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STUDY OF A SHOTBLASTING TURBINE'S EFFICIENCY

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ABSTRACT
Efficiency of the shotblasting process depends on: shot velocity, shot mass-flow distribution, and the shot-flow angle in the area being shotblasted. Using these three parameters, it is possible to predict the effect of shotblasting, and they can also be applied for estimating the efficiency of a shotblasting turbine. Shot mass-flow distribution measurement was performed using a multi-hole collector device. The particle stream was intercepted and the mass of shot particles collected in a particular hole of the collector was weighed and the partial mass-flow calculated by dividing the collected mass by the interception time. The shot-flow angle was measured by the application of a ladder-shaped obstacle placed in front of a piece of soft cardboard, which allowed the particle trajectories to be determined from the coordinates of the particular obstacle and its shadow on the cardboard. In order to measure shot velocity, a cross-correlation based velocity measurement system was developed which allowed the local shot velocity to be measured. Two different turbines were analyzed in this way. The obtained results are compared and discussed.
Keywords: Shotblastig, Measurements, Efficiency

1. INTRODUCTION
Shotblasting is widely used in the metal industry for the surface cleaning of different metal products. These are exposed to the flow of shot particles, and the energy of the particles' impact is used to remove rust, paint or any other deposits from the surface of the object being cleaned. Small steel spheres with a mean diameter of 1 mm are usually used as shot particles. These are accelerated within electrically-powered radial turbines to the final velocity which can exceed 100 m/s. The jet of shot particles is directed towards the target from a distance between 1 and 2 m. Very high flow-rate up to 10 kg/s (350.000 particles per second) assures quick and effective surface cleaning. In order to estimate the effectiveness of the shotblasting process, shot velocity, shot distribution and the shot-flow angle in the area being shotblasted have to be known [1]. Using these three parameters it is possible to predict the effect of shotblasting and they can also be applied for estimating the efficiency of a shotblasting turbine, which is defined as

$$\eta = \frac{\dot{W}_{kin}}{P_{el}} \tag{1}$$

Where: - $\dot{W}_{kin}$ flow of kinetic energy of shots,
- P_{el} turbine power consumption.

The flow of kinetic energy may be calculated by integrating the product of mass flow and the square of velocity across the domain of interest:

$$\vec{W}_{kin} = \oiint_A \dot{m} \cdot \frac{w^2}{2} \cdot d\vec{A} \qquad (2)$$

Where: $\dot{m}$ local mass flow rate,

w local shot velocity,

$d\vec{A}$ surface element vector.

As it follows from equation (2), mass-flow distribution, velocity distribution and shot-flow angle have to be known in order to predict kinetic energy flow.

2. SHOT-FLOW ANGLE MEASUREMENT

The flow of shot particles may be considered as two dimensional. As can be seen from Figure 1 the flow spreads from the turbine at an angle, the so-called 'spread angle'. The trajectories of the particles are, therefore, not parallel, but appear more like a radial flow. When the radial flow pattern is assumed, then the flow-angle at the particular point *P* in two-dimensional space may be predicted simply from the coordinates of source point *S* and *P*, as shown in Figure 1.

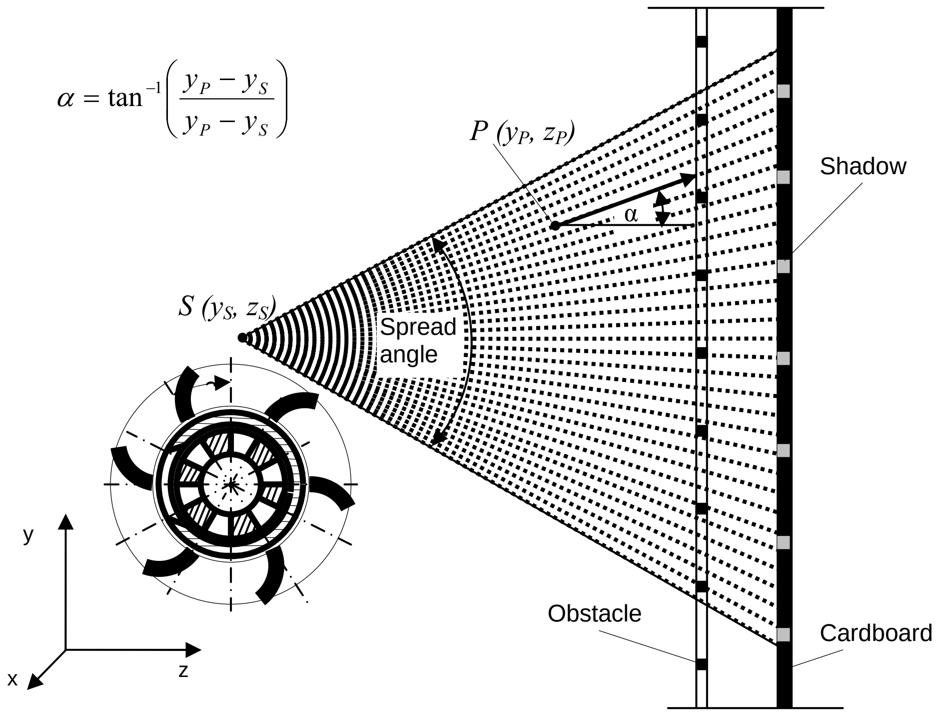

Figure 1. Shot flow angle

Coordinates of the source-point *S* are determined by measurement. A ladder-shaped obstacle placed in front of a soft cardboard is applied. This allows the particle trajectories to be determined from the coordinates of the particular obstacle, and its shadow on the cardboard. The trajectories are then extended in the direction of the turbine and the intersection of each pair of trajectories is determined. The position of the source point is finally calculated by averaging. Any measurement uncertainty of this procedure is very small, in spite of its simplicity. Standard measurement uncertainty of coordinates y_S and z_S is less than 10 mm, which confirms the assumption of radial-flow regarding shot particles. The spread-angle of the flow is determined using the same measurement. It is calculated from the coordinates of the highest and lowest points on the cardboard hit by the shot particles.

3. MASS-FLOW DISTRIBUTION MEASUREMENT

There are several methods which can be used for mass-flow distribution measurement. Different methods applying capacitive [2] and electrostatic sensors [3] are used for particulate solids' concentration and velocity measurement in pneumatic pipelines. Optical methods are successfully applied for the droplet-distribution measurement of sprays [4] and even for measurement at the nozzle of a shot-peening machine [5]. None of these methods were used in our case. Very harsh conditions within the testing chamber prevented their application. An alternative method was, therefore, used. The particle stream was intercepted by a multi-hole collector device (Figure 2). The mass of shot particles collected in a particular hole of the collector was weighed and the partial mass flow was calculated by dividing the collected mass by the interception time. The mass-flow (shot particle) distribution was obtained by moving the collector device step by step through the inspected area. Relative mass-flow distribution measured 800 mm from the tip of the turbine, is presented in Figure 3. It has an approximately two-dimensional normal distribution, with expressive peak 50 mm below the horizontal centre line. More than 60 % of the particle shot flow is concentrated within a 600 mm high and 50 m wide ellipse.

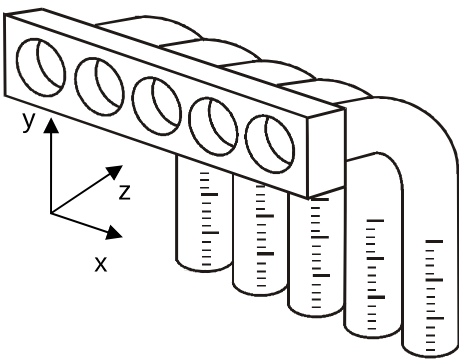

Figure 2: Multi hole collector

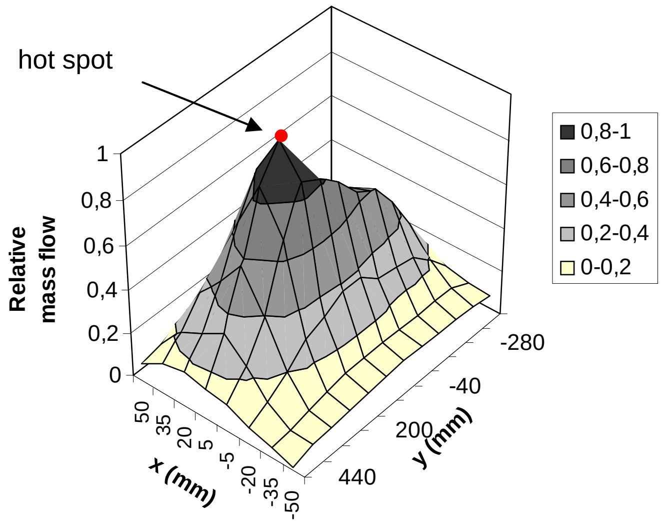

Figure 3: Relative mass flow distribution

4. SHOT-VELOCITY MEASUREMENT AND TURBINE EFFICIENCY PREDICTION

In order to measure shot-velocity, an electronic velocity measurement system was developed which allowed the local shot velocity to be measured. The measurement system is presented in detail in [6]. The pulsatile nature of particle flow enables application of a cross-correlation based method. Three axially-spaced impact sensors (Fig. 4) are placed in the shot particles' stream and the phase-shift between their signals, which is correlated to particle velocity, is measured. Cross-correlation is used for phase-shift determination between the signals, and the velocity is calculated from the ratio of the distance between sensors S1 and S2 (see Figure 4), and the phase-shift. Sensors S2 and S3 are placed in the same plane, thus the phase shift between their signals equals 0 when the sensor's carrier is collinear with the trajectories of the shot particles. Correct positioning of the sensors is, therefore, possible with phase-shift S2-S3 control.

Table 1: Comparison of turbine parameters

	6 blade turbine	8 blade turbine
Electric power (kW)	10,38	11,06
Mass flow (kg/s)	3,070	3,065
Spread angle (^{0})	50	50
Mean shot velocity (m/s)	68,0	69,9
Turbine efficiency (%)	0,684	0,677

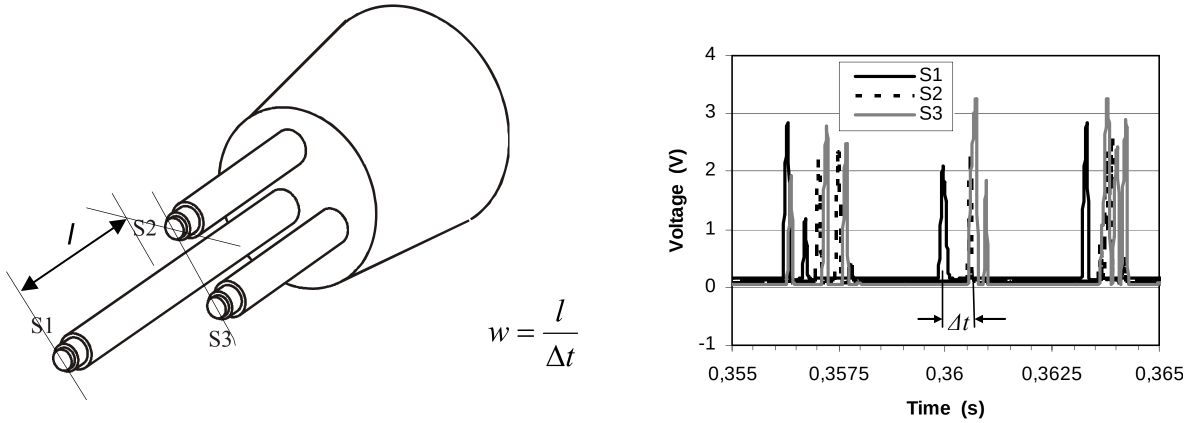

Figure 4: Shot velocity measurement

Shot-particle velocity measurements were performed 800 mm from the tip of the turbine. Vertical and horizontal velocity profiles, respectively, were measured, which allowed two-dimensional velocity profile to be predicted. Having both velocity and mass flow distribution profiles known, it was possible to apply equation (2) for kinetic energy flow prediction and, finally, to predict turbine efficiency. Two similar prototype turbines were examined both having the same geometry but, however, different numbers of blades. The main goal of the test was to make the decision for the optimal number of blades. Some of the results are presented in Table 1. Mass-flow rate and spread-angle are the same for both turbines, however, there are some differences in the power-consumption and shot-velocity. Shot-velocity and power-consumption both increase with the number of blades, while turbine efficiency reduces slightly with any increased number of blades. Better efficiency was the deciding factor for a 6 blade turbine to be selected for the final production design.

5. CONCLUSIONS

A test procedure was presented for shotblasting turbine efficiency prediction, and methods for shot-velocity, spread-angle and shot mass-flow distribution measurement were proposed. Two shotblasting turbines were examined both having similar design but different number of blades. Regarding shot particles' velocity, the 8 blade turbine was advantageous over the 6 blade turbine, however, more favourable turbine efficiency and power consumption decided in favour of the 6 blade design.

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