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A. FEDORYSZYN[*] P. ZYZAK[*]

CHARACTERISTICS OF THE ABRASIVE STREAM DEPENDING ON DESIGN FEATURES AND OPERATIONAL PARAMETERS OF A THROWING UNIT IN AN AIRLESS SHOT-BLASTING MACHINE

CHARAKTERYSTYKA STRUMIENIA ŚRUTU W ZALEŻNOŚCI OD PARAMETRÓW KONSTRUKCYJNO-EKSPLOATACYJNYCH ZESPOŁU RZUTOWEGO OCZYSZCZAREK WIRNIKOWYCH

The paper summarises the research data gathered to find how the design of a throwing unit should affect the velocity and range of an abrasive stream. A thorough analysis of the abrasive blast cleaning cycle shall be useful in optimisation of the throwing unit operation, in terms of the intensity and range of the abrasive stream and hence the quality of castings being cleaned.

Keywords: shot-blasting machine, design features of a throwing unit, velocity of the abrasive stream, scattering of the abrasive stream

W opracowaniu przedstawiono wyniki analizy wpływu parametrów konstrukcyjnych zespołu rzutowego na prędkość i zasięg strumienia ziaren śrutu. Analiza procesu roboczego oczyszczarek wirnikowych może być, zdaniem autorów, podstawą do optymalizacji pracy zespołu rzutowego, co ma wpływ na intensywność (gęstość) padania strumienia śrutu i jego zasięg, a w konsekwencji na jakość powierzchni czyszczonych odlewów.

1. Introduction

Cleaning of castings is a surface treatment process aimed to remove the residues of the sand mix and core sand and to improve the overall surface quality. Cleaning is now a mechanised process. There are many types of cleaning machines currently available, including barrel-type shot-blasting machines where a high-speed stream of steel or cast iron abrasives is thrown onto the castings to be cleaned.

The main parameters of the rotary barrels are:
- velocity of the abrasive stream v; m/s,
- kinetic energy E_k; J,
- scattering of the abrasive stream Z; °,
- flow rate of abrasive W; kg/min,
- abrasive charge q; kg.

These parameters are controlled by the design features of a throwing unit, operational parameters and properties of the cleaning agent.

2. Motion of abrasives in a rotary barrel

Key components of a typical rotary barrel include:
- blast wheel, comprising discs of the radius R with paddles in between,
- immobile adjusting sleeve, with the radius r_r,
- barrel with the radius r_z, the abrasive is fed via a charging hopper with an inside radius $r_{r.w}$.

Fig. 1 shows the adjusting sleeve and the rotary barrel in a shot-blasting machine manufactured in Poland [1, 4].

The components of a throwing unit shown in Fig. 1 are used in currently available shot-blasting and blast-cleaning machines.

The authors undertook a research program to find out how the design features and constructional parameters of a throwing unit should affect the abrasive stream. A throwing unit in an experimental blast-cleaning machine was chosen as an object of study. Characteristics and the operating parameters of a throwing unit are summarised in table 1. The underlying theoretical backgrounds are given as (5) and (6). The authors chose

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[*] FACULTY OF FOUNDRY ENGINEERING, AGH UNIVERSITY OF SCIENCE AND TECHNOLOGY, 30-059 KRAKOW, REYMONTA 23, POLAND

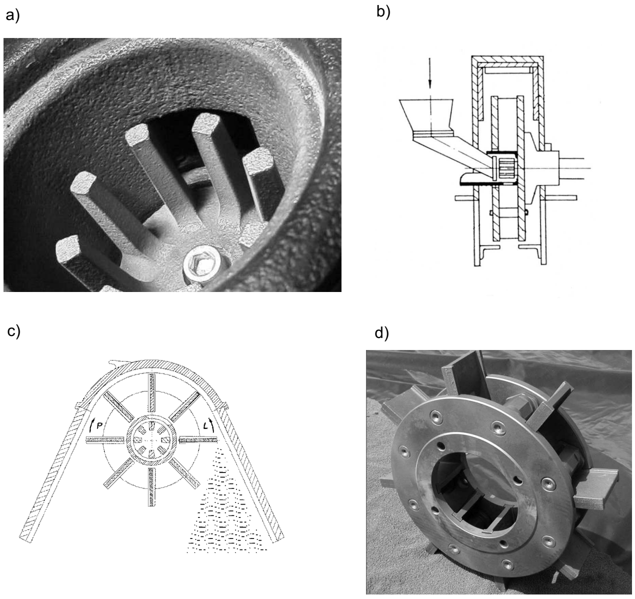

Fig. 1. Throwing unit in an experimental shot-blasting machine [1, 4]: a) barrel and an adjusting sleeve, b, c) schematic diagram of a throwing unit; d) blast wheel with paddles

investigate how the actual design of a throwing unit should affect the parameters of the abrasive stream: velocity, cross-section of an abrasive charge, the amount of an abrasive charge, the time of abrasive motion on paddles, angle of scatter. In turn one operating parameter of the throwing unit was varied: barrel rpm, bulk density, the number of windows in a barrel and the number of paddles to find out how this variation should affect the stream parameters.

An experimental shot-blasting machine allows for validation of calculation data. Rotational speed can be varied in the range 1440÷3000 rpm and the sleeve positioning angle can be adjusted by 20°.

TABLE

Operating parameters of an experimental throwing unit

Parameter	Barrel I
Shots flow rate W, kg/min	100
Barrel rpm ω, 1/s	305.782
	209.44
	146.7
Bulk density of the abrasive $\rho_{śr}$, kg/m^3	2500 (cast-iron round abrasive $d_{śr}$ = 0.8÷2.5 mm)
	3650 (steel abrasive $d_{śr}$ = 1.0÷1.7 mm)
Barrel diameter d_z, mm	86
Number of paddles i, -	6, 8, 10
Blast wheel diameter D, mm	300

The following values are assumed in calculations:

- coefficient of friction between the abrasive and the paddle f = 0.2,
- coefficient of internal friction of the abrasive f_{tw} = 1.

3. Parameters of an abrasive stream blasted by the barrel

The barrel is the first element that divides the abrasive stream into doses before it reaches the paddles. Barrel geometry, rpm and the type of applied abrasive determine the velocity at which the abrasive hits the paddles.

Fig. 2 shows the barrels which were considered in the study to find the parameters of the abrasive stream.

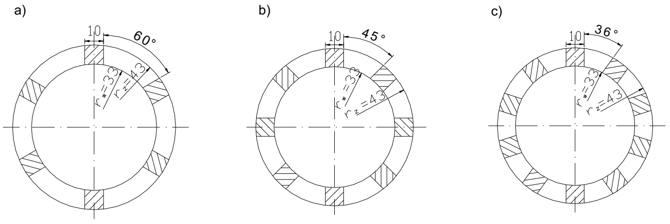

Fig. 2. Schematic diagram of barrels: a) 6 windows; b) 8 windows (fig. 1a); c) 10 windows

Fig. 3 shows the distribution of an abrasive charge on the side surface of a barrel's window.

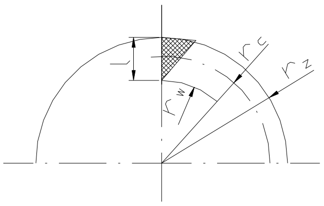

Fig. 3. Distribution of an abrasive charge on the side surface of the barrel's window: l – abrasive size, r_c – radius of the abrasive change's cog; r_z – barrel's outside radius, r_w – barrel's inside radius

Velocity and scattering of the abrasive stream are obtained from formulas derived for barrels with straight paddles. Equations (5) and (6) yield all parameters describing the shifting of an abrasive charge from the paddle [2÷4].

Taking into account the forces acting upon the abrasive (Fig.4):

– centrifugal force

$$F_0 = m \times \omega^2 \times x, \tag{1}$$

– Coriolis force

$$F_C = 2 \times m \times \omega \times \frac{dx}{dt}, \tag{2}$$

– friction force between the abrasive particle and the paddle

$$F_{tar} = f \times F_C = m \times f \times \left(2 \times \omega \times \frac{dx}{dt}\right), \tag{3}$$

we finally get the equation of motion:

$$\frac{d^2x}{dt^2} + 2 \times \omega \times f \times \frac{dx}{dt} - \omega^2 \times x = 0 \tag{4}$$

where: x – instantaneous coordinate of a particle at a point 2 reached after the time t, m; ω – barrel rpm; 1/s; t – time after the particles' displacement due to the centrifugal force, s; f – coefficient of friction between the abrasive particles and the element of a throwing unit; m – mass of an abrasive particle, kg.

Solving the equation of motion yields the formula expressing the abrasive particles' path s and velocity v. For abrasives moving along the throwing paddles we get:

$$\begin{aligned} s = {} & \frac{\omega \cdot x_1 \cdot (\sqrt{f^2+1} + f) + w_1}{2 \cdot \omega \cdot \sqrt{f^2+1}} \cdot e^{\omega \cdot t \cdot (\sqrt{f^2+1} - f)} + \\ & + \frac{\omega \cdot x_1 \cdot (\sqrt{f^2+1} - f) - w_1}{2 \cdot \omega \cdot \sqrt{f^2+1}} \cdot e^{-\omega \cdot t \cdot (\sqrt{f^2+1} + f)} \end{aligned} \tag{5}$$

$$\begin{aligned} \mathrm{v} = {} & \frac{\omega \cdot x_1 + w_1 \cdot (\sqrt{f^2+1} - f)}{2 \cdot \sqrt{f^2+1}} \cdot e^{\omega \cdot t \cdot (\sqrt{f^2+1} - f)} - \\ & - \frac{\omega \cdot x_1 - w_1 \cdot (\sqrt{f^2+1} + f)}{2 \cdot \sqrt{f^2+1}} \cdot e^{-\omega \cdot t \cdot (\sqrt{f^2+1} + f} \end{aligned} \tag{6}$$

where: x_1 – initial position of the abrasive charge's cog on the paddle, m; w_1 – initial velocity of a particle with the mass m at the initial position, for the specified initial moment equal zero, m/s; v – relative velocity of the charge along the paddle, at the moment it gets down, m/s; f – coefficient of friction between the abrasive and paddle.

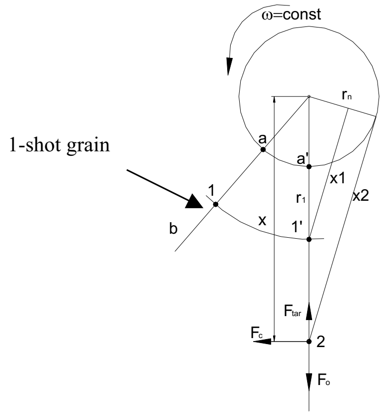

Fig. 4. Forces acting upon the abrasive particle moving along the paddle surface [7]

In order to show the process of shifting and scattering of an abrasive charge, the movements of extreme particles are analysed [2÷4]. An adequately accurate assumption is made that the cross-section of an abrasive charge on the barrel's window has the shape of a right triangle. Recalling all these assumptions and knowing the barrel's blasting capacity, the number of paddles and barrel's windows as well as barrel's dimensions, one is able to determine the parameters of extreme particles' downward motion.

Equations (5) and (6) yield the radial and tangential velocity and a particle's path both inside the barrel and over the paddles.

Abrasive particles' downward movement from the barrel marks the initial phase of particles' movement in the throwing unit. Particles move from the barrel's side window portion by portion, and the final velocity becomes the initial velocity of their movement on the paddles.

In the initial phase the portion of abrasive particles moves under the action of the centrifugal force along the section from r_c to r_z, reaching the radial velocity (along the window surface) [7]:

$$\mathrm{v}_r = \sqrt{\omega^2 \cdot (r_z^2 - r_c^2) + \mathrm{v}_1^2}, \tag{7}$$

where: ω – barrel rpm, 1/s; v_1 – initial velocity of an abrasive packet inside a barrel, m/s.

Tangential velocity is given as:

$$u_o = r_z \cdot \omega, \tag{8}$$

Absolute velocity of particles' downward motion from the barrel is expressed as:

$$\mathrm{v} = \sqrt{\mathrm{v}_r^2 + \mathrm{v}_o^2}, \tag{9}$$

Absolute velocity of abrasive particles reaching the paddles falls in the range 1.5÷4.5 m/s for the barrel I (table 1) and the bulk density $\rho_{śr} = 2.5$ g/cm^3, and 2÷4.5 m/s for the density $\rho_{śr} = 3.65$ g/cm^3. The cross-section of the abrasive charge on the windows' side surfaces falls in the range 30÷90 mm^2 for the bulk density $\rho_{śr} = 2.5$ g/cm^3, depending on the number of windows and actual rpm. When the bulk density approaches $\rho_{śr} = 3.65$ g/cm^3, this parameter falls in the range 20÷70 mm^2. Dimensions of the abrasive charge on the windows' side surfaces vary from 6÷13 mm.

For simplicity, parameters of abrasive particles are displayed in graphic form and shown in Figs 5÷8.

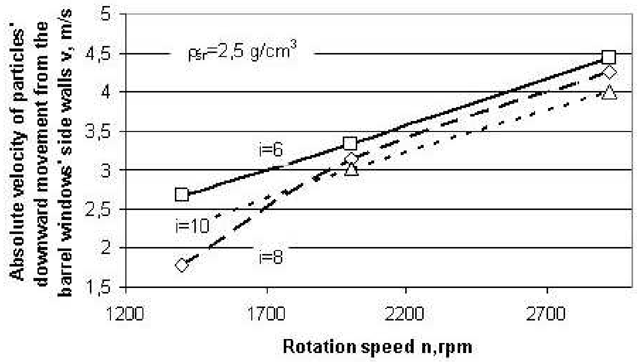

Fig. 5. Absolute velocity of particles' downward movement from the barrel windows' side walls – barrel 1; 1 – the number of windows

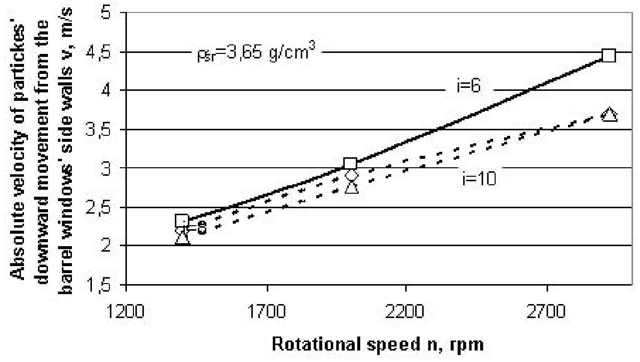

Fig. 6. Absolute velocity of particles' downward movement from the barrel windows' side walls – barrel 1; 1 – the number of windows

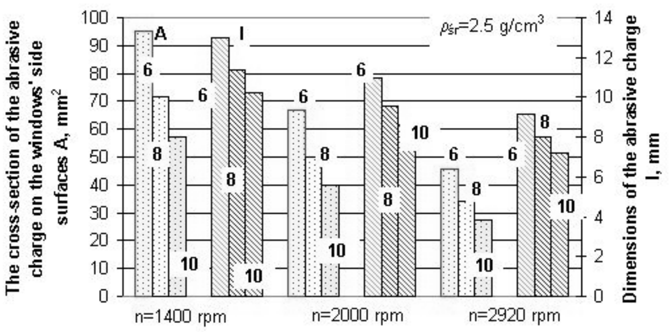

Fig. 7. Parameters of abrasive portion on the barrel windows' side walls – barrel 1; 6, 8, 10 – number of windows

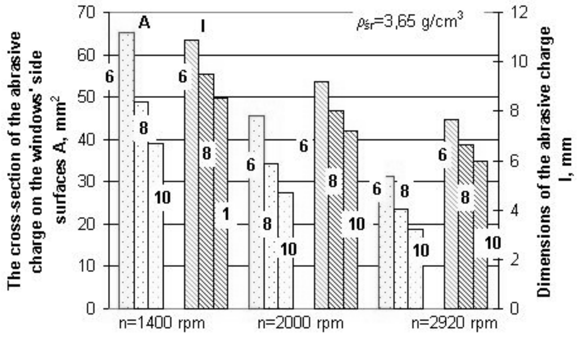

Fig. 8. Parameters of abrasive portion on the barrel windows' side walls – barrel 1; 6, 8, 10 – number of windows

4. Parameters of an abrasive stream leaving the hole in an immobile adjusting sleeve

The sleeve controls the motion of the abrasive fed on the paddles. The abrasive stream is directed through adjusting the side hole. The edge of this hole is subjected to considerable wear [5].

The shots move through a hole in an immobile sleeve with the dimension $b_t \times l_t$. The width of this hole is taken as $b_t = 50$ mm [1].

5. Parameters of the abrasive stream blasted by paddles

A multi-stage procedure is required to compute the shots displacement in rotating elements of a throwing unit.

The following shot displacements are considered [2÷4]:

- along the side surface of the barrel window,
- from the point they leave the barrel to the point they encounter a paddle,
- on the paddle.

The design and constructional parameters are:

- blast wheel dimensions: R_w, R_z in m,
- paddle dimensions: b×l in m,
- paddle shape: flat, shaped,
- barrel size: r_w, r_z in m (Fig. 2),
- sleeve position and window size α_{tul}, $b_r \times l_r$ in °and m.

Other operating parameters assumed for calculations are: the amount of abrasive charge and barrel rpm. Parameters of the abrasive include: particle diameter, bulk density, homogeneity, which, beside the constructional parameters, control the properties of an abrasive stream at each stage of particle motion inside the throwing unit.

The dynamics of particles' movements on the paddles depends on the exact spot where the particle enters the paddle and its initial and final shape [8].

In order to find the parameters of particles- paddle interface, one has to investigate the particles' movements with respect to the barrel disc during their free passage, after leaving the separating windows [2].

Time that passes from the instant the particles leave the barrel right till the moment they hit the paddles as well as angular coordinates of contact points are: $t = 1.067 \cdot 10^{-3} \div 2,219 \cdot 10^{-3} s$, and $\phi_c = 13 \div 18^0, \phi_{a,b} = 17 \div 26^0$. Symbol $\phi_{a,b,c}$ designates the angular coordinate of contact between the extreme particle a, b, c on the barrel's side surface and the paddle.

Right at the moment a particle hits the paddle, the final stage of the process begins when a particle moves along the paddle. This stage is over when the particles leaves the barrel, having reached the outlet [2].

Knowing relative velocities and the tangential velocity at the outlet radius, one constructs parallelograms representing particles' velocities at the outlet. Positions of outlet points $\mathrm{y_a}, \mathrm{y_b}, \mathrm{y_c}$ of extreme particles with respect to the contact points are determined by the respective angles $\Theta_\mathrm{a}, \Theta_\mathrm{b}, \Theta_\mathrm{c}$. The limits for theoretically predicted particles' scatter are contained between the absolute velocity vectors for the extreme particles a, b, c.

Equations (5) and (6) were utilised to derive the parameters of an experimental throwing unit summarised in table 1: time of motion, velocity of particles' leaving the paddles, angle of scatter. Selected parameters of the abrasive stream blasted by the paddles are shown in Figs. 9÷12 in a graphic form.

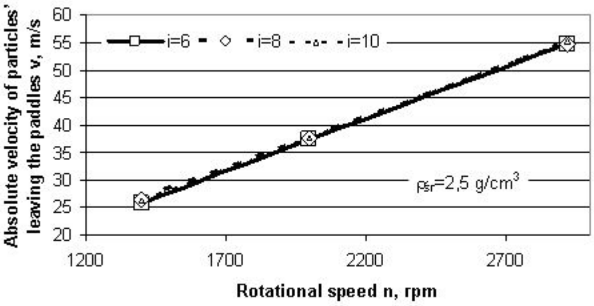

Fig. 9. Absolute velocity of particles' leaving the paddles; 1 – number of paddles

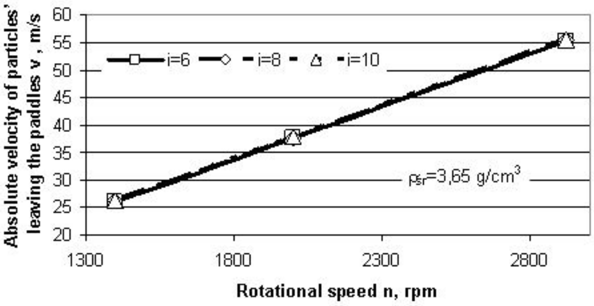

Fig. 10. Absolute velocity of particles' leaving the paddles; 1 – number of paddles

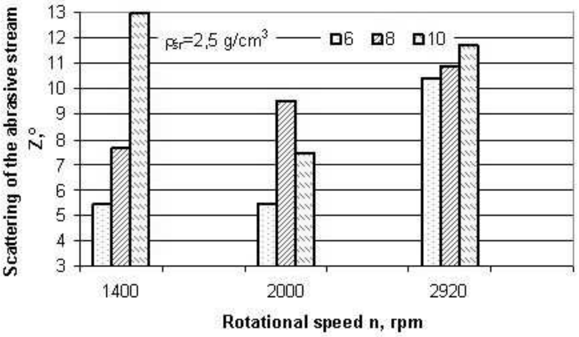

Fig. 11. Calculated angles of scatter, cast iron shots

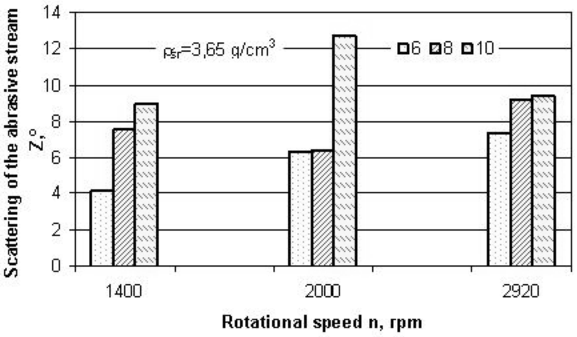

Fig. 12. Calculated angles of scatter, steel shots

6. Conclusions

Theoretical and experimental data were utilised to calculate the parameters of the abrasive stream for various designs of the throwing units. The influence of the design of the throwing unit on the parameters of the abrasive stream is investigated, making it a contribution to the industrial testing of show-blasting cleaning machines. Parameters of abrasive particles' leaving the paddles: velocity, mass intensity are used to determine the conditions for cleaning performance. The analysis of the research data leads us to the following conclusions:

- Velocities of abrasive particles entering the paddles: ~ 4.5 m/s,
- The number of paddles does not affect the absolute velocity of particles' leaving the paddles, for the analysed barrel type this velocity would fall in the range 27÷58 m/s,
- In order to ensure that predicted values should better agree with the calculation data it seems expedient to investigate how heterogeneity of the abrasive stream should affect the velocity, charge and the angle of scatter,
- Angle of scatter in an 8-paddle barrel delivering 1400 rpm approaches 7.65°, for the rpm 2920 it equals 10.84°. The maximal angle of scatter is 13°. The real scatter appears to exceed the predicted lev-

els, which might be attributable to the rebounding of abrasive particles hitting the paddles at large angles, step movements of particles along the paddle, the slipping effect (neglected in this study), collisions between blasted and rebounded particles (moving in the opposite direction), roughness and unevenness of paddle surfaces and incorrect shapes of abrasives,

- Paddle dimensions and the blast wheel diameter appear to be the major determinants of the absolute velocity of particles' leaving the paddles,
- The abrasive stream has the most favourable parameters when the throwing barrels operate at rpm in excess of n = 2000, which is confirmed by performance data of industrial shot-blasting machines.

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