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# Methodology of Testing Shot Blasting Machines in Industrial Conditions

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## Abstract

Shot blasting machines are widely used for automated surface treatment and finishing of castings. In shot blasting processes the stream of shots is generated and shaped by blasting turbines, making up a kinetic and dynamic system comprising a separating rotor, an adapting sleeve and a propelling rotor provided with blades. The shot blasting performance- i.e. the quality of shot treated surfaces depends on the actual design and operational parameters of the unit whilst the values of relevant parameters are associated with the geometry of turbine components and the level of its integration with the separator system. The circulation of the blasting medium becomes the integrating factor of the process line, starting from the hopper, through the propeller turbine, casting treatment, separation of contaminated abrasive mixture, to its recycling and reuse.

Inferior quality of the abrasive agent (shot) and insufficient purity of the abrasive mixture are responsible for low effectiveness of shot blasting. However, most practitioners fail to fully recognize the importance of proper diagnostics of the shot blasting process in industrial conditions. The wearing of major machine components and of the blasting agent and quality of shot treated surfaces are often misinterpreted, hence the need to take into account all factors involved in the process within the frame of a comprehensive methodology.

This paper is an attempt to formulate and apply the available testing methods to the engineering practice in industrial conditions.

**Keywords:** Non-Destructive Testing, Finishing Treatment of Castings, Blasting Units, Operation and Maintenance, Test Methodology

## 1. Shot blasting techniques- introduction

The final stage in the manufacturing of cast products involves the surface treatment and finishing of castings to remove the residues of the moulding and core mix to obtain the required surface quality and condition.

Among surface treatment methods, mechanical methods seem prevalent, particularly the abrasive (or shot blasting) methods. Their key advantages include low energy demands, high quality of treated surfaces, good potentials for process automation, the use of shot blasting units made of more durable materials, work safety and environment-friendly features.

In shot blasting processes a stream of abrasive medium with the required kinetic energy is generated and propelled onto the surface to be treated. The stream of the cleaning agent, being a mixture of metal shots, is a dynamically variable system, involving a concentrated and dispersed zone, as revealed by numerous studies.

The actual proportion of particular zones in the structure of the shot stream strongly impacts on the shot blasting efficiency. The greater the concentrated zone, the more effective the process. Other determinants of shot treatment efficiency include:

- satisfying the criteria underlying the design of blast mechanisms,
- properties of the cleaning agent which has to meet the specific process requirements,

- the optimal shape of the shot stream in terms of its geometric, kinetic and dynamic parameters,
  - direction of the jet hitting the surface of the treated field.
- These factors determine the surface quality of shot-treated castings.

As shot-blasting processes are most complex, extensive research and analytical studies are conducted to optimize the process and mechanical parameters of the system components and to identify the key phenomena involved in shot-blasting. Of particular importance is the methodology of measurements and evaluation of process parameters as they are necessary to ensure good efficiency of the process.

## 2. Characteristics of mechanisms in shot-blasting machines

Constructional and operational parameters of shot-blasting machines are closely related to the efficiency of the shot-blasting operation. The fundamental process involved in shot-blasting is the circulation of an abrasive agent, assuming the form of heterogeneous mixture. This heterogeneity is associated with:

- composition of various types of abrasive materials (for example metal shots and scrap material separated from the surface being treated),
- shape and size of shots and proportion of particular grain size fractions.

The heterogeneity of the mixture circulation is also associated with the geometry, kinetics of motion and dynamic behavior of the abrasive agent flowing through particular elements of the shot-blasting unit (Fig. 1.)

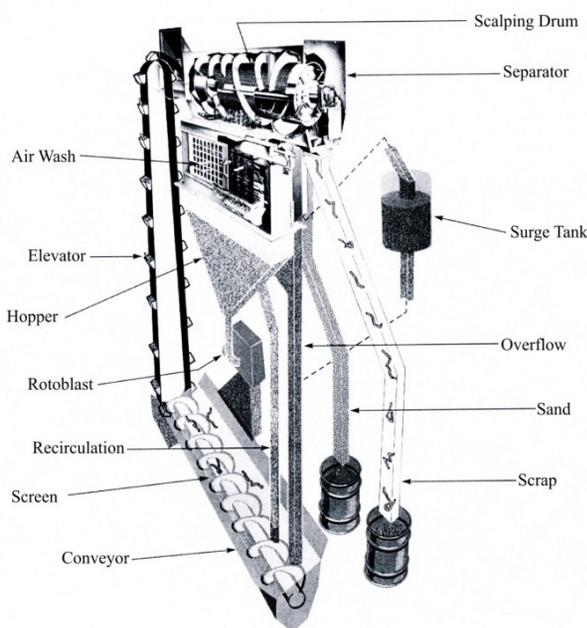


Fig. 1. Circulation of the abrasive agent in the shot-blasting machine [1]-schematic diagram

The circulation of the abrasive agent involves two stages. The first stage begins in the hopper placed on the highest level in the shot-blasting machine. The hopper has two functions: it holds the required amounts of the abrasive agent to ensure the continuity of the process and acts as a dosing unit, supplying the shots to the blasting turbine through the action of the gravity force via a piping installation. The characteristic parameter in the dosing process is the concentration of the shot column, which determines the amount of shots and the dynamics of their flow to the turbine. At that point the abrasive mixture contains the recycled abrasive agent purified to remove scraps of the core and sand mix as well as fresh agent added successively to fill up to the required amount. Addition of fresh shot further contributes to homogeneity of the grain size, which improves the process performance. Purity of the recycled abrasive agent is a major requirement, besides the shot fractions have to be first separated in a separator. The most typical option uses a magnetic-pneumatic separator. The further stage of the abrasive agent circulation involves its flow to the separating rotor.

In the context of operational requirements, the flow rate of the abrasive agent to the rotor should be precisely controlled such as to fill the entire rotor volume. This requirement is expressed by the relationship between the cross-section of the circular outlet opening of the feeding pipe and the circular internal cross-section of the separating rotor. In the rotor the compact column of abrasive agent is separated into batches of smaller volume directed to the blast blades via the hopper. The stream is separated by rectangular slots cut in the cylinder-shaped side wall of the rotor. In the existing rotor solutions the number of slots varies from 8 to 12. Most practitioners recommend 8 –slot options [2, 3, 4].

The separating rotor and an adapting sleeve form a kinematic pair. The main function of the adapting sleeve is to supply the doses of abrasive agent onto the blades of the blast rotor (Fig. 2.). The feeding is effected on the inside of the rotor where the stream of abrasive agent begins to be formed. In terms of its design, the sleeve is a cylinder with the specified wall thickness, in which a rectangular slot is cut. The slot dimensions (length, width and thickness derived as the difference between the outside and inside radii) make up its volume, which controls the mass flow rate of abrasive agent fed via the separating rotor.



Fig. 2. Separating rotor- adapting sleeve

Testing done by major manufacturers of shot blasting systems has revealed that the optimal slot length is the sum of widths of two slots in the separating rotor and the width of the wall in between those two slots. This requirement should be met to

ensure the continuity of the stream of abrasive agent between the separating rotor and the sleeve. This continuity is maintained until the stream of the abrasive agent gets in contact with the blade surface.

In terms of operational requirements, the sleeve position is of key importance. It is defined by the slot's inclination angle with respect to the horizontal plane. The value of this angle determines the dynamic behavior of abrasive agent ejected under the action of the centrifugal force. Test results reveal that the best dynamic effects are achieved at the angle of 20 degrees.

The key mechanism at the final stage in the controlled circulation line of abrasive agent is the blast rotor with blades (Fig. 3).

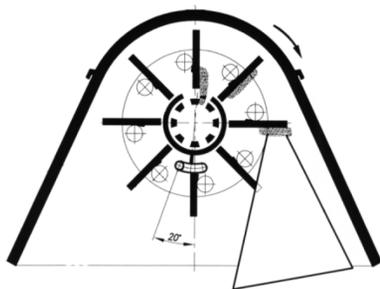


Fig. 3. Schematic diagram of a 8-blade turbine TR-150 [5, 6]

On the turbine blades the shot forms a stream flowing along the blade length. Depending on the actual arrangement of the separating rotor and the sleeve, the flowing stream will be roughly uniform on the blades' width and length.

As soon as the stream of shot leaves the blades, its direction is controlled by setting the wheel, whilst its shape changes both in width and in length, thus forming a range of shot flow. The concentration of the shot stream changes, leading to formation of a concentrated and dispersed stream, arranged along the outer perimeter of the concentrated stream. The efficiency of the shot blasting process is associated with the flow intensity of the concentrated stream.

In the second stage of shot circulation we get a mixture of sand and moulding mix. In order that the sand could be recirculated (stage 1) it is required that the moulding mix should be first separated from the sand. This is done by mechanical separation methods, such as screening or by electromagnetic or pneumatic methods. Combination of those methods offers very good effects (Fig. 5.).

The separation system involves:

- separation of sand from contaminants on a continuous basis,
- removing crushed shot fractions to stabilize the grain size distribution,
- removal of particulate matter.

Key indicators of the separation efficiency are:

- shot contamination with moulding mix, the admissible content of contaminating agents up to 1%,
- separation performance: the amount of separated contaminants in kg/min.

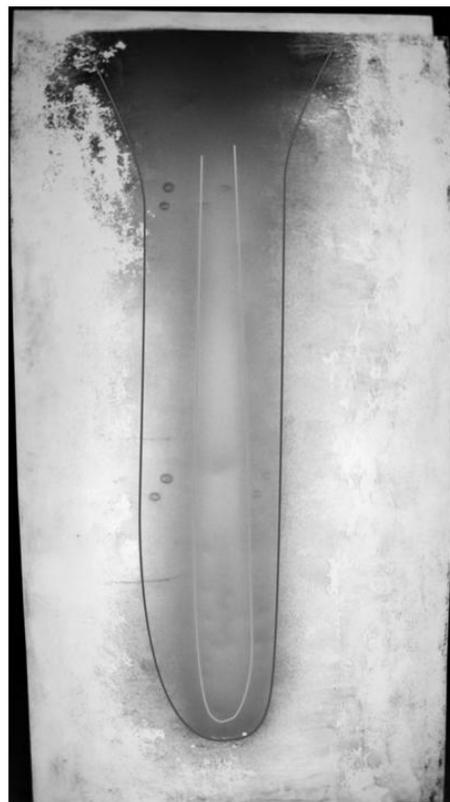


Fig. 4. Surface area of the effective action of the concentrated (green) and dispersed (red) stream of shots blasted from the lower rotor [5, 6]

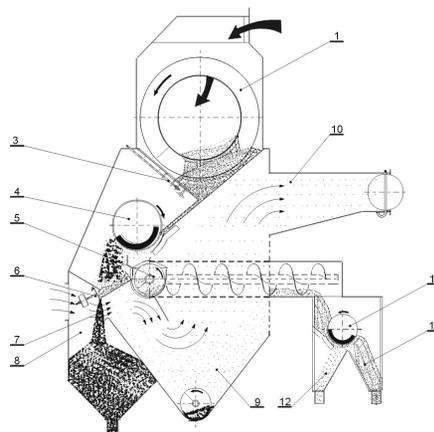


Fig. 5. Separation system: screening drum (1), worm mechanism (2), adjustable cover (3), magnetic drum (4), damming lid (6), air curtain (7), tank (8), tank (9), helical conveyor (5), magnetic drum (11), tank (12), tank (13), exhaust fan (10) [7]

The separation (shot cleaning) process is of key importance. Homogeneity and purity of the abrasive agent have an impact on:

- durability of machine components (blades, rotors, sleeve),

- process efficiency, quality and condition of surfaces being treated,
- control of the shot stream and the effective blasting zone.

Regardless of the actual machine design and process parameters, the type of the abrasive medium plays a major role as well. The shot form and material directly impact on the quality and efficiency of treatment processes, as well as wearing and tearing of the machine components.

Most shot blasting systems in foundry engineering use the abrasive media in the form of round-shaped or sharp edged metal shots of variable grain size, abrasion-resistant, highly elastic and of specified hardness. The selection of shots to be used depends on the casting technology, the surface quality requirements and the assortment of castings to be treated.

### 3. Investigation of the service condition of machines

In the context of methodology, the investigation of the service condition of systems should cover the following processes:

- process preparation, organizational and managerial activities,
- operation and maintenance of the system when the potentials of all mechanisms are utilized in the designed manner,
- evaluation of the system operation, involving the performance testing of all mechanisms and the entire blasting process.

The procedures included in the structure of the process operation are closely associated with the predicted production capacity.

The management process combines the decision-making and reporting activities, required for successful operation of the system. The reporting should include all phenomena and events taking place in the shot blasting machine, in conjunction with organizational activities. The decision-making process involves all events associated with processing and transmission of all data having relevance to the evaluations of the system operation.

Of particular importance is the system operation, here understood as the use, operation and maintenance of machines. Machine use applies to fully efficient machines- able to perform the shot blasting operations.

The process of machine operation and maintenance applies to malfunctioning machines or which display some mechanical failures. The main aim of the process is to perform the specified task, or to maintain or restore the condition of full usability.

Investigation of system operation may involve single machines, groups of machines or the entire workplaces. The programme of testing a single machine is extended and should include:

- selection of the machine (for instance a shot blasting machine), evaluation of its service parameters, durability, reliability,
- the extent of using its production capacity,
- efficiency, control of machine operation,
- intensity of use and maintenance,
- economic analysis.

Tasks included in the test program include:

- identification of factors affecting the condition of the machine, analysis of technical and organizational parameters,
- analysis of tendencies in the state variations,
- creation of a model of operating conditions and involved phenomenon,
- development of a program to encourage the desired changes in the relevant processes.

In the context of the testing methodology, two predominant models are stipulated:

a) operation and maintenance model, with operational parameters at the input and characteristic parameters at the output, associated with the machine or process conditions,

b) decision-making model, providing the criteria for evaluating the condition of the machine.

### 4. Operation and maintenance model for diagnosing mechanisms and processes in shot blasting machines

Diagnosing the status of mechanisms and processes in shot blasting machines is the absolute prerequisite and the necessary condition of effective machine operation. Physical wearing of machine components changes the efficiency of the casting treatment. The wearing and tearing is caused by recirculation of the abrasive medium and associated kinetic and dynamic processes. The extent of wearing varies at different points of the shot circulation system and depends on the design and interrelated operational parameters. The analysis of the process, starting from the shot feeding right to the moment of shot hitting the surface to be treated leads us to formulate the conditions for its effective operation, regulation and control of the blasting time, loading of the blasting rotors and the number of operated turbines.

Since the blasting turbine and the shot separator play a major role in the system, they are analyzed separately and the synthesis of the results helps in making the final assessment of the system's performance.

The methodology of such analysis in industrial conditions involves:

Stage 1- technical specifications of the shot blasting machines

Table 1.  
Technical specifications of the shot blasting machine [8]

ROTOR	1	2	3	4
Power ratings, kW	22	22	22	22
Voltage, V	400	400	400	400
Rotor's OD, mm	380	380	380	380
Rotor's ID, mm	130	130	130	130
Blades (S-straight, C- arc-shaped)	5	5	5	5
Number of blades	4	4	4	4
Rotor, rpm	2930	2930	2930	2930
Linear velocity of the blast shots, m	76	76	76	76
Maximal loading, A	39	39	39	39
Current intensity under idle run, A	10	10	10	10
Loading- operation, A	34	28	28	32
Efficiency	81%	60%	60%	74%
Blasting rate, kg/min	288	213	213	263

Stage 2- Observation

1. Screen conditions and the level of purity

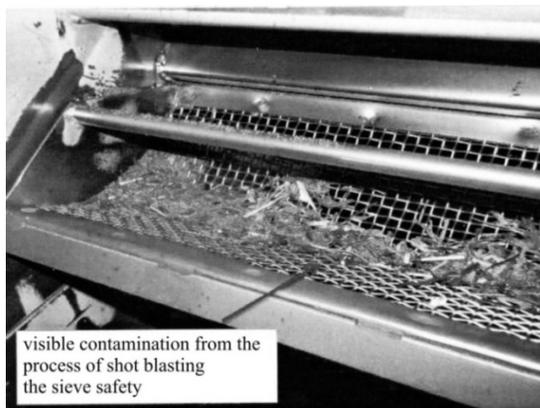


Fig. 6. Screens in the shot separator [8]

2. Characteristics of the pellet curtain

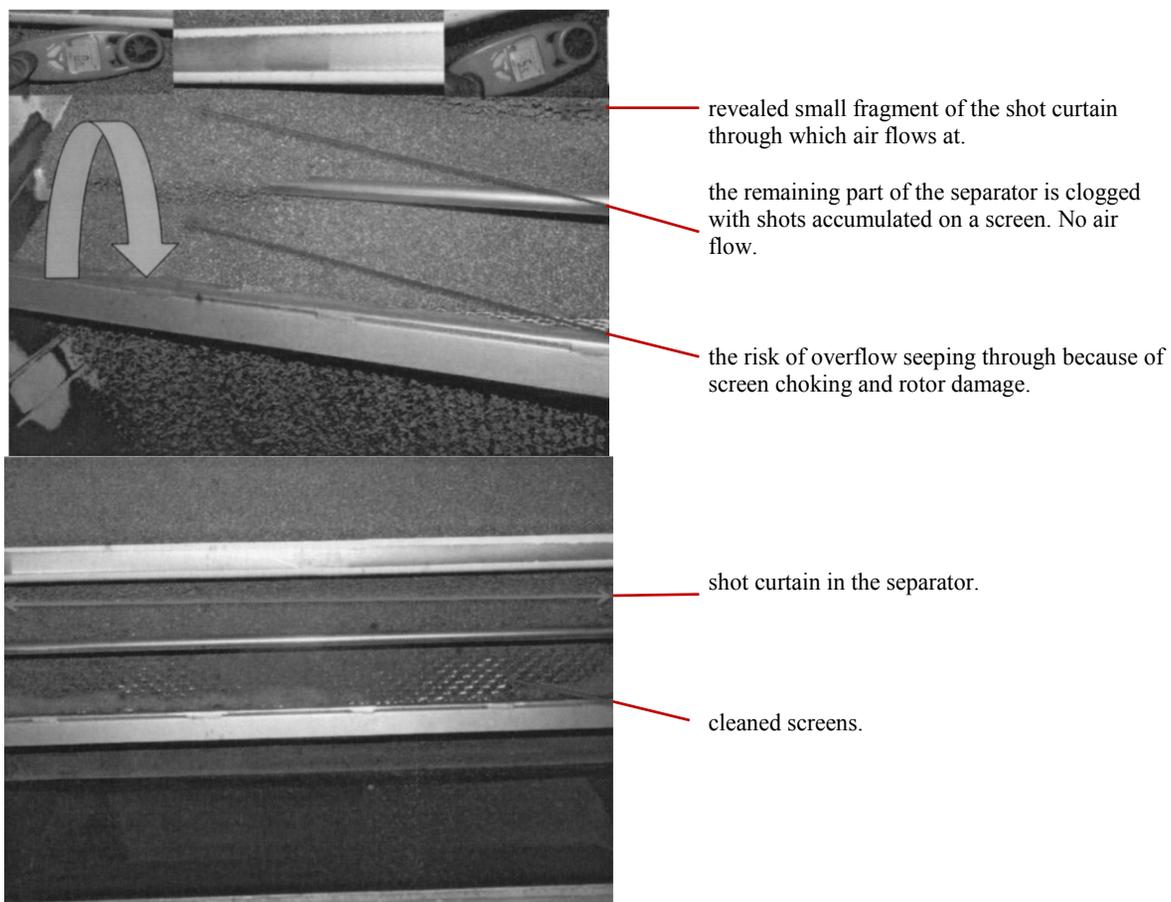


Fig. 7. Separator conditio - analysis [8]

### 3. The level of tank filling with shot Stage 3. Measurements and calculations

#### Blast turbine

##### 1. Recording of the power uptake, electric drives in rotors

- current measurement during the idle run,
- current measurement under loading,
- graphic representation of measurement data.

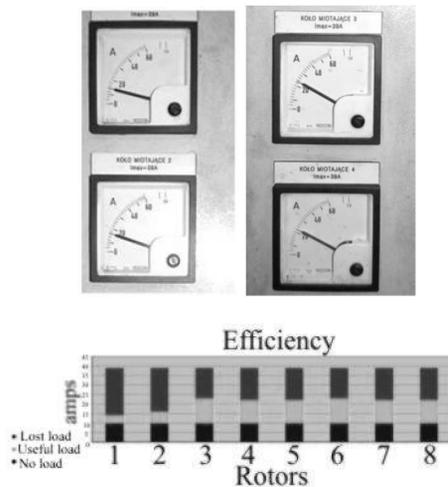


Fig. 8. System of ammeters, current plots [8]

##### 2. Performance testing of the rotor

- measurement of shot blasting time 60 s,
- determining the weight of blasted agent.

##### 3. Operational parameters of the shot stream, stream control, the angle of stream dispersion, concentration

- positioning the adapting sleeve,
- mass distribution of the shot grains,
- measurements of the blast traces,
- graphic and computer-assisted analysis of the stream concentration and the range of stream action.

##### 4. Measurements of wearing and tearing of machine components: blades, wheel discs, sleeve, the separator rotor

- monitoring of the wearing and tearing along the width and across their depth,
- experimental test until total wearing,
- checking the blade assembly.

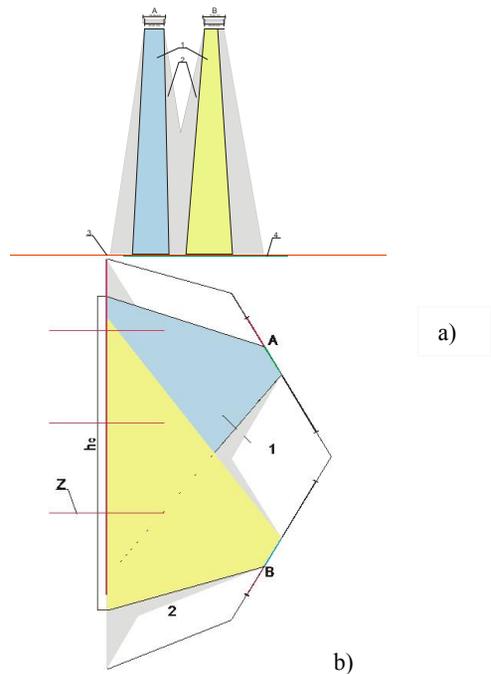


Fig. 9. Width (a) and height (b) of the shot stream range from the rotor:

- a) A-upper, B-lower: 1- zone of concentrated stream, 2- zone of dispersed stream, 3- control screen, 4- trajectory of the lifting sling
- b) A-upper, B-lower, hc-height of high-intensity cleaning zone, 1- zone of concentrated stream, 2- zone of dispersed stream, Z- lifting sling [5, 6]

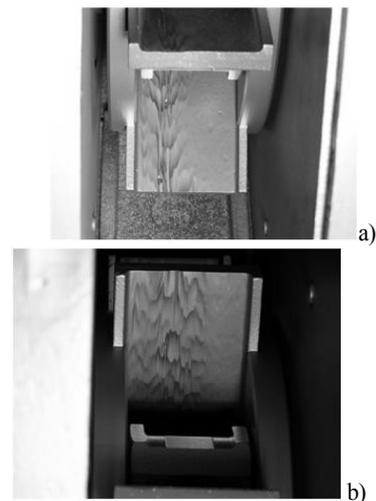


Fig. 10. Comparison of the condition of the blades' surfaces in the function of time of their operation: a) blade in the lower rotor after 62 hours, b) blade of the upper rotor after 72 hours [5, 6]

## Shot separator

### 1. Measurements of non-metallic fraction contents in the shot circulation system

- collecting the shot sample from the system (by weight),
  - magnetic separation of the metallic fraction from shot grain fractions,
  - finding the (percentage) proportion of a non-metallic fraction.
- ### 2. Grain size analysis of the abrasive agent (shot mixture)
- screen analysis,
  - graphic representation of result,
  - determining the indices of polydispersive grain sets.

## Shot blasting machine as an integrated plant

### 1. Measurements of sound emissions

- noise measurements taken with a sound level meter during three phases of machine operation: idle run, shot feeding, cleaning of castings.

Sieve (mm)	Mixture Op. Measurement %	MO 2 Measurement %	MO 3 Measurement %	SEP 1 Measurement %	SEP 2 Measurement %	SEP 3 Measurement %	Filter Measurement %	
2,36								
2,00								
1,70								
1,40	8	2%						
1,18	8	2%						
1,00	39	10%						
0,85	94	23%						
0,60	162	40%		17	7%			
0,42	96	24%		114	30%			
0,30	1	0%		25	13%		8	16%
0,21				24	12%		2	4%
0,15				14	7%		3	6%
0,12				3	2%		3	6%
Dno				2	1%		24	65%
Sum of	408	100%		195	100%		50	100%

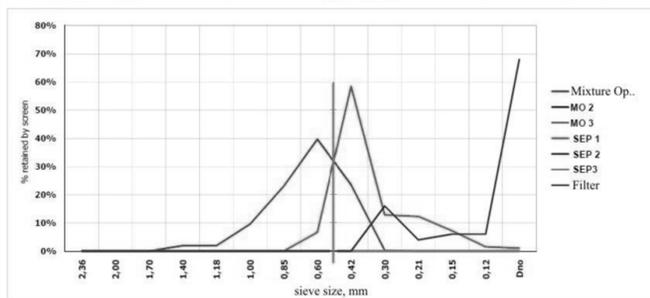


Fig. 11. Grain size distribution of the shot mixture [8]

## 5. Evaluation of the operation status and the shot blasting effect

The main purpose of the evaluation procedure is to prepare the data for the decision-making, having relevance to the process conditions, its mechanisms and the surface-cleaning performance. Hence it provides the background for actions aimed to improve the performance of shot blasting machines and to make the process more effective. The methodology outlined here stipulates the simplest methods of measurements and quantitative calculations.

### Cleaning performance

The measure of the degree of the casting's cleanliness after separating the adhering moulding mix is the surface roughness. The cleaning effect is the function of the amount of abrasive agent supplied to the turbine and the effective blasting time. The lower level of the cleaning agent in the tank, the lower the concentration

of the shot column and the moulding mix removal may become less effective.



Fig. 12. Evaluation of the cleaning efficiency [8]

### Loading of driving motors in the blast turbines

It is recommended that high loads should be applied to maintain the maximal power ratings. Depending on the power level, the shot blast rate (kg/s) should be as large as possible. The maximal power level guarantees the short cleaning time and effective separation of the moulding mix. The level of applied load is associated with the level of the tank filling with the abrasive agent.

### Condition of protecting screen in the separator

Keeping the screens clean is necessary to ensure safe operation of the separating rotor, of the adapting sleeve and the cleaning rotor. The layer of abrasive agent, flowing freely through clean screens forms a uniform curtain, which ensures effective dust removal from the abrasive agent. Besides, fine grains of used shots are easily removed, too. The air flow is required at the specified velocity.

### Proportion of non-metallic fractions

Tests have revealed that the proportion of contaminants in the circulation system of an abrasive agent, such as shot, or shot mix, should not exceed 1%. A higher proportion of such fractions causes the durability of the machine components to deteriorate dramatically, even by 80%.

### Grain size distribution in the abrasive medium

Indicators characterising the grains are used in the decision making as to whether fresh agent should be added to homogenise the mixture or to replace the used medium. The grain size distribution in the abrasive agent and its quality have to be evaluated since the presence of an abrasive material leads to the wearing and tearing of the machine components, particularly the blast blades.

### Noise and vibration levels

Noise and vibrations typically appear and exceed the admissible levels when the machine components are already worn and damaged. When the rotating elements are unbalanced or the screw connections get loose, the noise and vibration levels will increase.

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