of the executive tasks set is obligatory. There are possible several algorithms of the manufacturer's actions: introducing or making available on the market the construction product that was covered by a harmonised standards after the Regulation No 305/2011 (Commission Delegated Regulation (EU) No 574/2014...), applying for the European Technical Assessment or application of simplified procedures. Three among four stated procedures are presented on Figures 2, 3 and 4.

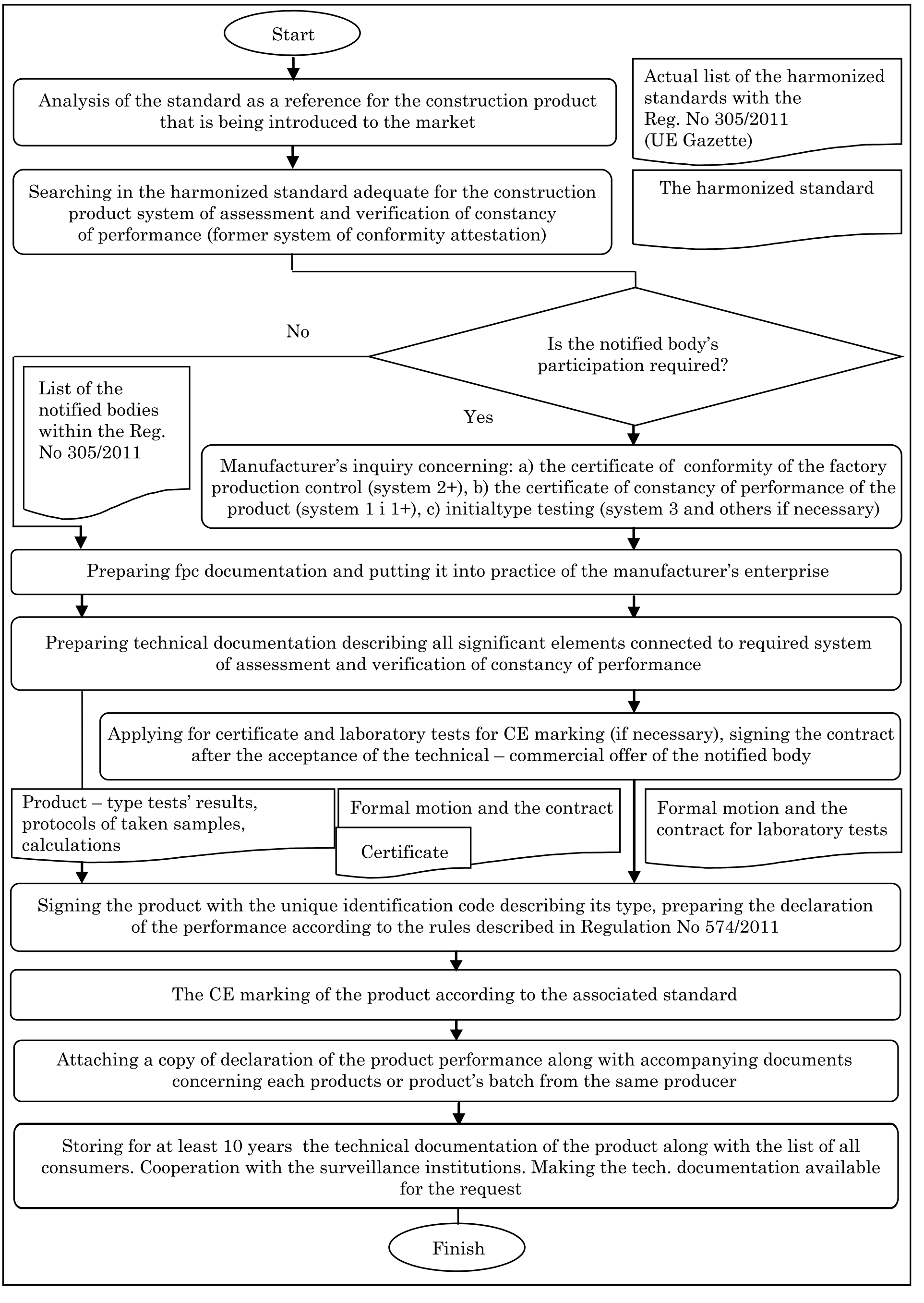


Fig. 2. Algorithm for the manufacturer's proceedings introducing a new construction product to the market after the Regulation No 305/2011
Source: The author's own study on the basis of *Wprowadzanie – udostępnianie*... (2013).

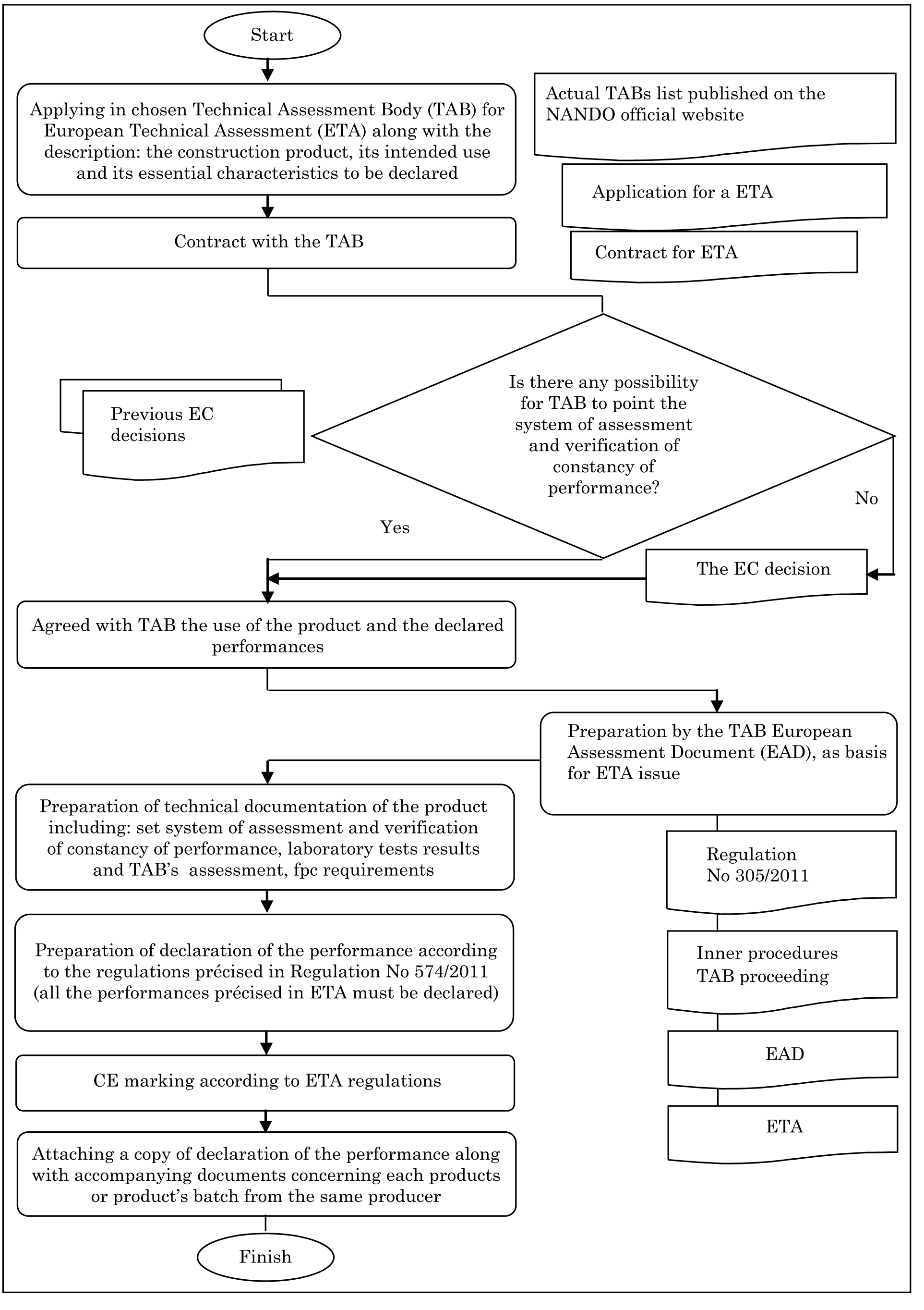


Fig. 3. Algorithm for the manufacturer's proceedings making a construction product available on the market after the Regulation No 305/2011
Source: The author's own study on the basis of *Wprowadzanie – udostępnianie...* (2013).

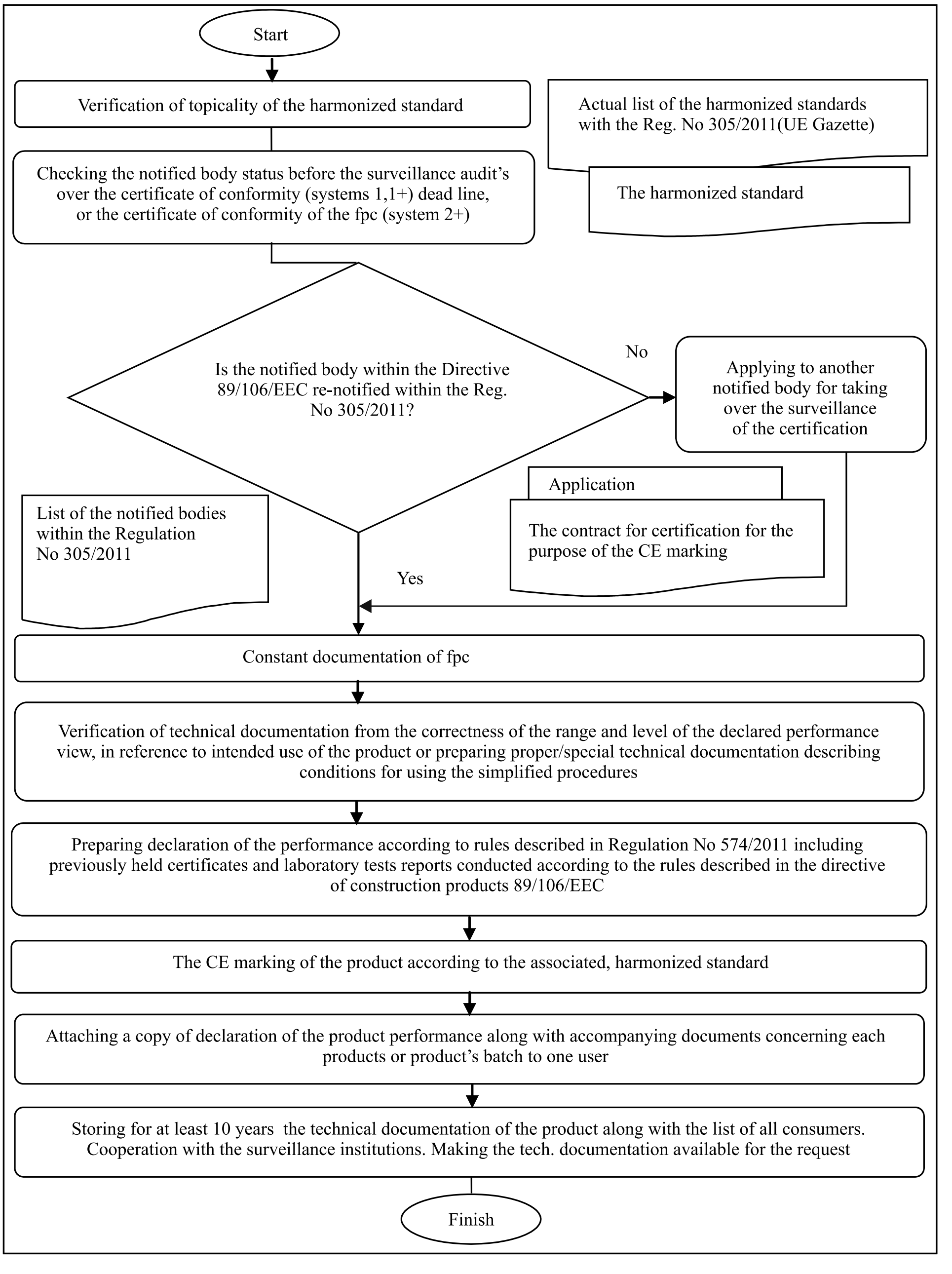


Fig. 4. Algorithm for the manufacturer's proceedings applying for European Technical Assessment
Source: The author's own study on the basis of *Wprowadzanie – udostępnianie...* (2013).

Conclusions

Regulation No 305/2011 introduced significant changes in the structure of sub-system that manages with introducing new construction products with CE marking to the market, that influence the functioning of the sub-system.

Next to the European system of marketing of construction products, based on European regulations, there is still functioning a domestic system, based on the novelized Act of Construction Products and its regulations. Applying the European system is obligatory for the products covered by harmonized standards and free for individual manufacturers who were granted with European Technical Assessment on their demand.

General rules for functioning the domestic system of technical approvals has not been changed. Any changes of the domestic system will require new novelization of the Act of building materials.

Regulation (EU) No 305/2011 was to break the barrier of free trading among EU countries, but through ambiguity of its records it still causes problems for the construction products manufacturers.

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SOLAR IRRADIANCE FORECASTING BASED ON LONG-WAVE ATMOSPHERIC RADIATION

Michał Piątek, Jędrzej Trajer, Dariusz Czekalski

Faculty of Production Engineering
SGGW in Warsaw

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Key words: artificial neural networks, irradiance forecasting, cloudiness.

Abstract

This work contains information concerning long-wave atmospheric radiation. Artificial neural networks were developed to forecast total mean hourly irradiance based on long-wave atmospheric radiation as cloudiness indicator. It was proved that using this variable in models for forecasting irradiance is wellgrounded. The proof was based on the neural networks sensitivity analysis. It was proved that neural network model is capable to utilize information carried by long wave atmospheric radiation only when the air temperature is provided as additional explanatory variable.

Nomenclature

The following variables were used for the purpose of the this research:

– Itot-2 – mean global irradiance registered two hours prior to the current time [W/m^2]

– Itot-1 – mean global irradiance registered one hour prior to the current time [W/m^2]

– Itot – mean, hourly, current total irradiance at the current time [W/m^2]

– Itot+1 – mean global irradiance registered at the hour following the current time [W/m^2]

– IR – mean hourly long-wave atmospheric radiation registered at the current time [W/m^2]

– Temperature – mean hourly temperature at the current time [^{o}C]

– RH – relative humidity at the current time[%]

– Pressure – mean atmospheric pressure at the current time [hPa]

– Time – current time [hours]

– No of day – number of the day of the year (Julian calendar day), variable that assumes values from 1 to 366.

Correspondence: Jędrzej Trajer, Katedra Podstaw Inżynierii, Szkoła Główna Gospodarstwa Wiejskiego, ul. Nowoursynowska 164, 02-787 Warszawa, phone: +48 22 5934617, e-mail: jedrzej_trajer@sggw.pl

Introduction

Development of distributed power energy based on renewable resources of energy has recently enjoyed popularity not only among scientists and researchers but also politicians and various business circles. Multi-faceted development of related technologies can be observed. One of them is the need to predict future states of electrical power production in order to balance both the electrical power system and „off grid" systems. This knowledge allows both to optimize the cost of energy consumption and to maintain normal work of the system, and, given the development of renewable resources of energy, including solar energy, will assume growing importance. Forecasting radiation is, therefore, an important issue. However, there is a significant difficulty connected with the development of models related to in changes in radiation caused by cloudiness. Although this is a complicated and chaotic process, factors that have an impact on it are known. It is a difficult task to model these relations using classical computational methods, and new methods need to be sought to solve these problems such as computational intelligence, which seems promising. Particular attention ought to be focused on artificial neural networks which can „learn" relations between variables and generate correct results, with no need to possess knowledge related to said relations. In this work, authors propose artificial neural networks for forecasting total mean hourly radiation using long-wave atmospheric radiation as cloudiness indicator. It was proved that using this variable in models for forecasting total radiation is wellgrounded.

Long-wave atmospheric radiation

Long-wave atmospheric radiation (infrared, IR) is an object of interest to researchers who study atmospheric phenomena. Infrared IR radiation has an impact on plant growth by influencing the process of water evaporation. There exist mathematical models that allow to forecast IR index for clear sky and take cloudiness into account. Steam and, to a lesser degree, carbon dioxide, ozone, methane, aerosols, nitrogen oxides are responsible for the emission of infrared radiation to the atmosphere (KJAERSGAARD et al. 2007). It is thermal (heat) radiation related to air temperature. Therefore, models that estimate IR in clear sky conditions are based on air temperature as the main parameter, sometimes partial pressure of steam is additionally used (KJAERSGAARD et al. 2007). Presence of clouds causes increase in long-wave atmospheric radiation (LHOMME et al. 2007). The change depends on cloud density and composition, and, due to the decrease of temperature connected with the altitude of clouds, this parameter is also significant (KJAERSGAARD et al. 2007). Based on the above description of the phenomenon, it can be supposed that IR may introduce information concerning the amount and type of clouds for the neural model. An example course of long-wave atmospheric radiation in successive hours of April is shown in Figure 1.

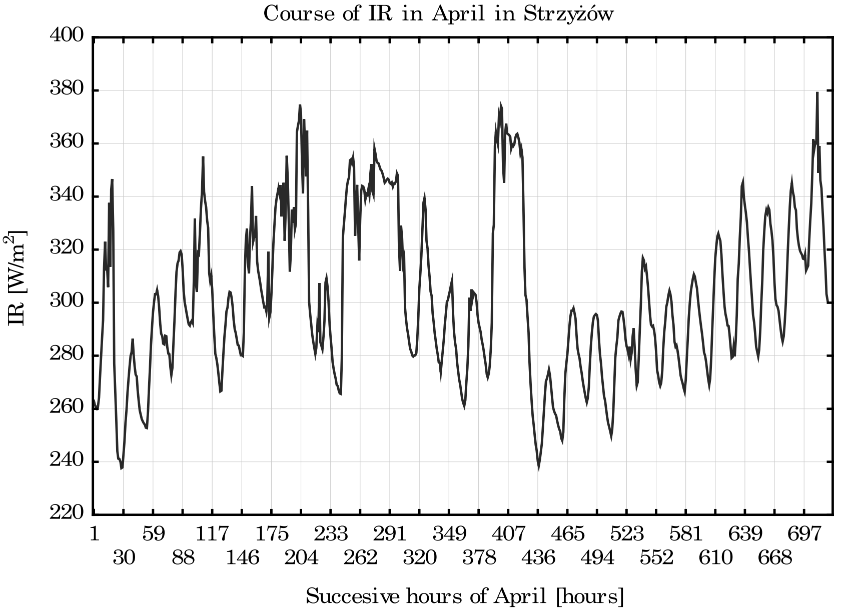

Fig. 1. An example course of long-term atmospheric radiation in Strzyżów

Material and methods

Data come from a radiation transfer SolarAOT research station operated by Krzysztof Markowicz. The station belongs to the Warsaw University Institute of Geophysics. The station is located in Strzyżów (49.8786°N, 21.8613°E). The data set contains measurements from march 2009 to august 2013, which were collected with one minute basic time interval. The metrological data were collected using Ulitmeter 2100 electronic metrological station, global solar irradiation was measured using Eppley Black and White 8-48 pyranometer and long wave atmospheric radiation was collected by Eppley PIR pyrgeometer.

Artificial neural networks with the structure as in Figure 2 were used.

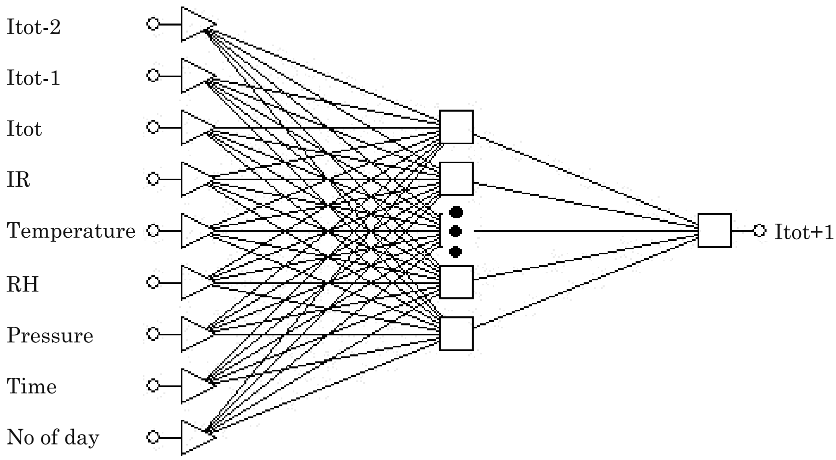

Fig. 2. Structure of neural networks for forecasting solar radiation

Usefulness of variables was assessed based on sensitivity analysis, calculated as a quotient of the error that network generates, when no data is given instead of the value of the examined variable, and the error calculated when all variables are available. As a result of the performed analyses using different sets of input variables, it was proved that using temperature and number of the day of the year is indispensible in order to „sensitize" the model to variable IR. Otherwise, the network generated forecasts based on the radiation values for previous hours. Based on these variables, EM algorithm (modified algorithm k – mean described in detail in (WITTEN, FRANK 2000)), was used to perform cluster analysis. In all these combinations pressure sensitivity was equal 1, and, therefore, was omitted in further examinations.

Discussion and research results

The cluster analysis proved two similar phenomena that occurred. It was observed that these phenomena can be identified based on the number of the day of the year. Cluster 1 was called a warm period, and included summer months, most days in spring and autumn months, and cluster 2 was called a cold period as it included winter months mostly. While developing models for the clusters obtained as a result of analyses performed for other combinations of data it was proved that clusters identified based on IR, temperature and the number of the day of the year, were the best cognitive formulae for neural models. Figure 3 shows the results of cluster analysis. Selection of input variables was based on sensitivity analysis.

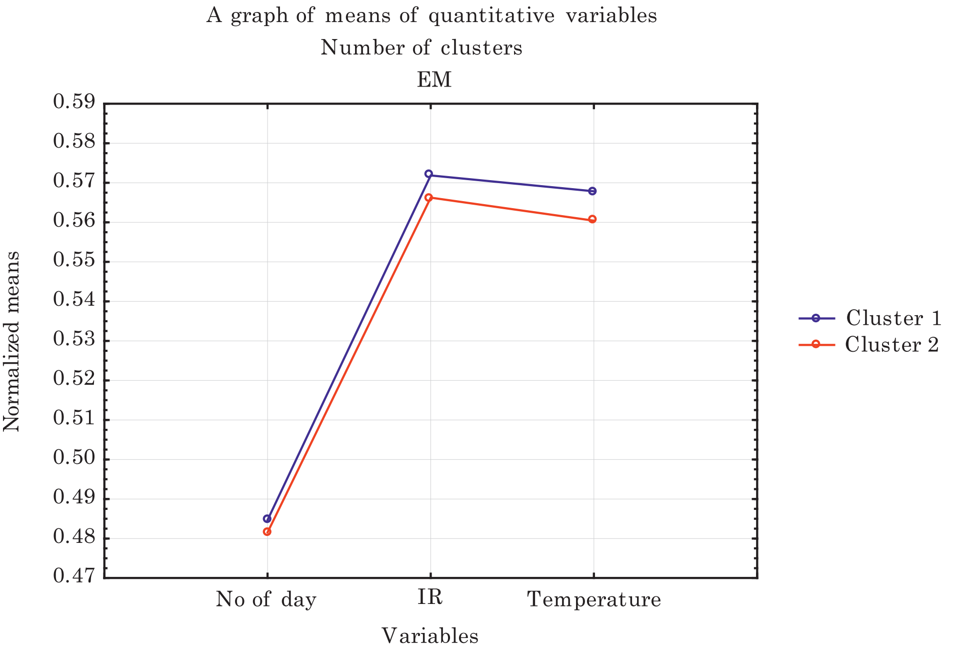

Fig. 3. Results of cluster analysis using EM method

Forecast for the warm period

Table 1

Data of a neural network that forecasts radiation in the warm period

Network name	Quality (learning)	Quality (testing)	Quality (validation)	Learning algorithm	Activation (hidden)	Activation (output)
MLP 8-10-1	0.935	0.935	0.942	BFGS 98	Exponential	Linear

Table 2

Sensitivity of the network that forecasts radiation in the warm period

Predictor	Itot [W/m^2]	Time [hours]	Temperature [°C]	IR [W/m^2]	No of the day of the year	Itot-2 [W/m^2]	RH [%]	Itot-1 [W/m^2]
Error quotient	4.414	3.174	2.186	1.817	1.269	1.110	1.099	1.081

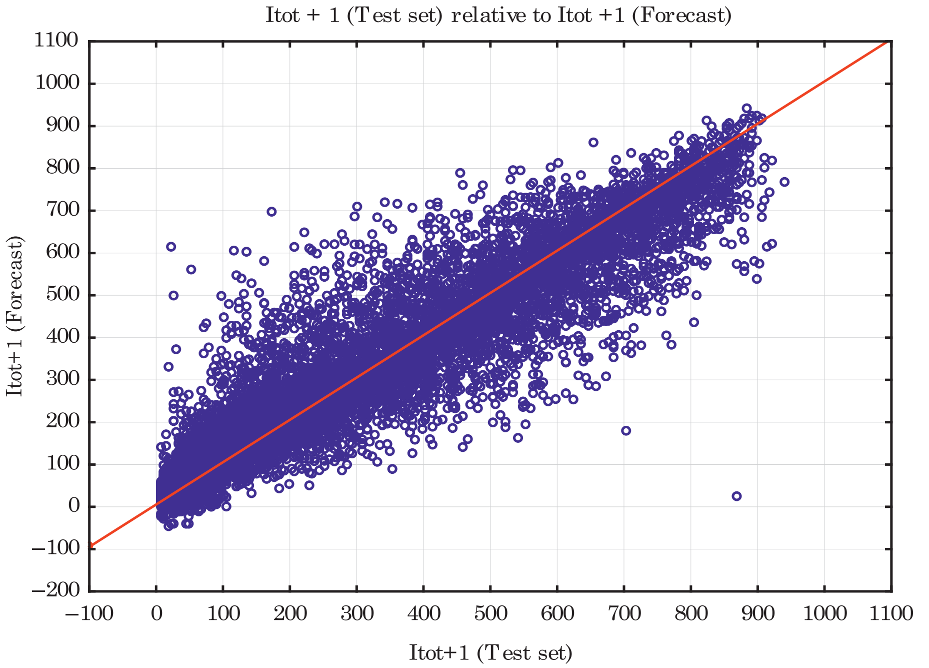

Fig. 4. Scatter of measurements from the test set relative to the forecast values

Forecast for the cold period

Table 3

Data of a neural network that forecasts radiation in the cold period

Network name	Quality (learning)	Quality (testing)	Quality (validation)	Learning algorithm	Activation (hidden)	Activation (output)
MLP 8-13-1	0.969	0.967	0.968	BFGS 138	Logistic	Hyperbolic Tangent

Table 4

Sensitivity of the network that forecasts radiation in the cold period

Predictor	Itot [W/m^2]	Time [hours]	No of the day of the year	IR [W/m^2]	Temperature [°C]	Itot-1 [W/m^2]	Itot-2 [W/m^2]	RH [%]
Error quotient	8.869	3.618	2.792	1.737	1.649	1.252	1.104	1.020

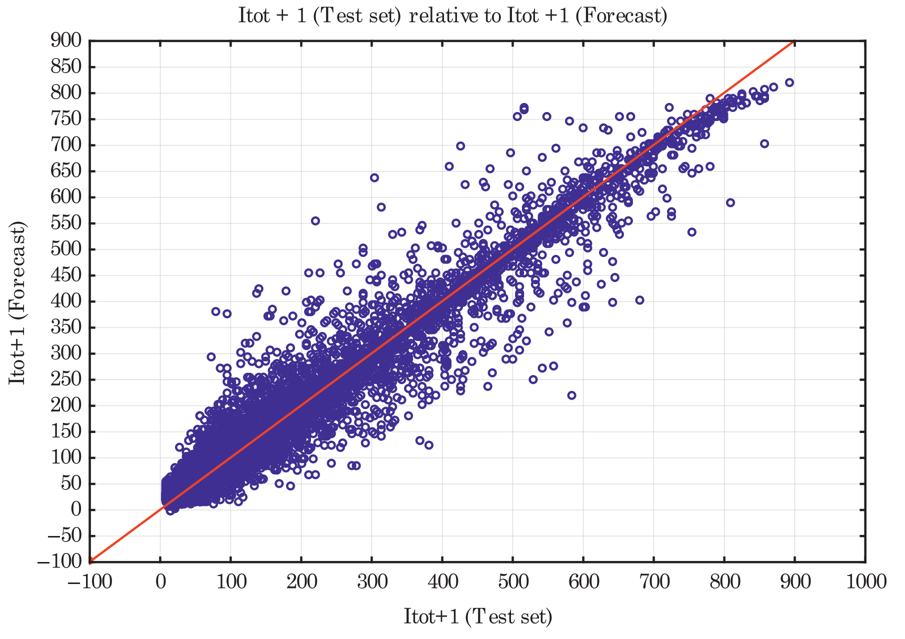

Fig. 5. Scatter of measurements from the test set relative to the forecast values

Table 5

Assessment of developed forecast models

Name	δ [%]	RMSE	NRMSE
All year	20.798	72.041	0.280
Warm period	21.798	86.274	0.278
Cold period	17.665	45.293	0.252

The results suggest that models, which did not use long-wave atmospheric radiation, and, in which data about cloudiness were introduced to the network in the form of octants, exhibited larger error in the winter period in European conditions, where the degree of cloudiness is much higher than in the summer period (TRAJER, KOZŁOWSKI 2005). Models developed by the authors do not possess this feature. However, they exhibit larger errors in the summer period when the degree of cloudiness is subject to more dynamic changes, which makes them more difficult to predict. Simultaneously, cloudiness in the summer period has a smaller influence on atmosphere transparency in the winter period. Nevertheless, networks that use IR generate better forecasts than in the cold period. Hence, it can be assumed that long-wave atmospheric radiation is an indicator of cloudiness.

For the model that forecasts total radiation for the whole year, graphs showing how the forecast depends on the predictors were generated. Figure 6 presents the relationship between the solar radiation intensity and the temperature during a year. It should be noted that temperatures below +5 degrees Celsius for days numbered 150–210 (summer) as well as temperatures above +20 degrees Celsius for days numbered 0–60 and 300–360 (winter) have no physical sense. This should also be considered while interpreting the graph. Although the model can generate forecasts for the above values, they should be omitted while analysing the graph. Figure 7 shows changes in IR influence on solar radiation during the year. The higher temperature and smaller IR, the higher total radiation intensity.

Together with the increase in IR, solar radiation intensity decreases. It is caused by greater opacity or cloudiness. Additionally, increase in opacity or cloudiness results in the horizon temperature rise, and consequently, long-wave radiation increase.

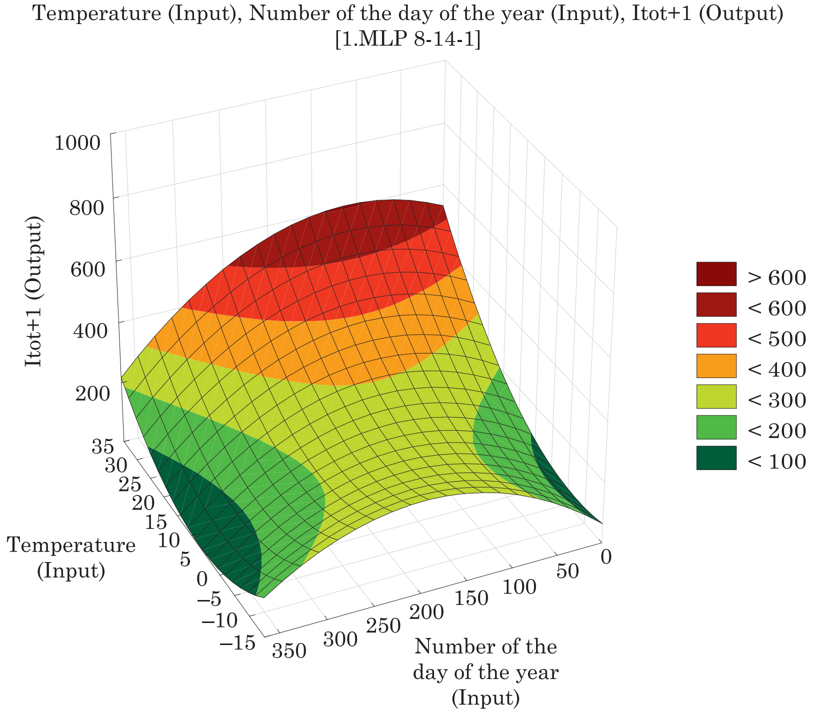

Fig. 6. Dependence of solar radiation intensity relative to the temperature in the period of the year

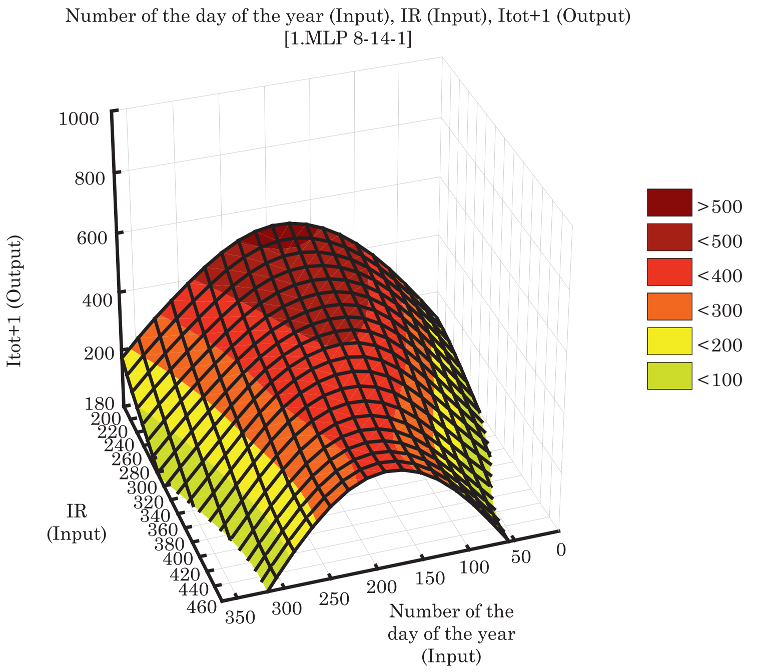

Fig. 7. Dependence of solar intensity radiation relative to long-wave radiation IR in the period of the year

Conclusions

Based on the performed examinations, the following conclusions were formulated:

1. Application of cluster analysis allowed to develop models for two periods (summer and winter), for which the quality of forecasts is better than for the whole year.

2. MLP neural networks are an appropriate tool to forecast mean hourly total solar radiation, and these networks should be applied in this field to a greater extent.

3. The examinations confirm that long-wave atmospheric radiation may be cloudiness indicator, which high quality of forecasts confirms.

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INTEGRATION OF HETEROGENEOUS PHOTOGRAMMETRY DATA FOR VISUALIZATION OF CULTURAL HERITAGE OBJECTS

***Jakub Markiewicz*[1], *Dorota Zawieska*[1],**
***Aleksandra Bujakiewicz*[2]**

[1] Faculty of Geodesy and Cartography
Warsaw University of Technology
[2] Faculty of Civil Engineering, Environmental and Geodetic Sciences
Koszalin University of Technology

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Key words: Cultural heritage, Integration, Visualization, Data base.

Abstract

Technologies of digital photogrammetry provide the metric and thematic information for various data bases, including those which are created to visualize and archive the cultural heritage objects. Due to different sizes, shapes, locations and environmental conditions of objects, data is acquired by means of various photogrammetric methods based on aerial and terrestrial digital imagery and laser scanning data. They are also very often integrated with data from other sources.

Photogrammetric products dedicated for the cultural heritage are usually collected and integrated in 3D GIS data bases, which are used by various specialists involved in restoration of the historical monuments. The variety of photogrammetric data and possibility of multi criterion spatial data processing and analysis in 3D GIS, allow to reconstruct the accurate terrain topography and 3D models of valuable heritage monuments. In this paper, an integration of various photogrammetric products (created in the past and within the discussed project), used for the needs of visualization of the terrain topography and 3D models of historical buildings and vegetation for the Museum of King Jan III's Palace at Wilanów area, is presented. The following photogrammetric products were utilized: the orthophotomap of 0.1 m resolution from the Geodetic and Cartographic Documentation Centre (CODGiK), ALS – ISOK data, 3D vector data from stereo digitalization of 0.1 m resolution images, the vegetation layer for the area of the Museum of King Jan III's Palace at Wilanów, acquired from the 3D data base. In addition, some symbols of missing objects were used from the Google 3D WareHouse.

Correspondence: Jakub Markiewicz, Zakład Fotogrametrii, Teledetekcji i Systemów Informacji Przestrzennej, Politechnika Warszawska, pl. Politechniki 1, 00-661 Warszawa, phone: 48 22 2347694, 237587, e-mail: j.markiewicz@gik.pw.edu.pl

Introduction

The cultural heritage area of high importance requires a permanent control and monitoring of historical architectural and vegetation objects. Results of revalorization and changes of historical objects should be regularly monitored and measured. In the case of a large area, which includes many historical, architectural and vegetation elements, the number of changes should be estimated a priori basing on interpretation of the high resolution images, before the real photogrammetric and/or surveying measurements are performed (BUJAKIEWICZ, ZAWIESKA 2013).

Due to the variety of heritage objects, in particular their sizes, shapes, locations and environmental conditions, data is acquired by means of various photogrammetric methods, which are based on aerial and terrestrial digital images and laser scanning data. This data is often integrated with data from other sources. The universal solution for analysis and storage of all available data (acquired in the past and at present) is a data base created in the 3D GIS environment. The advantage concerns not only the possibility to store the data in various forms (raster, vector, descriptive), but also the data integration with recently acquired data, as well as the easy way of data processing and administration. The Architectural Data Bases, which are created for the selected cultural heritage areas, can serve as the knowledge bases for various specialists involved in restoring of the historical monuments.

The variety of photogrammetric data and the possibility of multi criterion spatial data processing and analysis in 3D GIS, allow to reconstruct the accurate terrain topography and 3D models of objects and also to determine their geometric characteristics, that is very important for the cultural heritage.

In this paper, an integration of various photogrammetric products (created in the past and generated within the presented project), used for the needs of visualization of terrain topography with 3D models and historical buildings and vegetation for the Museum of King Jan III's Palace at Wilanów area, is presented.

Main assumptions of data integration for 3D modelling

Intensive development of photogrammetric technologies in the field of source data acquisition and its automatic processing allows to generate many different, complementary products, which are useful for documentation and analysis of cultural heritage objects. Documentation of architectural objects in the form of 3D models with texture has been widely applied (MARKIEWICZ 2013). Both approaches, based on digital images and high resolution laser scanning, are useful. In the case of historical monuments, which are frequently characterised by complicated shapes and are located in compact sites covered by dense vegetation, it is not sufficient to apply only one source data acquisition system (ANGELLO, LO BRUTTO 2007). In such cases, integration of photogrammetric data from aerial and terrestrial systems, supplemented by data from other sources, is necessary and recommended. Such approach allows for 3D modelling and visualization of the terrain surface and all spatial objects. The use of ALS data only is not sufficient for texturing of the terrain surface (KRAUS 2007).

Integration of ALS data with aerial images allows to generate 3D realistic models of the terrain topography and all objects existing on the terrain surface. High resolution digital aerial photographs and ALS data are used for creation of orthomosaics and provide information on the terrain elevation, vegetation cover and roofs of buildings. The basements of buildings can be acquired from the vector basic map or by monoploting the orthomosaic. The terrestrial scanning laser and close range photogrammetric image data provide supplementary spatial information on 3D objects and also for texturing of their walls. Using TLS data, some imperfections, such as dead areas or lack of information in case of very smooth or glass surfaces, must be considered. To avoid such problems, the additional scans from other TLS stations, supplemented by terrestrial photographs, should be applied (DORNINGER, BRIESE 2005, AGNELLO, BRUTTO 2007).

Taking into account the integration of data acquired from various sources, the *a priori* analysis of many factors which may influence the data usefulness for modelling the terrain and objects, should be performed. In respect to (EL-HAKIM et al. 2005), the discussed factors include: the ability to acquire all details with the high geometric accuracy and reality, low cost and availability of equipment and universal software, and the fidelity of reconstruction and visualization of the terrain topography and 3D models of objects.

One of the data integration methods consists of hierarchical allocation of data into classes of different accuracy and resolution, aiming at creation of general shapes of objects and their details (AUGILERA et al. 2006).

The essential problem of the data integration process, which is connected with the variety of data sources, is to guarantee the common georeference of data. This can be achieved either by independent transformation of each data type (source) to the common reference system (ANDERSON et al. 2011), or by *a priori* matching the particular co-ordinate systems in which the data are determined. The simultaneous relative orientation of aerial and terrestrial data performed at the stage of the data integration results in some restrictions. They are connected with different ways of data recording by different systems and with various specifications of measurement. The examples of relative orientation of ALS data and aerial images and integration of close range images with point clouds are presented in (ANDERSON et al. 2011, BOEHM et al. 2007, BOULAASSAL et al. 2011, MARKIEWICZ 2013). In some cases, data integration is carried out by visualization and connection of final products with the use of external software tools (ANDERSON et al. 2011).

Integration of multi-source data of the Museum of King Jan III's Palace at Wilanów

Description of the object

The area of the Museum of King Jana III's Palace at Wilanów area comprises the palace, the garden, the park and the Wilanów lake. The Palace-Park set of 89 ha size, is located in the south part of Warsaw. In the past, the palace and park were the suburban, summer residence of King Jan III Sobieski. Under his order, the nobleman's mansion located in the central part of the area, was considerably extended. As the result of developments between 1681 and1696 the wonderful baroque Palace was built. The Palace history is indissoluble tided with the famous aristocratic families, such as Czartoryski, Lubomirski and Potocki.

At present, the Palace-Park set is administrated by the Museum of King Jan III's Palace at Wilanów, which was created in 1995. Recently, many essential works have been executed. In the period 2004–2008 the Palace was completely renovated and in 2011 the gardens were set in order. Since 2010, the Documentation Section has been involved in the development of the Spatial Information System (GIS), and at present the data base contains large files of data, 3D models of buildings, sculptures and other items, and also some results of archaeological research carried out in gardens.

For the needs of the discussed project, for presentation of the results of the multi source data integration, the most representative fragment of the Museum area has been selected. It comprises the most important buildings, such as the baroque Palace with the wonderful gardens located around on the upper bottom terraces.

The source data

Data integration and edition of information layers in the GIS have to be preceded by acquisition of photogrammetric products. The data base layers, acquired using various software tools, should have suitable accuracy and formats, which allow to input and display the data in the GIS system.

The following data were utilized in this project: (1) data from the Geodetic and Cartographic Documentation Centre (CODGiK), from the ISOK Project (the System of the Country Protection Against Extreme Hazards), ALS data in LAS format, the orthophoto with GSD of 0.25 m resolution, (2) vector data from the stereo digitizing of 0.1 m resolution aerial images using the Summit Evolution System, Inpho (KASPRZAK 2012), (3) the vector data base from the Museum of King Jan III's Palace at Wilanów, (4) symbols of trees from 3D Warehouse library.

The ALS data, with the average density of 12 points/m^2, in the „1992" co-ordinate system. 8 basic classes were distinguished in the point cloud (CODGiK 2014).

Modelling of selected 3d object types

The integration process was preceded by modelling of various 3D objects which were to be introduced in the projected data base. For this process the Google SketchUp 6 software was used. Such approach allows to input both, the digital images in .jpg format and the vector .dxf data.

Modelling of 3D trees. For visualization of 3D trees (Fig. 1), the symbol library of 3D Warehouse was utilized. This is a free set of 3D models available for Google SketchUp users.

a *b*

Fig. 1. Examples of 3D models of trees: *a* – oak, *b* – lime

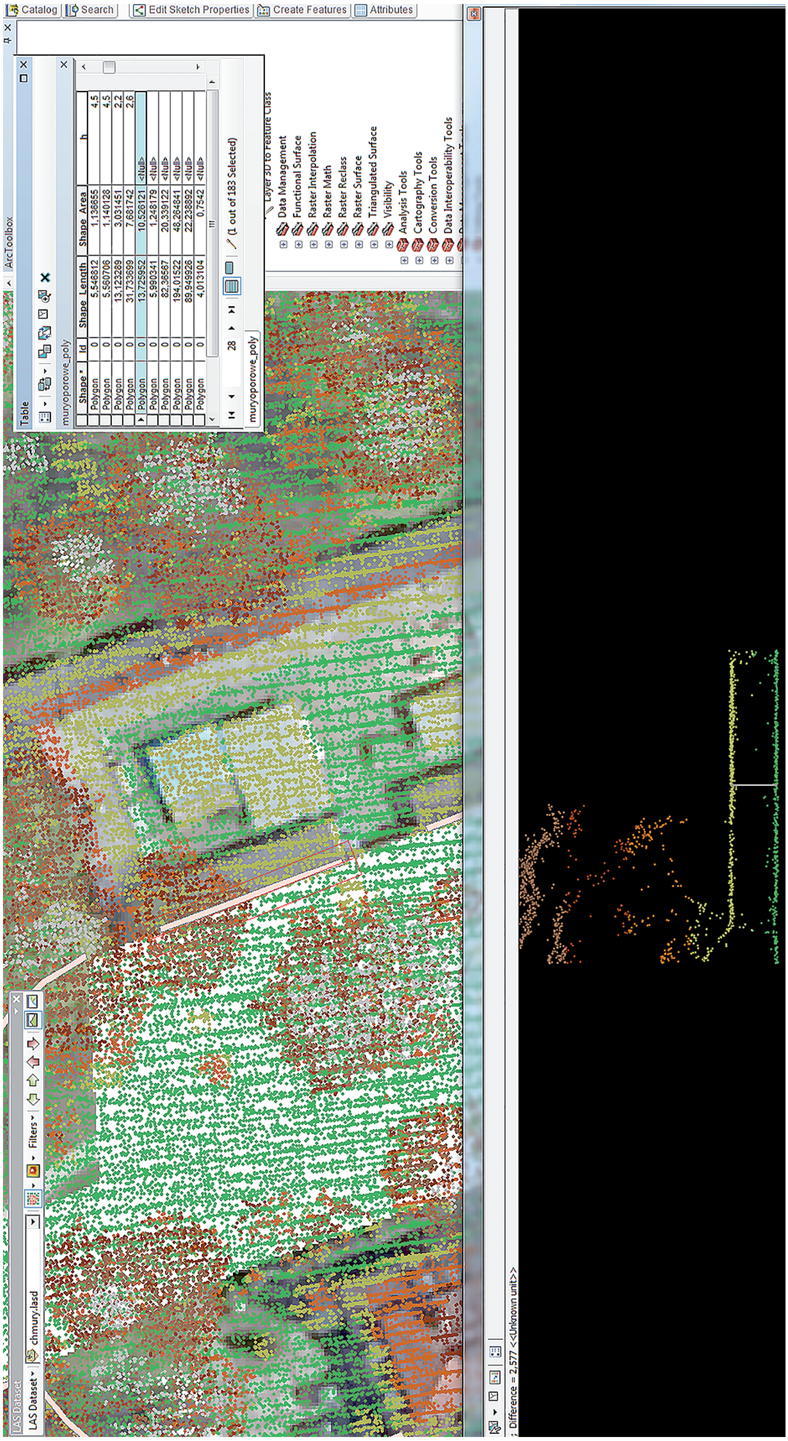

Fig. 2. Measurements of heights using the ALS point cloud in ArcGIS

3D modelling of fences and walls. 3D modelling of fences and walls was carried out in two steps with the use of ArcScene 10.2.1 (ArcGIS).

Step. 1 Utilisation of 2D vector data of walls and fences, from the vector data base of the Museum of King Jana III's Palace at Wilanów.

Step. 2 Interpolation of heights of walls and fences basing on the ALS data (Fig. 2).

3D modelling of the structure of the Palace and other historical buildings. For modelling of the Palace and other historical buildings located within the area of the Museum, the vector data base of buildings basements and edges of roofs was utilized (KASPRZAK 2012).

In the first step, all data was imported to Google SketchUp free software (version SketchUp Pro has not been available). Unfortunately, during this process all georeference information was lost. Therefore, the models were georeferenced again during the next step (Fig. 4).

During the final modelling stages, for the Palace, the basement data and data concerning the complicated shape of the roof, was used. For other historical buildings, only information on heights and shapes of roofs was available. The final models of all historical structures were generated at the level between LoD1 and LoD2 (Fig. 3).

a

b

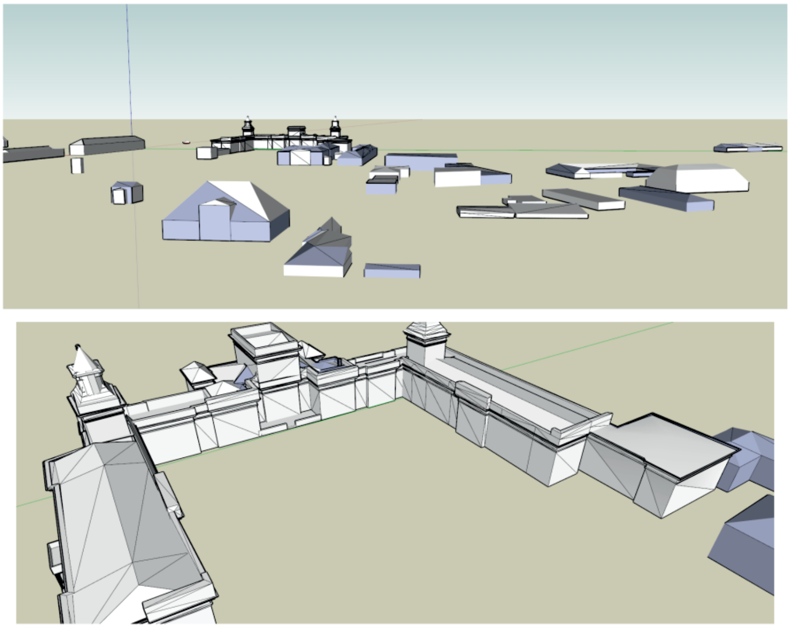

Fig. 3. The 3D model of monumental buildings of the Museum of King Jan III's Palace at Wilanów: *a* – other historical buildings, *b* – Palace

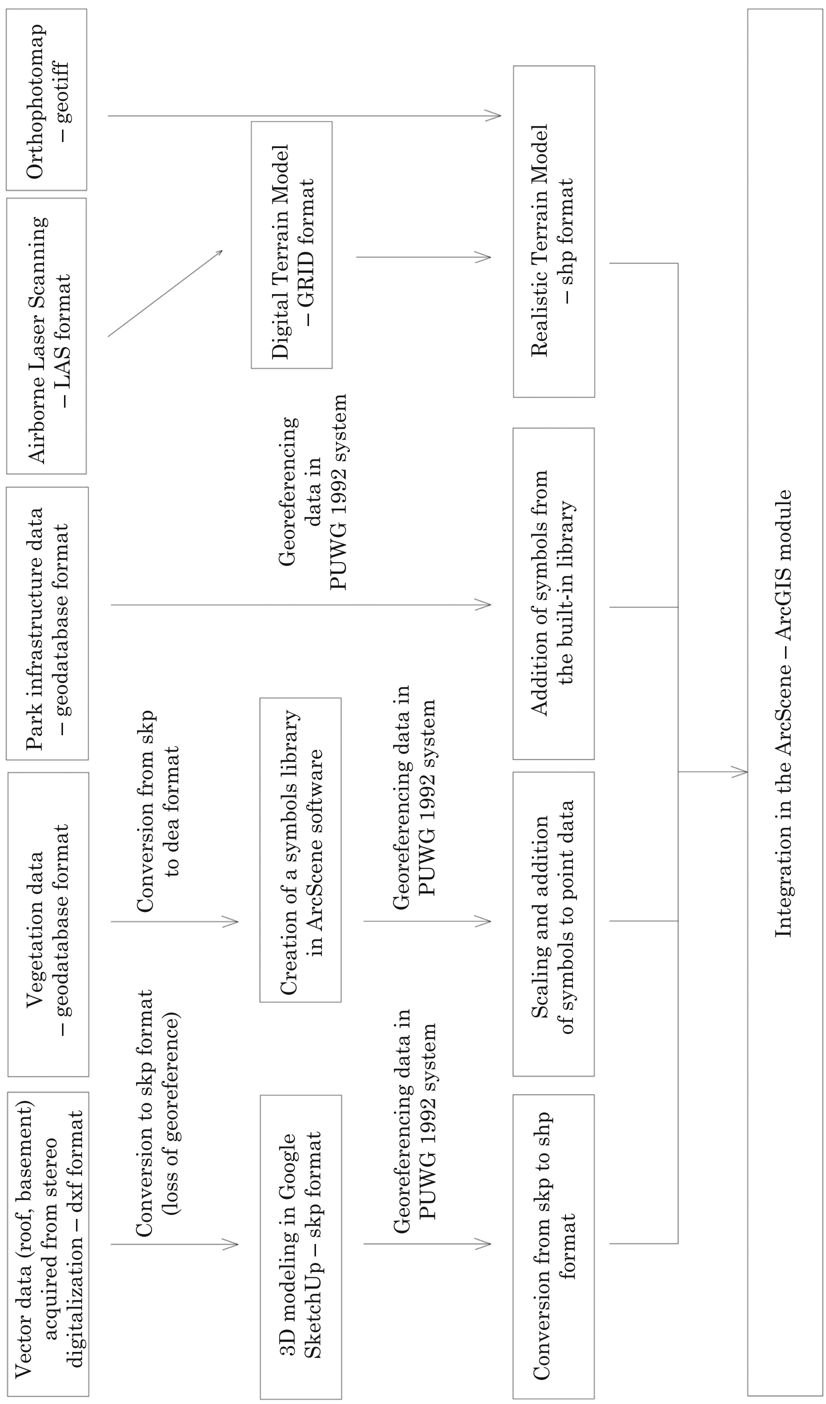

Fig. 4. The scheme of photogrammetric data processing and integration for modelling and visualization of 3D objects

Data integration and vizualization of the object

Integration of all data from various sources has been carried out basing on the block diagram proposed in (ANDERSON et al. 2011).

Figure 4 presents the scheme of programs and file formats used in the final data integration process, carried out by the authors.

During integration of data from various sources some problems were noticed, which were mainly caused by incompatible data formats. The main problem resulted from the missing georeference of data during the data input to SketchUp. Therefore data reference had to be introduced manually basing on the source data. According to the ArcScene manual, it should be possible to import data directly from *skp,* but unfortunately, it was not confirmed by the executed experiments. To solve such problems in this project, *skp* format was substituted by COLLADA format.

Format *skp* is used to store files in SketchUp (Trimble Navigation) software. This format is adequate not only for recording information on the objects' geometry but also on texture and type of materials (SketchUp 2014). Format COLLADA is used to record 3D data. Models described in such a way are compatible with the open XML standard, recorded with *dae* format (COLLADA 2014). This allows not only for correcting the read-out of symbols but also for assigning their heights. All elements of the data base were recorded in the PUWG 2000 reference system.

The limitation which was noticed during the processing concerned the lack of possibility to transform the point clouds recorded in the LAS format from the „1992" to the „2000" co-ordinate system. This caused the necessity to supplement data concerning trees, when the terrain surveys were not available.

The binary LAS files, containing ALS data, are recorded according to the standard 1.2. They contain information on the point co-ordinates and the intensity of the laser beam reflection, and classes of points and colours (RGB), from aerial photographs (CODGIK 2014).

The results of visualization after the final data integration are presented in Figure 5.

Analysis of data integration

The 3D model, reconstructed in the realistic scale, was transformed to the „1992", 2D co-ordinate system and to the 3D co-ordinate system „Kronsztad 86" using the 6-parameter transformation (translation and rotation).

The accuracy was estimated with the use of data from the basic map recorded in data base, which was utilized for 3D modelling and visualization.

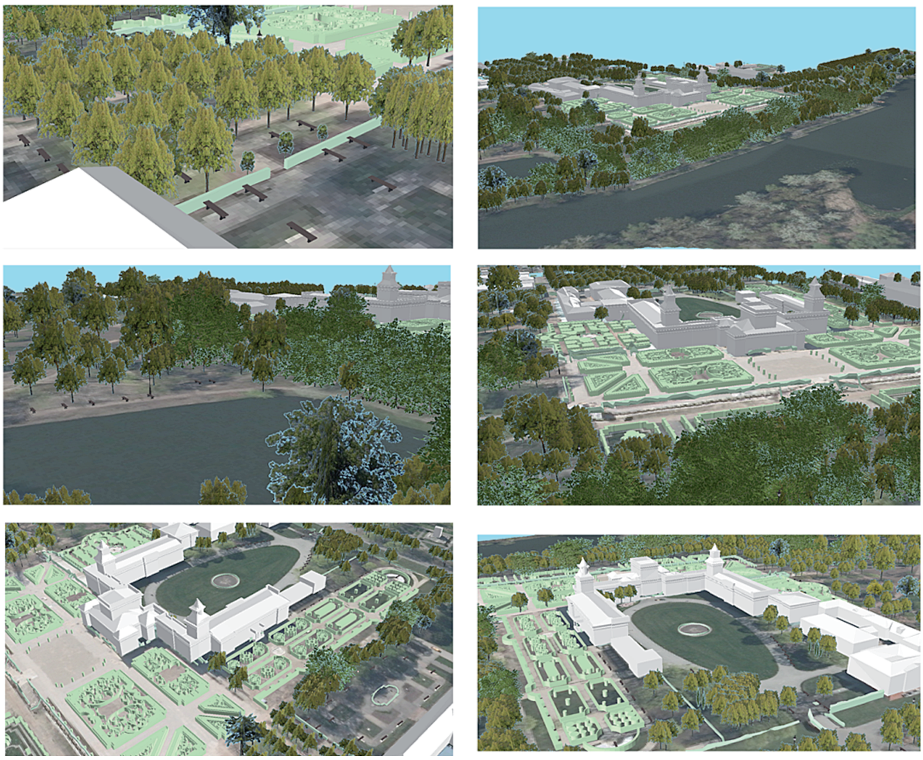

Fig. 5. Visualization of the final data integration for the Palace and park in Wilanów

Twenty control points were randomly chosen, their distribution is presented in Figure 6. These points were the corners of building basements, well visible in the data. The high values of errors of the model matching (above 1 m) result from modelling the buildings basing on vectorized roofs only.

Basing on the majority of points (16) the statistical indicators were estimated:

– Avarage deviation: 0.62 m

– RMSE: 0.28 m

– Deviation distribution: 25% of points between 0 and 0.4 m; 44% of points between 0.4 and 0.8 m; 31% bigger than 0.8 m.

The accuracy results show, that the average linear deviation does not exceed 0.95 m. This means that the accuracy condition for 3D modelling of buildings on the level LoD1 – LoD2 has been met.

Fig. 6. Distribution of 20 control points within the analyzed area. Points with deviations from the reference data which exceeded 1 meter are marked in blue

Conclusions

Summarizing the experiments concerning the photogrammetric data integration for visualization of cultural heritage objects, it should be emphasized that the process is labour-consuming with restricted degree of automation. Many intermediate processes require adequate data preparation and suitable software. The final general conclusions can be included in the following groups:

(1) In spite of intensive development of 3D modelling and GIS software, the problem of 3D visualization of architectural objects and their surroundings has not been properly solved yet.

(2) The typical problem related to the spatial modelling and processing of data from various sources concerns the difficulty of using various data formats and their exchange between different programmes.

(3) The 3D Google SketchUp (free of charge) software for modelling does not preserve data georeference information. Therefore, this requires reiteration of spatial orientation of the objects, resulting in additional difficulties and errors in data reference.

(4) The use of GIS software allows to manage and process data acquired from various sources. This is useful not only for the experts of conservation of monuments, analyzing particular scenes, but also for spatial analyses performed with the use of metric characteristics of the source data.

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RESONANT VIBRATIONS OF THE MOVING BAND SAW BLADE WITH VARIABLE TENSION

***Lidiya Dzyuba*[1], *Olha Khytriak*[2], *Olha Menshykova*[1], *Ihor Rebeznyuk*[3]**

[1] Department of Applied Mathematics and Mechanics, Lviv State University of Life Safety; Ukraine
[2] Department of Engineering Mechanics, Army Academy named after hetman P. Sahaidachnyi, Lviv, Ukraine
[3] Department of Woodworking Machinery and Tools, Ukrainian National Forestry University, Lviv, Ukraine

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Key words: transverse vibrations, resonance, band saw, tension force, speed, frequency response.

Abstract

Resonant transverse bending vibrations of the band saw blade have been investigated taking into consideration variable in the time tension force of the blade and the external periodic perturbation. Amplitude of resonant vibrations of the band saw blade piece has been determined by the Bubnov-Galerkin method and basing on the idea of perturbation theory.

Introduction

Significant dynamic loads arise in the elastic system of horizontal cutting mechanism of the band saw machine when it is turned on. This is caused by the variable electromagnetic engine torque and springy elements of this mechanism (REBEZNYUK 2009, DZYUBA et al. 2012). The vibrations and dynamic loads that occur during transition process and steady-state mode of the band saw machine adversely affect durability of a band saw and quality of received timber. In particular, the transverse vibrations of band saw blade, i.e. vibration in blade plane of the least stiffness, what causes cyclic tension, which reduces durability of a band saw. These vibrations are especially dangerous when their amplitude increases significantly and resonance occurs.

The known researches of oscillating occurrences in cutting mechanisms in general and of band saw machines vibration sin particular did not take into account movement of the saw blade and variability of tension force (MOTE

Correspondence: Olha Menshykova, Lviv State University of Life Safety, vul. Kleparivs'ka 35, Lviv, Ukraine, 79000.

1965, 1966, Sugihara 1977, Isupova 1981). Therefore it is advisable to study transverse vibrations of band saw blade, taking into account the speed of its longitudinal movement (cutting speed) and the variation of tension force.

Theoretical studies

A band saw is a component of a cutting mechanism elastic system, which is set and pulled on the saw pulleys. A working branch of a band saw is directed by leading rollers. A small eccentricity of saw pulleys and leading rollers and variable angular speed of attraction saw pulley during the transitional mode (turning on the machine) leads to change of the initial tension of band saw blade. In general, we shall assume that tension force is variable in time.

Vibrations of the working branch section between the leading rollers and of the non-working branch section between saw pulleys may occur due to external perturbation. In both cases, the design scheme of the saw blade sections is considered to be a bar on two hinged beams (Fig. 1). We assume that contact of a band saw blade with saw pulleys and leading rollers is constantly unseparated. Therefore, we suggest that there are no transverse displacement in the points of contact of a saw blade with saw pulleys and leading rollers. Considering the longitudinal movement of a saw we calculate speed v and study transverse displacement $u(x,t)$ of a saw blade section.

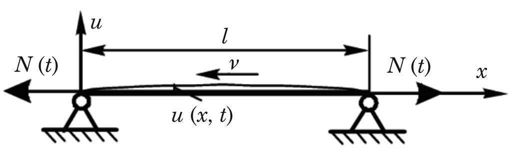

Fig. 1. The design scheme of a band saw blade

Forced transverse vibrations of a band saw blade as a moving bar with constant cross-section, can be described in Euler's variables by the differential equation with partial derivatives (Chen et. al. 2004, Mote 1965, Mote, Naguleswaran 1966, Sze et. al. 2005, Sugihara 1977):

$$\frac{\partial^2 u}{\partial t^2} + 2v\frac{\partial^2 u}{\partial x \partial t} + v^2\frac{\partial^2 u}{\partial x^2} - \frac{N(t)}{m}\frac{\partial^2 u}{\partial x^2} + \beta^2\frac{\partial^4 u}{\partial x^4} = \varepsilon f(x,t) \qquad (1)$$

where:

$u(x,t)$ – transverse displacement of band saw blade with the coordinate x of an arbitrary point in time,

ε – a small parameter, which in the right side of the equation means small value of perturbation force $f(x,t)$ versus regenerative force,

$\beta^2 = \frac{EI}{m}$,

m – mass per unit length of a saw blade,

E – modulus of elasticity of the material (steel),

$I = \frac{B \cdot s^2}{12}$ – moment of inertia of a rectangular cross-section of a saw blade with respect to the neutral axis,

B, s – width and height of the cross-section of a saw blade,

$N(t)$ – variable tension force.

According to the design scheme (Fig. 1) boundary conditions needed to solve the differential equation (1) are as follows

$$u\big|_{x=0} = u\big|_{x=1} = 0; \quad \left.\frac{\partial^2 u}{\partial x^2}\right|_{x=0} = \left.\frac{\partial^2 u}{\partial x^2}\right|_{x=1} = 0 \tag{2}$$

where l – length of the respective section of a band saw blade.

The effect of external perturbation force that may arise from eccentricity of a saw pulley or leading rollers is set as follows:

$$f(x,t) = H \sin(\Omega t) \tag{3}$$

where:

H, Ω – amplitude and frequency of the external perturbation.

Tension force variable is set inharmonic law (HASCHUK, NAZAR 2008, SOKIL, LISCHINSKA 2008)

$$N(t) = N_0 + \varepsilon N_1 \cos \mu t \tag{4}$$

where:

N_0 – a constant component of tension force,

μ – frequency of tension force variation,

N_1 – the amplitude of a variable component of tension force.

We assume that the static component conveys initial tension in the band saw blade (ISUPOVA 1981). When there is no cutting process the dynamic component, defined by oscillating occurrences and dynamic loads in the elastic cutting mechanism system, is negligible compared with static. This reflects the small parameter *4* in relationship (4).

Given (3), (4), the differential equation (1) becomes:

$$\frac{\partial^2 u}{\partial t^2} + 2v\frac{\partial^2 u}{\partial x \partial t} - \left(\frac{N_0}{m} - v^2\right)\frac{\partial^2 u}{\partial x^2} + \beta^2 \frac{\partial^4 u}{\partial x^4} = \varepsilon\left(H \sin \Omega t + \frac{N_1}{m} \cos \mu t \frac{\partial^2 u}{\partial x^2}\right) \quad (5)$$

Therefore, the challenge is to find the solution of equation (5) under boundary conditions (2). Depending on the ratio between frequency of free vibrations of a band saw blade ω, frequency of the external perturbation Ω and frequency of tension change μ different cases of transverse vibrations can be considered: nonresonant, approximate to resonant and resonant. As noted above, it is the most important to study the vibration of a band saw blade under the influence of periodic perturbation and variable tension force in the resonant case. In this case, a significant increase of the amplitude fluctuations results from periodic forces, frequencies of which are in rational relationship to the main frequency of the frequency spectrum $\Omega \approx \frac{p}{q}\omega$ where p and q are relatively prime integers. In case $p = q = 1$, (i.e. $\Omega \approx \omega$) then resonance is called main or ordinary. In case $q = 1$ (i.e. $\Omega \approx p\omega$) the overtone resonance at the eigenfrequency (parametric resonance) occurs. Regarding the parametric resonance it should be noted that if we consider the dynamic component of tension force as the perturbation force and take into account the average effect of external force for a long period of time, then in the first approximation there is only one kind of resonance $2\omega \approx \mu$ (VASILENKO 1992).

We will study main and parametric resonance in a complex. This allows for a small harmonic perturbation to confine only to the first approximation. The analytical solution of this task considering the speed of the longitudinal movement poses considerable mathematical difficulties. We therefore suggest a way of solving that is based on the use of the basic ideas of the Bubnov-Galerkin methods (VASILENKO 1992) and perturbation theory (NAIFE 1976). Accordingly, the solution of (5) satisfying the boundary conditions (2) can be represented as:

$$u(x,t) = \sum_{k=1}^{\infty} X_k(x)\, T_k(t) \quad (6)$$

where:

$X_k(x)$ – functions that satisfy the boundary conditions (2), i.e. $X_k(0) = X_k(l) = 0$ and $X_k''(0) = X_k''(l) = 0$.

It is easy to check that the function system $\{X_k(x)\} = \left\{\sin \frac{k\pi}{l}x\right\}$ is acceptable.

Single solution of equation (5) under homogeneous boundary conditions (2) can be represented in the form

$$u(x,t) = \sin\left(\frac{k\pi x}{l}\right) T(t),\ k = 1, 2, ... \tag{7}$$

where the function $T(t)$ is determined depending on the initial conditions. Hereinafter index k that indicates the shape oscillations is omitted.

Substituting (7) into (5), we obtain:

$$\begin{aligned}&\ddot{T}(t)\sin\left(\frac{k\pi x}{l}\right) - 2v\frac{k\pi}{l}\dot{T}(t)\cos\left(\frac{k\pi x}{l}\right) + \left(\frac{N_0}{m} - v^2\right)\left(\frac{k\pi}{l}\right)^2 T(t)\sin\left(\frac{k\pi x}{l}\right) + \\ &+ \beta^2\left(\frac{k\pi}{l}\right)^4 \sin\left(\frac{k\pi x}{l}\right) = \varepsilon\left(H\sin\Omega t - \frac{N_1}{m}\left(\frac{k\pi}{l}\right)^2 T(t)\cos\mu t\cdot\sin\left(\frac{k\pi x}{l}\right)\right)\end{aligned} \tag{8}$$

Multiplying both sides of the differential equation (8) by $\sin \frac{k\pi}{l}x$ and integrating the expressions in the range of 0 to l, we obtain the differential equation to find the unknown $T_k(t)$:

$$\ddot{T}(t) + \omega^2 T(t) = \varepsilon\left(\omega^2 H_2 T(t)\cos\mu t + H_3\sin\Omega t\right) \tag{9}$$

By definition, put, $\omega^2 = \left(\frac{k\pi}{l}\right)^2\left[\left(\frac{k\pi}{l}\right)^2\beta^2 + \frac{N_0}{m} - v^2\right]$, $\quad H_2 = \frac{2H(1-\cos k\pi)}{k\pi}$,

$$H_3 = \frac{-N_1}{S_0 - mv^2 + m\left(\frac{k\pi}{l}\right)^2\beta^2}.$$

Equation (9) belongs to the class of non-homogeneous linear differential equations with quasiperiodic coefficients. Their research is much complicated compared to the homogeneous linear differential equations with periodic coefficients, but the presence of the small parameter ε greatly simplifies the task. The above mentioned fact allows using asymptotic methods of Krylov-

-Bogolyubov to build solution of equation (9) and basing on it to study amplitude of resonant vibrations.

It is known (NAIFE 1976) that at resonance the phase difference between free vibrations and the external perturbation significantly influences amplitude and frequency of resonant vibrations. Therefore, to build a differential equation describing the change of amplitude and phase fluctuations, it is convenient to introduce the phase difference in the form:

$$\gamma = \psi - \theta$$

where $\theta = \frac{\mu t}{2}$, ψ denotes free vibrations phase.

Using a general idea of the method of Krylov-Bogolyubov-Mitropolsky (BOGOLIUBOV, MITROPOLSKY 1961), one-frequency solution of (9) in the first approximation we get:

$$T(t) = \alpha \cos(\theta + \gamma) + \varepsilon T_1 (\alpha, \gamma \theta) \tag{10}$$

where the amplitude α and the phase difference between the free vibrations and the external perturbation γ are values variable in time. They are determined basing on the differential equations:

$$\begin{aligned} \frac{d\alpha}{dt} &= \varepsilon \Lambda(\alpha, \gamma); \\ \frac{d\gamma}{dt} &= \omega - \frac{\mu}{2} + \varepsilon \Xi(\alpha, \gamma) \end{aligned} \tag{11}$$

where $\Lambda(\alpha, \gamma)$, $\Xi(\alpha, \gamma)$ are unknown functions that need to be found so that the relation (10), when $\alpha = \alpha(t)$, $\gamma = \gamma(t)$ which is solution of system (11) satisfies equation (9). It should be noted that the function $\Lambda(\alpha, \gamma)$, $\Xi(\alpha, \gamma)$ must be periodic with variable γ to the period 2π. To find these functions let's differentiate (10) in time:

$$\frac{dT}{dt} = \frac{d\alpha}{dt}\cos(\theta + \gamma) - \alpha \sin(\theta + \gamma)\left\{\frac{\mu}{2} + \frac{d\gamma}{dt}\right\} + \varepsilon\left\{\frac{d\alpha}{dt}\frac{\partial T_1}{\partial \alpha} + \frac{d\gamma}{dt}\frac{\partial T_1}{\partial \gamma} + \frac{\partial T_1}{\partial t}\right\};$$

$$\frac{d^2T}{dt^2} = \frac{d^2\alpha}{dt^2}\cos(\theta + \gamma) - 2\frac{d\alpha}{dt}\sin(\theta + \gamma)\left\{\frac{\mu}{2} + \frac{d\gamma}{dt}\right\} -$$

$$-\alpha \cos(\theta + \gamma)\left\{\frac{\mu}{2} + \frac{\mathrm{d}\gamma}{\mathrm{d}t}\right\}^2 - \alpha \sin(\theta + \gamma)\frac{\mathrm{d}^2\gamma}{\mathrm{d}t^2} + \tag{12}$$

$$+ \varepsilon\left\{\frac{\mathrm{d}^2\alpha}{\mathrm{d}t^2}\frac{\partial^2 T_1}{\partial\alpha} + \left(\frac{\mathrm{d}\alpha}{\mathrm{d}t}\right)^2\frac{\partial^2 T_1}{\partial\alpha^2} + \frac{\mathrm{d}^2\gamma}{\mathrm{d}t^2}\frac{\partial T_1}{\partial\gamma} + \left(\frac{\mathrm{d}\gamma}{\mathrm{d}t}\right)^2\frac{\partial^2 T_1}{\partial\gamma^2} + \right.$$

$$\left. + 2\frac{\mathrm{d}\alpha}{\mathrm{d}t}\frac{\mathrm{d}\gamma}{\mathrm{d}t}\frac{\partial^2 T_1}{\partial\alpha\partial\gamma} + 2\frac{\mathrm{d}\alpha}{\mathrm{d}t}\frac{\partial^2 T_1}{\partial t\,\partial\alpha} + 2\frac{\mathrm{d}\gamma}{\mathrm{d}t}\frac{\partial^2 T_1}{\partial t\,\partial\gamma} + \frac{\partial^2 T_1}{\partial t^2}\right\}$$

From the relations (11) it follows that:

$$\frac{\mathrm{d}^2\alpha}{\mathrm{d}t^2} = \varepsilon^2\frac{\partial\Lambda(\alpha,\gamma)}{\partial\alpha}\Lambda(\alpha,\gamma) + \varepsilon\left(\omega - \frac{\mu}{2}\right)\frac{\partial\Lambda(\alpha,\gamma)}{\partial\gamma} + \varepsilon^2\frac{\partial\Xi(\alpha,\gamma)}{\partial\gamma}\Xi(\alpha,\gamma);$$

$$\frac{\mathrm{d}^2\gamma}{\mathrm{d}t^2} = \varepsilon^2\frac{\partial\Xi(\alpha,\gamma)}{\partial\alpha}\Lambda(\alpha,\gamma) + \varepsilon\left(\omega - \frac{\mu}{2}\right)\frac{\partial\Xi(\alpha,\gamma)}{\partial\gamma} + \varepsilon^2\frac{\partial\Xi(\alpha,\gamma)}{\partial\gamma}\Xi(\alpha,\gamma);$$

$$\tag{13}$$

$$\left(\frac{\mathrm{d}\alpha}{\mathrm{d}t}\right)^2 = \varepsilon^2\Lambda^2(\alpha,\gamma);\ \frac{\mathrm{d}\alpha}{\mathrm{d}t}\frac{\mathrm{d}\gamma}{dt} = \varepsilon\left(\omega - \frac{\mu}{2}\right)\Lambda(\alpha,\gamma) + \varepsilon^2\Lambda(\alpha,\gamma)\Xi(\alpha,\gamma);$$

$$\left(\frac{\mathrm{d}\gamma}{\mathrm{d}t}\right)^2 = \left(\omega - \frac{\mu}{2}\right)^2 + 2\varepsilon\left(\omega - \frac{\mu}{2}\right)\Xi(\alpha,\gamma) + \varepsilon^2\Xi(\alpha,\gamma)^2$$

Substituting (10) into equation (9) and taking into account (12) and (13), after equating coefficients of the same ε powers, we obtain the differential equation of the first approximation, which combines functions t_1 (α, γ, θ), $\Lambda(\alpha, \gamma)$, $\Xi(\alpha, \gamma)$:

$$\left(\omega - \frac{\mu}{2}\right)\frac{\partial\Lambda(\alpha,\gamma)}{\partial\gamma}\cos(\theta + \gamma) - \left(\omega - \frac{\mu}{2}\right)\alpha\frac{\partial\Xi(\alpha,\gamma)}{\partial\gamma}\sin(\theta + \gamma) -$$

$$- 2\omega\Lambda(\alpha,\gamma)\sin(\theta + \gamma) - 2\omega\alpha\Xi(\alpha,\gamma)\cos(\theta + \gamma) + \tag{14}$$

$$+ \left(\omega - \frac{\mu}{2}\right)^2\frac{\partial^2 T_1}{\partial\gamma^2} + 2\left(\omega - \frac{\mu}{2}\right)\frac{\partial^2 T_1}{\partial t\partial\gamma} + \frac{\partial^2 T_1}{\partial t^2} + \omega^2 T_1 =$$

$$= \omega^2 H_2\alpha\cos(\theta + \alpha)\cos 2\theta + H_3\sin\theta$$

The resonance (14) takes the form:

$$\frac{\partial T_1}{\partial t^2} + \omega^2 T_1 \; \omega^2 H_2 \alpha \cos(\theta + \gamma) \cos 2\theta + \\ + H_3 \sin \theta + 2\omega \, \Lambda(\alpha,\gamma) \sin (\theta + \gamma) + 2\omega \alpha \Xi(\alpha,\gamma) \cos(\theta + \gamma) \tag{15}$$

For unambiguous determination of $\Lambda(\alpha,\gamma)$, $\Xi(\alpha,\gamma)$ additional conditions are applied to function $T_1(\alpha, \gamma, \theta)$ (BOGOLIUBOV, MITROPOLSKY, 1961). It is believed that the function $T_1(\alpha, \gamma, \theta)$ and its partial derivatives up to the second order including are 2π periodic for $\psi = \theta + \gamma$ and do not include in expansion items proportional to sin ψ and cos ψ .

Thus functions $\Lambda(\alpha,\gamma)$, $\Xi(\alpha,\gamma)$ are defined in such way that the following equations are satisfied.

$$\int_0^{2\pi} T_1(\alpha,\psi) \cos \psi d\psi = 0; \quad \int_0^{2\pi} T_1(\alpha,\psi) \sin d\psi = 0$$

From physical point of view application of the mentioned above conditions corresponds to choosing a as full amplitude of the first fundamental harmonic of oscillations.

The mentioned conditions provide absence of terms with first harmonics in the right part of equations for determining the desired functions $\Lambda(\alpha, \gamma)$, $\Xi(\alpha, \gamma)$, which makes it possible to avoid secular terms in solutions.

The differential equation (15) allows to get an equation (16) to find functions $\Lambda(\alpha, \gamma)$, $\Xi(\alpha, \gamma)$:

$$\omega^2 H_2 \alpha \int_0^{2\pi} \cos \psi \cos 2(\psi - \gamma) \sin \psi d\psi + \int_0^{2\pi} H_3 \sin (\psi - \gamma) \sin \psi d\psi + \\ + 2\omega \Lambda(\alpha,\gamma) \int_0^{2\pi} \sin \psi \sin \psi d\psi + 2\omega \alpha \Xi(\alpha,\gamma) \int_0^{2\pi} \cos \psi \sin \psi d\psi = 0$$

$$\omega^2 H_2 \alpha \int_0^{2\pi} \cos \psi \cos 2(\psi - \gamma) \cos \psi d\psi + \int_0^{2\pi} H_3 \sin (\psi - \gamma) \cos \psi d\psi + \\ + 2\omega \Lambda(\alpha,\gamma) \int_0^{2\pi} \sin \psi \cos \psi d\psi + 2\omega \alpha \Xi(\alpha,\gamma) \int_0^{2\pi} \cos \psi \cos \psi d\psi = 0$$

Calculating integrals, we have:

$$\begin{aligned} &\frac{\omega^2 H_2 \alpha \pi}{2} \sin \gamma + H_3 \pi \cos \gamma + 2\omega \pi \Lambda(\alpha, \gamma) = 0 \\ &\frac{\omega^2 H_2 \alpha \pi}{2} \cos 2\gamma - H_3 \pi \sin \gamma + 2\omega \alpha \pi \Xi(\alpha, \gamma) = 0 \end{aligned} \tag{16}$$

Defining from (16) functions $\Lambda(\alpha, \gamma)$, $\Xi(\alpha, \gamma)$ based on (11), we obtain system of differential equations which describes the basic parameters of vibrations:

$$\begin{aligned} \frac{d\alpha}{dt} &= -\frac{\varepsilon}{(\omega + 0.5\,\mu)} \left(\frac{\alpha H_2 \omega^2}{2} \sin 2\gamma + H_3 \cos \gamma \right) \\ \frac{d\gamma}{dt} &= \omega - 0.5\,\mu - \frac{\varepsilon}{(\omega + 0.5\,\mu)} \left(\frac{H_2 \omega^2}{2} \cos 2\gamma - \frac{H_3}{\alpha} \sin \gamma \right) \end{aligned} \tag{17}$$

Results and discussion

Graphic dependences of the amplitude of resonance oscillations for a band saw blade, which is $s = 1$ mm thick, $B = 26$ mm wide, and $l = 0.5$ m long on the working section (provided that: band saw material is steel, $E = 2.1\times10^5$ MPa, density $\rho = 7850$ kg/m^3, speed $\rho = 30$ m/s), were built basing on solution to equation (17) for the static component of tension force, which corresponds to different tensions of a saw blade (Fig. 2).

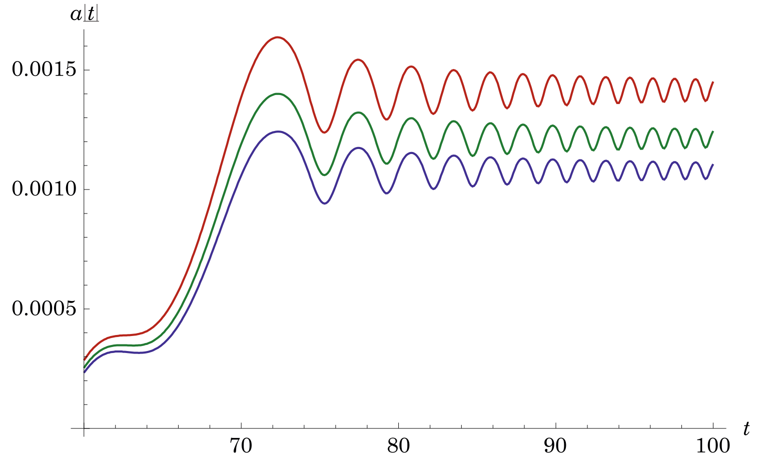

Fig. 2. Amplitude of resonant vibrations of working area for a band saw blade under initial tension: curve 1 – 200 MPa; curve 2 – 160 MPa, curve 3 – 120 MPa

As shown on Figure 2, on the area of a band saw blade between the leading rollers, when tension increases from of 120 MPa (curve 3) to 200 MPa (curve 1), the amplitude of resonance vibrations decreases by 0.4 mm. Thus a band saw blade under greater initial tension smoothly enters into saw cut under the condition of minor fluctuations of pretension force when the variable component of this force is 0.1% of the static one.

Resonant vibrations amplitudes of a band saw blade non-working branch under different pretension stresses are received under the same geometrical parameters of saw blade cross-section as for a working branch and a section l_1 = 1.3 m. When the length of the blade increases, the resonance vibrations amplitude grows to 4.4 mm in the middle section at the slightest pretension of 120 MPa and decreases to 3.3 mm for the pretension stress of 200 MPa (Fig. 3).

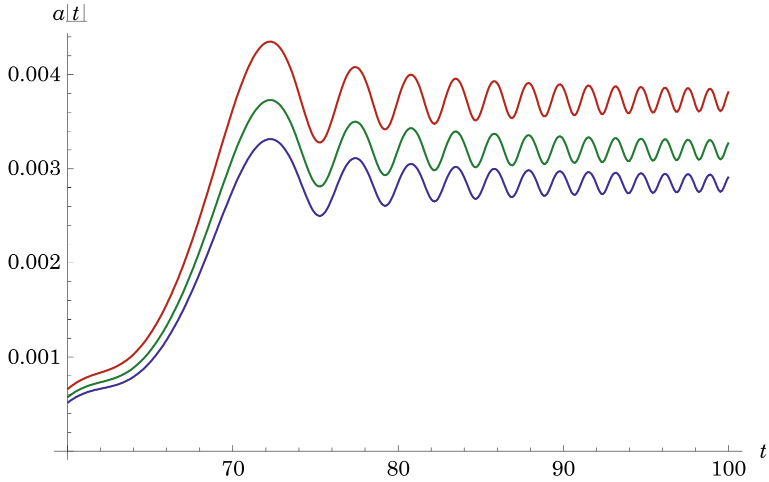

Fig. 3. Resonant vibrations amplitude of a band saw blade non-working branch under pretension stress: curve 1 – 200 MPa; curve 2 – 160 MPa, curve 3 – 120 MPa

Conclusions

Amplitude and frequency features of band saw blade sections were obtained in the result of solving the differential equation of forced transverse vibrations of a band saw blade as a stretched moving rod with stable cross-section, under condition of variable tension force. It was theoretically determined that section of a working branch of a saw blade between the leading rollers and an area of a drawn non-working branch can vary in resonant mode, if there is even a small perturbation force that results from the eccentricity of the leading rollers or saw pulleys. However, varying tension forces determined by oscillating occurrences and dynamic loads in the elastic cutting mechanism system were taken into account.

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MODELLING OF BOLTS IN MULTI-BOLTED CONNECTIONS USING MIDAS NFX

Rafał Grzejda

Department of Mechanics and Fundamentals of Machine Design
West Pomeranian University of Technology, Szczecin

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Abstract

In the paper a fragment of research on development of modelling methods of asymmetrical multi-bolted flange connections is presented. The effect of the bolt modelling method in a single bolted joint on both the stiffness characteristics of elements joined in the multi-bolted flange connection and bold forces have been examined. An analysis of the multi-bolted flange connection is carried out for selected models created using the finite element method (FEM). Guidelines for the selection of the bolt modelling method in the case of both the stiffness analysis and the load analysis of multi-bolted flange connections have been pointed out.

Introduction

Starting a process of designing the mechanical system, the designer needs to find a compromise between the level of model simplification and the required accuracy of performed calculations results (for a review, see SZABRACKI, LIPIŃSKI 2014). This applies particularly to FE-modelling of systems of many bodies being in a contact, an example of which are multi-bolted connections (Fig. 1).

In the papers (GRZEJDA 2013, WITEK, GRZEJDA 2006) modelling and calculations of selected multi-bolted flange connections were presented. The described models of these connections can be used to calculate asymmetrical systems, in which a flange element is joined with a rigid support. The most important feature of the proposed method of modelling is the treatment of the multi-bolted connection as a system composed of three subsystems, which are: bolts,

Correspondence: Rafał Grzejda, Katedra Mechaniki i Podstaw Konstrukcji Maszyn, Wydział Inżynierii Mechanicznej i Mechatroniki, Zachodniopomorski Uniwersytet Technologiczny, al. Piastów 19, 70-310 Szczecin, phone: +48 91 4494969, e-mail: rafal.grzejda@zut.edu.pl

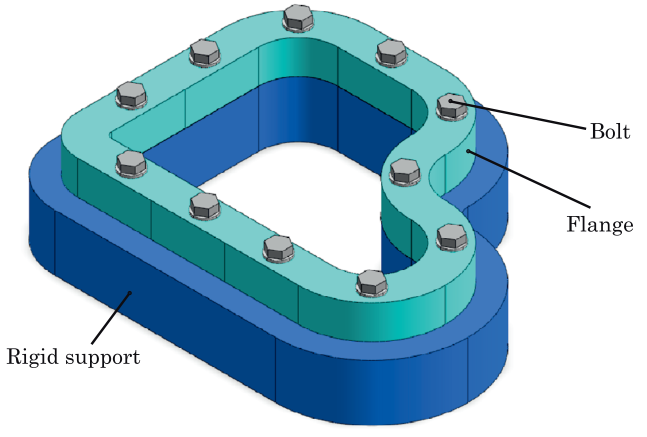

Fig. 1. Multi-bolted flange connection

the flange element and the contact layer between the flange element and the rigid support. Through this approach each subsystem can be modeled and developed separately.

In the paper (GRZEJDA 2014) the effect of the method of single bolted joint modelling on stiffness values of elements joined in this connection was investigated. Continuing with this work is the current paper, dedicated to developing the subsystem of bolts as a part of the multi-bolted system. Considerations are limited to testing the effect of simplifications of the single bolted joint model on both the stiffness characteristics of the connection and forces in the bolds. All analyses were carried out using the Midas NFX 2014 program.

Basics of the analysis

One of the important problems considered in the case of calculations of multi-bolted connections is the stiffness analysis of its elements. Treating the bolts as linear elements, their elastic flexibility can be easily and correctly determined by the instructions given in the standard VDI 2230 (GRUDZIŃSKI 2012) or by using the simplified method (BOUZID, BEGHOUL 2003). However, to determine the elastic flexibility of elements joined in multi-bolted connections, the finite element method is increasingly applied (for a review, see PEDERSEN, PEDERSEN 2008).

Analyzing publications on FE-modelling of bolted connections, it can be concluded that the following models are most commonly used by researchers:

– models without any bolts, but with the influence of the preload (CALISKAN 2006, TIROVIC, VOLLER 2005),

– plane models (TENMA et al. 2011),

– models, wherein the plain part of the bolt is modeled as a beam and its head as a rigid or deformable element (MONTGOMERY 2002, MONTGOMERY 2006),

– spatial models (NAGATA et al. 2011, WANG et al. 2013).

In the paper the usefulness of bolt models described in the literature for modelling of a set of bolts in multi-bolted connections is examined. For this purpose the following models of the separated bolted joint are chosen:

– the 3DB model, with the bolt modeled using cylindrical spatial elements,

– the SB model, in which the plain part of the bolt and its head are modeled with use of beam elements but the total volume of beam elements for the head is assumed to be equal to the volume of the head of the bolt in the 3DB model,

– the RBB model, consisted of the flexible plain part of the bolt and the rigid head of the bolt.

FEM-based models of the multi-bolted connection

Research were executed on an example of the multi-bolted flange connection shown in Figure 1. Calculations are carried out for the thickness of the flange h equal to 30 mm. The flange is fastened to a rigid support by means of eleven bolts M10 made in the mechanical property class 10.9. The preload of the bolt F_m is equal to 17.2 kN and it was set down on the base of Polish Standard PN-EN 1591-1. However, the total surface area of preload acting A_m is equal to 24.1 cm^2 and it was set down based on Polish Standard PN-EN ISO 7091. In the 3DB model of the connection, for modelling of the contact joint between the head of the bold and the flange default contact elements available in the Midas NFX 2014 program is used. In other models, contact elements are not included. Developed computational models of the multi-bolted connection are shown in Figure 2.

Calculations of the multi-bolted connection

The elastic flexibility of the bolt e_s is calculated according to the standard VDI 2230 (GRUDZIŃSKI 2012) as the sum of the elastic flexibility of the individual fragments of the bolt e_{si}

$$e_s = \sum_i e_{si} \tag{1}$$

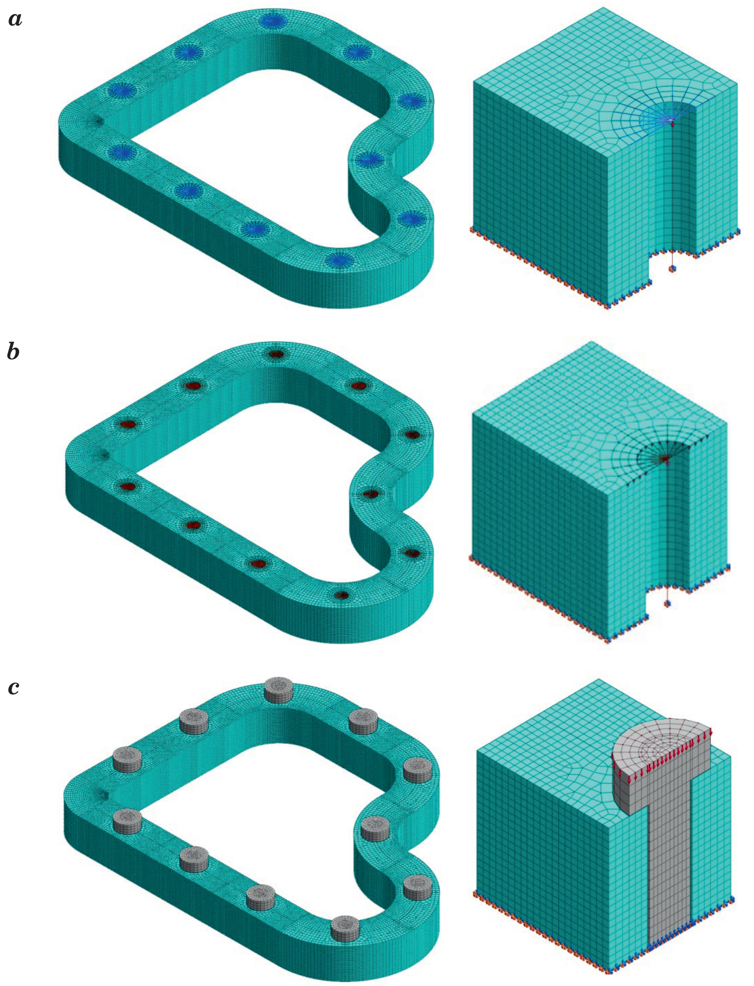

Fig. 2. Computational models of the multi-bolted connection: a – RBB model, b – SB model, c – 3DB model

Calculated from the formula (1) the elastic flexibility of the bolt is adopted equal for all models of the multi-bolted connection. Its value is given in Table 1.

However, the elastic flexibility of the joined flange element $e_{p,j}$ is defined based on the relationship (for a review, see HAIDAR et al. 2011)

$$e_{e,j} = \frac{\delta_\Sigma}{F_m} \tag{2}$$

where:

δ_Σ – average normal displacement of nodes lying in the total surface area A_m, under the action of forces F_m;

j – symbol of the consecutive FEM model of the connection, j = {RBB, SB, 3DB}.

The elastic flexibility of the joined flange element for all models are given in Table 1.

Table 1

Elastic flexibility values of the joined flange element [mm/MN]

e_s	$e_{p,\mathrm{RBB}}$	$e_{p,\mathrm{SB}}$	$e_{\mathrm{p,3DB}}$
2.91	0.177	0.188	0.184

The relative difference between the obtained elastic flexibility values is analyzed on the basis of the W_x index

$$W_x = \frac{e_{p,x} - e_{p,\mathrm{3DB}}}{e_{p,\mathrm{3DB}}} \tag{3}$$

where:

$e_{p,x}$ – flange elastic flexibility obtained for beam models of the connection (x = RBB lub SB),

$e_{p,\mathrm{3DB}}$ – flange elastic flexibility received for 3D model of the connection.

Calculated W_x index values are summarized in Table 2.

Table 2

W_x index values [%]

W_{RBB}	W_{SB}
–4.16	1.72

In the case of the stiffness analysis of the multi-bolted connection, the best bolt model among the proposed equivalent bolt models in relation to the 3D model is the SB model. The assumption of this model of the multi-bolted connection may result in increased values of the elastic flexibility of the joined flange element by approximately 2%.

The average value of the bolt force $F_{s,j}$ can be determined according to relations arising from the joint diagram in the form (JUVINALL, MARSHEK 2006)

$$F_{s,j} = F_m + F_e \cdot \frac{e_{p,j}}{e_{p,j} + e_s} \tag{4}$$

where:
F_e – external load.

It can be assumed that the external load F_e is proportional to the preload F_m

$$F_e = \alpha \cdot F_m \tag{5}$$

where:
α – ratio of the external load to the preload.

The $F_{s,j}$ values are set up in Table 3 for the parameter α adopted at the level of 0.5.

Table 3

Bolt force values [kN]

$F_{s,\mathrm{RBB}}$	$F_{s,\mathrm{SB}}$	$F_{s,\mathrm{3DB}}$
17.692	17.721	17.713

The relative difference between the obtained bolt force values is analyzed on the basis of the Z_x index

$$Z_x = \frac{F_{s,x} - F_{s,\mathrm{3DB}}}{F_{s,\mathrm{3DB}}} \tag{6}$$

where:
$F_{s,x}$ – average bolt force obtained for beam models of the connection (x = RBB lub SB),
$F_{s,\mathrm{3DB}}$ – average bolt force received for 3D model of the connection.

Calculated Z_x index values are summarized in Table 4.

In the case of the load analysis of the multi-bolted connection, the best bolt model among the proposed equivalent bolt models in relation to the 3D model is the SB model. The use of this model may cause a negligible increase of bolt force values up to 0.05 %.

Table 4

Z_x index values [%]

Z_{RBB}	Z_{SB}
–0.11	0.05

Conclusions

Studies on multi-bolted connections are often carried out in the aspect of the selected problems, in which knowledge of the distribution of stress and strain levels in all elements of the connection is not necessary. In the case of FEM analysis of the stiffness characteristics of multi-bolted connections or forces acting on the bolts in such connections, it is better to use simplified models of bolts and multi-bolted connections. Then the results of calculations can be obtained in shorter time and modelling becomes more efficient.

In the paper the load analysis is conducted based on the classical joint diagram, taking into account elastic flexibility values calculated using FEM. It is worthwhile to carry out a similar analysis based entirely on FEM. Results of this analysis will be described in a separate article.

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Guide for Autors

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