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(RESEARCH ARTICLE)

Design of laboratory pellet press: Measurement and control system for load and temperature

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Abstract

For the structural design and dimensioning of all parts of the pellet machine, including the pressing tools, it is necessary to know in detail their force or pressure load, stress course, working conditions and exact function. A detailed knowledge of the load is crucial for the correct structural design and functionality of the tools and the entire machine. The contribution is devoted to the structural design of an experimental pellet press with a flat die and the design and implementation of a system for measuring and regulating selected parameters of the pressing process. Such experimental research finds application in the structural design, dimensioning and optimization of individual structural nodes of the pellet machine based on different principles.

Keywords: Pellet Press; Pelleting; Measurement; Regulation; Pressing Force; Pressing Temperature

1. Introduction

Pelleting technology is a progressive way of compacting crushed and dried material by extrusion through a pressing die. It is mostly used for biomass to produce the wood pellets as a solid biofuel. In this technology, the feedstock with suitable fraction size and moisture content is forced through holes in the die by pressing tool. At very high pressure and associated temperature, the lignin component of the biomass plasticizes and takes over the function of a binder. The pellets are very hot and plastic after passing and cutting from the pressing tool. They gain hardness and mechanical resistance only after cooling. The raw material is compressed with or without the addition of an additive as a binder (depending on the type of material being pressed). The pelleting technology is characterized by the fact that at one point in time several compacts (pellets) are formed, which have a cylindrical shape.

Each time a press channel passes a roller, feedstock is compressed and pressed into the channel. As material is pressed into the channels, cylinders of compressed material are extruded from the outside of the die, where blades break them into pellets. Frictional heating in the die causes the pellet temperature to reach 90–105°C [1,2,3]. The heating causes moisture to flash off from the pellets, and thereby drying the pellet. The final moisture content of wood pellets is in the range of 7–10% on a wet basis (w.b) [4]. In order to meet the standard requirements for wood pellets, the moisture content of the final pellets must be below 10% (w.b). [5]

The technology is suitable for processing various types of waste, such as wood sawdust, straw, bark, feed mixtures, but also coal dust, mineral waste, fertilizers, stabilizers, or PVC waste. The technology is suitable for applications in the pharmaceutical industry and is also used in the chemical industry. The work will continue to focus on pelleting biomass. This technology is very demanding for the treatment of the input raw material before compaction. It requires dimensional adjustment of the raw material to a fine fraction, such as adjustment of the moisture content to a value in

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the range of a very narrow interval. The high surface to volume ratio of the pellets results in high wear of the functional parts of the pelleting machines per unit of production. Compared to briquetting technology, investment and energy consumption of pelleting is much higher. Pellets as a form of solid biofuel have one major advantage over briquettes, which outweighs all the weaknesses of this technology. This advantage and basically the only reason for the production of solid biofuels in the form of pellets is their suitability for automated combustion systems in small combustion equipment. Pellets have some properties of loose materials, they can be transported pneumatically, and due to their size and shape, they can be transported by screw conveyors, which predestines them for use in small combustion plants. For this purpose, they are produced from pure sawdust and shavings without the addition of any other binders (with the exception of additives of organic origin permitted by the standard up to 2% by weight). They burn with a steady and smooth flame due to their homogeneity and high energy density. [6]

When designing compaction machines, it is necessary to thoroughly know the properties of the material being processed and the entire technology of its treatment. Compaction machines use drive energy to press various materials. The operation of the machine is accompanied by high pressing pressures, the individual components are heavily stressed. Therefore, it is necessary that the devices must be correctly dimensioned. When designing compaction machines, it is necessary to start from the pressing process of a specific material and determine the size of the pressing force and other technological parameters affecting the pressing process. Currently, however, there are no exact mathematical models expressing the process of compacting biomass into the form of biofuel. In the scientific literature, it is possible to find some mathematical models of pressing of a general nature, but these are insufficient and do not at all reflect the pressing of biomass as a "living" material of a special category. As a result, the designed machines are either oversized, unreasonably high-performance machines are used for pressing a certain material, or on the contrary, they are undersized and not very powerful. With oversized machines, the customer overpays for an expensive machine that is very energy-intensive, which is also reflected in the price of production. On the other hand, when the machine is undersized, the entire structure is overloaded, the machine cannot reliably press the material, which causes frequent downtime and breakdowns, and is the cause of low quality production. In order to avoid these shortcomings, it is necessary to seriously deal with the biomass compaction process and to create a mathematical model of the biomass compaction process based on real loading, which would be able to accurately describe the event itself in the pressing chamber and the pressure or force ratios acting on functional parts of the machine. Such a mathematical model could then be used to optimize the design parameters of pressing tools from the point of view of minimizing the energy requirements for the pressing process, and subsequently to dimension and optimize the entire machine structure with respect to the specific compacted material.

Optimizing the process of biomass pressing is currently a highly relevant topic. When designing the machine, manufacturers usually follow the "trial-error" method, as there is no exact mathematical model of the biomass pressing process. The pressing issue is not only the optimization of the design of already existing compaction machines in order to eliminate the failure rate, but also the reduction of the energy demand of the compaction process, which results in the need to modify existing structures or to search for new principles of work of compaction machines with higher efficiency. The issue of the energy demand of the process of compacting biomass into the form of a solid noble biofuel must be seen as a priority, as this directly affects the price of such biofuel, and thus its competitiveness on the market compared to fossil fuels.

When designing and dimensioning all mechanical parts of a compaction machine, including pressing tools, it is necessary to know in detail their force or pressure load, stress profile, working conditions and exact function. Pelleting tools intended for biomass compaction are often exposed to abrasive and corrosive environments, high pressing temperatures and are loaded with complex force or pressure ratios. Detailed knowledge of the force load of the tools is crucial for the correct structural design and the very functionality of the tools and the entire machine.

2. Pelleting machine with flat die

The material is pressed between two or more cylindrical (Fig. 1) or conical rollers rotatably mounted on static shafts, and a flat circular die with holes of the required diameter, through which the material is pushed. The die is driven by a screw. The material is supplied from above, so it is evenly distributed over the entire surface of the die. After pressing, the pellets of the required length are broken off by knives fixed under the die. The vertical design of the machine makes it more compact and dynamically balanced, as the rotating particles are located in one axis. The supply of material is more uniform compared to horizontal constructions of pelleting machines. The disadvantage is the relatively high wear of the pressing rollers, which in most cases are permanently pressed against the surface of the die. In the case of cylindrical rolls, this unfavorable fact is exacerbated by uneven peripheral speeds along the width of the rollers, which cause slippage and uneven wear of the rollers. However, some manufacturers of vertical pelleting machines prevent the pressure of the cylindrical rolls on the die by design, they set a small gap so that the tools do not touch, thus reducing the wear rate. At the same time, they use the otherwise undesirable effect of unequal peripheral velocities in the case of cylindrical rollers to tear off the pressed layer of material on flat surfaces on the surface of the die outside the holes and move it into the hole, which prevents layers of material from sticking in these places and possibly uneven loading of the structure.

Figure 1 Machine model of AMANDUS KHAL Company [7]

Flat die pellet presses are characterized by a compact design with a vertical main axis of rotation, high variability, but lower hourly production output and lower efficiency. Their principle (shown in Fig. 2) is based on the relative movement of the die and the pressing rolls. Depending on the manufacturer, power and type of press, the drive is solved by means of a belt transmission or by means of a helical gearbox, or for higher outputs also by using two helical gearboxes at the same time. Depending on the manufacturer, either the die or the central shaft with the rolls is driven. Their number varies from 2 to 5 depending on the power of the press. With the correct assembly and definition of the mutual position of the tools (dies and rollers), there is no mutual contact during the operation of the machine due to the reduction of the wear rate. [7] The gap between the tools is usually set to a minimum value so that a continuous pressed layer is not formed during pressing. Rolling of the rolls occurs only due to the friction caused by filling the pressed raw material into the pressing space between the tools from the top. At the same time, the raw material is pressed and pressed into the pressing chambers of the die. The selected geometry of these chambers is responsible for the amount of resistance to extrusion of the raw material, which increases the compacting pressure and at the same time the density and strength of the pellets. The length of the pellets after extrusion is defined by the adjustable position of the breaking knives.

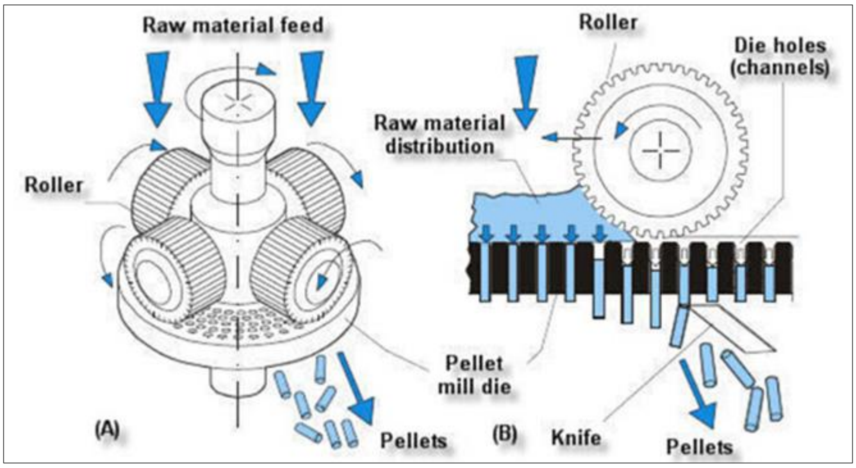


Figure 2 The principle of pelleting on presses with a flat die [8]

The adjustable gap between the pressing tools - the die and the rolls - is usually set to a minimum value so that a continuous pressed layer is not formed during pressing, but to avoid excessive wear of the tools in contact with each other. However, the size of this gap is an important parameter of pelleting technology. In the case of a minimal (almost zero) gap (Fig. 3), the raw material in the form of a uniformly thick layer is pressed on the die by the action of a roll and subsequently pressed into the pressing chambers in the die. If the gap between the tools is larger (Fig. 4), the particles of the pressed raw material pass several times under the rolls before they are pressed into the pressing chambers. During this time, they go through several processes of kneading, cutting, pressing, mixing, which leads to intensive pre-compaction of the raw material. The larger fraction is reduced and the natural binders contained in the raw material are activated here, which results in a higher quality of pellets (higher mechanical resistance and hardness), but also a significant increase in energy consumption per unit of production.

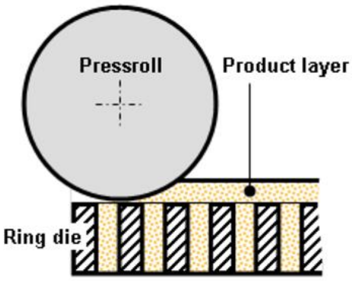


Figure 3 Zero gap between pressing tools [9]

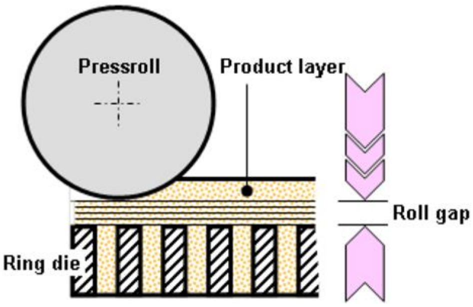


Figure 4 Larger gap between pressing tools [9]

3. System of measuring and controlling selected parameters of pressing process on a pellet press

3.1. Parameters affecting the quality of pellets

A quality indicator of pellets from the point of view of the compaction process is their mechanical properties (density, mechanical durability, abrasion, strength, etc.), which depend on many factors. If we want to achieve the quality specified by the ISO 17225 standard, we need to know the influence of individual parameters on the quality of the pellets. From the point of view of the construction of compaction machines, only the parameters affecting the compaction process are important. Based on an in-depth analysis, we can divide these into three groups:

- material parameters (type of pressed material, fraction size, moisture content, temperature),
- technological parameters (method of pressing, pressure in the pressing chamber, temperature in the pressing chamber, pressing speed, holding time and stabilization time),
- design parameters (geometry of the pressing chamber, type and geometry of the pressing tool, friction parameters of the pressing process (surface roughness, material of the tools, their surface treatment), length of the cooling channel).

The material parameters affecting the quality of the pressings are tied to the properties of the input raw material and are largely unchangeable. Technological parameters can significantly influence the compaction process and the quality of pressings. Likewise, design parameters have an irreplaceable place in the pressing process. The parameters of all three groups must be in synergy to successfully achieve a high-quality pressing. [10]

3.2. Construction of a small pellet press for laboratory use

For a more complex research on the pelleting of various types of raw materials, it is necessary to design an efficient experimental device as well as ways and methods of regulation and measurement of important parameters of the pelleting process. For this purpose, a complex structural design and development of an experimental pellet press with a flat die (Fig. 5) was made, which will enable control and measurement of important parameters of the pelleting process.

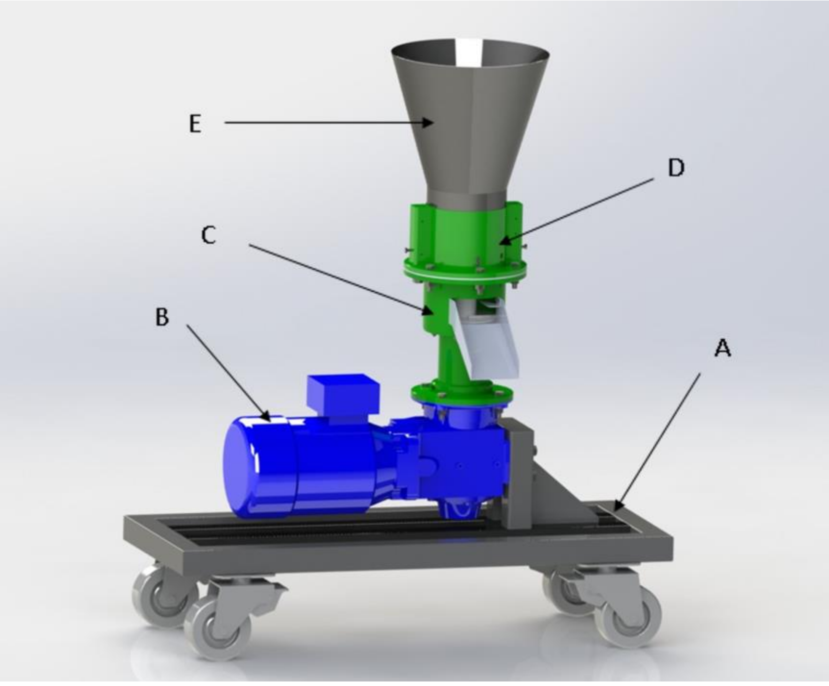


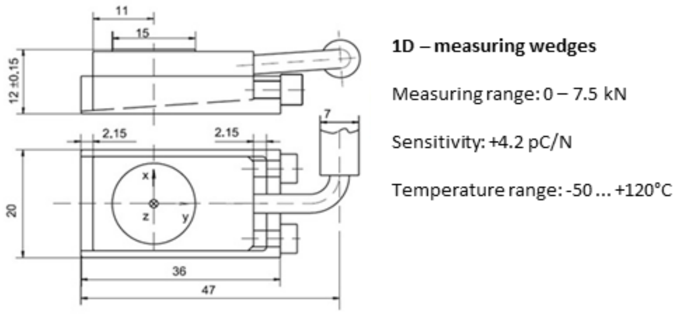
Figure 5 Construction of the developed laboratory pellet press (A – supporting frame of the machine, B – electric gearbox, C – lower working chamber,D – upper working chamber, E – hopper)

This experimental research finds application in the structural design, dimensioning and optimization of individual structural nodes of the pellet machine, as well as pellet pressing tools. It is the quantification of pressure ratios and their functional dependence on a number of variable parameters that can be obtained primarily through experimental research in simulating real conditions and their integration in the dimensioning of structural nodes and pressing tools, which makes it possible to design an effective construction optimized for a specific pressed material and at the same time eliminates the failure rate of these parts.

3.3. Design of a system for measuring and controlling selected parameters of the pressing process

The proposed pellet press is intended for laboratory purposes, i.e. to be able to measure and regulate the basic parameters during the pelleting process itself. Selected measured or adjustable parameters for the proposed construction are pressing pressure (pressing force), temperature in the working space, length and diameter of holes in the die, thickness of the die, length of pellets, revolutions of the die and distance of pressing rollers from the die.

A radial piezoelectric sensor (Fig. 6) was chosen to measure the course of the pressing force, which is capable of measuring dynamic load. This sensor is placed in milled grooves in the flange (Fig. 7). The sensor will not capture directly the total derived pressure under the pressing rollers, but only a part of it in the place of the aforementioned groove under the bearing (Fig. 8). For this reason, the sensor must be properly calibrated. And that in a subsequent way. After insertion, the sensor must be pre-wired to the specified value. This value will be considered as measured zero. Then, the torque wrench will tighten the thrust pin (on its end there is a milled square for the torque wrench) to at least seven preselected values of the thrust force. A calibration curve will be created, which will represent the dependence of the value measured by the sensor and the real value of the torque wrench. According to this curve, it will be possible to calculate any real pressure value arising during the pressing process.



1D – measuring wedges

Measuring range: 0 – 7.5 kN

Sensitivity: +4.2 pC/N

Temperature range: -50 ... +120°C

Figure 6 Basic parameters of the piezo-crystal sensor

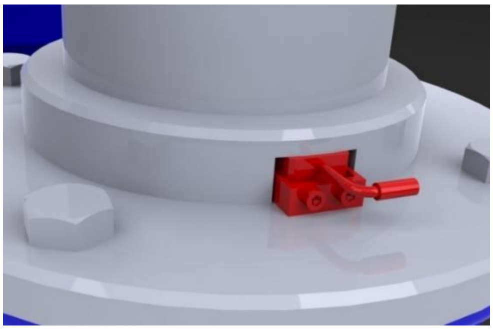


Figure 7 Placement of the piezo-crystal sensor in the groove of the flange of the press structure

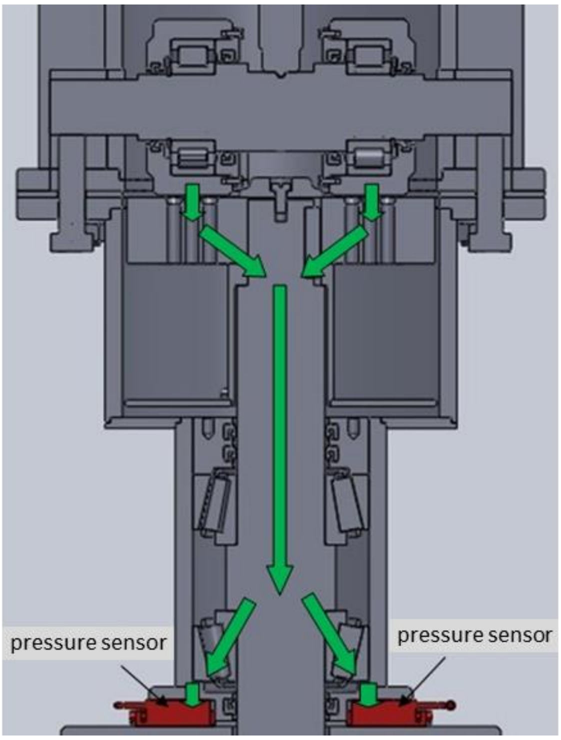
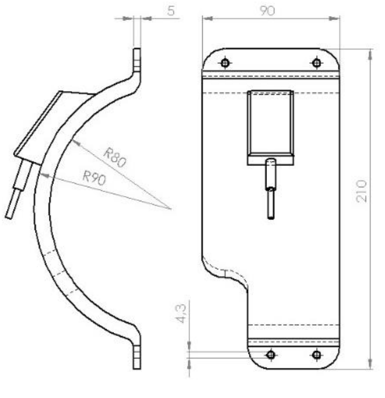
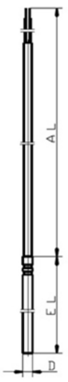


Figure 8 Representation of the load flow in a section of the press structure

To regulate the temperature in the working chamber, two semicircular heating rings (Fig. 9) are used, placed on the outer wall of the upper working chamber with the help of screws in the support columns of the press structure (Fig. 11). The heating hoops are made in a non-standard shape (cut-out in the lower part) in order to free up space for the placement of sensors used to measure the temperature in the working space, namely rod thermocouples with compensating lines (Fig. 10). Thermocouples are inserted into the so-called screws for protective pipes. The screwing was chosen according to the dimensional parameters of the used thermocouple and screwed into the wall of the working chamber. The extension length (the length of the penetration of the thermocouple into the pressing space) can be changed by loosening the adjusting screw on the screw and then manually moving the thermocouple itself. Between the flanges of the upper and lower working chamber there is a 3 mm thick circular graphite gasket that prevents heat from escaping through the flange joint.





Rod thermocouple with compensation line

Measuring range: -50...+300 °C

Diameter of the protective tube D: 6 mm

Insertion of EL: 50 mm

Ending of compensating line: free endings

Compensating line: 2500 mm

Figure 9 Used heating ring **Figure 10** Basic parameters of a rod thermocouple with compensation line

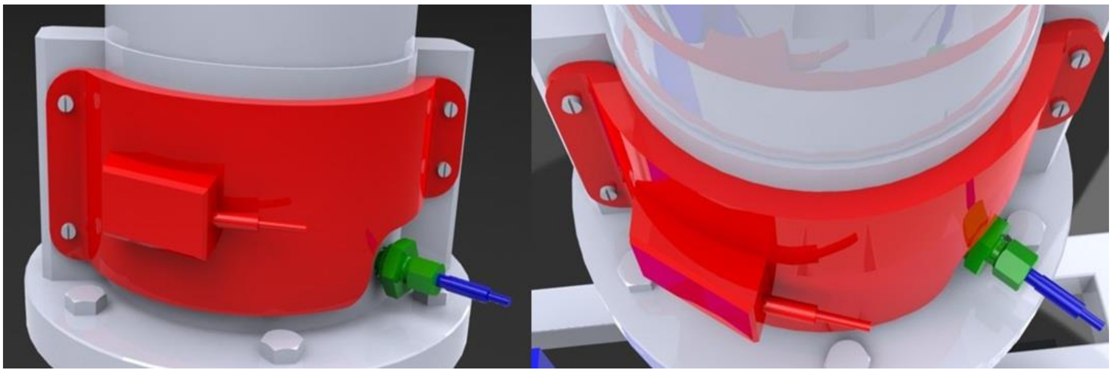
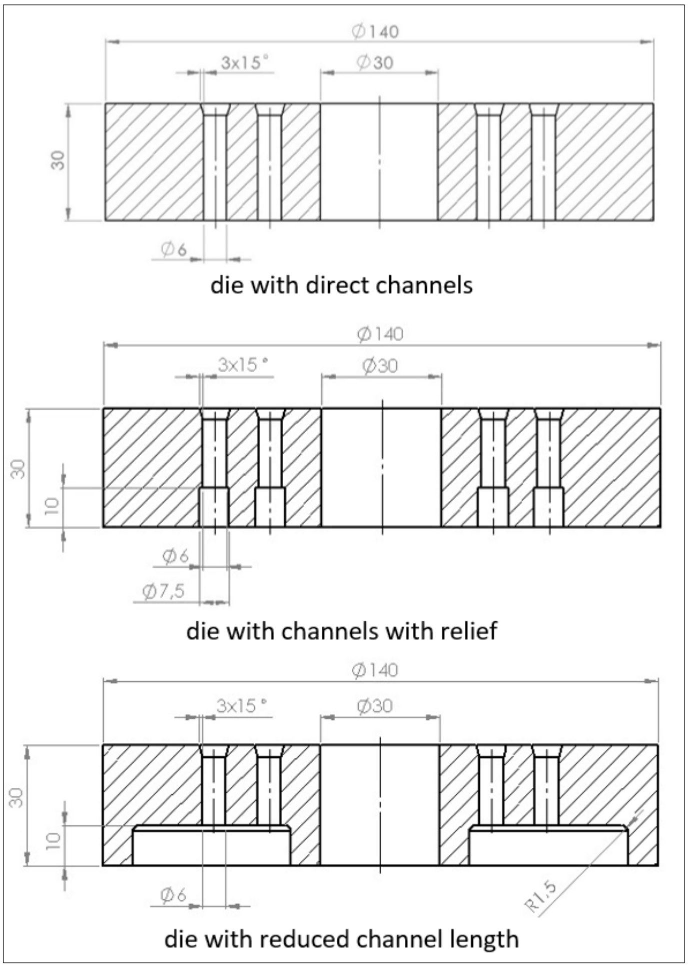


Figure 11 The method of fixing the heater, thermocouple and screwing on the structure of the press

In order to be able to detect changes in the values of the investigated parameters, which arise when using dies with different holes, several types of dies were designed. Their design considered changing the diameters of the pressing channels, their lengths, the relief of the pressing channels in the die and also its thickness itself. Fig. 12 shows three structural types of designed dies with uniform diameters of pressing channels Ø 6 mm.

For the pressing process, it is important that there is a certain gap between the pressing rollers and the die (Fig. 13). If this gap were not observed, in the places between the holes of the die, the material would be pressed without pushing through the hole, it would be packed, and thus the applied pressure during pressing would increase. It is known that the peripheral speed is not the same over the entire surface of the press rollers. This results in their uneven wear. However, the advantage of this fact is that if even a small gap is reached between the pressing tools, the so-called slipping of the pressing rollers. This will ensure that the pressed material is pulled from the spaces between the openings. In this design, the size of this gap is adjusted using two setting screws located in the flange of the upper working chamber (Fig. 13). The gap distance is regulated by tightening and loosening the limiter screws. The shaft, on which the pressing rollers are placed, is freely placed at both ends on the delimiting screws.



die with direct channels

die with channels with relief

die with reduced channel length

Figure 12 Structural types of designed dies in section

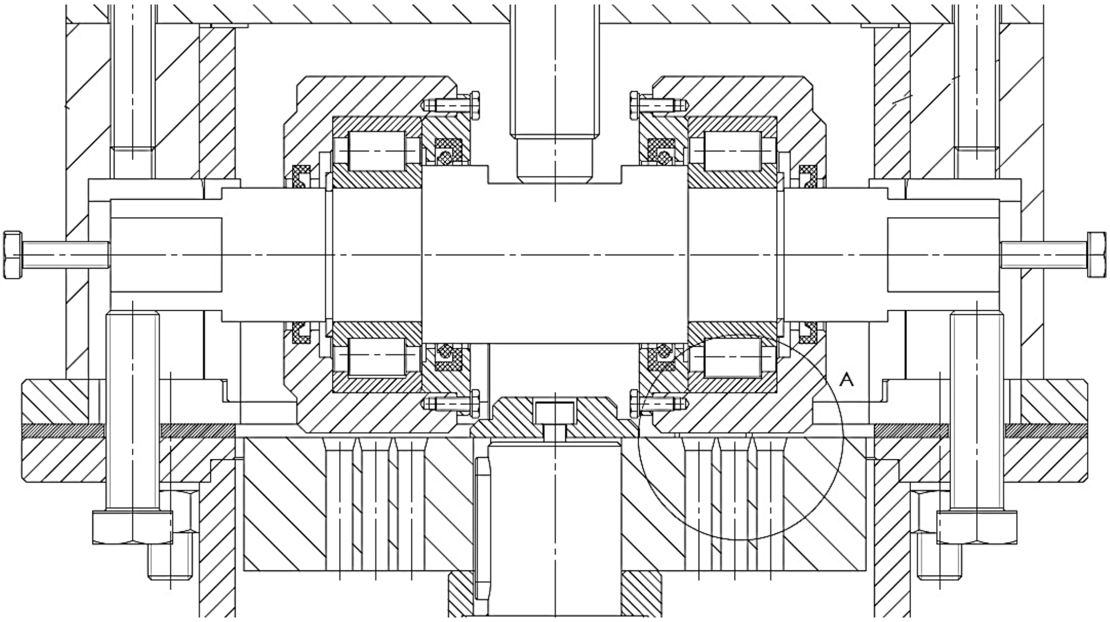


Figure 13 Setting the gap between the pressed roller and the die

4. Conclusion

For the structural design and dimensioning of all parts of the pellet machine, including the pressing tools, it is necessary to know in detail their force or pressure load, stress course, working conditions and exact function. A detailed knowledge of the load is crucial for the correct structural design and functionality of the tools and the entire machine. The contribution is devoted to the structural design of an experimental pellet press with a flat die and the design and implementation of a system for measuring and regulating selected parameters of the pressing process. Such experimental research finds application in the structural design, dimensioning and optimization of individual structural nodes of the pellet machine based on different principles. It is the quantification of pressure ratios and their functional dependence on a number of variable parameters that can be obtained primarily through experimental research in simulating real conditions and their integration in the dimensioning of structural nodes and pressing tools, which makes it possible to design an effective construction optimized for a specific pressed material and at the same time eliminates the failure rate of these parts.

Compliance with ethical standards

Acknowledgments

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Disclosure of conflict of interest

There is no conflict of interest.

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