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THE GEOMETRICAL AND MATERIAL PARAMETERS INFLUENCE ON THE MECHANICAL PROPERTIES OF ACTIVE ROTARY FENCE

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Abstract: *The paper presents impact analysis of geometrical and material properties arm of active fence (also known as pivoted paddle divert or paddle sorter) with the required stiffness on its mass and mass moment of inertia. Active rotary fences located above conveyor belt are used in stream sorting of unit loads. It turns out, that application of the structure idea presented in the article (curvilinear or trapezoidal outline fence with channel cross-section, that is made of polyamide), even causes several times improvement the above-mentioned parameters in comparison with the basic structure.*

Keywords: pivoted paddle divert, paddle sorter, stream sorting, optimization, numerical analysis

1. Introduction

Automated sorting processes in delivery companies' logistic centers should characterize high efficiency of sorting packages to enable deliveries continuity using limited space designated for transport lots preparation. High efficiency is achieved at the expense of dynamic overloads exerted on the packaging. Therefore, a manipulator should be designed to mitigate the dynamic overloads. In case of an active rotary fence (also known as pivoted paddle divert or paddle sorter), this is possible by selecting the appropriate mass moment of inertia and the flexibility of the fence. The concept of the flexible fence has been presented in the article (Piatkowski et al., 2007). The greater the flexibility of the fence, the more it can deform during a collision with the package and the more collision energy can absorb and dissipate. However, if the fence is too flexible for the desired scraping velocity, the inertial force of packaging causes the fence to bend so much that it will not be able to scrape the package at all.

An important issue is selection of such shape and dimensions of the fence arm's cross-section as they minimize arm's mass moment of inertia and mass, still achieving the desired flexibility. Achieving these objectives causes that putting fence in the rotary motion becomes less energy-intensive and the packaging collision against the light fence becomes milder (Piatkowski et al., 2009). In the paper (Piatkowski, 2010) the fence with curvilinear outline was presented, which provides constant bending stress along the arm. Minimizing the overload exerted on the packaging by the active rotary fence is also possible by appropriate selection of the trajectory and the method controlling the trajectory of the fence (Wolski et al., 2017).

This paper presents several variants of the fence arm with channel and flat-bar section as well as with rectangular, trapezoidal and curvilinear outline. The results of calculations relevant for the scraping process parameters are summarized for three different materials such as: steel, aluminum and polyamide. Obtained results of calculations allow to indicate the most advantageous type of structure.

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2. Calculation method

In order to compare to each other the various active fence structure solutions and used in it materials, the constant load conditions were adopted as follows: the cantilever beam of the length R_z = 1200 mm subjected to concentrated force F = 50 N at the free end obtains deflection $f_{0.1m}$ = 0.1 m.

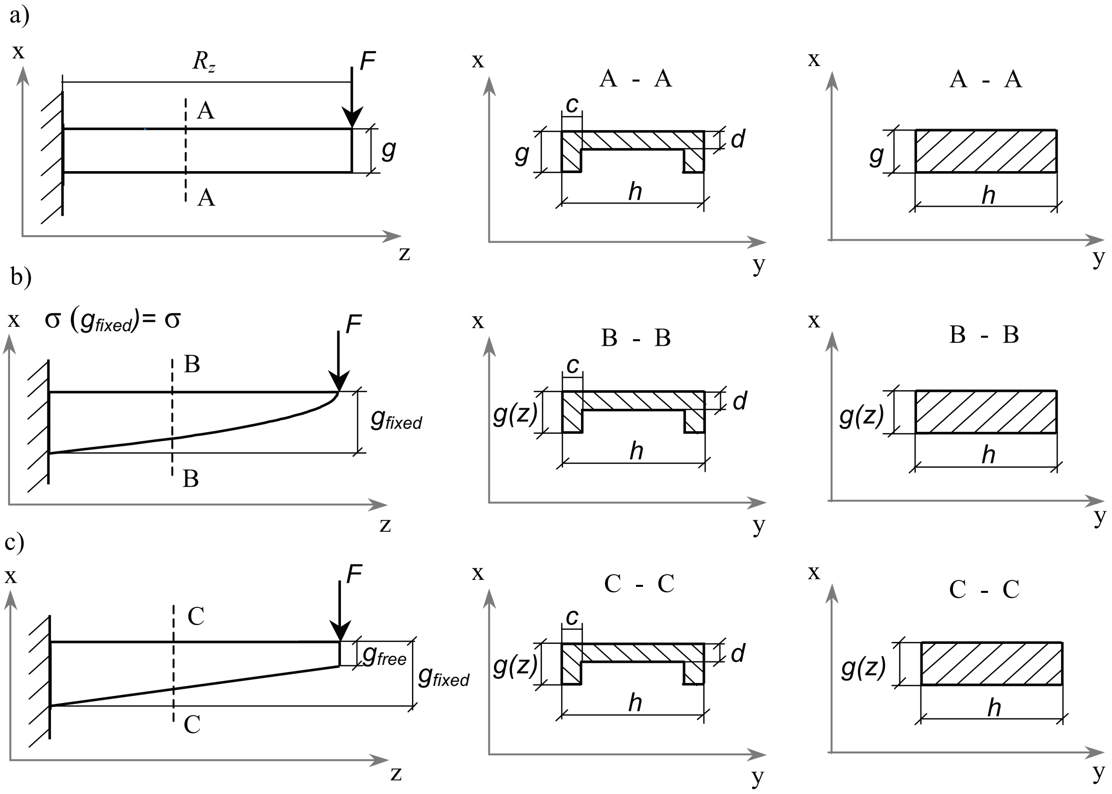

Fig. 1: Examples of active fence arm structures for two cross section variants – flat-bar and channel: a) fence arm with rectangular outline, b) fence arm with curvilinear outline providing constant bending stress σ along the length of the arm equal to the stress at the fixed end σ(g_{utw}), c) arm with trapezoidal outline; g_{free} – profile height at free end, g_{fixed} – profile height at fixed end, d = 2 mm, c = 2 mm, R_z = 1200 mm

Dimensions of the fence arm with trapezoidal outline and channel section have been determined using optimization (Zelinka et al., 2013) and (Skibicki et al., 2006), in which the objective function is mass minimizing:

$$\min mass(X) = (c(X_1 + X_2) + d(h - 2c))\rho R_z \tag{1}$$

where: $X = [g_{fixed}, g_{free}]$ – decision variables (Fig. 1c), d, c, h, R_z dimensions (Fig. 1c), ρ - material density. The equality constraint of acceptable solutions set is difference between assumed deflection $f_{0.1m}$ and double integral over z axis (Fig. 1) of second derivate of deflection line.

$$\int_0^{R_z} \int_0^z \frac{M_g(z)}{E \cdot I_y(X, z, c, d, h)} dzdz - f_{0.1m} = 0 \tag{2}$$

In addition, inequality constraints were adopted as follows:

$$-X_1 + X_2 < 0, -X_1 < -d, -X_2 < -d \tag{3}$$

where: $M_g(z)$ – bending moment of F force (Fig. 1), E –Young modulus, I_y – moment of inertia of the cross-section with respect to y-axis, $f_{0.1m}$ – arm deflection at the free end, equals to 0.1 m.

For curvilinear outlined fence arm, it is necessary to find such a function of the profile height $g(z)$ along z axis which satisfies the equation (4)

$$\int_0^{R_z} \int_0^z \frac{M_g(z)}{E \cdot I_y(z, g(z), c, d, h)} dzdz - f_{0.1m} = 0 \tag{4}$$

The $g(z)$ function should be determined from the equation (5) which ensure constant bending stress along the arm, that is equal to the stress at the fixed end.

$$(R_z - z) \cdot W_y(g_{utw}) = R_z \cdot W_y(g(z)) \quad (5)$$

where: $W_y(g_{fixed})$ – section modulus of bending strength at the fixed end. The $g(z)$ function in the equation (5) of the constant bending stress is raised to the fourth power (when considered is the channel section case), therefore this function is found numerically.

3. Presentation of the calculations results

The calculations were carried out for the following material constants: $\rho_{steel} = 7850\ kg/m^3$, $\rho_{aluminum} = 2700\ kg/m^3$, $\rho_{polyamide} = 1172\ kg/m^3$, $E_{steel} = 205\ GPa$, $E_{aluminum} = 69.0\ GPa$, $E_{polyamide} = 2{,}85\ GPa$. From the analysis of figures 2a) and 2b) it can be observed that the trapezoidal outline is strongly similar to curvilinear outline. Curvilinear outline allows to obtain 2% reduction in mas of arm and 10% reduction in mass moment of inertia. However, trapezoidal outline is easier to produce. Deflection of the curvilinear ((3) – Fig. 2c, d) and trapezoidal ((2) – Fig. 2c, d) fence is less intensive at the fixed and more intensive at the free end. The opposite relation appears in the case of the arm with a rectangular outline ((1) – Fig. 2c, d).

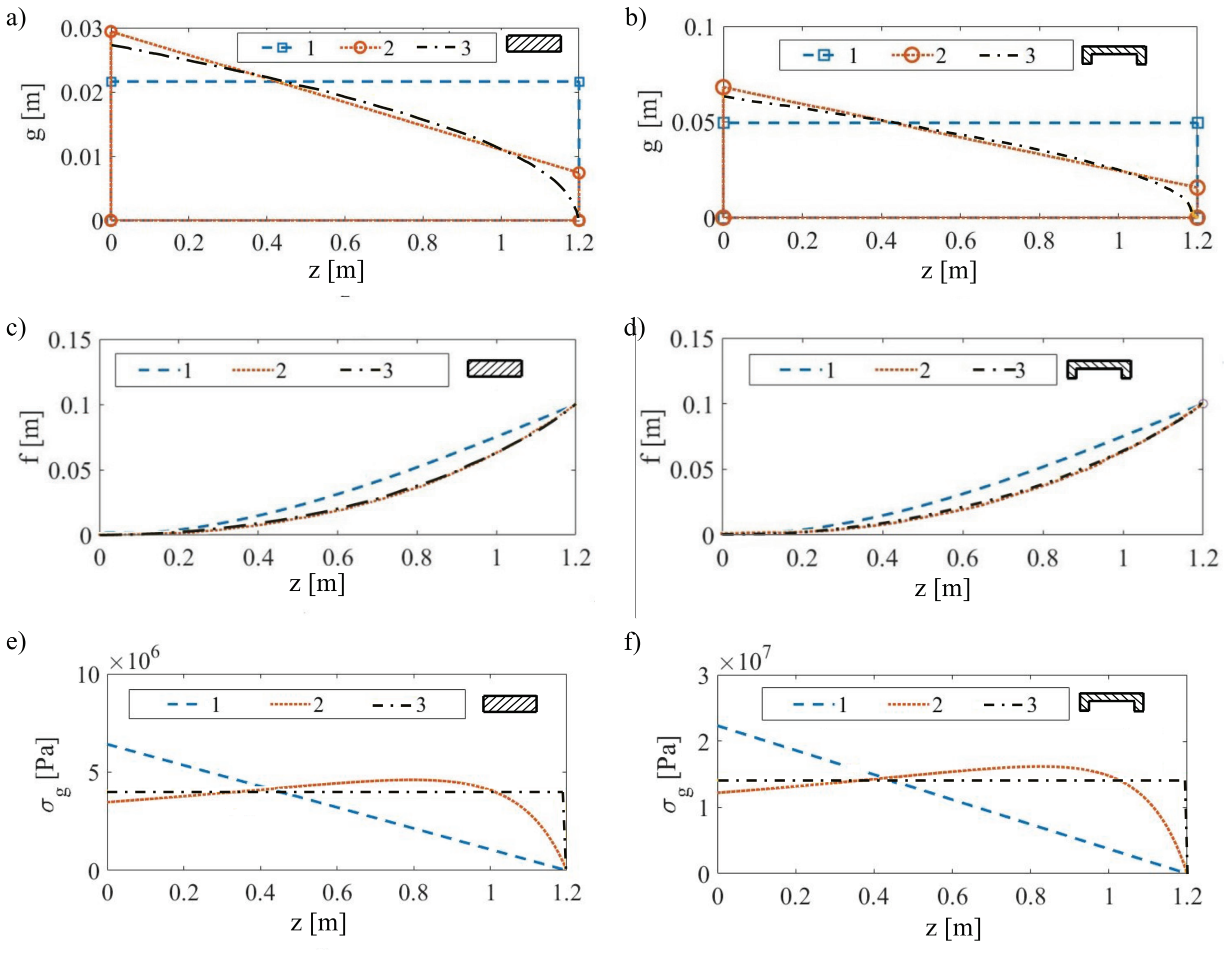

Fig. 2: Results of calculations carried out for the fence arm made of polyamide, with consideration of $f_{0.1m} = 0.1$ m, F = 50 N for outline: 1-rectangular, 2-trapezoid, 3-curvelinear; (a) graph of profile height g (z) for a flat-bar and (b) channel cross-section along the arm length, c) deflection line for flat-bar and (d) channel cross section along the arm length, e) bending stress for a flat-bar and (f) chanell cross-section as a function of the position along the arm

This relation is noticeable both for the flat-bar cross-section arm (Fig. 2c) as well as the channel cross-section arm (Fig. 2d). Bending stress for the channel section (Fig. 2f) are approx. 4 times higher than for a rectangular section (Fig. 2e), for all cases of outline. The smallest mass and the mass moment of inertia occurs in the case of a fence made of polyamide with a channel cross section and a curvilinear or a trapezoidal outline (Fig. 3). An additional advantage of polyamide is its higher damping property than metals. This feature should also positively impact on the course of the packaging sorting by the active fence.

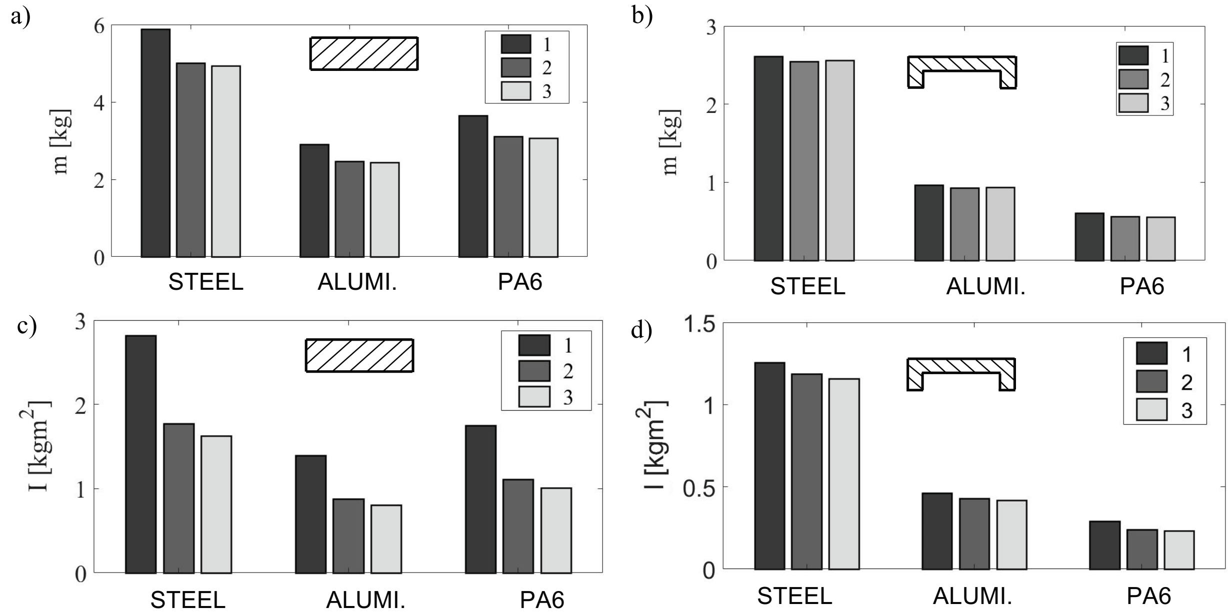

Fig. 3:Comparison of calculation results for mass and mass moment of inertia with respect to the rotation axis of the fence arm for a, c) flat-bar, b, d) channel cross-section; outline of the fence arm: 1-rectangular, 2-trapezoidal, 3-curvilinear

4. Conclusions

In the paper selected structures of fence arm considering three different materials were presented. The concentrated force was applied to the free end of the fence. As a result, adequate conditon with respect to scarping small packaging have been achieved, when the fence is most deflected at the last scraping stage. In this case, the object is in contact with the end of the fence, what's causing the most critical variant for the scraping effectiveness. The realized reserach allows indicate the most usefull solution of the fence. For all cases of outline, definitely more effective minimization of mass and mass moment of inertia occurs in case of using a channel section in comparison to a flat-bar section (Fig. 3). In case of flat-bar section arm, changing the rectangular outline to a trapezoidal outline or a curvelinear outline significantly reduces mass and mass moment of inertia. However, in case of a channel section arm, changing the rectangular outline to a trapezoidal or curvilinear outline does not cause such a significant decrease in the mass and moment of inertia. Therefore, a rectangular outline may be sufficient for a channel cross-section of fence. It also turns out that for all outline variants, in the case of a flat-bar cross-section, the most preferred material both in terms of mass and mass moment of inertia is aluminum, whereas for channel section, the most preferred material is polyamide.

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