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Magnetic pulse cleaning of products

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Abstract. The article deals with the application of a magnetic impact for inventing new equipment and methods of cleaning cast precision blanks from fragile or granular thickened surface coatings, which are difficult to remove and highly resistant to further mechanical processing. The issues relating to a rational use of the new method for typical products and auxiliary operations have been studied. The calculation and design methods have been elaborated for load-carrying elements of the equipment created. It has been shown, that the application of the magnetic pulse method, combined with a low-frequency vibration process is perspective at enterprises of general and special machine construction, for cleaning lightweight blanks and containers, used for transporting bulk goods.

1. Introduction
The magnetic methods of processing, whose foundations were laid in [1], are being developed in various fields of mechanical engineering. One of the perspective trends in the development of these methods is the application of their theoretical points for combined cleaning of products from polluting coatings. In our case, the magnetic method is implemented as a source of a low-frequency impact upon the striker, which causes the mechanical wall vibration in products having fragile or granular layers intended for removal. In mechanical engineering, the application of magnetic pulse processing makes it possible to replace the labor-intensive operations, which are intended for removal of the remnants of ceramic molds from blanks, obtained by precision molding (investment casting, shell-mold casting, etc.).

Many kinds of bulk goods (e.g. mixtures formation, construction materials, etc.) are delivered in sheet metal containers, where thick layers of transported products remain on walls after unloading. The cleaning of such containers, performed by vibration test systems, is quite cumbersome and not always feasible, since it can damage the products. The magnetic pulse method is characterised by versatility, and it is an effective means of mechanical cleaning of non-rigid blanks, steel sheet containers (up to 3 mm thick) and non-metallic vessels (with walls of up to 5…8 mm thick).

2. The scheme of magnetic pulse cleaning
The scheme, presented in Figure 1, shows that polluting coatings are removed by vibrations, caused by the striker, which produces the impact on the wall and is actuated by an electromagnetic force.
**Figure 1.** The scheme of a magnetic pulse installation for removing of pollutants from surfaces of products: 1 – chamber casing; 2 – striker; 3 – machine casing; 4 – sheet metal blank (shell); 5 – coating (pollutant) to be removed; 6 – resilient element (spring); 7 – magnetic pulse generator; 8 – inductor; S – initial gap between the striker and the shell.

The scheme presented in Figure 1, contains the novelty aspects and is protected by patent. Polluting coating 5 (Figure 1) is removed due to a difference in movement speed between shell 4 and coating 5, at the time of the pulse impact caused to shell 4 by striker 2. Inductor 8 causes the abrupt movement of striker 2, due to the action of high current flow (up to 300 KA) supplied by pulse generator 7. RC circuits (R – adjustable resistance, C – adjustable capacitance). When striker 2 hits shell 4, its reset is induced by spring 6. Before the process starts, striker 2 is installed so as to leave a gap varying in the range from 0.2 to 1.0 mm.

3. **An optimal degree of product cleaning**

While cleaning the workpiece walls, it should be noted that burnt particles of forming mixtures or ceramic forms can be found on workpiece segments, inaccessible for the striker action, or in places where stiffness of segments does not allow generating the workpiece vibration. If a coating is brittle, it can flake off even by action of weak shock waves. However, some kinds of pollution can only be removed by flushing, including the one performed in aggressive liquids. The impact of the continuous magnetic pulse can completely remove fragile and compressed granular pollutants. However, this method is not economically justified, since it does not require the removal of all foreign particles for subsequent mechanical processing, and the final part of the operation is the most labor-intensive.

The container design usually includes the stiffening elements (stiffening ribs, wall couplings, etc.) which restrict the transposition of shell components, and such containers require multiple pulses for cleaning their walls. Figure 2 demonstrates the economically attainable degree of steel container cleaning (wall thickness – 0.5 mm, volume – 2 m³) depending on the number of pulses (single-impulse energy – 0.5 kJ). Similar results can be obtained for workpieces of the same rigidity.
The degree of cleaning (Figure 2) is the ratio between the areas of a clean blank or container walls, and the total area of a workpiece wall or a segment to be cleaned.

To carry out the cleaning process presented in Figure 2, the pulse impact was induced in the resonant mode. As it is shown in Figure 2, the removal of pollutants from segments having no stiffening elements (curve 1) occurs after 3…4 pulses, i.e. within several seconds. In this case, the area of the clean segment is 0.15…0.25 m².

In places where container rigidity varies, the cleaning intensity decreases sharply (2, 3 in Figure 2). For instance, the complete cleaning of places located near wall couplings, is 2…2.5 times slower compared with case 1 (Figure 2). Meanwhile, even 15 pulses are not sufficient to perform full cleaning of places located near the metal angle-bar frame, since the frame almost entirely damps the wall vibrations.

Figure 3 shows the results of using various methods of container cleaning, under conditions laid down in Figure 3.

The resonant mode (A, as presented in Figure 3) permits threefold acceleration of the cleaning process, especially for segments adjoining the stiffening elements (2, 3, as presented in Figure 3). Consequently, it is necessary to constantly vary the pulse repetition rate in order to maintain the resonant mode for all container segments subjected to cleaning.

It is not always practicable to achieve complete removal of pollutants by the pulse impact. For this purpose, flushing or mechanical cleaning of containers is required, e.g. the one performed with a chisel and a hammer, which can often cause permanent damage to the product. Therefore, in the present case, the adequate cleaning implies the removal of most coatings (primarily, thick ones) from container walls. Usually, a supplier and a customer agree on removing of 95…98% of the total mass of bulk materials, after which a container is recognized suitable for reuse. If this condition is fulfilled, the container cleaning time for certain transported products is 4…5 times less. In this case, the cost saving can exceed the material losses by several times, due to the lost value of cargo particles remaining on container walls after their cleaning.
4. The feasibility study of rational application of techniques and equipment for removing thick coatings

Studies have shown, that the most efficient method of cleaning of containers and openwork products is the contact magnetic pulse vibration method, involving the impact produced by the tool (i.e. the striker). The pulse energy of the tool is regulated within the limits to ensure elastic deformation of products to be cleaned, avoiding residual shell deformation.

If the efficiency ratio of magnetic pulse processing is low (2…20 %), it is advisable to use satisfactorily light strikers. In a replaceable striker, the construction includes all moving parts affecting the workpiece walls (i.e. the shell).

Figure 4 presents the curve demonstrating the dependence of magnetic pulse processing parameters on the mass of the striker construction. From this figure, it can be seen that the increasing mass of the striker system causes the rise of pulse energy, while reducing the frequency of the striker impact on the shell. In such case, the total input energy per time unit remains practically unchanged.

Figure 3. The degree of container cleaning from pollutants (forming mixture): A – the cleaning performed in the resonant mode; B – the cleaning performed in the non-resonant mode (with the constant frequency pulse impact); 1 – the segment having no stiffening elements; 2 – the segment close to container wall couplings; 3 – the cleaning in places close to stiffening ribs (45×45 mm angle bars).

Figure 4. The dependence of the striker construction mass (m) on operating pulse frequency (v) and pulse energy (Au).
The conducted measurements have revealed (Figure 5) the optimal number of strikers, depending on frequency and efficiency of input energy utilization in an impulse.

![Figure 5. The efficiency of utilizing multiple inductors.](image)

Dependence $I_2/I_1$ demonstrates the efficiency of input energy utilization, i.e. the nature of efficiency change, which varies from 0.02 to 0.2 (according to [2-4]). From Figure 5, it can be seen that the optimal number of inductors ($n_{opt}$), supplied with strikers, is between 2 and 4. The further increase of ‘n’ does not produce any gain in the use of input energy, though it somewhat improves the operational performance. However, it should be taken into account that the growing number of inductors, powered by a single generator, disrupts the process stability, which can lead to product damage, resulting from the striker impact, along with the destruction of the mechanical part of the magnetic pulse vibration processing system.

5. Conclusion

The analysis has been conducted to study the contemporary magnetic energy utilization in systems, producing magnetic pulses for cleaning non-rigid workpiece segments and container walls, made of sheet materials. The conducted analysis has shown that the method of vibration is effective for cleaning the cast sections from the remnants of forming mixes (burned layers, ceramic shell fragments, etc.). In addition, the openwork elements of blanks are not damaged improving the safety. The mechanization of the large-scale casting cleanup makes it possible to resolve both technical and social problems, related to blank production (e.g. the improvement of the working conditions, the possibility of casting cleanup process automation, the reduction of environmental pollution, etc.)

The newly invented constructions of magnetic pulse systems have been proposed. The study has demonstrated the advantages of the cleaning method under review, and the efficiency of applying the newly created installations for removing the remnants of transported bulk goods from container walls made of sheet materials.

The methodological basis for calculating the parameters of the load-carrying element (striker) for magnetic pulse installations has been worked out.
The new technological processes of cleaning openwork blanks have been examined, which consider the geometric features of cast products, including the blanks for non-rigid precision components of perspective rocket and space equipment.

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