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GENETIC ALGORITHM BASED OPTIMISATION OF CONVEYOR BELT MATERIAL CROSS SECTION AREA

Željko Vrcan, Neven Lovrin

Original scientific paper

Belt conveyors are used to transport large quantities of bulk material quickly and economically over short to medium distances, e.g. for transfer from the extraction point to a processing station or shipment point. The load capacity of a belt conveyor depends on several factors, such as the trough cross section of the conveyor belt, belt speed, material density and material angle of surcharge. The load capacity of belt conveyors is mostly determined by the trough cross section, so cross sections of commercially available troughs have been compared to cross sections of matching roller layout, but optimised via a genetic algorithm. A comparison has also been made with deep semi-circular troughs, due to a significant increase in material cross section when compared to flat, v-shaped, trapezoidal and polygonal troughs.

Keywords: *belt conveyor, conveyor belt, genetic algorithm, load capacity, optimisation*

Optimizacija poprečnog presjeka materijala na transportnoj traci putem genetskog algoritma

Izvorni znanstveni članak

Trakasti transporteri se koriste za brzi i ekonomični transport velikih količina rasutog materijala na kratkim do srednjim udaljenostima, npr. za transport od mjesta iskopa do pogona za pročišćavanje ili mjesta pretovara. Kapacitet trakastog transportera ovisi o više vrijednosti, poput poprečnog presjeka materijala na transportnoj traci, brzine kretanja trake, gustoći transportiranog materijala te kuta nasipanja materijala. Poprečni presjek materijala ima najveći utjecaj na kapacitet trakastog transportera pa su uspoređeni poprečni presjeci za komercijalno dobavljive valjne slogove s poprečnim presjecima valjnih slogova odgovarajuće geometrije, no optimiziranih putem genetskog algoritma. Provedena je i usporedba s dubokim polukružnim valjnim slogom putem radne širine trake zbog bitnog povećanja poprečnog presjeka materijala kod tog valjnog sloga u odnosu na jednovaljčane, dvovaljčane, trovaljčane i peterovaljčane slogove.

Ključne riječi: *genetski algoritam, kapacitet, optimizacija, trakasti transporter, transportna traka*

1 Introduction
Uvod

Belt conveyors have important industrial applications. They are used to transport material between processing equipment, and are also used in conjunction with various transportation and machine equipment. The principles of belt conveyor operation have been known for thousands of years [1]. The ancients used logs as rollers to convey large stone blocks for the building of palaces and temples. Belt conveyors were quite simple in ancient times. They had wooden rollers and a belt that traveled over the wooden rollers. The earliest conveyor belts were made of leather, canvas or rubber. These primitive belt conveyors were very popular for conveying bulky items. In the 20th century, belt conveyors found more widespread application. Furthermore, the design of belt conveyors has improved over the years and now belt conveyors are an inevitable part of modern industry and everyday life (Fig. 1).

Today, belt conveyors are employed wherever there is a need to quickly transport large quantities of bulk material with minimal handling costs over short to medium distances, e.g. to transfer ore from a mine shaft to a processing station or a shipment point. Therefore, the load capacity is one of the most important design parameters of a belt conveyor, as expressed by the equation (1) [2]:

$$Q = A \cdot \gamma \cdot v_{\mathrm{t}} \tag{1}$$

where Q (kg/s) is the load capacity of the belt conveyor, A (m^2) is the cross section of the bulk material as loaded on the conveyor belt, γ (kg/m^3) is the density of the bulk material, and v_t (m/s) is the conveyor belt speed. As the density of the bulk material is constant, and belt speed is selected from a standard range, it is obvious that optimisation can be carried out by influencing the cross section of the bulk material A.

Figure 1 *Modern belt conveyor for coal in the port of Immingham - Great Britain* [1]
Slika 1. *Moderni trakasti transporter za ugljen u luci Immingham - Velika Britanija* [1]

The cross section of the bulk material depends on several factors, notably the trough type, placement angle and length of side rollers, material constituency and angle of surcharge, and finally the loading method of the conveyor belt.

Optimisation of the material cross section is important in load capacity calculation as it enables the selection of optimal belt width and speed. According to standards DIN 2201 [3] and ISO 5048 [4] the active belt width is assumed to be:

$$b = 0{,}9 \cdot B - 0{,}05 \quad \text{for } B \leq 2\ \text{m} \tag{2}$$

$$b = B - 0{,}25 \quad \text{for } B > 2\ \text{m} \tag{3}$$

where B (m) is the belt width, and b (m) is the active (material carrying) belt width.

Even though the material above the trough is shaped like a relatively flat and open parabola, it is assumed that substituting the parabola with an isosceles triangle whose base angles are equal to the material angle of surcharge (as it is proposed in [3]), produces no significant error while the cross section calculation is significantly simplified.

1.1 Overview of trough cross sections
Pregled valjnih slogova

The material cross section of a flat trough is determined by the active belt width b and angle of surcharge φ (Fig. 2), and is considered to be equal to the area of an isosceles triangle A:

$$A=\frac{b^2}{4}\tan\varphi\,. \tag{4}$$

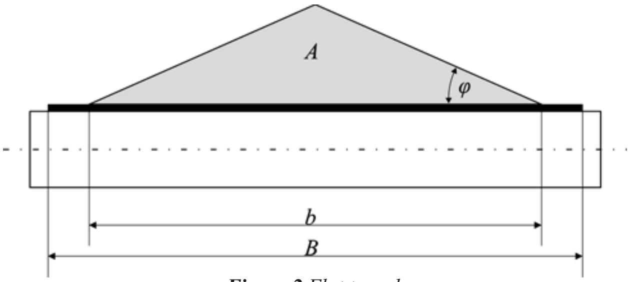

Figure 2 *Flat trough*
Slika 2. *Jednovaljčani slog*

It is quite clear from (4) that, for a given angle of surcharge, the area of the cross section of a flat trough depends entirely on the active belt width b and angle of surcharge φ.

The cross section of a V-shaped trough is determined by the active belt width b, angle of surcharge φ, and roller inclination angle λ (Fig. 3), and equals the summed area of two isosceles triangles, A_1 and A_2:

$$A=A_1+A_2=\frac{b^2}{4}\left(\frac{\sin 2\lambda}{2}+\cos^2\lambda\tan\varphi\right)=\frac{b^2}{4}K\,. \tag{5}$$

The largest possible surface area of the cross section will be achieved for

$$\frac{\partial K}{\partial\lambda}=0:$$

$$\frac{\partial K}{\partial\lambda}=\cos 2\lambda-\sin 2\lambda\tan\varphi=\cot 2\lambda-\tan\varphi=\frac{\cos(2\lambda+\varphi)}{\sin 2\lambda\cos\varphi}=0\,. \tag{6}$$

As (6) can be equal to zero only if its numeral is zero:

$$\cos(2\lambda+\varphi)=0\rightarrow 2\lambda+\varphi=\frac{\pi}{2}\rightarrow\lambda_{\mathrm{opt}}=\frac{1}{2}\left(\frac{\pi}{2}-\varphi\right). \tag{7}$$

Based on (7), it is clear that the optimal roller inclination angle λ_{opt} is a function of the material angle of surcharge, however the roller inclination angle λ is practically restricted to 15°…30° due to durability related belt bending constraints.

The trapezoid trough is an improvement of the V-shaped trough, and the material cross section area A is the sum of the isosceles triangle A_1 and trapezoid A_2 (Fig. 4):

$$\begin{aligned}A&=A_1+A_2=\frac{b_1^2}{4}\tan\varphi+\frac{b_1^2-a_1^2}{4}\tan\lambda=\\&=\frac{b_1^2}{4}\left(\tan\varphi+\tan\lambda\right)-\frac{a_1^2}{4}\tan\lambda\,.\end{aligned} \tag{8}$$

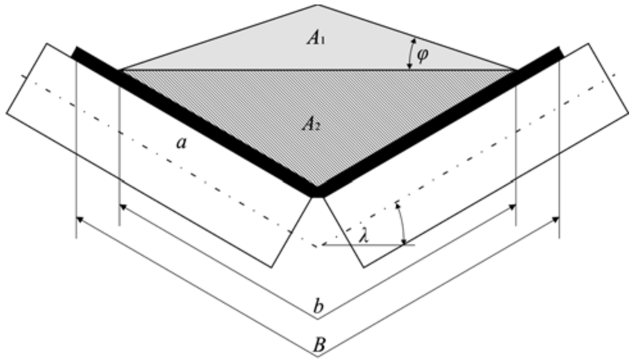

Figure 3 *V-shaped trough*
Slika 3. *Dvovaljčani slog*

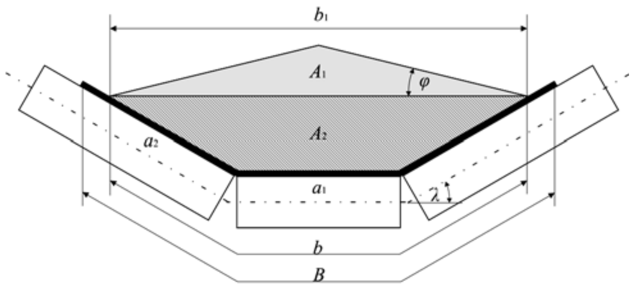

Figure 4 *Trapezoid trough*
Slika 4. *Trovaljčani slog*

After substituting the auxiliary variable $b_1=a_1+(b-a_1)\cos\lambda$, which was introduced for ease of calculation, and

$$c=\frac{a_1}{b}:$$

$$A=\frac{b^2}{4}\left\{\left[c+(1-c)\cos\lambda\right]^2\left(\tan\lambda+\tan\varphi\right)-c^2\tan\lambda\right\}=\frac{b^2}{4}K_3. \tag{9}$$

The coefficient K_3 is a function, $K_3=K_3(\varphi,\lambda,c)$. As φ and λ can be considered constants, the largest possible cross section will be obtained for

$$\frac{\partial K_3}{\partial c}=0:$$

$$\frac{\partial K_3}{\partial c}=2\left[c+(1-c)\cos\lambda\right](1-\cos\lambda)(\tan\lambda+\tan\varphi)-2c\tan\lambda=0. \tag{10}$$

When (10) is solved for c:

$$c_{\mathrm{opt}}=\frac{(\cos\lambda-1)\cdot(\cos\lambda\tan\varphi+\sin\lambda)}{(\cos\lambda-2)\cdot(\cos\lambda\tan\varphi+\sin\lambda)+\tan\varphi}. \tag{11}$$

Based on (11), it is clear that the optimal cross section is determined by material angle of surcharge, roller inclination, and middle roller length. Even though a trough with different roller lengths would offer greater loading capacity, it is customary to use troughs with all three rollers of equal length a i.e. $a = a_1 = a_2$ for ease of manufacturing. Belt durability issues constrain the belt bending angle of trapezoid troughs as well and therefore limit the load capacity.

In cases where a large load capacity is needed, or the belt banding angle must be limited to 140° or less, polygonal five roller troughs are used (Fig. 5). Additionally, the load capacity increases by about 10…12 % when compared to trapezoid troughs. The area A is calculated as the sum of the isosceles triangle A_3 and trapezoids A_1 and A_2:

$$
\begin{aligned}
A = b^2 \big[&(x_1 + x_2 \cos\lambda_1) x_2 \sin\lambda_1 + \\
+ &(x_1 + 2x_2 \cos\lambda_1 + x_3 \cos\lambda_2) x_3 \sin\lambda_2 \big] + \\
+ b^2 &\left[\frac{1}{4} (x_1 + 2x_2 \cos\lambda_1 + 2x_3 \cos\lambda_2)^2 \tan\varphi \right],
\end{aligned} \tag{12}
$$

where $x_i = \dfrac{a_i}{b}$, (i = 1...3).

The rollers are usually of equal length, $a_1 = a_2 = a_3 = a$, while the rollers are placed at angles of $\lambda_1 = 28°$, $\lambda_2 = 56°$ or $\lambda_1 = 22{,}5°$, $\lambda_2 = 45°$. The only significant disadvantage of the polygonal trough lies in the increased number of rollers, leading to an increased number of bearings and increased frictional losses.

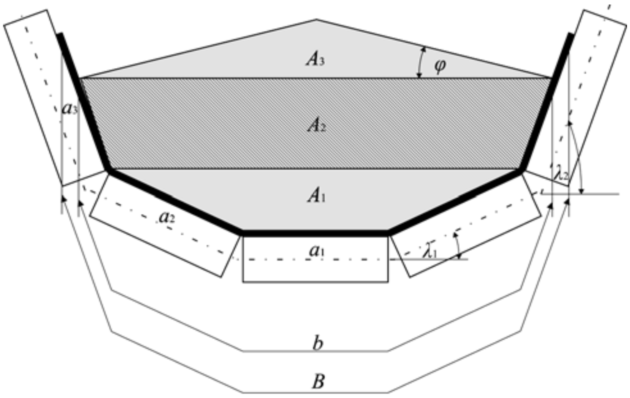

***Figure 5** Polygonal trough*
***Slika 5.** Peterovaljčani slog*

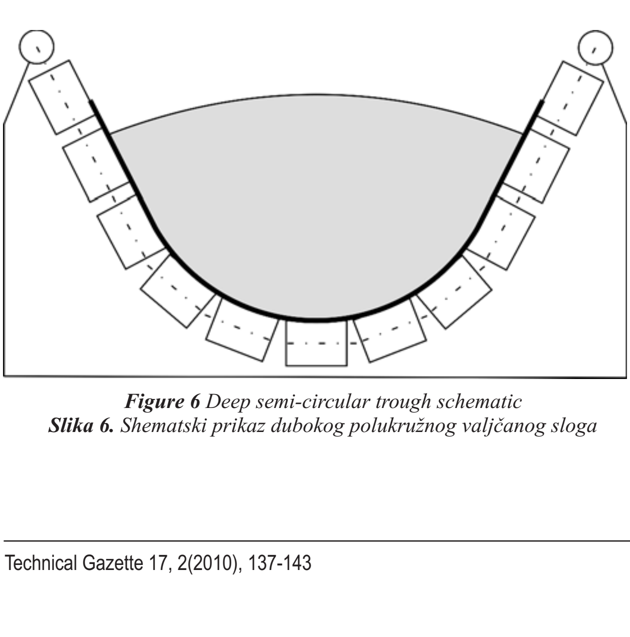

***Figure 6** Deep semi-circular trough schematic*
***Slika 6.** Shematski prikaz dubokog polukružnog valjčanog sloga*

Studies researching improved cross-sectional capacity of conveyor belts with regard to their trough shape have led to semi-circular shapes as they offer greatest capacity when compared to V, trapezoidal, or polygonal belts (Fig. 6 and 7 [5]). Another advantage of this shape is the largest possible angle between the rollers which significantly reduces belt bending stresses.

***Figure 7** Deep semi-circular trough roller configuration* [5]
***Slika 7.** Raspored valjaka dubokog polukružnog valjčanog sloga* [5]

This particular trough shape greatly reduces material spillage due to settling, and the transporter can be made to cross over higher slopes and bend through tighter curves (Fig. 8) [5]. Furthermore, roller set spacing can be increased as this particular shape reduces belt sagging.

Even though the cost of a single trough might be increased due to the greater number of components, maintenance costs are greatly reduced as a semi – circular trough can be easily disassembled at the joint links to replace just the failed part, and the parts themselves can be replaced without having to resort to lifting equipment as in the case of V, trapezoidal and polygonal shaped troughs.

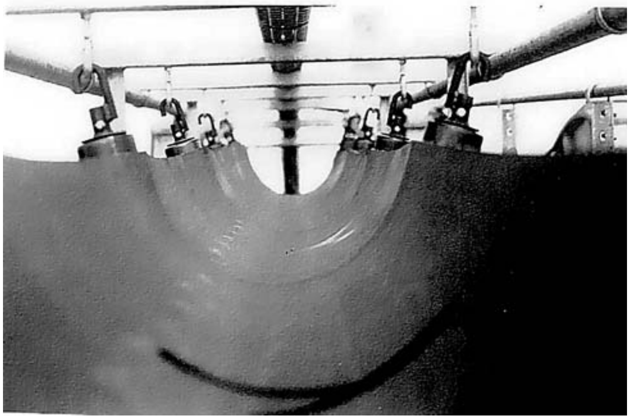

***Figure 8** Deep semi-circular trough with belt* [5]
***Slika 8.** Duboki polukružni valjčani slog s transportnom trakom* [5]

These improvements have been confirmed by various experiments and international patents [5], and the path to a new concept in belt conveyor design has been laid.

According to Fig. 9, the total cross section A of a deep semi-circular trough is made up of the circular section A_1 and triangular section A_2.

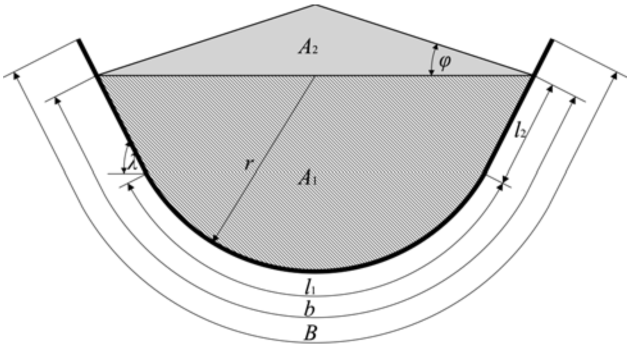

Figure 9 *Deep semi-circular trough optimisation*
Slika 9. *Optimizacija poprečnog presjeka materijala kod dubokog polukružnog valjčanog sloga*

$$A = A_1 + A_2 = r^2\lambda + \frac{2r^2}{\tan\lambda} + \left(\frac{r}{\sin\lambda}\right)^2 \tan\varphi \,. \qquad (13)$$

2 The genetic algorithm
Genetski algoritam

The genetic algorithm is a computer run process which mimics natural evolutionary processes and applies them to abstract units called individuals [6]. A full set of individuals forms a population which progresses through evolutionary stages called generations in which each individual represents a potential solution to the problem. The solution data attributed to an individual is a chromosome [7].

Every individual fulfils the parameters of the target function (the function being optimised) to a particular degree. Therefore, a new population is formed from the old one by selecting the most successful individuals, and filling the remainder of the population with individuals created by use of the genetic operators of mutation (solution data is randomly changed within selected parameters) and crossover (exchange of data between pre-existing individuals). After a certain number of generations, the final population should have an individual close to the ideal solution.

On initialising, the initial population is filled with individuals with randomly created data based on optimisation constraints, but a known solution can be also inserted into the initial population. The algorithm is stopped when it has been running for a predefined amount of time, or an optimisation constraint is met, e.g. the best value of the target function in two consecutive generations differs less than 1 %.

As the algorithm works, it uses the operators of mutation, selection and crossover. Selection removes individuals which do not fulfil minimum feasibility criteria from the population, while the others are subject to crossover and mutation in order to create the next population which will provide a better solution of the target function. When looking for the optimal solution of a function on a particular interval, it is sufficient to define the maximum of the function *f*, as max (*f*) = min (– *f*). One important characteristic of the genetic algorithm is that it places no requirements on continuity and derivability of the target function, as long as it is defined for the whole search interval of the genetic algorithm [7].

In order to operate on functions with multiple arguments, the genetic algorithm must be able to converge to the optimal solution after detecting the interval in which it exists, while it must also be able to continuously search for the global optimum in the whole definition area of the target function. As these characteristics are hard to implement at the same time, proper operation is usually a trade off between mutation and crossover in order to prevent early convergence to a local maximum [8].

The target function as well as the solution constraints must be correctly defined in order for the algorithm to provide adequate results. Experience has shown that genetic algorithms have poor performance in pinpointing an exact solution for a problem. Because of their stochastic nature, they slowly converge to a solution, and the exact nature of the solution is never known without additional post processing. As the output is a set of solutions, it is advisable to use the algorithm as a pre-processor to the main optimisation routine, or feed the results to a postprocessor. Finally, genetic algorithms take a long time to run due to the large number of calculations and logical checks involved [6].

3 Material cross section optimisation
Optimizacija poprečnog presjeka materijala

3.1 Algorithm parameters
Parametri algoritma

The MATLAB gatool solver was used to carry out optimisation on populations of 1000 individuals in all cases. The initial population was formed by uniform distribution within optimisation constraints, and the individuals were fitness scaled on basis of the target function.

The algorithm was operated using stochastic uniform selection, with 2 elite individuals crossing over to the next generation in each step. 80 % of the population was created by mutation using the adaptive feasible mutation function. Crossover was done using a heuristic function. 20 % individuals were passed on to the next generation unchanged every 20 generations.

The stopping parameters were defined as no changes in population values in 50 generations or the difference between two consecutive target function values being less than $1\cdot10^{-6}$. The gatool solver was used to create a set of raw results which were processed by the MATLAB fmincon postprocessor in order to find the global maximum within optimisation constraints [9].

In order for the algorithm to converge to a solution, the input data has to be prepared properly, which means that strictly non-dimensional values have to be used. To achieve this, the roller angles λ were expressed in radians, and belt section lengths a_i^* were expressed as submultiples of active belt width *b*. The area A^* of the material cross section was expressed as a submultiple of the area b^2 of a square with the sides of length *b* (*b* being the active belt width). In this paper, all data marked with an asterisk (*) is being presented in non – dimensional form, being divided by the active belt width *b*. The angle data in this article is being presented recalculated to degrees for ease of understanding.

3.2 Cross section area optimisation of V-shaped troughs
Optimizacija poprečnog presjeka kod dvovaljčanog sloga

The V-shaped trough was optimised for angles of repose $\varphi_1 = 15°$, $\varphi_2 = 20°$ and $\varphi_3 = 25°$. The optimisation constraints were set as belt sections being of equal length *a*, sum of belt section lengths equal $2a = b$, and the roller angle λ being in the interval $0° < \lambda < 90°$. No regard was given to belt bending constraints as the intent was to determine the maximum possible cross section area A. The optimisation target function F_V was derived from the trough cross section area expression (5):

$$F_V = -\left[\left(x_1^2 \cos x_2 \right)^2 \cdot \tan\varphi + \frac{1}{2} x_1^2 \sin\left(2x_2\right) \right]. \tag{14}$$

Where x_1 is belt section length a, x_2 is roller inclination angle λ, and φ is material angle of surcharge (Fig. 3). The results of the optimisation are presented in Tab. 1, and the trough cross section areas for optimized and commercially available troughs compared.

Table 1 *Optimisation results for V-shaped troughs*
Tablica 1. *Rezultati optimizacije za dvovaljčani slog*

Parameter	Material angle of surcharge $\varphi_1 = 15°$	$\varphi_2 = 20°$	$\varphi_3 = 25°$
Optimised trough			
λ /°	37,50008769	35,00027283	32,49988501
A^*	0,162903172	0,178518501	0,196210697
Commercially available trough			
λ /°	20		
A^*	0,139499724	0,160696902	0,183288457
Load capacity gain with trough optimisation, %	16,78	11,09	7,05
λ /°	15		
A^*	0,125	0,147397213	0,171267742
Load capacity gain with trough optimisation, %	30,32	21,11	14,56

Based on the results in Table 1, it is obvious that the capacity could be improved 7...30 % by using optimised trough shapes instead of commercially available ones, with the only limit being actual belt bending constraints.

3.3 Cross section area optimisation of trapezoidal troughs
Optimizacija poprečnog presjeka kod trovaljčanog sloga

The trapezoidal trough was optimised for angles of repose $\varphi_1 = 15°$, $\varphi_2 = 20°$ and $\varphi_3 = 25°$ (Fig. 4). The optimisation constraints were set as the side belt sections being of equal length a_1, sum of belt section lengths equal $a_1 + 2a_2 = b$, length of all sections $0{,}1b \le a \le b$ and the roller angle λ being in the interval $0° < \lambda < 90°$. No regard was given to belt bending constraints as the intent was to determine the maximum possible cross section area A. The optimisation target function F_T was derived from the trough cross section area expression (8):

$$F_T = -\left[\frac{1}{4}\left(2x_1 \cos x_3 + x_2\right)^2 \tan\varphi + x_1 x_2 \sin x_3 + \frac{1}{2} x_1^2 \sin 2x_3 \right]. \tag{15}$$

Where x_1 is belt section length a_1, x_2 is belt section length a_2, x_3 is roller inclination angle λ, and φ is material angle of surcharge. The results of the optimisation are presented in Tab. 2, and the trough cross section areas for optimized and commercially available troughs compared.

Table 2 *Optimisation results for trapezoidal troughs*
Tablica 2. *Rezultati optimizacije za trovaljčani slog*

Parameter	Material angle of surcharge $\varphi_1 = 15°$	$\varphi_2 = 20°$	$\varphi_3 = 25°$
Optimised trough			
a_1^*	0,1		
a_2^*	0,8		
λ /°	39,57763266	36,95405891	34,32762038
A^*	0,484323009	0,528487779	0,578667967
Commercially available trough			
a^*	0,33		
λ /°	20		
A^*	0,135151094	0,157220692	0,180742057
Load capacity gain with trough optimisation, %	258,37	236,14	220,16
λ /°	30		
A^*	0,158905346	0,178774182	0,199950015
Load capacity gain with trough optimisation, %	204,79	195,62	189,41
λ /°	36		
A^*	0,1688231	0,187068167	0,206513416
Load capacity gain with trough optimisation, %	186,88	182,51	180,21
λ /°	45		
A^*	0,177149321	0,192664124	0,209199509
Load capacity gain with trough optimisation, %	173,40	176,61	176,61

A closer look at the results in Tab. 2 shows that the load capacity can be improved 173...258 % in the case of trapezoidal troughs by using optimised trough shapes instead of commercially available ones, with the only limit being actual belt bending constraints and middle roller bearing life issues, as the middle roller would be subject to considerably greater loads than with commercially available troughs, and bearings with higher loading capacity would be needed.

3.4 Cross section area optimisation of polygonal troughs
Optimizacija poprečnog presjeka kod peterovaljčanog sloga

The polygonal five segment trough was optimised for angles of repose $\varphi_1 = 15°$, $\varphi_2 = 20°$ and $\varphi_3 = 25°$ (Fig. 5). The optimisation constraints were set as the side belt sections being of equal lengths a_1 and a_2, sum of belt section lengths equal $a_1 + 2a_2 + 2a_3 = b$, length of all sections $0{,}1b \le a \le b$ and the roller angles λ_1, λ_2 being in the interval $0° < \lambda_1 < 90°$, $\lambda_1 < \lambda_2 < 90°$. No regard was given to belt bending constraints as the intent was to determine the maximum possible cross section area A. The optimisation target function F_P was derived from the trough cross section area expression (12):

$$F_P = -\left\{ \frac{\left[2\left(x_2 \cos x_4 + x_1 \cos x_5\right) + x_3\right]^2 \tan\varphi}{4} + \right.$$
$$+ x_1\left(x_3 + 2x_2 \cos x_4\right)\sin x_5 + \frac{x_1^2 \sin 2x_5}{2} + \tag{16}$$
$$\left. + x_2 x_3 \sin x_4 + \frac{x_2^2 \sin 2x_4}{2} \right\}.$$

Where x_1 is belt section length a_1, x_2 is belt section length a_2, x_3 is belt section length a_3, x_4 is roller inclination angle λ_1, x_5 is roller inclination angle λ_2, and φ is material angle of surcharge. The results of the optimisation are presented in Tab. 3, and the trough cross section areas for optimized and commercially available troughs compared:

Table 3 *Optimisation results for polygonal troughs*
Tablica 3. *Rezultati optimizacije za peterovaljčani slog*

	Material angle of surcharge		
Parameter	$\varphi_1 = 15°$	$\varphi_2 = 20°$	$\varphi_3 = 25°$
Optimised trough			
a_1^*	0,1		
a_2^*	0,1		
a_3^*	0,6		
λ_1 /°	9,64345265	9,031533725	8,418468884
λ_2 /°	44,7262314	41,78065538	38,81216104
A*	0,397346439	0,430290516	0,467936987
Commercially available trough			
a*	0,2		
λ_1 /°	22,5		
λ_2 /°	45		
A*	0,178667654	0,196109311	0,214698301
Load capacity gain with trough optimisation, %	122,39	119,41	117,95
λ_1 /°	18		
λ_2 /°	56		
A*	0,1822109	0,197732136	0,214274378
Load capacity gain with trough optimisation, %	118,07	117,61	118,38

A closer look at the results in Tab. 3 shows that the load capacity can be improved 118...122 % in the case of polygonal troughs by using optimised trough shapes instead of commercially available ones, with the only limit being actual belt bending constraints and middle roller bearing life issues.

3.5 Cross section area optimisation of deep semi-circular troughs

Optimizacija presjeka kod dubokih polukružnih valjnih slogova

The deep semi-circular trough was optimised for angles of repose φ_1 = 15°, φ_2 = 20° and φ_3 = 25° (Fig. 9). The optimisation constraints were set as the straight side belt sections being of equal lengths, the sum of belt section lengths equal $l_1 + 2l_2 = b$, length of all sections $0{,}1b \le l \le b$ and surface area of the circular section A_1 being greater than the combined area of the triangular sections A_2 in order to preserve the deep semi-circular shape. No regard was given to belt bending constraints as the intent was to determine the maximum possible cross section area A. The optimisation target function F_{DC} was derived from the trough cross section area expression (13):

$$F_{DC} = -\left[x_1^2 x_2 + \frac{2x_1^2}{\tan x_2} + \left(\frac{x_1}{\sin x_2}\right)^2 \tan\varphi \right] \tag{17}$$

Where x_1 is the radius of the semi-circular belt section r, x_2 is the inclination angle of the straight section λ (rad), and φ is material angle of surcharge. The results of the optimisation are presented in Tab. 4, and the trough cross section areas for optimized and commercially available troughs compared:

Table 4 *Optimisation results for deep semi-circular troughs*
Tablica 4. *Rezultati optimizacije za duboki polukružni valjčani slog*

	Material angle of surcharge		
Parameter	$\varphi_1 = 15°$	$\varphi_2 = 20°$	$\varphi_3 = 25°$
Optimised trough			
r*	0,31		
λ /°	62		
A*	0,239411322	0,251275467	0,26392005
Capacity gain compared to commercially available troughs, %			
V-shaped, λ=15°	71,62	56,37	44,00
V-shaped, λ=20°	91,53	70,48	54,10
Trapezoid, λ=20°	77,14	59,82	46,02
Trapezoid, λ=30°	50,66	40,55	31,99
Trapezoid, λ=36°	41,81	34,32	27,80
Trapezoid, λ=45°	35,15	30,42	26,16
Polygonal, λ_1=22,5°, λ_2=45°	34,00	28,13	22,93
Polygonal, λ_1=18, λ_2=56°	31,39	27,08	23,17

As seen from the data in Tab. 4, the deep semi-circular trough offers serious advantages in load capacity over other commercially available trough shapes. The gains are most evident gains when compared to V – shaped troughs (54…91 %). The gains for trapezoid troughs are in the 28…77 % area, while the gains for polygonal troughs are somewhat more moderate, ranging 23…34 %, assuming equal belt width in all optimisation cases.

4 Conclusion
Zaključak

The genetic algorithm has proven itself as a useful optimisation tool in situations in which it is not possible to achieve an analytical solution [8], although care must be taken to prepare data in a proper way, and the results must be adequately post-processed in order to avoid convergence to a local instead of a global maximum value [6, 7].

Genetic algorithm based optimisation offers improved trough shapes, but these improved trough shapes have been calculated solely with the criteria of maximum material cross section, and improvements in belt or roller design might be needed for such troughs to be feasible, especially in the case of trapezoidal and polygonal troughs, where the uneven loading of horizontal and side rollers, or sharp belt bending angles might present a problem.

The results of the optimisation have shown that trough shapes in commercial use are still far from reaching theoretical maximal loading capacities, and that allowances have been made due to manufacturing and material constraints [5, 10, 11]. As the optimisation was based primarily on the trough material cross section, further research into belt conveyor load capacity can be performed by including other factors such as conveyor slope angle and belt speed, if non standard values are allowed.

Deep semi-circular troughs are expected to eventually supersede other trough types in use for all large scale applications, because they offer improved loading capacity, reduced material spillage and improved belt guidance, as well as the possibility of reversible belt conveyor operation [5].

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Authors' addresses
Adrese autora

Željko Vrcan
Department of Mechanical Engineering Design
Faculty of Engineering, University of Rijeka
Vukovarska 58, HR-51000 Rijeka, Croatia
e-mail: zeljko.vrcan@riteh.hr

Neven Lovrin,
Department of Mechanical Engineering Design
Faculty of Engineering, University of Rijeka
Vukovarska 58, HR-51000 Rijeka, Croatia
e-mail: neven.lovrin@riteh.hr