A Versatile Method and Device to Enhance the Particulate Material Pressing Process with Mechanical Vibrations

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Abstract—**Comprehensive laboratory tests were conducted on equipment used for the implementation of a unique process of pressing particulate materials, never so far used globally in an effective combination with the mechanical vibrations of a steplessly adjustable amplitude and frequency. It has been demonstrated that the pulsating pressure reduces by up to 27% the compression force required to achieve maximum density and - which is also very important – it reduces by up to 45% the ejection force necessary to remove the compact from a molding tool, eliminating also the formation of cracks. Using this process, it is possible to obtain an unprecedented homogeneity of the compact properties, which is particularly important for further performance of this compact. The result is the manufacture of compacts of a unique shape and density similar to the solid form. An offer for the global industry is tooling for the presses to enhance with mechanical vibrations the process of forming particulate materials.**

Index Terms—**pressing process, particulate materials, pulsating pressure, homogeneity of properties**

I. INTRODUCTION

An obvious barrier to development of the technique of making products from powders compressed and sintered is the lack of generally available presses with power-moved die tables, the lack of special tools and equipment like dies, punches, and cores, and also the insufficient training of workers to perform the pressing operations on products with intricate shapes and special properties. This barrier has the historical background, while the negative effect of a relatively low prevalence of this technique in the engineering industry has been and is the unreasonably high price of particulate materials. The dissemination of modern presses for products made from the particulate materials should help in a removal of this barrier, opening the way to progress in a manufacturing technology commonly known as powder metallurgy, considering its frequently undisputed unrivalness, and when matched by other technologies - high efficiency and low material consumption. The expected, though immeasurable, result of the ongoing research work will be a wide-scale application of the technology of making compacts from powders, in appropriate cases used as an alternative for the casting process or plastic forming of solid materials. The technology based on a free-flowing material yields the near-net-shape products, and if adequate technical culture is possessed it can be considered “clean technology”. Technical literature [1-12] and own experiments carried out for the past 30 years confirm this statement.

Therefore, further studies and development works will be conducted to better explain the phenomena that accompany each step of the process of making compacts from particulate materials.

Pulsatory pressing of particulate materials allows making parts with special properties and shapes hitherto considered as non-technological. These include thin-walled sleeves and discs. The developed tools and equipment constituting a novelty in the world-scale technology solve problems that occur during filling of the loading chamber with raw material, molding of homogeneous 'green' compacts and their effective ejecting from the workspace. The theoretical and experimental studies of new technological methods were carried out and functionality of the proposed design was evaluated [13]. The results obtained enabled the development of an automated method and apparatus for dynamic manufacturing of thin-walled components from particulate materials [14].

Compared to casting and plastic forming of solid feedstock, the manufacture of machine parts from particulate materials is relatively less common, and this fact is mainly due to the generally prevailing opinion that powder metallurgy consumes large volumes of energy. An innovative solution to this problem is the recently developed energy-efficient system of feedstock transport. It comprises a heat transfer system operating during transport of cold pressed compacts and hot sintered products between the press and the furnace, and a system of forced energy recovery during proper sintering. Under model conditions, empirical studies were conducted to examine time-related temperature variations in green compacts and heat treated products, to check next under real conditions the temperature distribution in these items. The possibility of using the newly developed solution in most of the already operating systems with only minor modernizing work and proper organization of the production process was stated [15]. Positive test results have led to the development of a system for the energy recovery and vapor separation in an air-tight, backward-type, pusher tunnel furnace [16] with energy-efficient feedstock transport system in a press – furnace arrangement [17].

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Extensive design and research studies were also undertaken to develop a versatile method and device enhancing the particulate material pressing process with mechanical vibrations [18]. Fragments of these studies are described in this paper.

II. THE DESIGN OF A PULSATORY PRESS OF THE THIRD GENERATION FOR SHAPING OF PARTICULATE MATERIALS

The type series of pulsatory hydraulic presses includes seven sizes with nominal pressure from 250 kN to 4 MN. The range below 250 kN is reserved for the pulsatory mechanical presses.

The power system designed for a PXPh-040 press is also used in the PXPh-063 and PXPh-100 units. Constant width and depth of the working space are maintained with the adjustable (increased) height. The PXPh-160 and PXPh-250 units also have constant width and depth of the working space and a variable height. This solution should significantly facilitate the manufacture of heavy parts with complex shapes, especially the upper and lower yoke assemblies, and the upper, middle and lower tables. The power systems for the PXPh-025 and PXPh-400 presses end the basic type series. Presses with the nominal pressure above 4 MN are designed as customized models. This product range also includes a simplified variant of the press used for briquetting of bulk waste product from the machine industry.

The hydraulic feed, the control system and the electric-electronic modules are located behind the power system or on its right side. The use of an automatic system filling the loading chamber, collecting compacts and stacking them on pallets or in “boats” allows operator to stand back from the work area.

A prototype design of the PXPh-040 press developed for the pulsatory shaping of machine parts from particulate materials (Figs. 1 - 2) is based on the following technical data:

--lower table: nominal pressure - 400 kN, maximum static force - 300 kN, maximum pulsation force - 100 kN, pulsation force frequency - 360 Hz, stroke - 140 mm, maximum compression speed - 20 mm/s, maximum speed of return - 20 mm/s;
--middle table: maximum force up - 40 kN, maximum force down - 220 kN, stroke - 320 mm, maximum speed up - 10 mm/s, maximum speed down - 20 mm/s;
--upper table: maximum force up - 125 kN, maximum force down - 45 kN, stroke - 160 mm, maximum closing speed - 40 mm/s, maximum opening speed - 40 mm/s;
--clearance between the upper and middle table - 610 mm;
--clearance between the middle and lower table - 1,340 mm;
--table dimensions - 650 x 650 mm;
--maximum operating pressure - 16MP,
--the projected installed capacity of the unit - 11 kW.

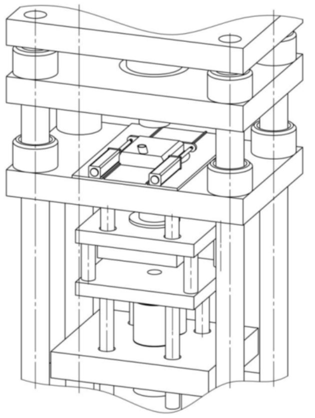

Fig. 1. Scheme of device to enhance the particulate material pressing process with mechanical vibrations

Fig. 2. Work stand for the test run of a pilot PXPh-040 press prototype

The operation of compact pressing consumes 75% of the total installed capacity. The remaining 25% is delivered to the generator assembly producing a pulsating jet of liquid which makes the equipment operate in a dynamic mode.

Using hydraulic press, the operator can bring the settings of the machine after a longer down-time to the starting position, perform a few checking pulsatory movements, start the semi-automatic cycle which enables manual removal of the compact, and then switch over to the automatic cycle in which the compact is pushed by the charging cartridge. Alternatively, suction grippers are applicable when the pore-free compacts are made. The operator, although standing back from the work zone, can watch closely the force – table movement relationship during both pulsatory and quasi-static work cycle.

The design of a pilot PXPh-040 press prototype for pulsatory shaping of parts from particulate materials comprises four units:

--power feed unit,
--pulsating force generator assembly,
--hydraulic feed unit,
--control unit.

The power feed unit comprises two yokes, the lower yoke and the upper yoke, supported by four columns. The entire structure has been compressed by the use of tension members in columns and nuts screwed on to the yokes of the power feed unit. At the same time, columns act as linear guides for the three tables: the lower table, the middle table, and the upper table.

Tables in the pilot PXPh-040 press prototype are driven by hydraulic cylinders. The operation of the cylinders is controlled by hydraulic valves via a PLC connected to the operator terminal equipped with a color touch screen.

To watch the working space of the press, an industrial camera has been installed. It transmits the image directly to a screen in the operator terminal. To measure pressure and the static and pulsating shaping forces, strain gauge transducers are used, while inductive transducers determine position of the press working units.

A composite straight edge, equipped with the three incremental high-resolution heads, enables independent measurement of displacement. Each head is rigidly mounted on one of the press tables. Signals emitted by the heads enable recording and visualizing the path of the moving press tables related to the force exerted and/or time elapsing, and determine the location of the rigid bumpers positioning the tables.

Vibration parameters of the lower punch Sd are measured by a set of the speed and acceleration sensors attached to the lower table.

The pressing process conducted on a pilot PXPh-040 press prototype for the pulsatory shaping of machine parts from particulate materials proceeds according to the following cyclogram (Fig. 3):

1. Feeding of particulate material

At the beginning of the process, the frontal planes of the lower punch Sd and of the die M are in the same position. Then the charging cartridge rolls into position. As soon as the cartridge is placed above the die, the lower punch Sd starts its downward movement, the die M starts its upward movement, and the loading chamber opens. When the required volume is charged, the charging cartridge moves back, and the downward movement of the upper punch Sg closing the loading chamber starts with bolts in the upper table locking the punch in position.

2. Pressing

First the generator conferring vibrations to the lower punch Sd is activated. The lower punch moves at a preset speed twice as high as the speed of the die M movement. Due to this, the compact is compressed on both sides.

3. Compact ejection

The lower punch Sd remains in position, the upper punch Sg opens the chamber in the die M. The die moves down releasing the compact. The die M and the lower punch Sd are in the starting position of the cycle. The moving cartridge pushes away the finished product.

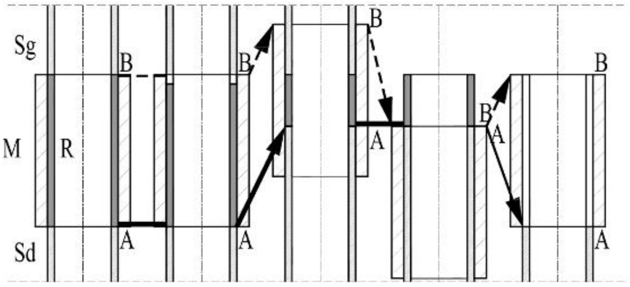

Fig. 3. Cyclogram for pilot pressing of a thin-walled sleeve

A and B show trajectories of the pressing punch and the die, respectively.

The tool assembly for shaping a sleeve-like product (Figs. 4-5) comprises two punches, the faces of which have the shape of the compact cross-section, a molding die and a core of the inner and outer diameter equal to the inner and outer diameter of the compact. To ensure proper alignment between the die and the core, a shelf suspended on four columns of the die table holding the core is used. To transfer the pulsating pressure from the lower table to the lower punch, a shelf suspended on four columns of the lower table is used, and it holds the lower punch. The columns and shelves are guided in respect of each other, thus ensuring accurate positioning of the core and the lower punch.

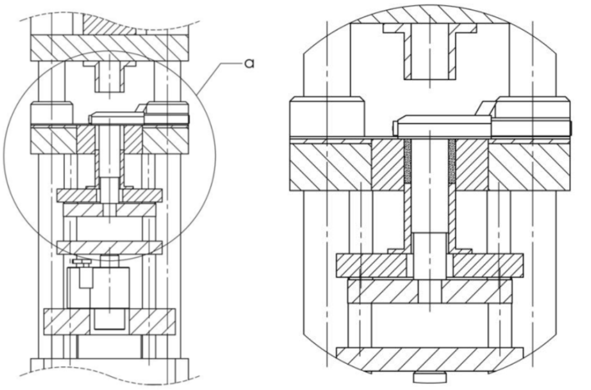

Fig. 4. Scheme of device for the dynamic manufacture of thin-walled components from particulate materials

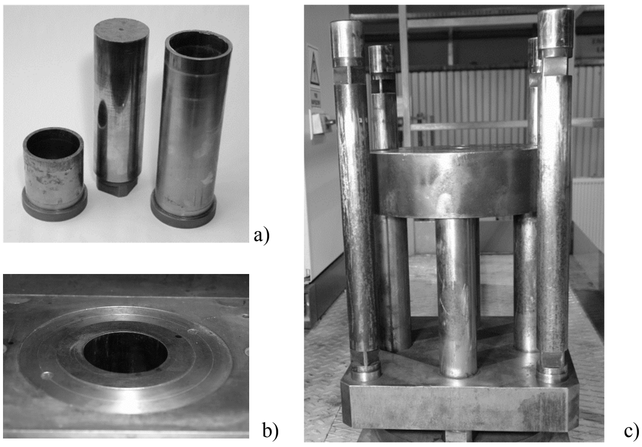

Fig. 5. Die (a), upper punch, core and lower punch (b) and an assembly of shelves and columns (c)

III. TESTING PILOT PULSATORY PRESS PROTOTYPE OF THE THIRD GENERATION FOR SHAPING OF PARTICULATE MATERIALS

The aim of the study was to gain new knowledge about the operating parameters of a pilot PXPh-040 press prototype and compare the data obtained with the data adopted in the project. The scope of work also included practical execution of the process of pressing a particulate material.

The adopted research methodology enabled solving the two closely interrelated problems:

--how to feed a hydraulic fluid under pressure to produce a pulsating jet generating a pulsating force - the cause, and

--how to produce a pulsating movement to shape the compacts from a particulate material - the effect.

The object of the study was described with the following quantities:

--the input quantities x1, x2, xi including the generator rotor speed, the inlet and outlet pressure in the generator, the liquid jet pressure components above the generator throat and in the main cylinder,

--the output quantities z1, z2, zj including components of the pulsating force and movement of the pressing tool,

--the constants c1, c2, ci including the number and dimensions of the generator control slots, and the dimensions of elements in a master cylinder,

--the disturbing parameters h1, h2, hk including the air volume trapped in the liquid, and temperature rise in the working fluid and in the generator components.

The basic tools used by the research team were mathematical computations based on the finite element method allowing also for a simulation of the process of the plastic forming of particulate materials. The Abaqus Version 6.8 by SIMULIA, Dassault Systèmes, and Wolfram Mathematica 8 programs were used. Planning of experiment and analysis of the results were based, among others, on own package of CADEX programs and on modern methods of the theory of an experiment.

The research technique was based on the elements of a control system and on archiving the operating parameters of the pilot PXPh-040 press prototype, including a sensor assembly to measure pressure, force, displacement and vibration. The research team used a basic set of devices to study the pulsatory process of the plastic forming of particulate materials. In the construction of the measurement channel, a DC HMT MGT 231 amplifier and a Tetronix 2214 oscilloscope were used. The conventional method of a computer-aided experiment was also applied.

The "pilot run" studies used tools for shaping a thin-walled Φ 70 / Φ 80 sleeve (Fig. 6). Relationships between the variable components of pulsating pressure, force and displacement were determined as a function of the total displacement at a frequency of 80, 180 and 280 Hz.

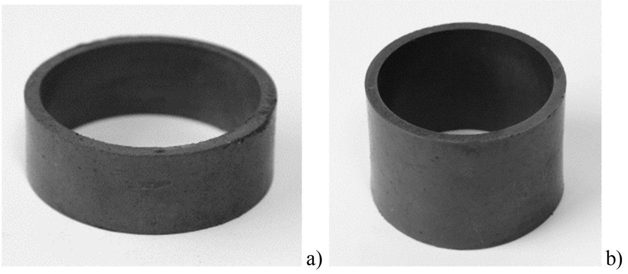

Fig. 6. Strongly compacted pilot sleeve ejected in quasi-static (a) and pulsatory (b) mode

Studies covered the pressing process of particulate material under quasi-static and pulsatory conditions determining the force - tool path relationship. For a quasi-static pressing process (Figs. 7-9), the P(l) relationship was approximated in the form:

Ppq = -1738.03 -95.6465 l+1.84136 l2-0.0129745 l3+2.5616×10-7 l5

Maximum and minimum values of the pulsating compression force were approximated for the frequency of 80Hz (Fig. 7) in the form:

Pppmax1 = -2456.93+176.763 l-5.04143 l2+0.0713538 l3-0.00050028 l4+1.40086×10-6 l5

and

Pppmin1 = -3972.93+280.568 l-7.82657 l2+0.107874 l3-0.000734029 l4+1.97933×10-6 l5

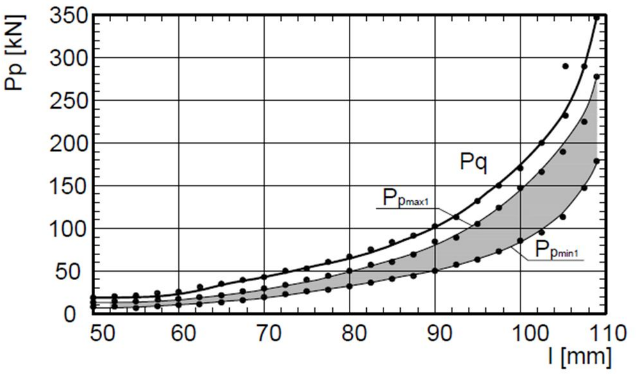

Fig. 7 Relationship between force Pp and tool feed path l during quasi-static and pulsatory pressing of particulate material at a frequency of 80 Hz

for the frequency of 180Hz (Fig. 8) in the form:

Pppmax2 = -1816.53+135.006 l-3.98833 l2+0.0585525 l3-0.000425407 l4+1.23389×10-6 l5

and

Pppmax2 = -1473.37+105.912 l-3.04102 l2+0.0436226 l3-0.000311274 l4+8.90588×10-7 l5

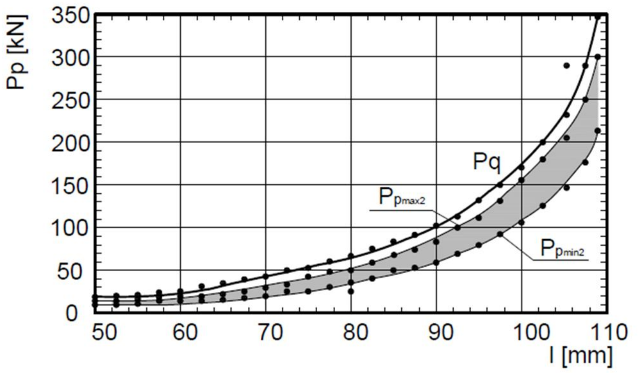

Fig. 8. Relationship between force Pp and tool feed path l during quasi-static and pulsatory pressing of particulate material at a frequency of 180 Hz

and for the frequency of 280Hz (rys. 9) in the form:

Pppmax3 = -2220.03+161.138 l-4.65016 l2+0.0667708 l3-0.000475293 l4+1.35274×10-6 l5

and

Pppmin3 = -613.839+51.1391 l-1.68909 l2+0.0275502 l3-0.000219847 l4+6.9513×10-7 l5

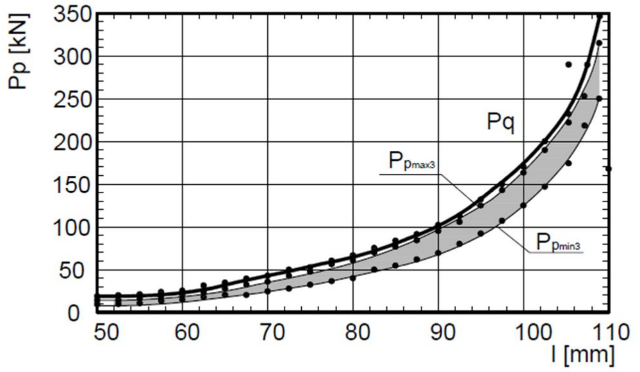

Fig. 9 Relationship between force Pp and tool feed path l during quasi-static and pulsatory pressing of particulate material at a frequency of 280 Hz

Then the process of ejecting the particulate material under quasi-static and pulsatory conditions was studied, determining the force - tool path relationship. For a quasi-static process of ejection (Figs. 10 - 12), the relationship Pw(l) was approximated in the form:

Pwq = 252.687 -5.58887 l+0.157737 l2-0.00179603 l3+3.46055×10-8 l5

for the frequency of 80Hz (Fig. 10) in the form:

Pwpmax1 = 94.069 +21.7062 l-2.19612 l2+0.0966125 l3-0.00213784 l4+0.0000231092 l5-9.73446×10-8 l6

and

Pwpmin1 = 2.9987 +23.6004 l-2.15611 l2+0.0923924 l3-0.00203483 l4+0.000022131 l5-9.42779×10-8 l6

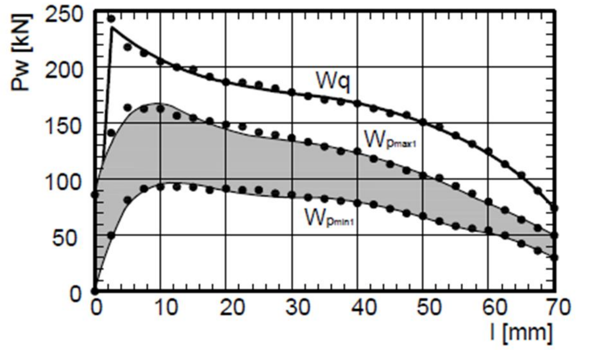

Fig. 10. Relationship between force Pw and tool feed path l during quasi-static and pulsatory ejection of thin-walled compact at a frequency of 80 Hz

for the frequency of 180 Hz (Fig. 11) in the form:

Pwpmax2 = 98.5435 +24.9097 l-2.557 l2+0.113928 l3-0.00254455 l4+0.0000277463 l5-1.17936×10-7 l6

and

Pwpmin2 = 14.6337 +31.6545 l-3.12473 l2+0.138895 l3-0.0031137 l4+0.0000341427 l5-1.45715×10-7 l6

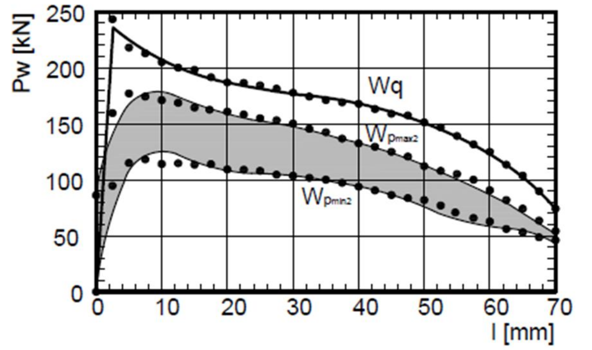

Fig. 11. Relationship between force Pw and tool feed path l during quasi-static and pulsatory ejection of thin-walled compact at a frequency of 180 Hz

and for the frequency of 280Hz (Fig. 12) in the form:

Pppmax3 = 74.1136 +37.5966 l-3.96321 l2+0.182853 l3-0.00420786 l4+0.0000470982 l5-2.0457×10-7 l6

and

Pppmin3 = 18.0982 +37.3613 l-3.75396 l2+0.169098 l3-0.0038333 l4+0.0000424509 l5-1.82834×10-7 l6

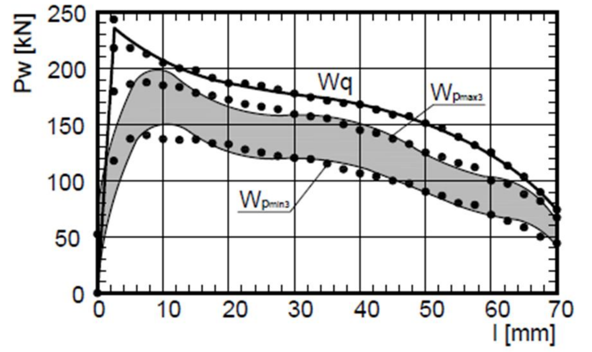

Fig. 12. Relationship between force Pw and tool feed path l during quasi-static and pulsatory ejection of thin-walled compact at a frequency of 280 Hz

IV. CONCLUSIONS

Presses from the PXP series represent an original Polish design solving problems related with the equipment used for plastic forming of products from powders of metals, non-metals and their respective mixtures, this including also plastic forming of sintered products. An innovative pulsatory technique was used, yielding high-density compacts. Using this technique it is possible to reduce the compression force, and consequently the unit pressure on a tool and energy consumption. The ready products are characterized by high accuracy of both shape and dimensions.

It has been demonstrated that the pulsating pressure reduces by up to 27% the compression force required to achieve maximum density and - which is also very important – it reduces by up to 45% the ejection force required to remove the compact from a molding tool, eliminating also the formation of cracks. Using this process, it is also possible to obtain an unprecedented homogeneity of the compact properties, which is particularly important for further performance of this compact. The result is the manufacture of compacts of a unique shape and density similar to the solid form. An offer for the global industry is tooling for the presses to enhance with mechanical vibrations the process of forming particulate materials.

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REFERENCES

[1] D. Denman, W. McNeil, “Multi-axial servohydraulics controls compaction press”, Hydraulics and Pneumatics 53 (2) , ss: 27-29, 2000

[2] N. Nies, “CPA technology permits combined use of withdrawal and counter-pressure process”, Advances in Powder Metallurgy and Particulate Materials , ss: 480-486, 2001

[3] X. Shen, Y. Zhang, L. Wang, Y. Zhu,” Design and application of semiautomatic adapter for general hydraulic presses”, Fenmo Yejin Jishu/Powder Metallurgy Technology 19 (3) , pp. 170-174, 2001

[4] W. Markeli, latest technology in powder compacting of complex geometries, Proceedings of the 3rd International Powder Metallurgy Conference , strony: 470-479, 2002

[5] B. Williams, “Mega presses keep pace with demand for large pm parts”, Metal Powder Report 59 (4), ss: 22-24, 2004

[6] L. Lackner, “The new generation of hydraulic presses”, CFI Ceramic Forum International 81 (11), ss: E12-E13, 2004

[7] Z.-Y. Zhou, C.-M. Huang, H. He, M. Shao, “Integrated hydrocylinder-driven multi-platen adapter for powder press”, 2006 Huanan Ligong Daxue Xuebao/Journal of South China University of Technology (Natural Science) 34 (2) , ss: 8-11, 2006

[8] X. Li, Z. Ruilin, “The hydraulic simulation of the wl3200 t press basing on amesim”, Ceramic (4), ss: 32-34, 2009

[9] P. Doremus, Y.L. Guennec, D. Imbault, G. Puente, “High-velocity compaction and conventional compaction of metallic powders; comparison of process parameters and green compact properties”, Proceedings of the Institution of Mechanical Engineers, Part E: Journal of Process Mechanical Engineering 224 (3), ss: 177-185, 2010

[10] P. Doremus, Y. Le Guennec, D. Imbault, et al., “High-velocity compaction and conventional compaction of metallic powders; comparison of process parameters and green compact properties”, Proceedings Of The Institution Of Mechanical Engineers Part E-Journal Of Process Mechanical Engineering, 224, E3, ss 177-185, 2010

[11] Z.Z. Gaodianrong, “Experimental study of hydraulic control system by 6800kn brick press”, Proceedings of 2011 International Conference on Fluid Power and Mechatronics, art. no. 6045797 , ss: 406-409, 2011

[12] S. Berg, Haggblad Hans-Ake, P. Jonsen, “High-pressure compaction modelling of calcite (CaCo3) powder compact”, Powder Technology, 206, 3, ss: 259-268, 2011

[13] R. Moszumański “Tools to manufacture thin-walled components from particulate materials by a dynamic method” Pro-Tech-Ma’2014 Progressive Technologies and Materials in Mechanical Engineering" 2014, METALLURGY and METALLURGICAL ENGINEERING NEWS 2014-7, 2014

[14] R. Moszumański, S. Knapik, J. Kryza, “Automated method and apparatus for dynamic manufacturing of thin-walled components from particulate materials” P.406692 Polish Patent Office, 2013

[15] R. Moszumański, “Energy-efficient system of feedstock transport operating in a system of: particulate material forming press – Compact Sintering Furnace”, ICME'14 The 2014 International Conference of Mechanical Engineering, 2014

[16] R. Moszumański, J. Kryza, S. Knapik, A. Tabor, “A system for the energy recovery and vapour separation in an air-tight, backward-type, pusher tunnel furnace” , P.406642 Polish Patent Office, 2013

[17] R. Moszumański, S. Knapik, J. Kryza, A. Tabor, “Energy-efficient feedstock transport system in a press – furnace arrangement”, P.406640, Polish Patent Office, 2013 United States Patent and Trademark Office, European Patent 2014

[18] R. Moszumański, M. Moszumański, “A versatile method and device to enhance the particulate material pressing process with mechanical vibrations”, P.406693 Polish Patent Office, 2013 United States Patent and Trademark Office, European Patent Office and 10 others 2014