Improvement of the technology of tribostate application of powder paints using fractal analysis of spray quality

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Abstract. The paper proposes a method of quantitative fractal evaluation of the quality of powder materials application on metal surfaces by tribostatic method. The developed design of tribometry spray, which provides efficient charging of powder with different fineness and moisture content of the particles. The computer implementation of the proposed algorithms for assessing and controlling the quality of powder coating is carried out. Laboratory experiments have shown that with an increase in the number of helical elements in the design of the sprayer, the fractal dimension of the corresponding sample images of spraying spots. The results support the hypothesis that the increase in the number of the screw elements leads to an increase in the length of the path of the powder in tribospayer. This significantly increases the number of collisions of individual powder particles between themselves and with the walls of the spray gun, and this contributes to a stronger charging of particles of different types of powder paints and, as a result, reduces the shedding of powder from experimental samples of different materials. The conducted research can significantly optimize the technological processes of tribostatic spraying of powder paints at small enterprises of machine-building or automotive industry.

Keywords: sprayer design, fractal dimension, quantitative analysis of spray quality, tribostatic gun.

1 Introduction

The technology of powder coating (polymer coating) originated in the early 80-ies of the last century almost simultaneously in the United States and France. In Eastern Europe, it has become widespread recently, because the technology was quite expensive and energy consuming. Today, the methods of powder coating are significantly improved. Experts say that the cost of applying powder paint for new technologies is ten times cheaper than before, so in the world "dry" paint constantly displaces "liquid technology" [1].

Powder paint (hereinafter PP) is a monosyllabic material. Instead of mixing with solvents, it is transferred to an aerosol state and passed through an electrostatic field. Electrostatic attraction causes the paint particles that have received a positive charge to be attracted and adhere to the painted object. After spraying the paint product is placed in a special oven. When heated, the paint is melted (polymerized), forming a smooth monolithic layer. Then the temperature rises to the values necessary for the final solidification of the coating [2, 3].

The use of a gun for powder coating significantly improves the quality of painting works and makes the spraying process convenient. Due to its unique properties, the painted surface is covered with paint more evenly and effectively even in the most inaccessible places.

However, during powder coating, there are technological problems associated with the loss, shedding of powders in the process of spraying on objects. The process of spraying should take place in special chambers. There are different types of such chambers, but the principle of operation is the same: powder paint, which is not settled on the surface, is pumped out by a powerful fan and cleaned with special filters. In this case, the paint particles accumulate on the filters and then either collected in special containers, or fed back into the gun. When you change the colour of the paint there is a need for the replacement of filters, flushing of pipes of ink and a full cleansing of the chamber for spraying. All this is quite expensive and long procedures, especially for small painting enterprises [4].

Thus, the study of powder spraying technology, improving the design of guns for the application of powder coatings, the development and application of modern methods of diagnosis of the quality of spraying is an extremely urgent task for the paint industry.

2 Literature Review

As noted above, one of the main and important devices for high-quality powder coating is a spray gun. At work the gun for powder painting can use either electrostatic or tribostatic method of powder spraying.

Electrostatic spraying PP allows you to get a high-quality surface and is quite an effective method of applying powders. In one of the channels gun powder paint is fed, and the other channel is supplied with compressed air. Directly in the gun is charging paint at a power of 60-70 kW [5].

Electrostatic is the most common method of powder coating and there are a number of serious reasons: high charging efficiency of all powder coatings, coating quality and sufficient spray performance on a relatively large area. Paints, sprayed by electrostatic method, almost do not experience the influence of humidity [6].

In addition, except the benefits electrostatic guns have also disadvantages. First, it is the appearance of an electric field between the sprayer and the surface to be painted. This can significantly reduce the quality of spraying in hard-to-reach places, grooves and deep cavities [7]. To avoid such a negative effect, it is necessary to calculate accurately the electrostatic characteristics of the sprayer and the distance from the nozzle to the surface. Otherwise, there may be a phenomenon of reverse ionization, which reduces the quality of the coating. High cost of guns is also a disadvantage.

The second type of guns are designs with tribostatic powder charging. There is no particle charge generator in this type of system. The charge during the spraying process is formed due to the friction of the filler particles against each other and with the charging tube.

The advantages of tribostatic are: first, tribespeople have less weight, compared to the same electrostate. This is due to the lack of electronic circuits and high voltage converters. Secondly, the tribostatic guns have a significantly lower price, which is sometimes a decisive factor. Third, the tribostatic sprayer makes it much easier to apply a layer of powder paint in hard-to-reach places (deep cavities, narrow slits or in places of coupling of parts) than the electrostatic.

However, the elimination of the main disadvantage of tribostatic devices – the complexity of achieving a sufficient amount of charge without prior regulation of powder mixtures for dispersion and humidity is an urgent scientific task and is of great practical importance for optimizing the processes of powder coating.

3 Research Methodology

Analysis of systems of tribostatic spraying of the powder coating showed that the research of technological functions of such physical processes as friction is one of the main tasks tribostatic. The input parameters that allow to describe the measure of charging of powder paint particles in tribostatic systems are:

- the geometry of motion of particles of powder paint in the channel of the stationary dielectric cylinder of the gun;
- repeated contact of powder paint particles (to simplify, we assume that each particle has the shape of a ball) of a certain mass with the inner surface of the cylinder;
- the distance between the sprayer and the product;
- climatic conditions of the process (humidity and temperature of the air-powder mixture).

It is quite complicated for the exact solution of the system of various parameters and factors, especially if we want to find the critical state of the system tribostatic charging.

The high-speed particles during the deposition of powder with a lack of electrification leads to deflation of parts and significantly reduces the deposition efficiency.

At the end of the last century, the developers of new equipment for powder coating were tasked with developing a triple sprayer, which would not be inferior in performance and efficiency (degree of charging) to the best systems with high – voltage (corona) charging. As a result, a schematic diagram of the gun was developed (see Fig. 1), which is still considered the most effective in the powder coating industry. This design allows for a high ratio of the surface area that is charged to the volume of powder, as well as the necessary degree of turbulence of the powder particles inside the charger to ensure high-performance charging of most particles.

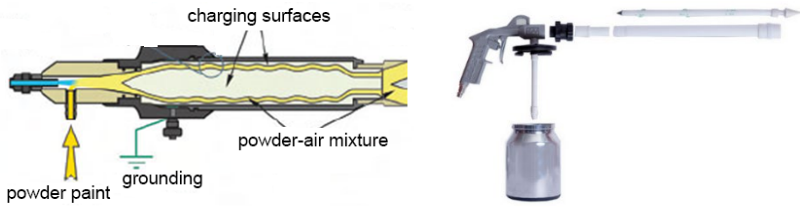

Fig. 1. The principle design of the sprayer and the design of the tribo gun

Since the charging efficiency is influenced by the number and strength of collisions between the powder particles and the charging surfaces of the atomizer, large powder particles hitting these charging surfaces with more force are charged better [8]. In addition, the large surface area of these particles also contribute to their more efficient charging.

Proceeding from this, we propose the design of a universal tribogun, which will allow, at the expense of specially designed equipment and the appropriate method of its application, to control the process of tribocharging of powder paints of varying dispersion, moisture, material.

The basis of the design of the standard tribogune (see Fig. 1) does not change. The main element of the improved design is a helical element (see Fig. 2) with special fasteners [9].

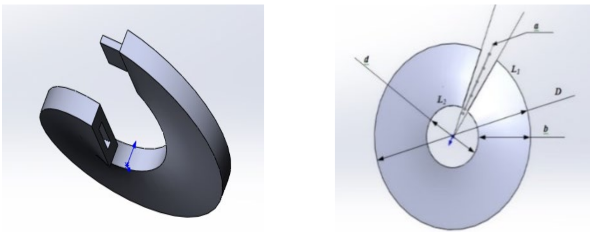

Fig. 2. Design scheme of the basic helical element

Calculation of geometrical parameters of such basic element (see Fig. 2) carried out according to the formulas:

$$L_1 = \sqrt{T^2 + (\pi D)^2}\,,$$

$$L_2 = \sqrt{T^2 + (\pi d)^2}\,, \tag{1}$$

$$d = \frac{2bL_2}{L_1 - L_2}\,,\quad \frac{D}{2} = \frac{d}{2} + b\,,$$

where T – the height of one spiral coil.

The angle of the process cut is determined from the ratio:

$$\frac{a}{360^0} = \frac{\pi D - L_1}{\pi D}\,. \tag{2}$$

Further, from such helical elements, as the designer, consists the core of tribo sprayer (see Fig. 3).

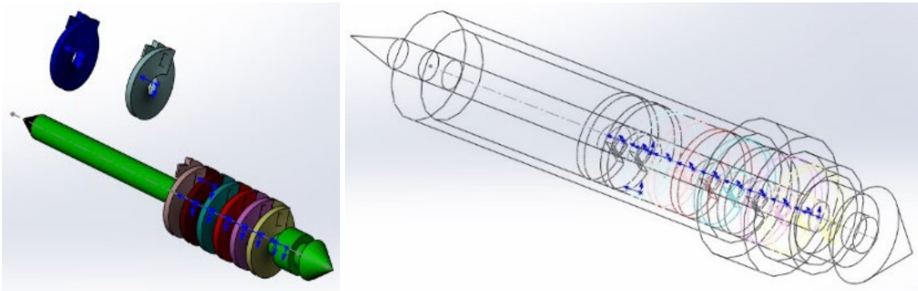

Fig. 3. Charger core and spray tube in the assembly

This improvement will quickly and effectively increase the path and the area of the charging surfaces, the number and force of collisions between the powder particles and the charging surfaces, as well as between the particles themselves, the force of interaction of particles with the charging surfaces of the sprayer, and thus control the degree of electrification of the powder, and hence the quality of its deposition on the parts that are painted [10].

However, for the effective application of the proposed design of the sprayer, effective methods for assessing the quality of the application of various powder materials with different dispersion and chemical properties on different surface geometries made of different materials are required.

Such effective methods include, on the one hand, equipment such as tribotester for measuring the electrification of powder paint particles, and on the other – methods of fractal geometry for the numerical analysis of technological processes and the quality of powder deposition on the painted parts.

However, the practical use of the tester revealed that it carries out measurements that do not answer the question of how to ensure the quality of powder coating for various painted materials, types of powders, climatic conditions and the like.

It was stated above that, in addition to the developed design of the universal spray powder paints, an effective method is needed to assess the quality of powder spraying with different technical parameters (powder material, dispersion, humidity, etc.). The basis of this technique can be based on a quantitative characteristic of the fractal dimension of the spraying spots, its analysis and development of recommendations for the transformation of the design of the sprayer for high-quality charging of various powder paints.

Analyzing the known methods of fractal modeling of structures and methods of calculating their dimension, we can draw the following conclusions [11, 12]: the vast majority of known fractal objects are discrete structures, which can be effectively modeled using known methods of discrete geometric modeling [13, 14]; spots of powder coating on surfaces can be considered as discrete point sets with the corresponding fractal dimension; methods related to the Minkowski dimension are the most suitable for calculating the fractal dimension of such powder spraying spots.

The content of the Minkowski method, or the so-called box-counting dimension method, is the need to approximate a certain, predetermined, compact set (in our case, a specially processed image of the sputtering spot) by elementary geometric shapes (for example, squares) and sum their areas.

Let *N(a)* – the minimum number of squares with a side that is needed to cover a certain set Ў . Their total area is proportional $N(a)a^D$. At

$$a \to 0,\ N(a) \to \frac{C}{a^D}, \tag{3}$$

where *C* – constant.

Logarithmizing this expression and carrying out a number of transformations, we find the Minkowski dimension as:

$$D = -\lim_{a \to 0} \frac{\ln N(a)}{\ln(a)}. \tag{4}$$

If the boundary does not even exist, it is possible, considering the table of values of dependencies between neighboring elements, to find an algorithm to obtain an approximate value of the Minkowski dimension.

If in (4) we remove the boundary of the relation, we can simulate it in iterations *(k)*, changing the sizes of our cells-squares covering the given set. Then the formula (4) will take the form:

$$N(k) \approx \omega a^{-D}(k), \tag{5}$$

where *D* – the desired fractal dimension; ω – typical for fractal geometry indefinite multiplier.

The technology of quantitative estimation of Minkowski fractal dimension for powder coating images consists in the following actions. Photo of the spraying spot (see Fig. 4 a), made with a professional camera Nikon D3500 with certain geometric parameters of its installation, processed using a specialized program to determine the deposition zones with different quality indicators for the polymerization of the powder coating (see Fig. 4 b). The zone of one colour of satisfactory polymerization (that is, the zone of continuous on the set area of melting of powder mass) is automatically allocated (see Fig. 4 c), which will form an image of the base of the spraying spot [15].

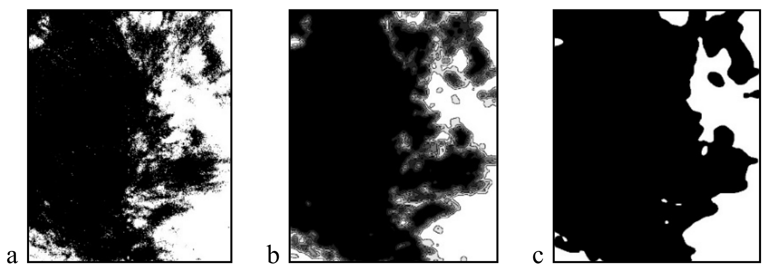

Fig. 4. The photograph and the processed image spot spraying

Further, according to the above technique, the image is covered with cells-squares with a side of a certain size and the number of such elements of the approximation is calculated at each iteration (see Fig. 5).

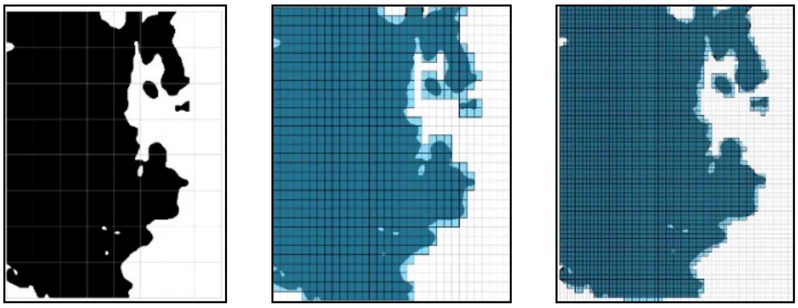

Fig. 5. Approximation of the image of the spraying spot by elementary cells with index *a*

Conducting such approximations the required number of times, we construct the dependence ln*N(a)* on ln*(a)*.

It can be noted that the dependence of the cell size on the number of cells at each step of the iteration in the logarithmic scale is approximately a linear function:

$$Y = C - DX\,, \tag{6}$$

where Y=ln(N), X=ln(a), D – the desired fractal dimension.

Let's sum up all our measurements by Y and X:

$$\sum Y = nC - D\sum X\,, \tag{7}$$

where n – number of measurements.

Then multiply the equation (7) by X and add it again:

$$\sum YX = C\sum X - D\sum X^2\,, \tag{8}$$

Now multiply equation (7) by $\sum X$, and (8) – multiply by n and find their difference.

$$\sum Y\sum X = nC\sum X - D(\sum X)^2\,, \tag{9}$$

and decide its relatively D.

$$D = \frac{\sum Y\sum X - n\sum YX}{n\sum X^2 - \left(\sum X\right)^2}\,. \tag{10}$$

This will be the fractal dimension of the spraying spot with powder paint of a certain painted area.

4 Results

For the practical implementation of the developed methodology and design of the sprayer of tribogun, in the enterprise of powder coating of elements of car bodies for the same painting material, a series of experiments were conducted to study the quality of powder coating.

To do this, a powder paint of different manufacturers was applied initially to a standard gun (see Fig. 1) on a grounded flat surface at a fixed distance. Examples of some samples with the image of spray with different powders are shown in Fig. 6 a, b, c.

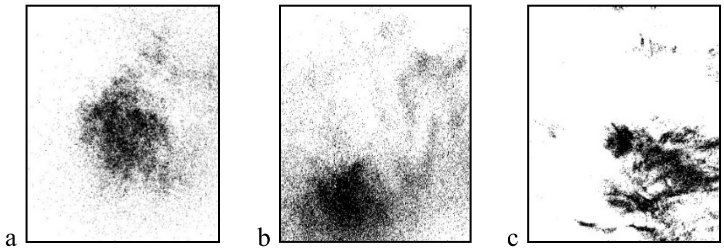

Fig. 6. Samples of images of spots spraying powder paints from different manufacturers.

Further, helical screw elements were added alternately to the design of the sprayer (see Fig. 2) and again carried out the process of spraying, photographing and fixing, as the effect of shedding powder materials. An example of the sprayer with four screw elements is shown in Fig. 7 a, b, c.

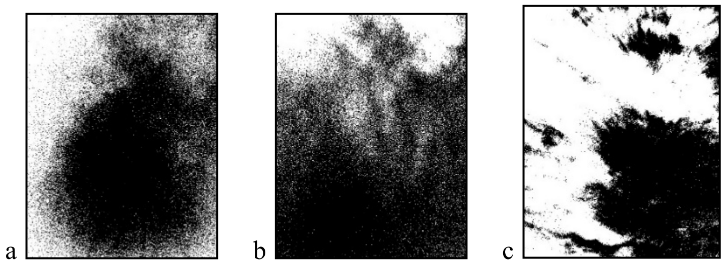

Fig. 7. The images of the spots on spraying with the use of four screw elements.

An example of the sprayer with seven screw elements is shown in Fig. 8 a, b, c.

Even visually you can see how under the same conditions the quality of application of different types of powder paints with different conditions of tribo-charging of powder particles changes.

However, a quantitative measure of the quality of powder adhesion on grounded surfaces can be an indicator of the fractal dimension of powder deposition images counted according to the above procedure.

Indicator of fractal dimensions of the images stains deposition grew with the application and increase the number of the screw elements in the design of the atomizer tribometry. So the fractal dimension of the images in Fig. 6 ranged from 1.54 to 1.58 units. Fractal dimension of spots in Fig. 7 is 1.6-1.7 units. Fractal dimension of the spray image in Fig. 8 was 1.72-1.84 units.

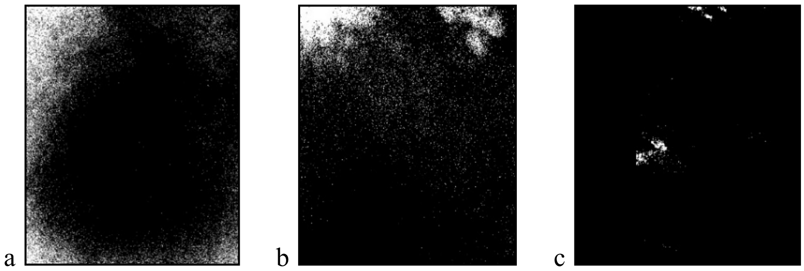

Fig. 8. The images of the spots on spraying with the use of seven screw elements.

The results are understandable and easily explained. Adding to the design of the helical screw elements, we thereby increase the length of the path of the powder in tribosphenomys, thus increasing the number of collisions of the individual powder particles among themselves and with the walls of the atomizer. This made it possible to charge stronger particles of different sizes of each powder paint, and from so-significantly reduce the effect of powder shedding on the painted material.

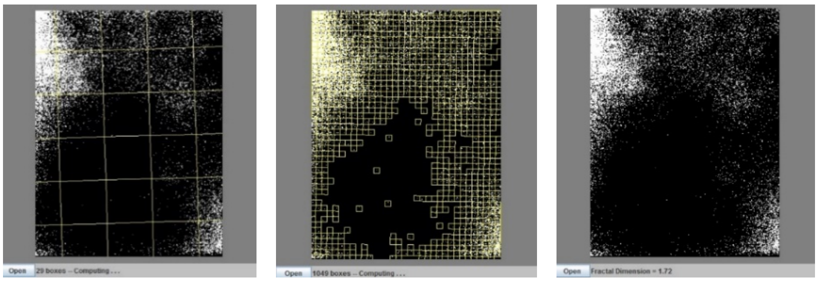

Fig. 9. The work of a computer program for calculating the fractal dimension of the sputtering

To verify the correctness of the proposed method for determining the fractal dimension of the samples, we used a computer program of calculation proposed in [15].

On Fig. 9 the stages of the program for determining the fractal dimension are shown. The error in determining the fractal dimension of the two methods is ±2%.

5 Conclusions

Based on the analysis of factors affecting the quality of spraying of powder coatings, the design of the tribogun, which provides efficient charging of powder with different fineness and moisture content of the particles. The method for the quantitative fractal evaluation of the quality of powder coating materials is developed. A computer implementation of the proposed algorithms for assessing and controlling the quality of powder coating is carried out.

Laboratory experiments have shown that with an increase in the number of helical elements in the design of the sprayer, the fractal dimension of the corresponding samples of the sputtering spots images increased from 1.52 to 1.84 units. The results confirmed the hypothesis that the increase in the number of the screw elements leads to an increase in the length of the path of the powder in tribosprayer, what significantly increases the number of collisions of the individual powder particles among themselves and with the walls of the spray gun. This contributes to a stronger charging of powder paint particles and, as a result, reduces the shedding of powder from different materials.

The conducted research will significantly optimize the technological processes of tribostatic spraying of powder paints at small enterprises of machine-building or automotive industry.

References

1. Sathish Kumar, P., Rajasekar, R., Pal, S. K.: Paints and Coating of Multicomponent Product. Springer Series in Materials Science. Nayak, G. C., & Syed Ismail, S. M. R. 157–226 (2016)
2. Lothongkum, A., Nonthapone, R., Seangkiatiyuth, K., Tanthapanichkoon, W.: Powder characteristics and coating conditions of fresh and reused polyester resins for electrostatic powder coating: powder recycling and loss prevention. Advanced Powder Technology. 18(2), 175-186 (2007)
3. Bareschino, P., Pepe, F., Salatino, P.: Shear-assisted fluidized bed powder-coating. Powder Technology. 215–216, 151-155 (2012)
4. Thomas, A., Saleh, K., Guigon, P., Claire, C.: Characterisation of electrostatic properties of powder coatings in relation with their industrial application. Powder Technology. 190(1–2), 230-235 (2009)
5. Meng, X., Zhang, H., Zhu, J.: Characterization of particle size evolution of the deposited layer during electrostatic powder coating processes. Powder Techn. 195(3), 264-270 (2009)
6. Mujumdar, A., Wei, D., Dave, R., Pfeffer, R., Wu, C.-Y.: Improvement of humidity resistance of magnesium powder using dry particle coating. Powder Technology. 140(1–2), 86-97 (2004)
7. Shah, U., Zhu, J., Zhang, C., Nother, J.H.: Numerical investigation of coarse powder and air flow in an electrostatic powder coating process. Powder Technology. 164(1), 22-32 (2006)
8. Kampen A., Kohlus R.: Statistical modelling of coating layer thickness distributions: Influence of overspray on coating quality. Powder Technology. 325, 557-567 (2018)
9. Cordier, F., Melkemi, M., Seo, H.: Reconstruction of helices from their orthogonal projection. Computer Aided Geometric Design. 46, 1-15 (2016)
10. Wang, F., Martinuzzi, R., Zhu, J.: Experimental study of particle trajectory in electrostatics powder coating process. Powder Technology. 150(1), 20-29 (2005)
11. Mandelbrot B.: The fractal geometry of nature. San Francisco: W. H. Freeman (1982)
12. Feder, J.: Fractals. Springer Science + Business Media, LLC (1988)

13. Pustiulha, S.I., Pridyuk, V.M., Prushko, I.V.: Diskretne vektorne formuvannya fraktal'nih struktur. Zb. nauk. pr. Luc'k. 37, 275-279 (2012)
14. Pustiulha, S., Samchuk, V., Klak, Y., Prushko, I.: Dyskretne modelyuvannya fraktal′nykh heometrychnykh ob'yektiv u mashynobuduvanni. Naukovi notatky. 42, 220-224 (2013)
15. Pustiulha, S., Samostian, V., Tolstushko, N., Korobka, S., Babych, M.: Fractal diagnostics of the degree of fuel atomization by diesel engine injectors. Eastern-European Journal of Enterprise Technologies. 6, 8(90), 40-47 (2017)