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OPTIMUM ADAPTATION OF A PRESET TECHNOLOGY FOR AUTOMATIC MANUFACTURING OF SINTERED PRODUCTS

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Abstract: The paper presents the issues of the establishment of modern high productivity technological procedures in production of the parts from metalic powders and the design principles of the automated production using the sintered pre-shapes stamping. The process and the equipment resulted in obtaining parts with notable structures and characteristics such as: cog wheels, levers, parts with complex configurations. The production technology of certain types sintered products is limited by the intervals of permitted values of technological factores: heating temperature; heating speed; time of heating; temperature regulation and control; maximum pressing force; pressing speed; lifting speed; cadence; the stamp heating temperature. Also, the paper gives a the method of this task solution which are based on the information theory presentation.

1. INTRODUCTION

The Powder Metallurgy industry ranks among the most rapidly growing manufacturing processes and is gaining increasingly in importance. One of the advantages is the capability of creating new materials. Another advantage is obtained by the process in offering the possibility to produce most efficiently mass-production of high precision structural parts at exceptional repetition accuracy.

The demand from the market to the Powder Metallurgy correspond to those of the competing processes, that is to be:

- faster
- more economical
- able to provide better quality

as todey and as the competitor. The innovative potentials are: design of products, raw materials, process technology. For this reason the object is to adapt the design of new parts to the requirements of the Powder Metallurgy, to improve the properties of existing materials, to develop new materials, to optimize processes and to evolve new processes. Our contribution to realize the innovative potentials is to design and deliver advanced press systems which have fulfill the market requirements, such as: faster, more economical, able to produce better quality. It is the aim to produce faster and more efficient structural complex parts with higher density and smaller process and product tolerance ranges.

For the very reason that in the automotive industry the demand for light weight design is increasing, the components are exposed to a higher degree of strength. Compared to the past, variation in performance characteristics, such as non-uniform density or even slight cracks are, if at all, only acceptable within smallest tolerance ranges. Therefore when designing powder compacting presses: Process reliability, repetition accuracy, and automatic adjustment of parameters have to be considered significantly as well as: productivity and efficiency. Based on these requirements University of Craiova has developed a completely new drive concept for powder compacting presses.

Therefore, it is laid the foundation of a new working method superior to these old not only in point of precision, but also in point of productivity that is " The update technological process of great productivity in parts achieving from powders through sinterstamping method". The sinterstamping process combines the efficiency of cold pressing with advantages of hot pressing in order to obtain parts with performant properties and structure (profiled disks, cylindrical and bevel gear wheels, etc).

It is possible the sinterstamping of parts with the section up to 200 cm^2. The row material consumption is inferior to another technological processes. Are obtained parts with complex configuration at final geometric dimensions without any other machinings. On the other hand the process is limited by the densification pressure of the material, on an average 4 - 6 t/cm^2 and by the present technological possibilities.
Sinterstamping creates favorable conditions for efficient and rapid application of automation measures with a view to make the process profitable.

2. USED METHODS TO MAIN PROBLEMS SOLVE

The pre-shape configuration establishment. For each part from parts list to be manufactured through sintersrtamping a technico-economic analysis is achieved in order to establish the main elements of working technology. Depending on the part shape and dimensions as well as on the required resistance characteristics the shape of part to be stamped, the necessary material, the method of strain process are stablished. During axial strain of the material the preshape must be achieved at the dimensions closed to these of the part, complex tools being necessary for pre-shapes manufacturing and for their stamping if the strain is achieved by a lateral flowing of the material, perpendicular to the pressing direction, the pre-shape geometry is more simple and also the tools for forming and stamping are more simple. For sinterstamping must take into consideration the possibility of pre-shapes automation handling. In this respect will be preferred the revolution shapes that have the axis of symmetry perpendicular to longitudinal axis. The shapes which have great differences of temperature are avoided.
The pre-shapes heating. The pre-shapes of sintered iron powders are usually heated at the temperatures range of 1050 - 1250 ^{0} C with a deviation of $\pm$ 10^0 C through induction currents and automated installations. The heating is achieved in a protecting medium. Frequently, as protecting are used inert gases: argon, azote. The furnace feeding with parts is mechanized. The working regime and the heating period are automatically adjusted.
The initial stamps heating. It is achieved at a constant temperature in the range 250 - 350^0 C through a resistance ar induction. The installation is equipped with an automation system of temperature measuring and control.
The sintered pre-shapes stamping. During the pre-shapes stamping through one shock of the slide block the configuration, the dimensions and the surface quality of the manufactured parts are achieved. The product quality depends on the precision of temperature maintenance for pre-shape and stamp. The difference between the temperatures of pre-shape and stamp determine the stamped part dimensions after cooling.
The pre-shapes and finished product handling. The feeding/removal used method of semi-products as well as of finished products mainly depends on both parts shape and dimensions and on tool position. In order to allow automation loading/unloading the press is equipped with an automatic system of feeding/removal of feeder or manipulator type.

3. THE TECHNOLOGICAL MODEL

In a general case, the technological model should describe the relation between the technological factors and the characteristic values of finish rolled stock quality. Figure 1 shows a simplified diagram of the accepted model of the technological process which has several technologic stages (steps). x vector may be called “the technology”:

$$x = (x_1, x_2, ..., x_{n-1}, x_n) \quad (1)$$

Presetting of components values fully determines the technological process at different operations of preset rolled stock manufacture. Properties of a semifinished product are described by y_i, i=1,2,…,m vectors.

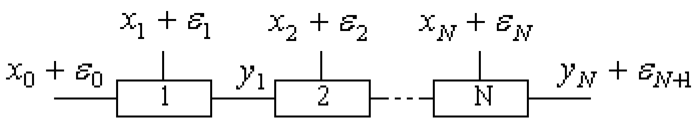

Fig. 1 The diagram of the technological process for sintered products forming

1, 2, …, N - technological operations;
$x_n = (x_{n1}, x_{n2}, ..., x_{ni_n})$ – technological factors;
n = 1, 2, …, N - a number of a technological operation;
i_n - a number of technological factors of "n" operation;
$\varepsilon_n = (\varepsilon_{n1}, \varepsilon_{n2}, ..., \varepsilon_{ni_n}), n = 0,1,..., N+1$ - measurement errors;
$x = (x_{o_1}, ..., x_{o_{10}})$ - the chemical composition ;
$y_n = (y_{n1}, y_{n2}, ..., y_{ni_n}), n = 1,2,..., N-1$ - characteristics of semifinished product quality;
$\eta_n = (\eta_{n1}, \eta_{n2}, ..., \eta_{ni_n}), n = 1,2,..., N$ - control errors of quality characteristics;
$y_N = (y_{N1}, y_{N2}, ..., y_{Nm})$ - characteristics of a finished product quality.

The values of quality characteristics of a finished product determined by a vector are of major importance:

$$y = (y_1, ..., y_m) \quad (2)$$

Where: m - is a number of production quality characteristics determined by a customer.
Measurement errors and technological factors optimization result in the fact that their actual values may be considered as random values. The production is considered to be qualitative if the measured values σ_i of quality characteristics y_i satisfy the limitation values:

$$y_i^{'} \leq \sigma_i \leq y_i^{''}, i = 1,2,..., m \quad (3)$$

In accordance with the same principle the technology is preset. For each technological factor x_j, j=0,1,…,n the limited values x_j , x_j of their actual value changes τ_{nj} are determined and the technology is assumed realized if limitations:

$$x_j^{'} \leq \tau_j \leq x_j^{''}, j = 1,2,.., n \quad (4)$$

are realized for all technological factors. x' and x" values are setting the technology and are determined in the process of its development. For obvious presentation with the geometric illustration usage, let us assume that a number of quality characteristics m=2. Considering the accepted dimensionality we may represent "y^2 quality space" in the plane as it is shown in figure 2.

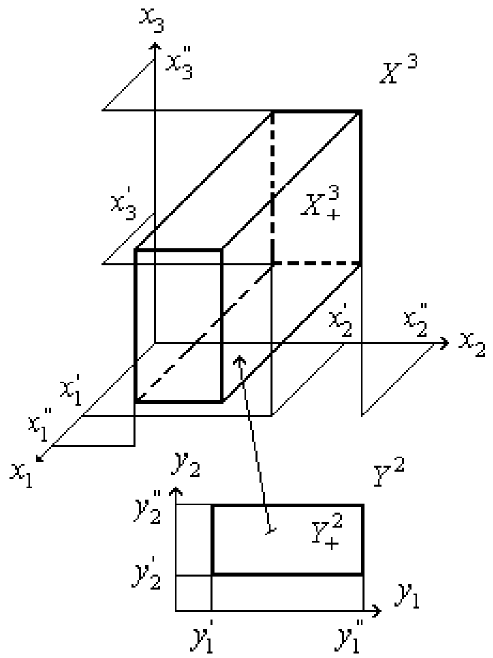

Fig. 2 Illustration of accordance between technology and product quality

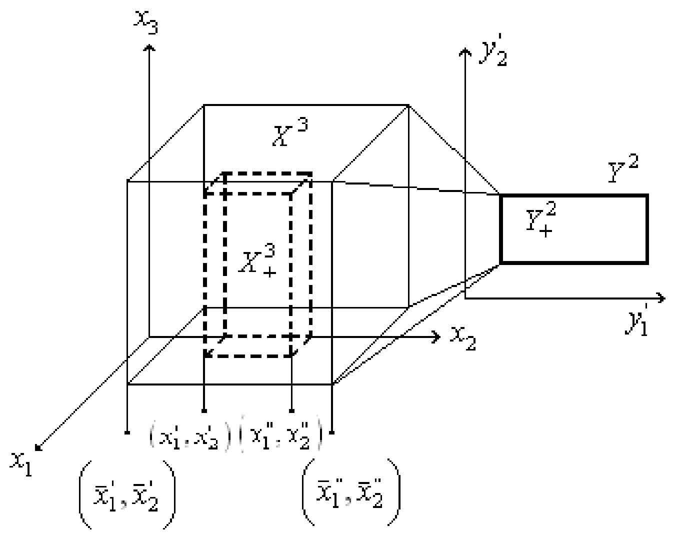

Fig. 3 The diagrams of two different technologies

Requirements (3) to the production quality were be evidently represented by $y_1 = y_1'$ and $y_1 = y_1''$ lines which are parallel to y_2 axis $y_2 = y_2'$ and $y_2 = y_2''$ lines which are parallel to y_1 axis. Thus inequalities (3) with m=2 on Y^2 plane single out Y_+^2 rectangle, all point of which corresponds to qualitative product. This fact is denoted as $(\sigma_1, \sigma_2) \in Y_+^2$. Similarly, using x_1, x_2, x_3 as coordinate axis we will get (in this case) X^3 three-dimensional "technological space". The production technology of the certain production unit, that is fixed values of technological parameters $x_1 = \tau_1$, $x_2 = \tau_2$, $x_3 = \tau_3$ were be represented by the point (τ_1, τ_2, τ_3) in X^3. Thus the inequalities (4) in this case determining the technology, we'll isolate X_+^3 three-dimensional parallelepiped all points of which are permissible technologies. We came to the conclusion that formally the production technology of any product type which is preset by the maximum permissible values in the form (5) represents $X_+^3 \subset X^3$ subspace. Any technological change brings to the change of configuration subspace position X_+^3 in X^3 . X_+^3 should be selected so that it gets high quality product with the technology realization. Let us designate the vector of measured values of the technological factors as $\tau = (\tau_1, \tau_2, \tau_3)$, and properties vector measured at the same product unit as $\sigma = (\sigma_1, \sigma_2)$. Then formally the task of the technology investigation consists in the following:

- there is a set of technological factors measurements and their respective quality characteristics of one type product:

$$T = \{(\tau \leftrightarrow \sigma)_k, k = 1,2,...,K\} \tag{5}$$

where: K - is a number of product lots (units) at which measurements were done;

- maximum permissible values of quality characteristics y_i' y_i'', i=1,2 are specified, meaning that Y_+^2 is set;

- it's necessary to determine $x_j^{'}$, $x_j^{''}$, j=1,2,3, that is X_+^3 , so that for the whole set of T measured values (τ,σ) the conditional probability $P(\sigma \in Y_+^2 / \tau \in X_+^3)$ should reach the maximum value.

4. THE TECHNOLOGY ADAPTATION

As initial material we may use the information which is contained in a set of the experimental T data (5). Meanwhile x values are in X^3: $\{\tau\} \subset X^3$ and y values are in Y^2: $\{\sigma\} \subset Y^2$. Point wise sets {τ} and {σ} are preset and fixed. Hitting or missing the separate points of a set {τ} in X_+^3 and points {σ} in Y_+^2 depends on X_+^3 and Y_+^2 configuration that is on x',x",y',y" values which preset hyper planes position determining X_+^3 ,Y_+^2 subspace. But y',y" are preset from outside and Y_+^2 is fixed in Y^2.
That's why we may influence the correspondence of the technology and properties changing x', x" values that is changing the technology. Figure 3 shows 2 "technologies" X_+^3 and X_+^3 which differ by x', x" and x', x". Naturally with a fixed self learning point wise set {τ} each of which will correspond to their H_x and H_{xy} values. If we speak about an ideal technology then we may expect that $H_x(X_+) \neq H_x(X_+)$ and $H_{xy}(X_+) \neq H_{xy}(X_+)$ and, therefore, the amount of information will change too $I_{xy}(X_+) \neq I_{xy}(X_+)$. Thus the amount of information is the function of the technology, the technological intervals more precisely, which determine a set of permissible technologies for the product unit.

$$I_{xy}(x',x'') = I_{xy}(X_+) = H_x(X_+) + H_y - H_{xy}(X_+) \quad (6)$$

where: H_x – the entropy (uncertainty) technologies; H_y - the entropy (uncertainty) properties; H_{xy} - the combined entropy (uncertainty) of technology and properties;
Naturally we assume that X_{+*} is the best technology.

$$I_{xy}(X_{+*}) = \max_{x_+ \subset x} I_{xy}(X_+) \quad (7)$$

Criterion (7) may be used for the identification of existing or determination of a new technology which is optimum concerning its single-valued communication with the properties for the whole data array T. As soon as T array is renewed the technology may be adapted. If the supply conditions of the product and $y^{'}$, $y^{''}$ requirements to it vary due to mutual agreement, then there are no obstacles for the technology adaptation in accordance with new requirements of sintered products customer (user).

5. THE OBTAINED RESULTS

The experiments for sitered parts stamping are achieved on a sintering automatic installation of which principle drawing is shown in figure 4. The installation is composed by the hydraulic press with a closed bed which is equipped with a puller 16 and a possibility to adjust the pressing force and speed. On the upper part of the press there are the furnance 5 heated through induction as well as the own automatic feeding device 2 where the pre-shapes are put in order. During manufacturing of one part handled from the accumulator the whole parts column moves downwards under the gravitation force.
The protecting gas stocked in recipients under pressure is sent to the furnance through the connecting pipe. After the heating temperature has been achieved the heated pre-shape is moved by the gravitation conveyer 7, enters the convergent nozzle 10 and than the stamp cavity 6. Afterwards, photorelay FP perceives the part passing and by a timing relay, it controls the coupling of upper punch 12.

The photorelay blockings is dlubled by the limit stops on the machine. Thus, the part does not enter the stamp cavity before ending the whole stamping cycle. The active parts of the stamps are heated by a resistance at 350^0 C. The maintenance of the constant temperature is achieved automatically, by the adequate installations. After strain the stamped part lifted by the puller 9 is grasped by a handling device in order to be laid in the container. At the end of the slide block stroke the stamp is cleaned and lubricated with a solution of graphite in water. Further on the cycle is automatically resumed according to the initial program established by the place confirmations.

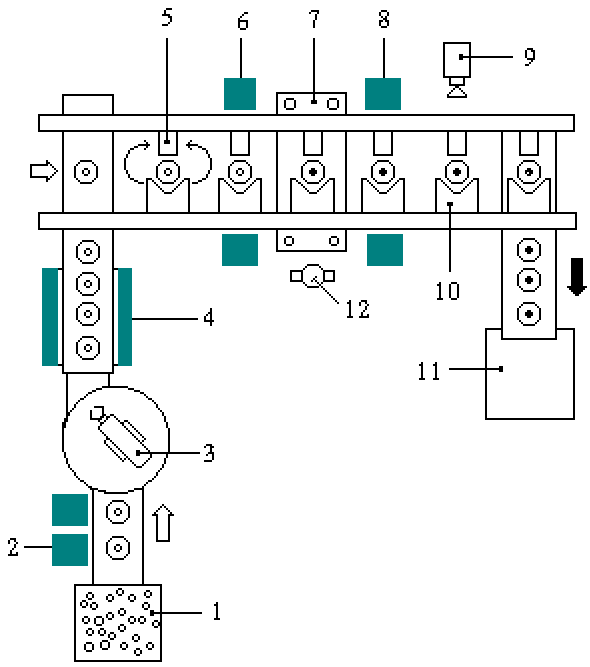

Fig. 4 Sinter-stamping automatic installation

For determining of tehnological parameters influence upon compressed parts characteristics, the paper has in view the procedural research method which consists in establishing of a strategy concerning an operations succession in predetermined situation. The procedural model for achieving a part through sinterstamping includes several instructions upon the shape and dimensions, working pressure, time of decompression.
From value parameters analize of the working regime used for the researches upon powders pressing with in the reference literature [1] for effective compression under the conditions previously mentioned were recommended the followings:

- Heating temperature 1120 ^{0}C
- Heating speed 20 - 50 ^{0}C/min
- Maximum pressing force 630 kN
- The stamp heating temperature 250 - 350 ^{0}C

In order to achieve results as well as possible for automatic pressing it is necessary a manufacturing controls follows: control of powders preparing; control of technological flow operations; control of parts quality. The preparing of powders mixture for pressing is achieved accordig to existing norms.
More over, for automatic pressing it is recommended to control graining and particles humidity which influence the process of automatic dosage.

The full automation of the process allows the following and the control of all manufacturing flow stages. The switching on of these cycles is achieved by confirming the kits position of the machine.

The properties which are currently tested are: diameter, density, hardness, tensite strength and compression test. The experimental results which will be statistically processed are presented in table 1.

For uniaxial strain compression where (ε_z=0):

$$\sigma_{pc}=\sigma_{uc}/ (1-\nu^2)^{1/2} \tag{8}$$

For sinter-stamped in closed die powder preforms:

$$\sigma_{pc}=[(1-\nu)/ (1-\nu-2\nu^2)]^{1/2}\sigma_{uc} \tag{9}$$

where: σ_{rc} = stress required for repressing; σ_{uc} = yield stress in uniaxial compression;
ν = Poison ratio; σ_x = axial compressive stress required for plane strain compression.

The above data indicate that densities calculated from deformation staines agree well with actual measured densities. Although the range in variation in the differences in densities were approximately 5 to 6% maximum, most of the data in agreement to within 3-4%. It is observed the influence of the compact pressure, the form and dimensions of the powders particles, the mould density, the presence of the lubricants and oxide particles on the value of the lateral pressure coefficient, in different sinterized weakly alloyed steels. The density increases when the mould density, the die construction, and the compacting pressure are increased. There is a linear ratio between the final density of the part and the density of the mould at a fixed volume of deformation.

Table 1

Preform density $\rho_{pf.}$ (g/cm^3)	Force stamping $F_{cu.}$ (KN)	Uniaxial compression			Sinter-stamped parts in closed die		
		ε_z ln(H/H$_0$)	σ_{uc} (N/mm^2)	Part density ρ (g/cm^3)	ε_z ln(H/H$_0$)	σ_{rc} (N/mm^2)	Part density ρ (g/cm^3)
6,32	30	0,10	163,39	6,50	0,08	236,17	7,60
	40	0,20	217,86	6,84	0,10	314,94	6,89
	50	0,40	272,32	7,36	0,15	392,63	7,08
	60	0,60	325,78	7,40	0,20	472,35	7,32
	70	0,70	381,26	7,51	0,25	551,09	7,43
6,71	30	0,10	166,65	6,82	0,02	252,78	6,90
	40	0,20	222.20	7,08	0,06	336,92	7,04
	50	0,30	277,75	7,22	0,08	441,14	7,10
	60	0,40	333,30	7,47	0,10	505,37	7,42
	70	0,60	388,86	7,58	0,15	589,81	7,51
6,97	30	0,10	168,39	7,05	0,06	272.84	7,28
	40	0,15	224,52	7,20	0,07	362,79	7,33
	50	0,25	280,60	7,35	0,08	452,79	7,42
	60	0,35	336,78	7,46	0,09	544,17	7,56
	70	0,50	392,93	7,59	0,10	634,89	7,66

Qualitatively the achieved parts through sinterstamping are comparable with those hot working metal pressing, extrusion, in pond of surface aspect as well as dimensional tolerances inclusively the mechanic characteristics. In point of dimensional precision have been achieved parts of a new precision class. The parts hardness achieved by sintering method are superior to sintering state. Moreover, if the sintered product annealed, the maximum hardness of finished product is superior to that rolled steels, adequate for these.

7. CONCLUSIONS

On the results obtained from the laboratory and industrial experimental research there were laid the foundations of automated technologic flow for achieving the metallic powders. There were obtained parts with precise dimension contour, with a dense and thin structure and the surface roughness is R_a = 0,2 - 0,4 μm according to existing norms.
Qualitatively the achieved parts through sinterstamping are comparable with those hot working metal pressing, extrusion, in pond of surface aspect as well as dimensional tolerances inclusively the mechanic characteristics. In point of dimensional precision have been achieved parts of a new precision class. Moreover, if the sintered product annealed, the maximum hardness of finished product is superior to that rolled steels, adequate for these.
The method helps to formalize the task of the optimum technology adaptation which is preset by the ranges of permissible values of the technological factors. The optimum ranges consist in the fact that the maximum probability of the production manufacture is reached the quality characteristics values of which are within the preset ranges with the factors values being within these ranges. The method is a good basis for the majority of tasks automatization which constitutes the essence of activities of research laboratories of companies.
Using a 40-125 μm steel powder weakly alloyed, compressed at a compacting pressure comprised in the domain 100 - 400 Mpa, and temperature t = 1100^0 C, the parts hardness obtained was 99,5 - 99,9 % DT.

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