TEKA. COMMISSION OF MOTORIZATION AND ENERGETICS IN AGRICULTURE – 2013, Vol. 13, No. 1, 103–108

Polyoptimalization of the construction of subatmospheric pressure press with implementation of the finite element method

Dariusz Lodwik, Włodzimierz Malesa, Zbigniew Wiktorski

KONTENER, Production of Building Elements LLC
8 Kostrogaj Street, 09-400 Płock, Poland, e-mail: polsw@pw.plock.pl

Received February 9.2013; accepted March 14.2013

Summary. In this paper, implementation of CAD systems and the finite element method applied to the parametrization and poyoptimalization process of the test stand of subatmospheric press were discussed. The results, obtained in this way, are presented as electronic maps, tabular listing, charts and graphs. The proposed methodology of research is practically used to place orders for the needs of industry producing agricultural machines and devices, building industry and defense industry.
Key words: computer aided design, finite element method, contact stresses, distribution of stresses in the soil, subatmospheric press, parametrization, polyoptymalization.

INTRODUCTION

The subatmospheric press is intended for cohering large-size, multilayer composite elements. Composite elements are employed for the contraction of, among other things, self-supporting container constructions of various usage. Wall composite elements are also used in agricultural technology for cold store erecting and farm building construction [7].

In this work, practical aspects dealing with polyotimalisation of a digital model of test stand of the large-size press intended for subatmospheric cohering multilayer composite panels were discussed. The work on the project of the test stand of the subatmospheric press is co-supported financially by the European Regional Development Fund as a part of the Innovative Economy Programme [10].

In the project, a parametric digital model of the press (3D) with implementation of solid modeling with CAD system application was created. Sample constructional variants of presses, with different selected geometrical features, were generated [6]. The next stages of work were devoted to carrying on calculations of strength and stiffness for selected constructional cases of main components and parts constituting the supporting structure of modeled test stands with implementation of tools of analytical systems CAD (a frame analyzer, the finite element method). The last element of this work was devoted to finding optimal constructive solution to the problem of press construction, considering adopted scalar criteria [1, 2, 3, 4].

Fig. 1. The test stand of subatmospheric presses

DETERMINATION OF PARAMETRIC CONSTRUCTIONAL FEATURES (DECISION-MAKING VARIABLE) OF THE SUBATMOSPHERIC PRESS

The carrying frame, designed with closed-profile steel sections, is the basic constructive element of subatmospheric press. The frame construction is constituted with two stringers and two outer cross-bars which are connected in a process of welding. The inner construction of the carrying frame's truss was made of cross-bars which are perpendicularly welded to stringers of the frame. Perpendicularly to outer cross-bars and inner cross-bars, struts were welded, placed in two rows in a particular way that they constitute, together with stringers and cross-bars, a uniform surface on which a unit of panels was placed [7].

The features which played the role of parameters were selected in the construction of the subatmospheric press. The assigned parameters were coordinates describing constructive shape of particular constructive features and, determined on a stage of assumptions, values of layout dimensions [15, 17, 18, 19]. Two basic parameters, describing geometry of the carrying frame – ie. the length of the frame LR and its width SR, were determined in the construction of the press. It was presented in Figure 2.

The place for possible constructional solutions was generated, in the design process of the subatmospheric press, based on series of types [5] of the parameters. The determined unit of probable constructional solutions made realization of the assigned task of polyoptimalisation possible. The aim of this action was selection of possible constructional features of the subatmospheric press in order to optimise the basic criteria. The result of polyopimalisation is selection and conceptualisation of the concept of the press to be put into practical realization .

The units of values for the parameters, for which series of types of the construction of the subatmospheric press were set, are presented in Tables 1 and 2.

Table 1. The unit of the value for the L_R parameter [mm]

$L_R(1)$	$L_R(2)$	$L_R(3)$	$L_R(4)$	$L_R(5)$	$L_R(6)$	$L_R(7)$
3400	5200	7000	8800	10600	12400	14200

Table 2. The unit of the values for the S_R parameter [mm]

$S_R(1)$	$S_R(2)$	$S_R(3)$	$S_R(4)$	$S_R(5)$	$S_R(6)$	$S_R(7)$	$S_R(8)$
1380	1680	1980	2280	2580	2880	3180	3480

The whole number of choices for series of types was estimated at 8x7=56, but the number of selected options for the further analysis was limited because of time consuming complexity of calculations for this problem. The need for comparison of options due to technological conditions of cohering process of composite panels, was an additional reason for the choice.

Table 3. Dimensional values of parameters selected from series of types of the optional variety of the subatmospheric press

Working name of optional selection from series of types of the press	L_R [mm]	S_R [mm]
A	8800	2580
B	8800	2280
C	7000	2580
D	7000	2280

DETERMINATION OF QUANTITATIVE CRITERIA FOR POLYOPTIMALISATION OF THE SUBATMOSPHERIC PRESS

The aim of optimization deals with selection, from the unit of acceptable solutions, such a solution for which the objective function (optimisation criteria) reaches the extreme value (minimum or maximum). In case of the task of polyoptimalisation, lots of criteria of optimisation, sometimes opposing one another [12], come into existence.

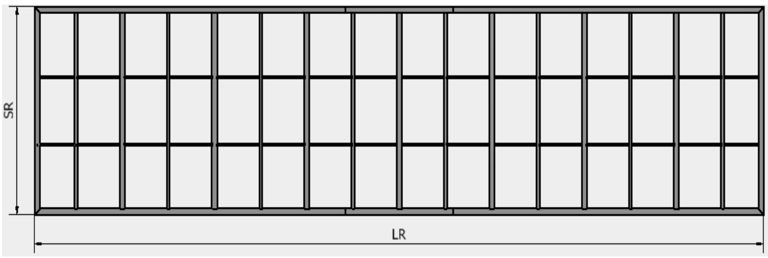

Fig. 2. Constructional parameters for the carrying frame of the subatmospheric press.

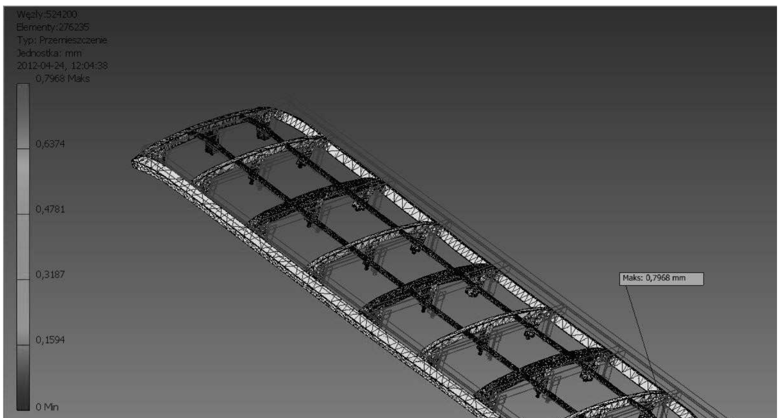

Fig. 3. The numeric map of displacement of the frame of the subatmospheric press formed during the cohering process (subatmospheric pressure of 400 hPa applied) – a view from the side of the supports

Two criteria for the task of polyoptimalisation were set in the discussed case of the construction of the subatmospheric press:

q_1 – the weight of the press (the carrying frame, the support, laminated panels, the rebate) given in [kg],

q_2 – maximal displacement in [mm] of constructive elements of the press operated with implementation of subatmospheric pressure at 400 Pa, determined with the use of the MES calculations [8, 9, 11, 13, 16, 20, 21].

The choice of the presented criteria was introduced due to the following matters:

– reduction of expenses spent on materials used to build the subatmospheric press,
– reduction of costs necessary to build the press (minimisation of weight directly results in the drop of technological expenses, e.g. the welding process),
– reduction of deformations of the carrying frame of the press during cohering process (400 hPascals' worth of subatmospheric pressure applied), due to this fact the circumstances affecting deformation of the formed element (multilayer composite panel) are held down.

The value of the q_1 criterion was determined based on a digital model of the press and qualities of materials used for its construction. This task was completed using the Inventor system by applying appropriate functions of this program (the Proprieties function). The value of the q_2 criterion was determined in a digital model by applying the finite elements method, implemented in the Autodesk Inventor. Pairs of numbers, valued for the q_1, q_2 criteria, were assigned for any constructional variety of series of types of subatmospheric press.

According to the above, for the problem analyzed, the positive cone will have coordinates set down for the a=(a1, a2) point, whose values were determined in the process of polyoptimalisation.

The mathematical notation is recorded as:

$$C_a = \{q = (q_1, q_2) : (q_i - a_i) \geq 0, \qquad i = 1{,}2\}.$$

In view of that, the $x_p=(x_{1p}, \dots, x_{np})$ polyoptical element will be such constructive solution (allotted for the Φ unit of possible solutions); it means that for any $x=(x_1, \dots, x_n)\in\Phi$ possible element there will not be any relation of minority according to the partial order set up by the positive cone between the $Q(x)=(q_1(x), q_2(x))$ elements and the $Q(x_p)=(q_1(x_p), q_2(x_p))$ element.

The polyoptimal constructions, which were set up in this way, comprise the Pareto unit for modeled series of types of the subatmospheric press construction.

DETERMINATION OF THE PARETO-OPTIMAL UNIT (UNDOMINATED SOLUTIONS) FOR SELECTED CASES OF THE PARAMETRIC MODEL OF THE SUBATMOSPHERIC PRESS

Two criteria q_1, q_2 were accepted to carry on the task of polyoptimalisation of the subatmospheric press construction. The q_1 criterion means the weight of the construction of the carrying frame of the subatmospheric press, together with supports, whereas the q_2 criterion means the maximal dislocation set up for the construction of the carrying frame and supports.

Four acceptable constructional x_A, x_B, x_C, x_D solutions were examined in the project task and also an appropriate value for quality indicators was calculated for every solution. In the target space, a unit of four $a_A(q_1, q_2)$, $a_B(q_1, q_2)$, $a_C(q_1, q_2)$, $a_D(q_1, q_2)$ points, which comprises quality vector for every constructional solutions, was obtained.

The polyoptical solution, in terms of the Pareto sense, is any acceptable solution, for which any other acceptable dominating solution does not exist. No solution, for which the value of all criteria would be better than any optional polyoptimal solution, exists in the unit of the correct solutions.

The Pareto relation (equal to the relation of partial order specified by the positive cone) is the most frequently met relation which is implemented to defy the polyoptimal solution [12].

In the analyzed task, the following coordinates of the a_A, a_B, a_C, a_D points, in the (q_1, q_2) criterion space, were determined in the process of the MES calculations.

Table 4. Coordinates of the a_A, a_B, a_C, a_D points in the q_1, q_2 criterion space

real results	q_1 [kg]	q_2 [mm]
a_A	1842,74	0,7915
a_B	1707,84	1,3990
a_C	1495,85	0,6801
a_D	1391,18	0,7968

In order to make the values for the points in the criterion space more readable and comprehensive, the subsequent measure was implemented – normalisation of their coordinates in concordance with the following dependence:

$$q_i^N = \frac{q_i}{q^{MAX}} ,$$

$$where: q^{MAX} = MAX(q_i(a_A), q_i(a_B), q_i(a_C), q_i(a_{AD}))$$

The maximal values for the q_1^{MAX}=1842,74 kg, q_2^{MAX} = 1,3990 mm. criterion function was determined, running Table 4. Based on this action, the normalizing measure of the value for the q_1, q_2 and function was implemented, according to the dependence presented in Table 5.

$$q_i \xrightarrow{normalisation} q_i^N$$

Table. 5. Normalized values for the coordinates of the $a_A^N, a_A^N, a_A^N, a_A^N$ points in the (q_1^N, q_2^N) criteria space.

Normalized results	q_1^N	q_2^N
a_A^N	1,0000	0,5658
a_B^N	0,9268	1,0000
a_C^N	0,8118	0,4861
a_D^N	0,7550	0,5695

In Figure 4, the dimensional graph of the (q_1, q_2) target space was presented, where the unit of four a_A, a_B, a_C, a_D points, or vectors of quality for particular constructional solutions of (A, B, C, D), was also illustrated.

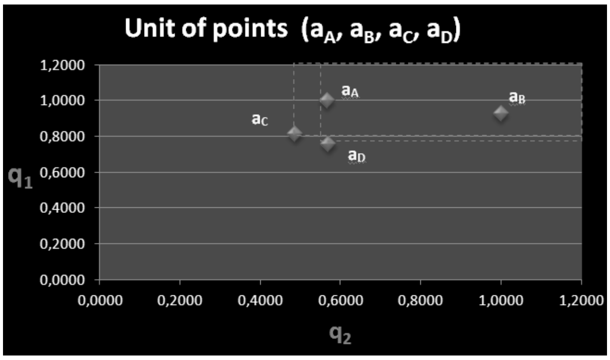

Fig. 4. Graphic illustration of the target space

When investigating into relations between the elements, the Pareto unit was determined, following the dependence:

$$x_p \in \Phi: \bigwedge_{x \in \Phi} \text{does not occur } Q(x) \overset{c}{\prec} Q(x_p),$$

polyyoptimal values were determined in the unit of obtainable targets or a_C and a_D. Consequently, polyoptical constructions are constructions valued by vectors of the x_3, x_4 decision-making variables. The element matched as a_A exists in the space determined by the positive cone of the a_C point, which means that a_C dominates over a_A. The similar situation is observed in the next case, where an element lies in the area of the cones of the aC and aD positive points, and this results that it is dominated by them. On the other hand, the aC and aD points are not dominated by one another, which means that they constitute representation matching the Pareto unit, that is poloptimal constructions. The graphic illustration of this problem is provided in Figure 5.

And subsequently, the task of polyoptimalisation was solved and also “the best element” was determined by the implementation of the target polyoptimalisation method.

DETERMINATION OF THE OPTIMAL SOLUTION WITH APPLICATION OF THE TARGET POLYOPTIMATISATION METHOD

The target method is applied when the target point in the target space, which would be an ideal solution if could be gained, is given. Such a point is always physically unapproachable (utopian) and usually it is the beginning of the co-ordinate system in the target space [12].

The target point forms the q_1=0 and q_2=0 co-ordinates (zero value for the weight of the frame construction and zero value for displacement), in the discussed problem.

The target polyoptimalisation depends on the searching for such solution of the Pareto unit (the x_3, x_4 constructions), for which the distance, in terms of the selected norm from the target solution, reaches its minimum in the target space. The solution existing in the closest range of the target point is treated as the most optimal.

In this way, a new target function is generated; it is made as the distance between the target state and the optional state in the target space, which can be recorded in the following way:

$$Q^*(x) = \|Q_0 - Q(x)\|,$$

where:

$$Q_0 = (q_{10}, \ldots, q_{s0}).$$

In the discussed case of polyoptimalisation of the construction of the subatmospheric press, when s=2 the Q_0 target point forms the following expression:

$$Q_0 = (q_{10} = 0, q_{20} = 0).$$

The Q*(x) function is a scalar function and determines the distance of the point belonging to the target space from the point at which it is aimed, and its value depends on the decision-making variables making up the x=(x_1, …., x_n). construction. The calculating methods of the one-criterion optimalisation are applied to reduce the Q*(x) function, and finds the .optimal solution in this explicit way.

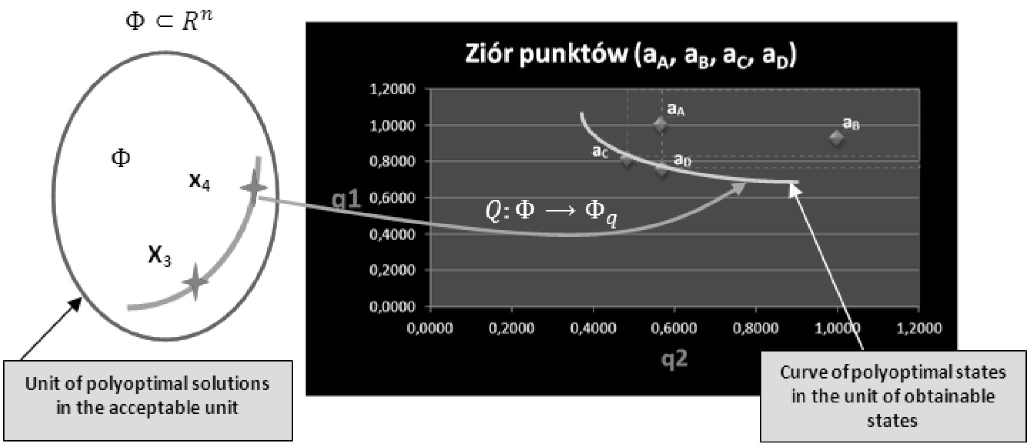

Fig. 5. Graphic illustration of the Pareto unit

The way the Q*(x) function is recorded depends on the accepted norm. In case of the Euclid norm, it forms the following expression:

$$Q(x) = \sqrt{\sum_{i=1}^{i=s} \left(q_{i0} - q_i(x)\right)^2}\ .$$

In case of polyoptimalisation of the subatmospheric press, for the case when s=2 and the qi values were normalised, the $Q_j(x)$ function will form the expression:

$$Q(x) = \sqrt{(q_{10} - q_1)^2 + (q_{20} - q_2)^2}.$$

Because of the fact that, in the discussed case, the co-ordinates of the target point in the target space are equal to zero, the Q(x) function forms the expression:

$$Q(x) = \sqrt{q_1^2 + q_2^2}\ .$$

In the analysed process of polyoptimalisation of the construction of the subatmospheric press, the Pareto unit is constituted of two (x_3, x_4), solutions, for which the values of the functions in the q_i target space as well as the distance from the Q(x) point at which it is aimed is presented in Table 5.

Table 6. Values for the Q(x) function

Normalised results	q_1^N	q_2^N	Q(x)
X_3	0,8118	0,4861	0,9462
X_4	0,7550	0,5695	0,9457

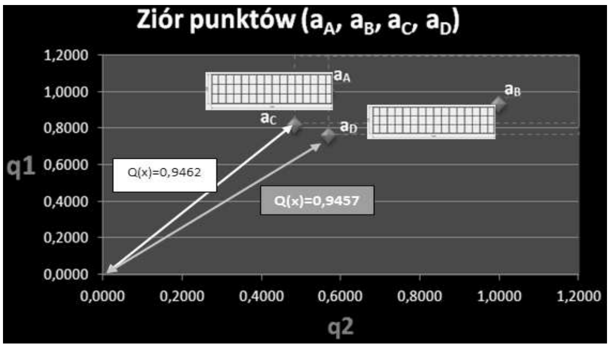

Fig. 6. The selection of the optimal point in the target space

The findings derived from the analysis of the calculations results, presented in Table 6 with graphic representation in Figure 6, lead to the ultimate conclusion that, it is the choice number 4 of the press for the construction of the subatmospheric press which is the optimal solution (the lowest value for the Q(x)=0,9457 function).

CONCLUSIONS

The results of the calculations are presented in the form of numerical maps, tabular listing, charts and graphs. The analysis of theoretical calculations demonstrated the compatibility with the results gained based on empirical research carried on in the “KONTENER” – Production of Building Elements LLC in Płock, Poland. Practical application of the CAD systems and the MES calculations, presented in the discussed matters, gives the following practical benefits:

- vast cut of time of applied researches and designing work due to numerical analysis of many possible options for the press,
- relief given to the investigational team from routines and uncreative working,
- completion of reliable researches with implementation of computer systems, at the project-stage of the press,
- possibility of optimalisation of the construction on the grounds of the chosen criterium.
- proposed methodology of researches was practically used to place orders for the needs of industry producing agricultural machines and devices, building industry and defense industry.

REFERENCES

1. **Branowski B., 1998:** Wprowadzenie do projektowania, PWN.
2. **Chlebus E., 2000:** Techniki komputerowe CAx w inżynierii produkcji, WNT.
3. **Dietrych J., 1978:** System i konstrukcja, WNT.
4. **Encarnacao J.L., Lindner R., Schlechtendahl E.G.,** Computer Aided Design, Springer-Verlag.
5. **Gendarz P., 1998:** Aplikacje programów graficznych w uporządkowanych rodzinach konstrukcji, Wydawnictwo Politechniki Śląskiej, Gliwice.
6. **Jaskulski A., 2009:** Autodesk Inventor 2009PL/2009+ metodyka projektowania, PWN.
7. **Jakliński J., Lodwik D., Malesa W., Wiktorski Z., 2012:** The test stand calculations of the research station of sub-atmospheric pressure press with implementation of the finite element method, TEKA Kom. Mot. I Eng. Roln. OL PAN, Vol 12. No. 2. 81–86.
8. **Król K., 2006:** Metoda elementów skończonych w obliczeniach konstrukcji, Politechnika Radomska, Wydawnictwo.
9. **Kruszewski J., Gawroński W., Wittbrodt E., Najbar F., Grabowski S., 1975:** Metoda sztywnych elementów skończonych, Arkady.
10. **Maksimow V., Galgash R., Synytsya L., 2010:** Information and organizational-economic aspects of innovative development management of regional enterprises, TEKA Kom. Mot. I Eng. Roln. OL PAN, 10D, 184–189.
11. **Niezgodziński M.E., Niezgodziński T., 1996:** Wzory, wykresy i tablice wytrzymałościowe, WNT.
12. **Osiński Z., Wróbel J., 1995:** Teoria konstrukcji, PWN,
13. **Rakowski G., Kacprzyk Z., 2005:** Metoda elementów skończonych w mechanice konstrukcji, OWPW.
14. **Rohatyński R., Miller D., 1994:** Problemy metodologii i komputerowego wspomagania projektowania technicznego, tom 1, Wydawnictwo Politechniki Wrocławskiej.

15. **Sydor M., 2009:** Wprowadzenie do CAD. Podstawy komputerowo wspomaganego projektowania, PWN.
16. **Szmelter J., Dacko M., Dobrociński S., Wieczorek M., 1979**: Metoda elementów skończonych w statyce konstrukcji. Przykłady obliczeń, Arkady.
17. **Szymczak C., 1998:** Elementy teorii projektowania, PWN.
18. **Tarnowski W., 1997:** Podstawy projektowania technicznego, WNT.
19. **Wróbel J., 2004:** Technika komputerowa dla mechaników, OWPW.
20. **Zagrajek. T., Krzesiński G., Marek P. 2006:** Metoda elementów skończonych w mechanice konstrukcji. Ćwiczenia z zastosowaniem systemu ANSYS, OWPW.
21. **Zienkiewicz O.C., 1972:** Metoda elementów skończonych, Arkady.

POLIOPTYMALIZACJA KONSTRUKCJI PRASY PODCIŚNIENIOWEJ Z ZASTOSOWANIEM METODY ELEMENTÓW SKOŃCZONYCH

Streszczenie. W artykule przedstawiono zastosowanie systemów CAD i metody elementów skończonych w procesie parametryzacji i polioptymalizacji stanowiska badawczego prasy podciśnieniowej. Uzyskane wyniki obliczeń przedstawiono w postaci map numerycznych, zestawień tabelarycznych oraz wykresów. Zaproponowana metodyka badań została praktycznie wykorzystana do realizacji zleceń dla potrzeb przemysłu maszyn i urządzeń rolniczych, budownictwa oraz przemysłu obronnego.

Słowa kluczowe: komputerowo wspomagane projektowanie, metoda elementów skończonych, naprężenia kontaktowe, rozkład naprężeń w glebie, prasa podciśnieniowa, parametryzacja, polioptymalizacja.