Chapter

Research and Development of the New Progressive Construction Press Machines

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Abstract

Throughout the world in the last two decades, solid noble biofuels produced on the basis of wood and agricultural biomass have been widely used. Many European Union countries have enacted legislation for solid noble biofuels oriented primarily to energy carriers manufactured from wood raw materials. The production of noble biofuels is a fitting direction for the recovery of biomass and other energy wastes. Fuel in the twenty-first century must, in addition to environmental and economic criteria, fulfil the criterion of high comfort and safety in its combustion. Modern energy carriers must have uniform size, density, moisture and shape. One of the most progressive means of waste recovery is the compaction of particulate matter into different shapes and sizes. The technologies of transforming biomass into biofuels with the required properties are compacting, briquetting and pelleting. I am working on a research of compaction technologies and the development of compacting machine design at the Institute of Production Systems, Environmental Technology and Quality Management of the Faculty of Mechanical Engineering of STU in Bratislava for more than 26 years. In its scientific research activity, the definition of equations describing the dynamic process of compaction, experimental tests of the compaction process, design and testing of new press machine were undertaken. Over the stated period, we have designed and developed several machines that are today in serial production. Chief among these is the BL 55–280 briquetting press, the DZ 240 disintegrating machine, the KUDO 2009 mobile unit for treatment of wood waste, the TR 200 solid material separator, the PLG 150 round pelleting press, the ZBL-2-860 double-screw briquetting press or the RCM 650 ring compacting machine. We have submitted over 53 patents and industrial models. The aim of this chapter is to describe the new original and progressive designs of these press machines.

Keywords: research, press technology, original design, machine, patent, fuels

1. Design of the new press machines

Research into compaction technologies and the development of compacting machine construction have been undertaken by the Institute of Production Systems, Environmental Technology and Quality Management of the Mechanical Engineering Faculty at the Slovak University of Technology in Bratislava (ÚSETM SjF STU) for more than 18 years. In its scientific research activity, the definition of equations

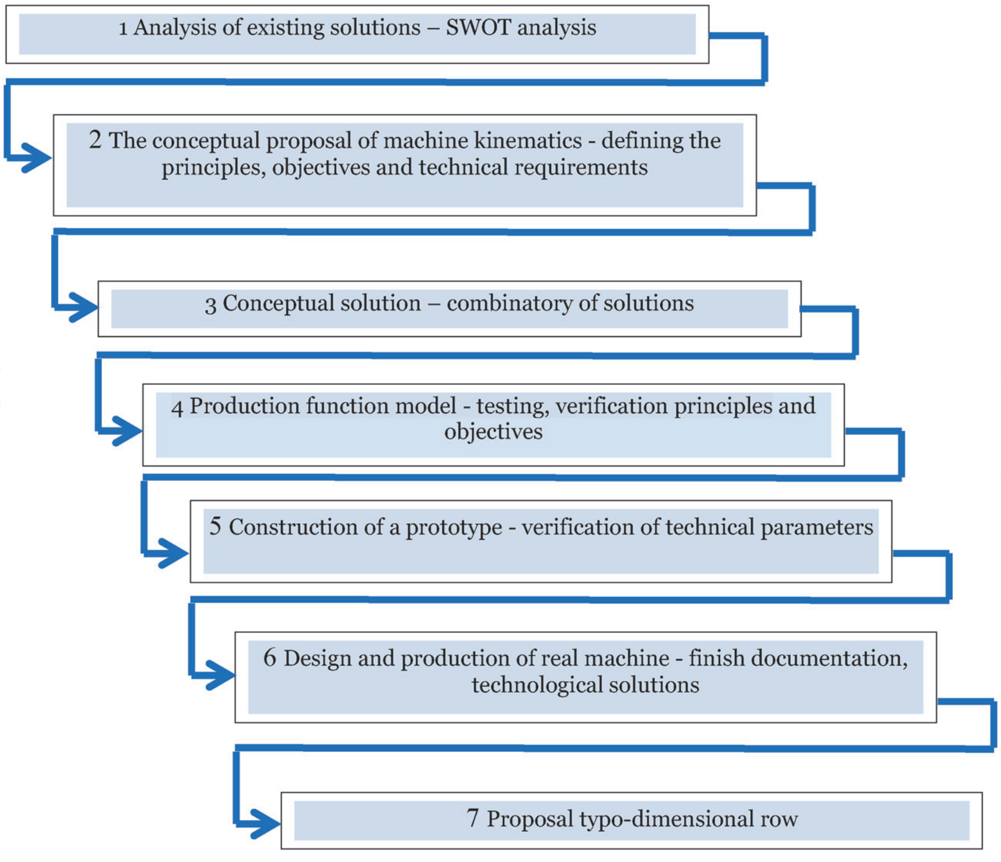

Figure 1.
Project management and coordination design of a new machine [1].

describing the dynamic process of compaction, experimental tests of the compaction process, and the analysis of existing legislation in the area of solid enriched biofuels were undertaken. Over the stated period, the ÚSETM SjF STU has designed and developed several machines that are today in serial production. Chief among these is the BL 55–280 briquetting press, the DZ 240 disintegrating machine, the KUDO 2009 mobile unit making use of wood waste, the TR 200 solid material separator, the PLG 150 round pelleting press, the ZBL-2-860 double-screw briquetting press and others. In this area, members of the institute have submitted over 55 patents and industrial models. The workplace has carried out some 64 national and 48 international projects in this area. Over 50 pelleting and briquetting production lines have been designed and subsequently implemented here, of which projects over 10 were carried out abroad.

When designing a new machine, we used a standard process customary in our department (**Figure 1**).

2. Research of compacting machines

The production of enriched biofuels is a fitting direction for the recovery of biomass and other energy wastes. Fuel in the twenty-first century must, in addition to the environmental and economic criteria, fulfil the criterion of high comfort and safety in its combustion. Modern energy carriers must have uniform size, density, moisture and shape. One of the most progressive means of waste recovery is the compaction of particulate matter into moulds with different shapes. The press technologies of transforming biomass into biofuels with the required properties are compacting, briquetting and pelleting. A common mark of these technologies is the pressing of raw materials under a certain pressure so that the mouldings achieve the required strength and shape. Compaction has several advantages:

- Higher calorific value when incinerating high-quality mouldings compared to combustion of the same material in an uncompressed state.
- A more uniform and longer process of burning of the mouldings than the material in an uncompressed state.
- Sufficient strength of mouldings guarantees high biofuel comfort during transport.
- High density of mouldings minimalizes costs for transport and storage.
- The high temperature and pressure during press process of the biofuel prevent the onset of biodegrading processes.
- The processing of otherwise hard-to-use waste into the form of enriched biofuel and others.

Immense progress in the usage of compacting technologies for the production of solid enriched biofuels has been recorded throughout the world. For instance, in Germany, Denmark and Austria, the demand for such biofuels exceeds domestic production. On the other hand, a certain limit in the energy usage of solid enriched biofuels from biomass has been reached at present, since many times their price is not commercially comparable with using fossil fuels [2]. The price of enriched biofuels is increased directly by high transport and in particular energy costs for their production. A reduction of such expenses is only possible by the application of new advanced progressive technologies and new constructions of the machinery necessary for production. These machines must be more economically effective with long working part lifetimes. Among the dominant problems for the producers of solid enriched biofuels are:

- Varying, often low-quality, mouldings (density, abrasion, strength) due to insufficient familiarity with the process.
- Excessive wearing of active parts of the compacting machines and devices.
- Inexact mathematic models, by which the compacting machines are designed.
- Mould shapes are not optimal, as mouldings are now produced as cuboid, e-angled (briquettes) or cylindrical (briquettes and pellets). These shapes are not optimal from the viewpoint of automatic supply in the combustion process.
- A lack of pure wooden biomass forces producers to search for new materials suitable for the production of enriched biofuels. These include agricultural raw materials or fitting industrial or separated municipal waste.

Compaction machines often are not constructed or designed for these materials, and therefore overloading, breakdowns and shortened operational life occur, as well as higher costs per unit of production and under- or over-dimensioning since the machines do not have optimised drive power. These all lead to increased energy demand which forces up the prices for such biofuels.

At present, it is necessary to develop and introduce into practice the highly effective press machines with extended lifetimes of their functioning parts and devices, optimised on the basis of precise mathematical models derived from experiments, and machinery with low energy and operation expenses per unit of compacted material. By such increases in effectiveness and reductions of production costs, it will be possible to produce biofuel at low prices that will make its use more widely applicable and its cost competitive with fossil fuels. This is a tool for achieving one of the primary goals of the European Union—increasing the implementation of renewable energy resources.

The contemporaneity of the project's intentions confirms the ever-increasing interest in producing energy carriers, increases in the number of users of biomass furnace for producing heat and also the continuing growth of production and consumption of solid enriched biofuels in Europe and around the world, not to mention in Slovakia.

3. Development briquetting machine

At the present time, we know three basic principles for operating briquetting presses: mechanical, hydraulic and screw (**Figure 2**).

Briquettes are suitable for kitchen stoves, brick ovens, level and central heating and fireplaces. Burning time of briquettes is from 30 to 60 min, depending on their shape and size. The moulds produced are generally in the form of cylinders, blocks or n-angles (**Figure 3**). In conformity with DIN 51731, the characteristic size is greater than 30 millimetres. Larger pressed fuels catch fire less easily and burn worse, and their combustion tends to be less ideal. Briquettes with larger diameters are also made with holes.

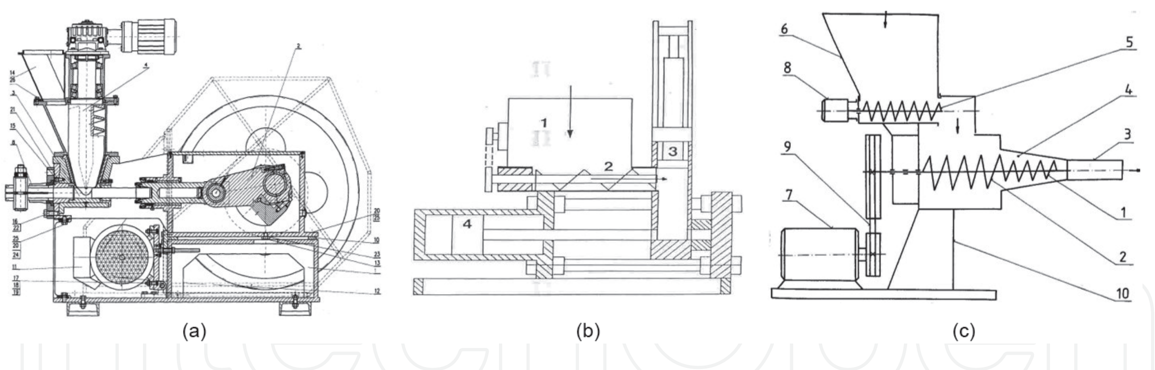

Figure 2.
Different principles of briquetting presses. (a) Mechanical, (b) hydraulic and (c) screw.

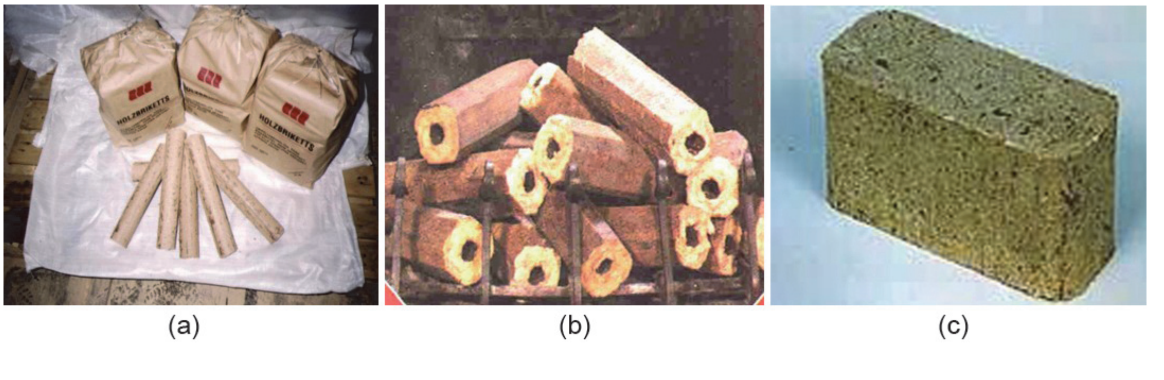

Figure 3.
Actual shapes of briquettes. (a) Cylindrical briquettes, (b) octagonal briquettes with holes and (c) block briquettes.

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3.1 Development of the screw briquetting press

The highest quality and strength of briquettes are achieved on screw briquette presses. But with this method, there is greater wear on the working equipment—the screw press. Screw briquetting presses (**Figure 2c**) clearly produce the best-quality briquettes (**Figure 3b**). The advantage of this sort of briquetting is that, as opposed to the other technologies, the moulds are produced continuously. The use of screw presses has a whole range of positive attributes. The briquettes are accordingly compact, with high densities, and can be produced in a number of shapes and sizes. The machinery is not noisy and do not create vibration comparable to other mechanical presses.

Despite the stated and undeniable benefits of this technology and the desirability of its moulds on the mark, such machines are almost non-existent. The primary reason is the very low service life of the tool and the lifetime of its axial bearings. The greater the expansion of screw briquetting presses, the shorter the lifespan of the work machine. The average life of screw and tools for such a press machine produced by today's manufacturers is from 50 to 120 hours, depending on the pressed material. This low durability and the consequent high cost for repair of screw or purchasing new tools outweigh the undisputed advantages of briquettes produced by this technology. Current designs of screw briquetting presses have several structural drawbacks. Among them are:

- High wear of the end of the screw
- Low axial bearing durability
- Heating of the rotating screw during start-up and cooling during operation
- Exerting high torque through the small diameter of the screwed shaft

Research into screw briquetting presses has also been intensively addressed. We have had successful cooperation with the Austrian company, Pini Kay. The result of the research is apart from other things a mathematical model for the design and optimization of the geometry of screw presses (**Figure 4a**), the design of a suitable abrasion-resistant material or the design of a rapidly replaceable screw head (**Figure 4b**).

The result of this research has been a solution for removing faults in the existing constructions of screw presses, not removing the reasons. With regard to the above, there emerged the original idea of designing a totally new conception of the construction and kinematics of the screw compactor. In order to eliminate the high axial load of bearings, we designed the original design *(UV 6045)* [4]—the

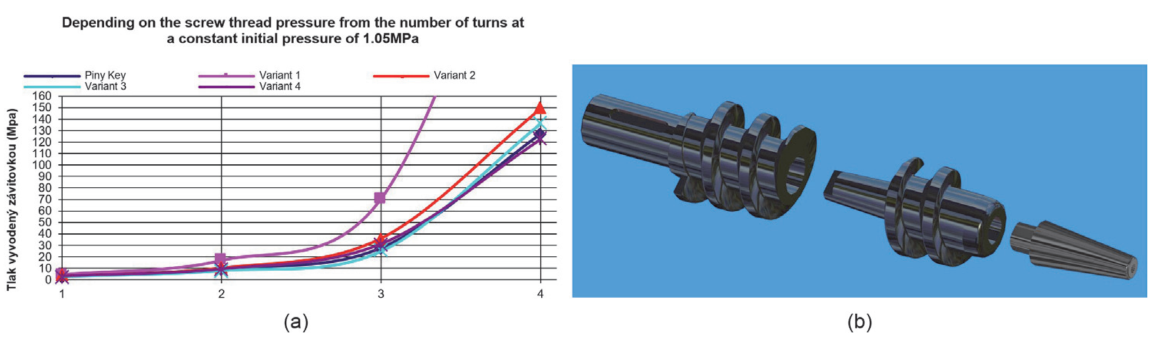


Figure 4.
Results of research on the screw press. (a) The course of pressures and (b) replaceable end (SK 288206) [3].

backward arrangement of the screws (**Figure 5**). A real outcome of this research is the prototype of a double-chamber screw press with a backscrew arrangement (**Figure 6**).

3.2 Development of the modular conception of mechanical briquetting machine

Constructional development mechanical briquetting press can be divided into development of an overall modular conception of a briquetting device and research into original design nodes. The basic requirement in the design of the modular conception was to achieve maximum universality of the individual construction elements and, with respect to the number of pressing chambers, the range of manufactured production offered. Research into original design nodes is focused on a significant expansion of the basic functions and technical parameters of the compaction machine as well as the possibilities of compacting waste with increased moisture and the production of briquettes and pellets on a single compacting machine.

3.2.1 Briquetting mechanical press BZ 50-300

The BZ 50–300 briquetting press is a mechanical briquetting press with an open pressing chamber (**Figure 7**) [5]. The press is driven by an electric motor, a pulley and a flywheel. The transformation of rotational movement to rectilinear is performed by the crank mechanism. The cylindrical piston tool performs direct rectilinear motion. The advantage of the press is its simple and reliable construction.

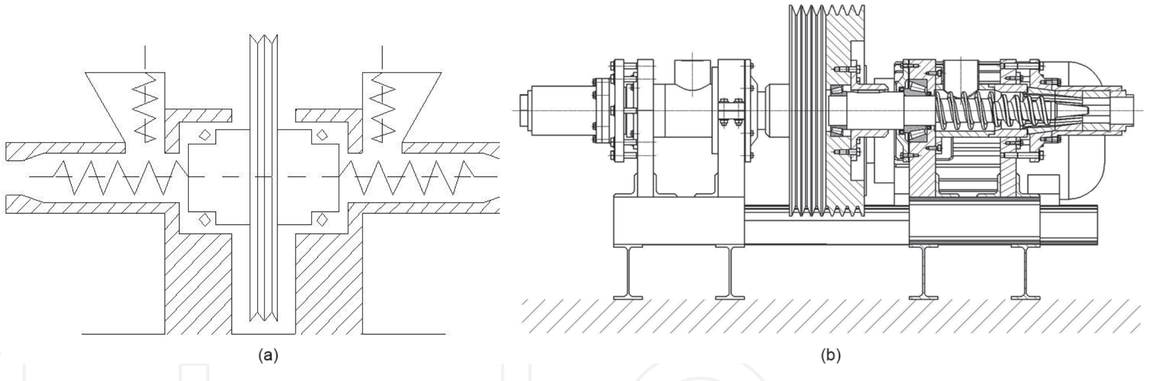
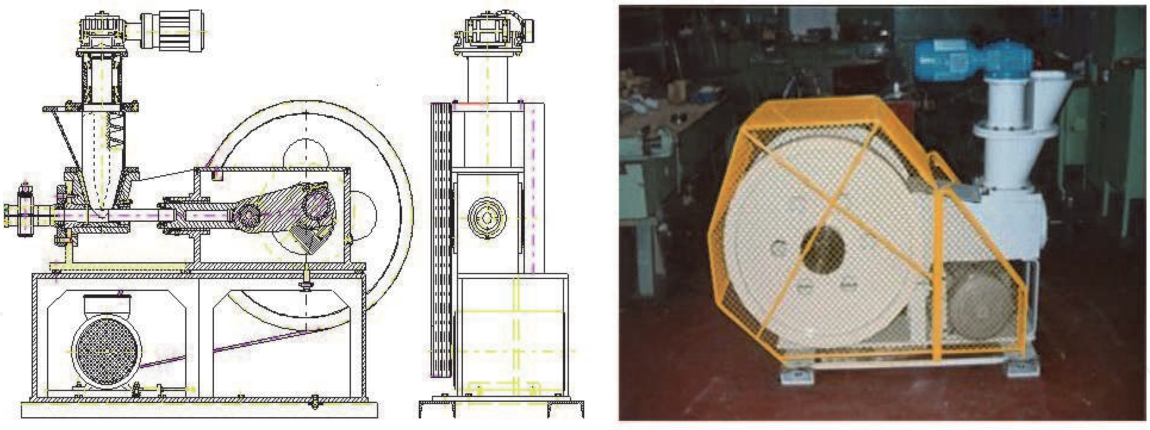


Figure 5.
Bicameral press of pressures. (a) Schema of press and (b) real design.

Figure 6.
Results of research on the screw press. (a) Prototype and (b) press in the production line.



(a) (b)

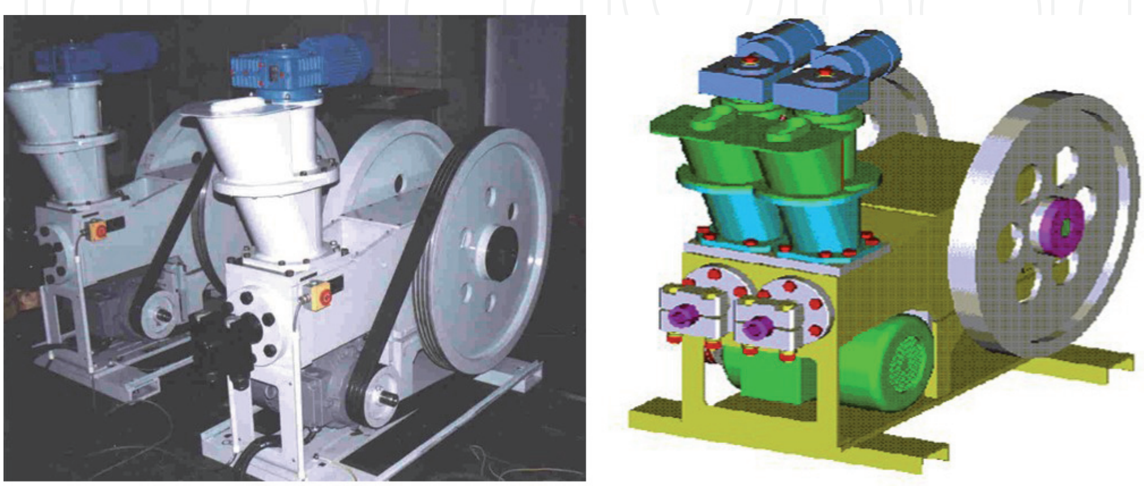
Figure 7.
Briquetting mechanical press BZ 50-300. (a) Press construction and (b) actual look.

The diameter of the briquettes produced is from 50 to 60 mm, the total press input power is 17.5 kW, and the hourly press performance is 250–350 kg of briquettes. Up to the present, more than 80 units have been produced, not only for the Slovakia market but also for export to the Czech Republic, Estonia, Hungary and Austria. The press is manufactured by Konštrukta Industry Trenčín, and at this time its production is also being prepared at the Vural Žilina company.

3.2.2 Dual-chamber briquetting press BZ 2-50-600

In cooperation with the Vural Žilina company, work on a dual-chamber briquetting press for the BZ 2-55-600 (**Figure 8**) is in preparation [6]. The advantage of the new resolution is lower machine input per unit of output. The hourly output is doubled while the press input power is less than twice. Accordingly, costs for the press are reduced because up to 83% of the pieces are not dependent on the diameters of the briquettes produced nor on the number of pressing chambers.

The individual parts as well as the entire machine are verified for strength according to the required diameter of the product and the type of material processed. In the design and dimensioning of the construction of the dual-chamber press, we needed to know, just like with the single-chamber press, the course of



(a) (b)

Figure 8.
Briquetting press. (a) Two single-chamber presses BL 55-300 and (b) dual-chamber press BL 2-50-600.

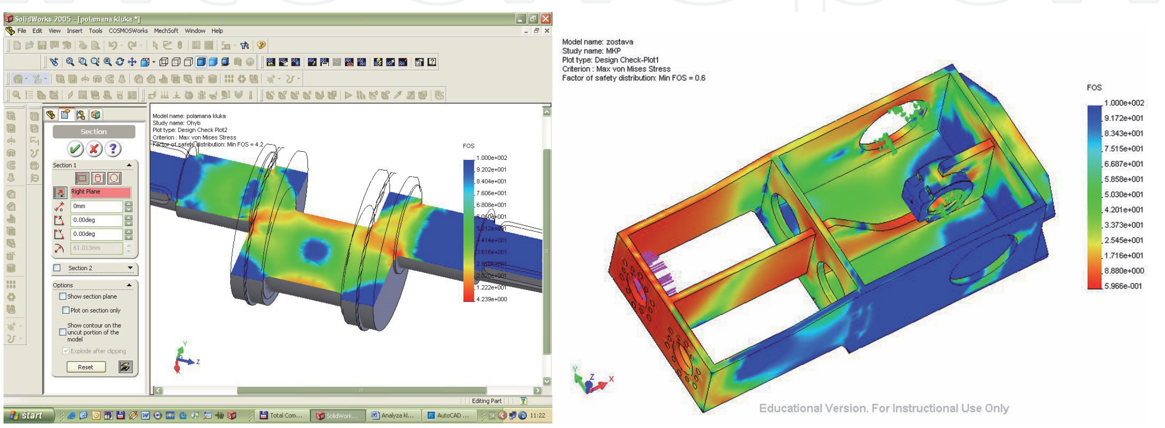
power during lifting and its maximum value so that we would be able to correctly dimension the amount of drive, the flywheels, the balance of the crank mechanism and the strength of the individual components. This strength changes quite dramatically in dependence on the type and current state of the material to be compressed. From the standpoint of dimensioning and of the production itself, the new crankshaft (**Figure 9a**) was critical. A completely new part of the press was the construction design and the dimensioning of the crankcase, for example, the crankshaft (**Figure 9b**).

3.2.3 Unification of the parts of the briquetting press

The final goal of this task was to rework the existing construction of the briquetting press to a modular state with varying dimensions of the briquettes or pellets produced, in single- or dual-chamber versions. According to the requirements of the client, we are able to design a machine tailor-made from the viewpoint of the type of processed material and the diameter of the produced mouldings and from the standpoint of the required output of mouldings hourly production.

For design optimization "Modullis" application software was created [7]. The software also includes an analytic part containing mathematical models for dimensioning and control of the individual parts of the press. The combinatorics of the design allows for a rapid choice of the suitable parts according to the selected press version (single-chamber or dual-chamber) and the diameters of the produced briquettes (∅ 50, 55, 60, 65, 70 mm) or pellets (∅ 6, 8, 10, 12, 16, 20, 24 mm). The advantage of the designed module make-up is that the parts are made separately from the final assembly, which greatly reduces the manufacturing costs. The optimization result is the choice of a final set of parts for assembly and guaranteed machine output for compression of the required material.

In **Table 1** all variants of the briquetting press (briquette diameters ∅50–70 mm, single-chamber or dual-chamber versions) are shown; for each variant a list of the optional parts is written. The idea of this sketch can be transformed into a computer program on the basis of briquette diameter requirement. The number of pressing chambers determines how many new parts will have to be used for the refitting of the existing briquetting press whose construction forms our starting point, as well as the hourly output of the selected briquetting press. The parts of the single-chamber press are identical, for easy fitting into the single-chamber press. The universality of usage of the individual parts is clear from **Table 1** and the graphs in **Figure 10**.



(a) (b)

Figure 9.
Simulation of burdening of press parts [6]. (a) Control of crankshaft for bending and (b) pressure course.

Dual-chamber briquetting press		
Subgroup	**New**	**Adapted from BL 50-250**
Frame	x	
Main drive (electric motor)	x	
Flywheel		X
Pulley		X
Crusader		x
Pressing chamber		x
Screw feeder		x
Spring collet		x
Fan belts		x
Feeding socket		x
Crank box	x	
Crank shaft	x	
Crank shaft roller bearing		x
Crank shaft sleeve bearing	x	

Table 1.
Unification nodes.

3.3 Development of original parts of compacting machine

Part of the development of compacting machines is the research of the original construction nodes focusing on the significant expansion of the basic functions and the raising of the technical parameters of produced machines. Here the "breathing hood", the "pelleting insert" or the "folded piston" of the machine belong primarily.

3.3.1 Breathing briquetting hood

All of the compaction technologies analysed up to the present allow compaction of only materials with relative moisture lower than 18%. At the same time, drying is demanding in both an energy and an investment sense. This problem can be solved in two ways.

The first method is the replacement of the technology of drying by a new, less energy-demanding, technology. This refers to centrifuging, pressure, drainage and chemical technologies and their mutual combinations.

The second method is managing the technological compacting process with a higher value of relative moisture than the limit (18%). For this purpose we developed in our workplace a so-called breathing press hood [8], which allows for the draining of water from the hood of the press (**Figure 11**). In this way it becomes possible to achieve quality mouldings with input raw materials with 22% relative moisture.

On the stated hood, we briquetted wood waste with input moisture of 22%, with the mouldings showing sufficient quality. Relative moisture w_r is defined by the ratio of the weight of the water and the total weight of the pressed raw material. Due to the high pressure in the pressing process, the water is in a liquid state. After the exiting of the briquette from the pressing chamber, the pressure falls, and the water changes into vapour and escapes from the briquette, while tearing it. The essence of the idea is to allow the escape of the vapour directly from the pressing

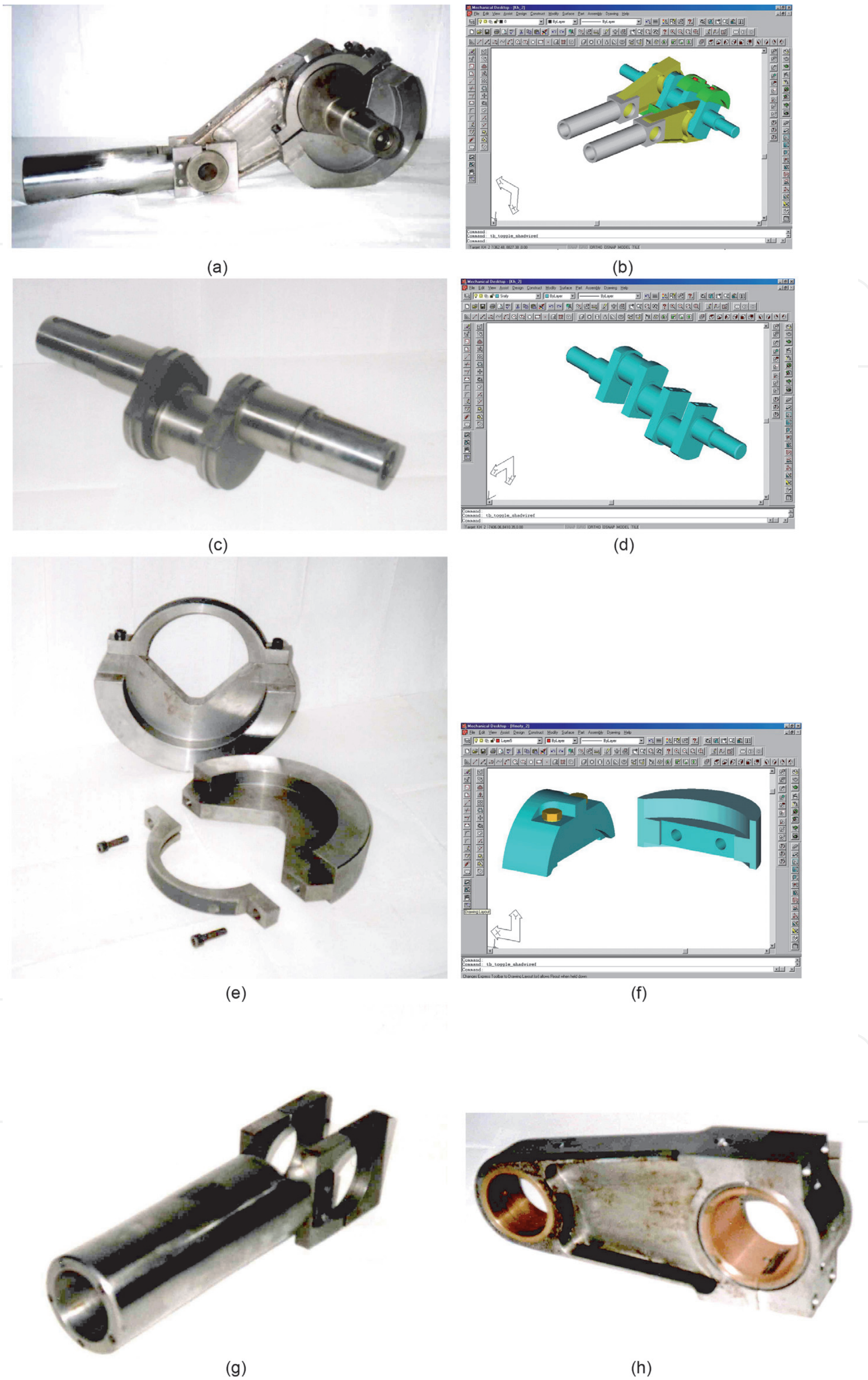


Figure 10.
Selection of parts for modular conception of a press. (a) Crank gear of single-chamber briquetting press BZ 50–250, (b) crank gear of dual-chamber briquetting press 2BZ 50–500. (c) Crank shaft of single-chamber briquetting press BZ 50–250, (d) crank shaft of dual-chamber briquetting press 2BZ 50–500, (e) counterweight of single-chamber briquetting press BZ 50–250, (f) counterweight of dual-chamber briquetting press 2BZ 50–500, (g) crusader – usable in both versions and (h) connecting rod.

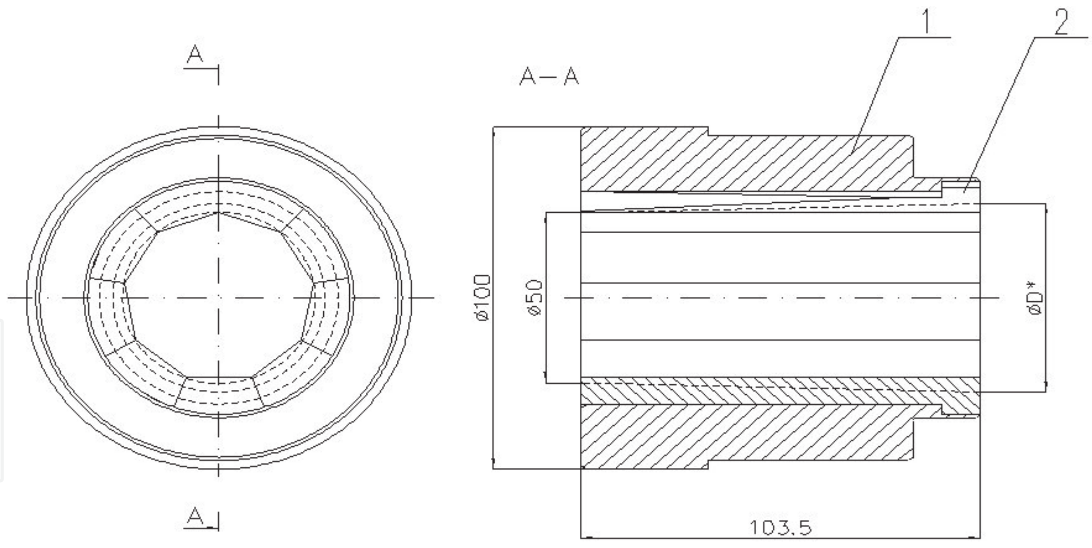


Figure 11.
Sketch of a breathing hood, 1 – hood body, 2– pressing segments, [8].

chamber during the reverse movement of the piston and a drop in pressure. Adjustments to the piston or drilling holes in the hood were not successful because their rapid shutdown resulted. The centre point of the proposed hood is that the formed vapour can escape through slots between the individual press segments. The slots close completely during the reverse movement and the drop in pressure.

3.3.2 Pelleting hood

The original result of the research into the construction of a briquetting press is the multi-technological construction of a press hood for a compacting machine [9]. Our attempt is to also produce pellets through a simple change of the compacting machine's press hood. The principle of the change is clear from **Figure 12**. In **Figure 12a**, we can see the briquetting hood of a crank briquetting press, which standardly produces briquettes with the required diameter. By adding (inserting) a pelleting insert (**Figure 12b**) to the briquetting hood, on that same press, we can make pellets with the required diameter (**Figure 12c**). In the two-dimensional range, we have designs of inserts that allow producing pellets with diameters of 8–20 mm. An example of a four-holed insert with a pellet diameter of 20 millimetres is seen in **Figure 12**.

Verification functioning tests were performed on straw and wood at the OPS company in Lehota pod Vtáčnikom. The positive result expanded the usage of the already existing briquetting press in producing economical pellets.

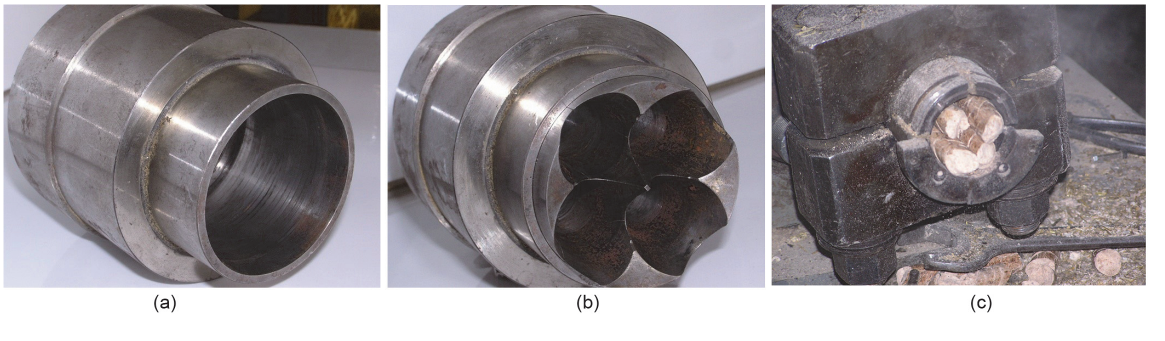


Figure 12.
Briquetting press pelleting Hood [9]. (a) Briquetting hood, (b) hood with pelleting insert and (c) production of pellets.

3.3.3 Folded press piston conception

A very quick wearing part of a briquetting press is the pressing piston, its front part in particular (**Figure 13a**). This problem can be solved through the use of quality materials and their thermal chemical treatment [10]. Another approach to the effective resolution of this problem is the construction design of a folded piston (**Figure 13b**).

4. Development of pelleting machine

The common feature of all press technologies, which include pelleting, is the compression of materials under high pressure [11].

A screw extruder is known, in which the screw feeder is also the tool of this press (**Figure 14a**). The disadvantage of this machine is the need for a cooling system and its low hourly rate of output during the moulding production. Another one is a horizontal pelletising machine with cylindrical rollers and a cylindrical die (**Figure 14b**). The disadvantage of this machine is the uneven supply of materials under both rollers. A horizontal pelletising machine with cylindrical die and compression rotor is also similarly designed. The disadvantage of this design is the increased friction between the tool and die and the resulting faster rotor wear. The construction of a horizontal pelletising machine with gears is also known (**Figure 14c**). Such a pelleting machine comprises a pair of hollow cylinders with gearing around their perimeter. There are holes drilled in the gearing through which the material is extruded into the interior of the cylinders. Cutters located in the interior of the cylinders cut the compressed pellets. The disadvantage of this machine is the small number of teeth on the cylinders, as a result of which it achieves a low hourly rate of output. There is also a vertical pelleting machine with conical rollers and a flat die (**Figure 14d**). The disadvantage of the machine is the high and uneven wear on the rollers.

The percent share of pellets on the refined fuels market is increasing dramatically. Currently, pellets are made in a cylindrical shape, with diameters of 6–25 millimetres and lengths of pellets equal to two to five times the diameter (**Figure 15**).

Greater sized pellets are used only for combustion in large furnaces and cement-making. The greatest advantage of pellets is that, due to the size and homogeneity of the fuel, a fully automated combustion process is possible. The disadvantages of pellets are the high ratio of the fuel's surface and its volume. With this the burning of volatile materials even at low temperatures (above 200°C), the very rapid

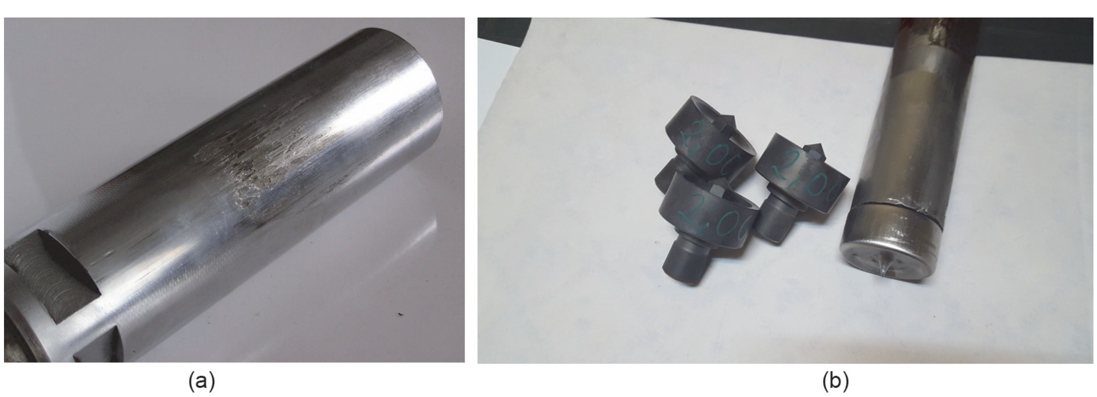


Figure 13.
Press piston. (a) Wearing of a press instrument and (b) stacked piston.

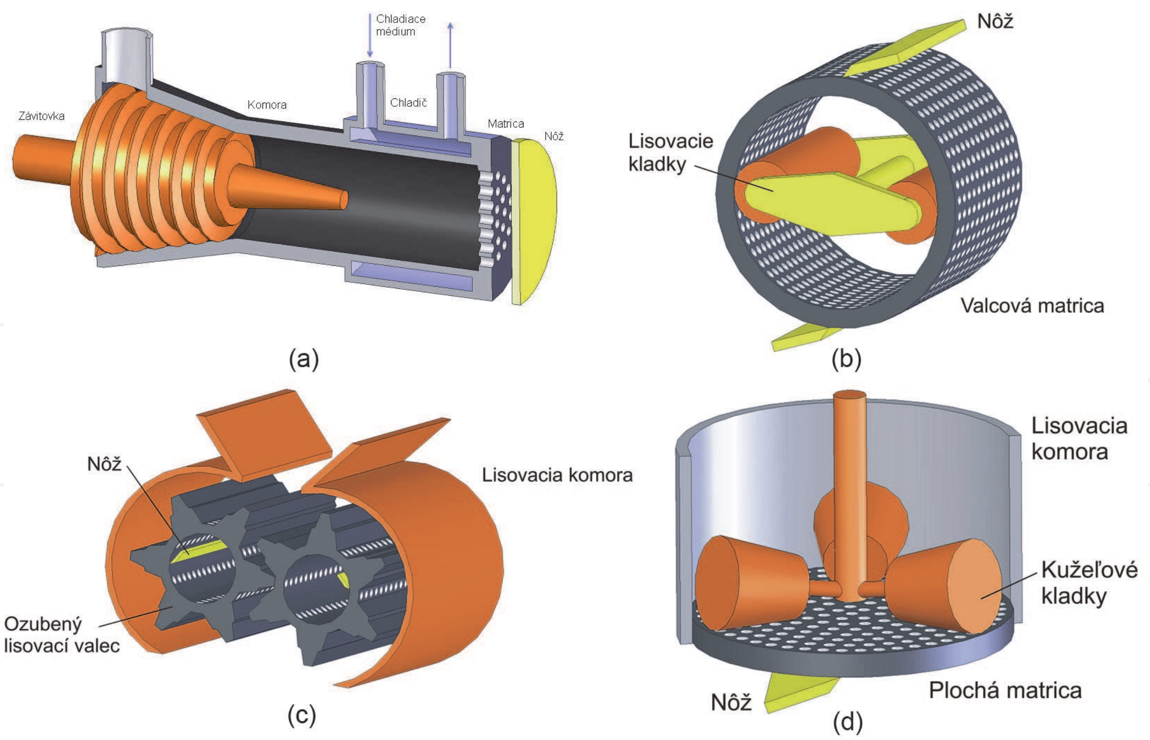


Figure 14.
Pelleting machine. (a) Horizontal screw, (b) cylindrical rollers and cylindrical die, (c) horizontal with gears and (d) vertical with conical rollers and a flat die.

Figure 15.
Pellets.

burning process (10–20 min) and also the high wear of the functioning parts (die, roller.) of the pelleting mills are related. Another disadvantage is the high demand associated with the production technology. The material must be of high quality, homogeneous, able to disintegrate into very small particles and have optimal humidity. The high investment costs associated with the manufacture of the fuel and with its usage are also disadvantageous. The input power for a unit of volume output "$P_{j,W}$" [W/(kg h^{-1})] is lower for pellet presses than for briquettes. This has to do with the fact that the ratio of the area of the press openings to the total area of the die on which the press pressure acts is less than 1. Only in special furnaces is it energy effective to recover pellets. The very high demands on investments also apply to the user of the fuel.

4.1 Pellet mill with spherical tool

As a consequence of the persistent problems with pelleting methods and with the design of pellet mills, there is an opening for the design of a pellet mill which would offer reduced energy costs and reduced wear of machine components [12]. The result of this effort is the pellet mill described further in the submitted invention. The first principle of the pellet mill was described in Slovak patent SK 286877 [13], titled as the "Method of pressing pellets of particulate organic and/or inorganic materials or raw mix and pellet press" (**Figure 16**).

Pellets compression is realised when the raw material with a required fraction and of maximum water content of 18% continues in to the open-work pressing chamber in the shape of the spatial effect of the V-ring.

The raw material is pulled in the work pressing chamber from the rotating screw and/or rotating balls. The rotating circular parts touch at the bottom. Open-work pressing chamber partially encloses a rotating spherical shape. After that the raw material is injected from the pressing chamber into the extrusion orifices or a whole die, from which mouldings emerge. Pellet mill consists of a hollow wedge-shaped body (1) with circular recesses for the wedge-shaped surface, wherein the wedge surface has a first and a second flange (2, 3). In the first flange (2) the first drive

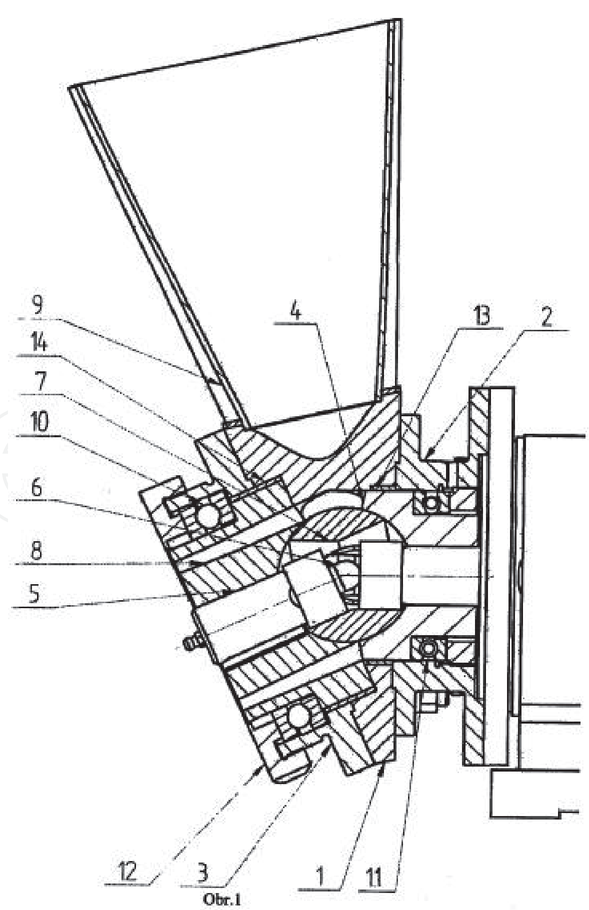


Figure 16.
Cut of the pelletizer PLG2010 [13]. 1 – Wedge body, 2 – first flange, 3 – second flange, 4 – first drive disk, 5 – second drive disk, 6 – the kinematics of the drive mechanism, 7 – ball tool, 8 – die, 9 – hopper, 10 – axial bearing, 11 – axial bearing, 12 – die, 13 – sliding sleeve, 14 – sliding sleeve.

plate is concentrically and rotatable mounted (4), which extends its face into a solid circle of the wedge surface of the wedge hollow body (1). The inner faces of the first drive plate (4) and the second disc (5) have a spherical recess which is fitted with a ball (7), the radius of which is equal to the radius of the spherical recesses. The second roll (5) comprises a concentric circle on the through-holes (8) by its width; the axial deflection of the first drive plate (5), together with a hollow wedge-shaped body (1) and the ball (7), is working in the pressing chamber of the spatial shape of the V-ring.

The main advantage of this idea is that press tool has got spherical shapes and contact between tool and die is theoretical in the point. Due to the small contact area (point), we obtained a small force-requiring pressing power, and we do not need the big motor power. For the construction of the mill, it is characteristic that the die is powered and its drive comes from the drive body. The spherical tool is hollow, and the kinetics of the drive mechanism for the die passes through the spherical tool. This can be achieved by coupling the die with a drive through the cardan joint or pivot joint. An important parameter of the mill is an axial shift of the drive's face from the die's face. In this design, the peripheral speed of the spherical tool during each revolution is not constant. This results in the uneven wear of the working tools, reducing the output efficiency of the mill and increasing the cost of the mill's repair due to the need of replacing the damaged parts.

To achieve a synchronised generating pressing space, it was considered appropriate to use the principle of cardan. The concept of the machine consists of two cylinders with axial and rotary roller with independent various axes of rotation, between which one ball was placed. These three members create the press chamber by the relative motion, in which the material is entrained and compressed on the principle of continuous changes in the geometry of the press jacket and thus its volume (**Figure 17**).

The first functional model was prepared at our institute in 2010 [13]. This machine was used to verify the proposed principles. The device has a ball diameter of 71.6 mm, a motor of 1 kW, an output per hour of 40–50 kg/h and a number of holes in a die of 21 x Ø 7 mm and belongs to the group of small pelleting presses. The production of individual parts of the pellet press is not technologically and financially very demanding, which can be an affordable solution of the pellet press with a high degree of financial recovery of biomass waste. The accuracy of the proposed structure was verified by testing the functional and technical parameters such as verification of pull material into the pressing chamber, the ability of pelleting, the performance verification and the validation of the quality of compression mouldings. The tests included pressed materials such as wood waste, MDF waste, straw, cecina, peat, black alluvial areas, wastewater treatment plant waste - sludge, rape, California earthworm humus, rat poisoning, cocoa waste. This principle was patented by the authors in 2006 and subsequently the basis for modification of the design and production of the pellet press prototype was created.

There was a development of a new prototype machine launched in 2011. The design of the machine has been subjected to a comprehensive analysis of the deficiencies of the machine. The analysis concerned the construction of the machine but also investigated the tribology machine and damage to various parts of the former variants of the machine. The current version of the ball pelleting mill is shown in **Figure 18**.

The current version of the machine has some fundamental changes from previous variants, which are its main advantages. The concept of the machine allows easy and rapid exchange of press tools, depending on the type of the pressed material. The tests of various materials using different matrices can be tried.

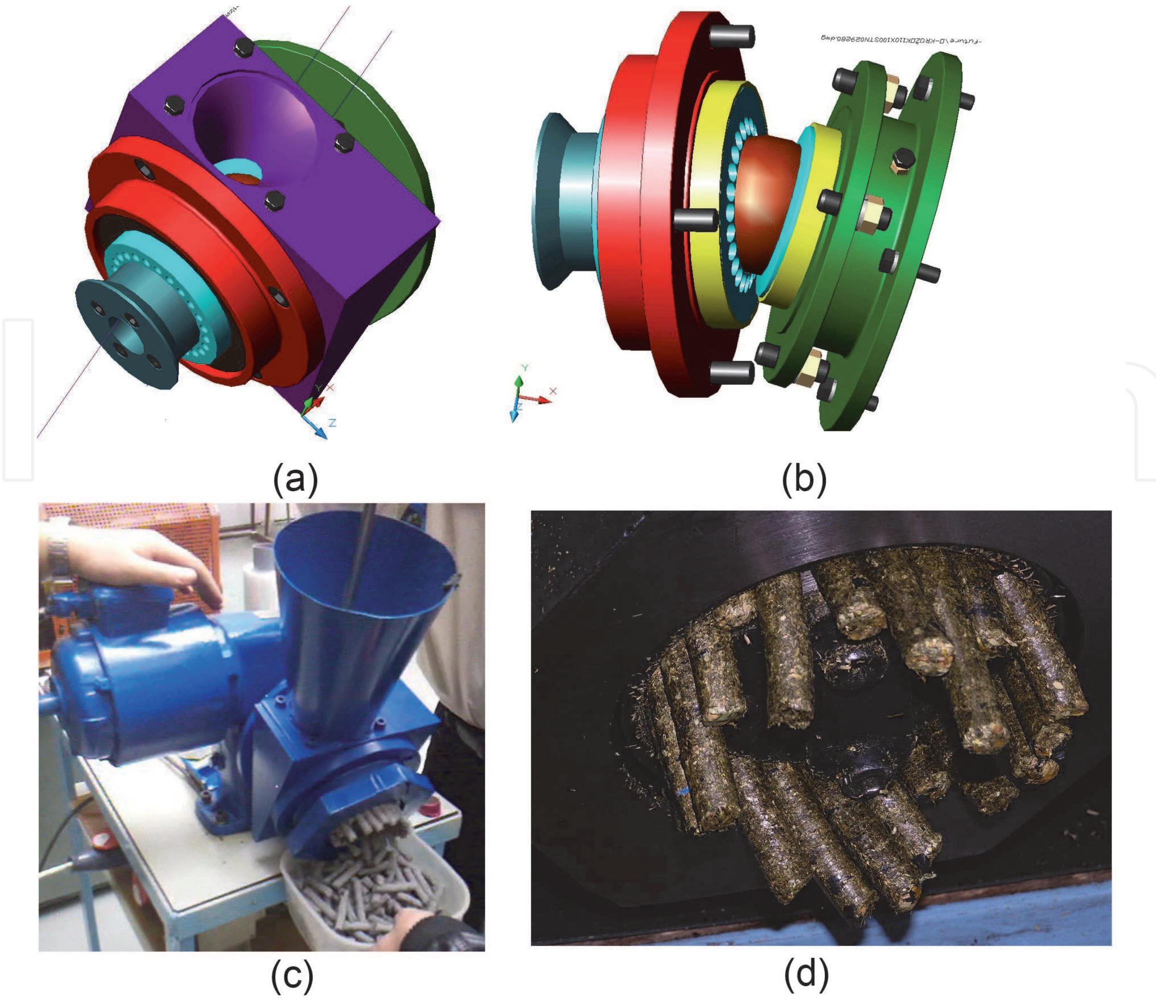


Figure 17.
The first concept of the pressing principle. (a) View of the 3D model, (b) view of the pressing chamber, (c) functional model and (d) view of the die.

It is also possible to change the length of the pressing channel by means of calibration matrices that can be added or removed. We can say that after the application is the modularity of the machine at a higher level which provides a simpler implementation of experiments. The final drive solution is modular machine tools on the same basic platform. Drive instruments may be by means of universal joints and friction bonds formed between tools using tools or gear using punch with projections. Each of these solutions helps to better ensure the transfer of torque from the stamp to the die.

There are ongoing long-term pilot plant verification test pelleting various types of materials. In the picture we can see pelleting paper sludge [14]. During the tests, the machine demonstrates compliance with the required operating parameters, quality and process reliability. Today, we are prepared to introduce its mobile technology lines for pellet horse dung. This line was started to be produced with the company IMC Slovakia, Banská Bystrica [1].

In the 2013, we prepared absolutely a new design of the modular pellet mills [14]. A pellet mill according to the invention will now be described in more detail in the sections with the accompanying drawings, where **Figure 19a** shows the mill mechanism with a freely placed spherical tool in a side cross-section. **Figure 19b** shows the mill mechanism with a hemispherical tool in a side cross-section, forming one block with the punch. **Figure 19c** is a side cross-section of the mill mechanism with a self-driven spherical tool.

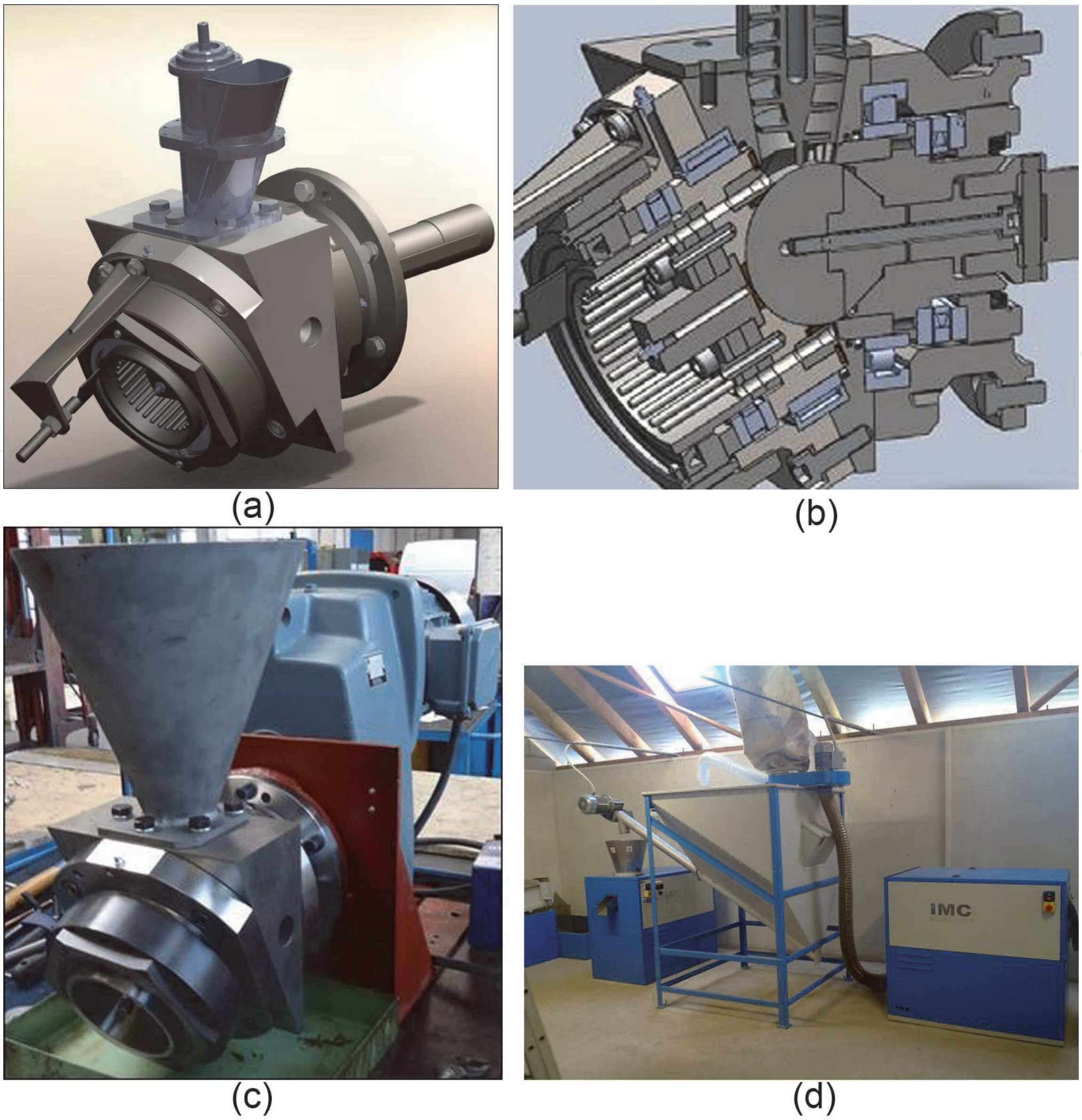


Figure 18.
Innovative spherical pellet machine (V4). (a) 3D model, (b) cut of the chamber, (c) prototype, variant V4 and (d) pellet in IMC line.

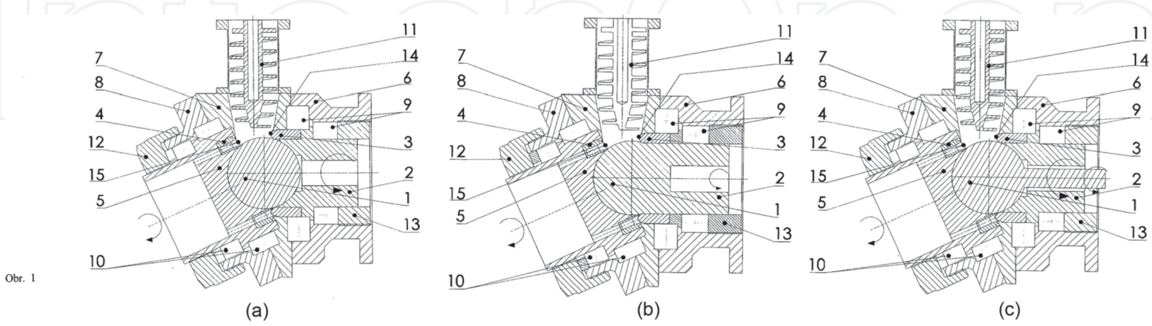


Figure 19.
Innovative spherical pellet machine [14]. (a) with loose ball, (b) mill with a spherical member associated with punch and (c) with a self-driven balls.

5. Compacting machine for produce new shape biofuels

The concept of an ideal briquette arose from a comparison of the properties, advantages and disadvantages of the briquettes of individual technologies (**Figure 20**). It is an attempt to create a briquette that would contain the advantages

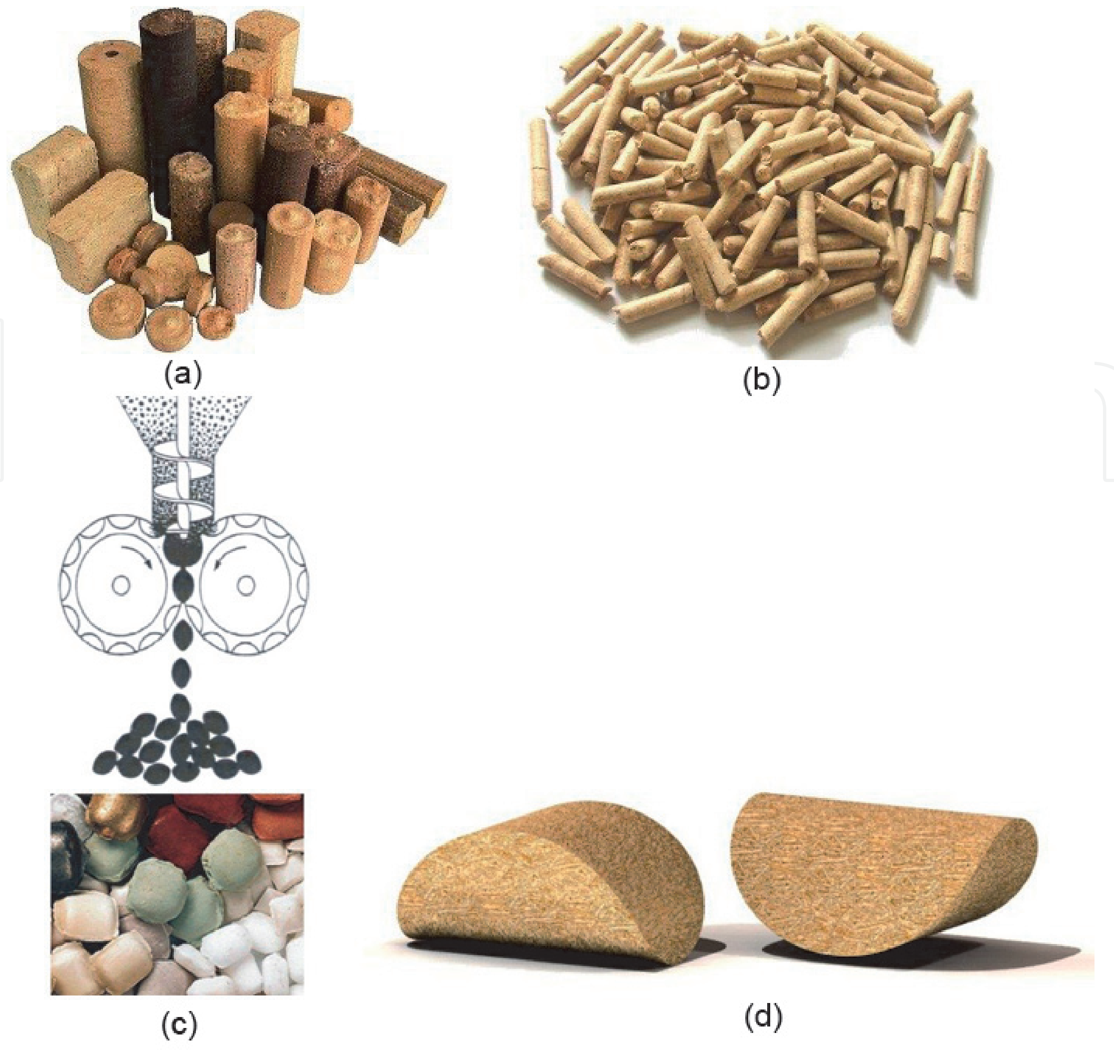


Figure 20.
Scheme of idealised granule [4]. (a) Briquetting, (b) pelleting, (c) compacting and (d) briquettes were valuated by: briquette burning process, automatization of combustion process, machine wear, and briquette storage and transit.

of pelleting, briquetting and compacting while at the same time eliminating the disadvantages of the individual technologies. A new briquette shape would be produced on the principle of compacting, which means being pressed between two rollers. In contrast with compacting, the new technology would have to allow for the briquette to be for a certain time under pressure, by which cooling would occur, as is common in pelleting and briquetting. Therefore, there arose the need to design a shape and, following that, a compactor machine that would manage to make newly shaped briquettes.

On the basis of the input requirements and later theoretic analysis, we created the almost-round briquette, which is designed as the intersection of two half cylinders each rotated through 90° and is suitable for automatic feeding. With such a briquette, it is possible to regulate the ratio of the surface to its volume. The edges at the intersection of the two cylinders allow optimal lighting of the briquette [15].

5.1 Kinematic

After the design of a suitable shape for the briquette, we continued with a combination of potential solutions and a design of a kinematic compactor that would be capable of producing such briquettes. The result of this combination was a proposal for a completely new principle "ring compaction machine". In 2012, we received a granted patent SK 287505 [16] for the stated principle. The invention belongs to the area of compaction of bulk organic and inorganic materials (**Figure 21**).

The essence of the new patented solution is a large ring (1) which has in its interior circumference a great number of slots (3) in semi-cylindrical shape whose axes are parallel with the axis of rotation of the ring. The compression instrument is also a disc (4), which on its outside circumference has a cylinder slot (5), which fits into the slots of the ring (1) and is turned 90° from the slots of the ring (1). So both the ring and the compression disc have independent movement. The hold-off stage under the pressure at which the moulds are cooled is ensured by the calibration struts (6). In stage A, there takes place the filling of the press chambers that appear during rotation, in stage B compression, in stage C partial expansion and finally in stage D gradual cooling of the briquette under pressure and its calibration. The effect of cooling of the binder brings the binder (lignin) from the plastic to the firm state, by which the briquette achieves the required rigidity [17].

5.2 Design and production of functional model

A further task arising out of the work on the overall project was designing the compacting machine itself. At the beginning, an analysis of kinematics of motions and the combination of possible structural solutions was carried out. In order to achieve the required briquette shape and kinematics of motions, we designed a functional model of the compacting machine as shown in **Figure 22**.

Design of force elements was based on a theoretical analysis of the forces calculated during the densification process. On the basis of such forces, calculations were made for the required input of the main drive, input of the drive of the compacting disc and the drive of the feeding screw. The final task in this part of the project was to prepare the manufacturing sketches and the final manufacture of the functional model (**Figure 22**). In this part of the task, two basic types of testing were

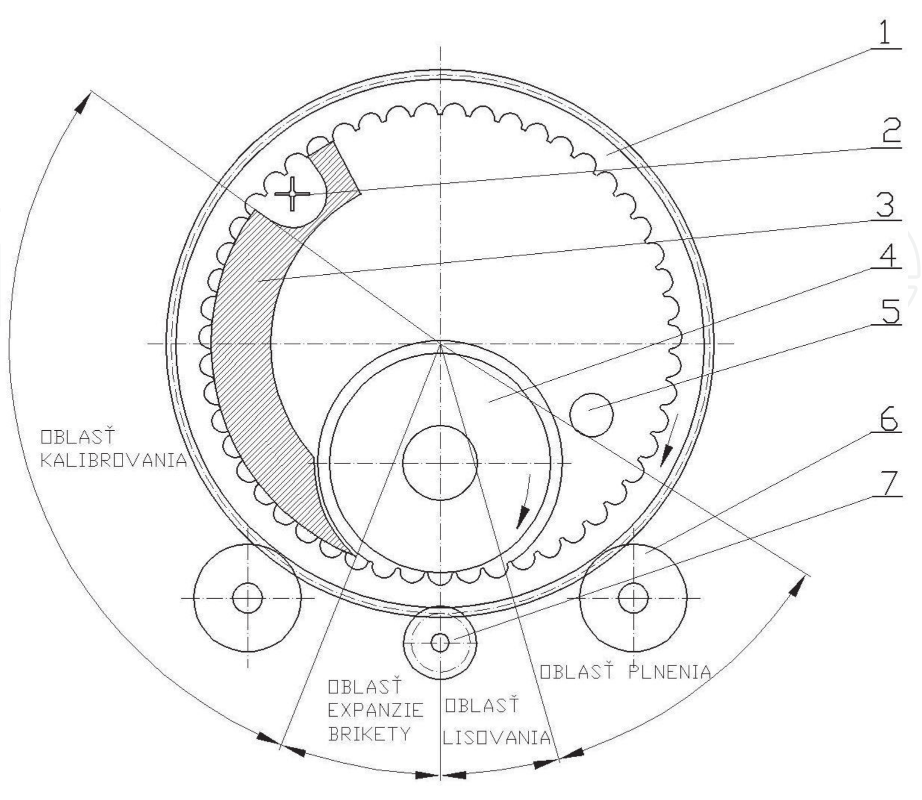


Figure 21.
Principle arrangement of annual compacting machine with internal pressing disc [16].

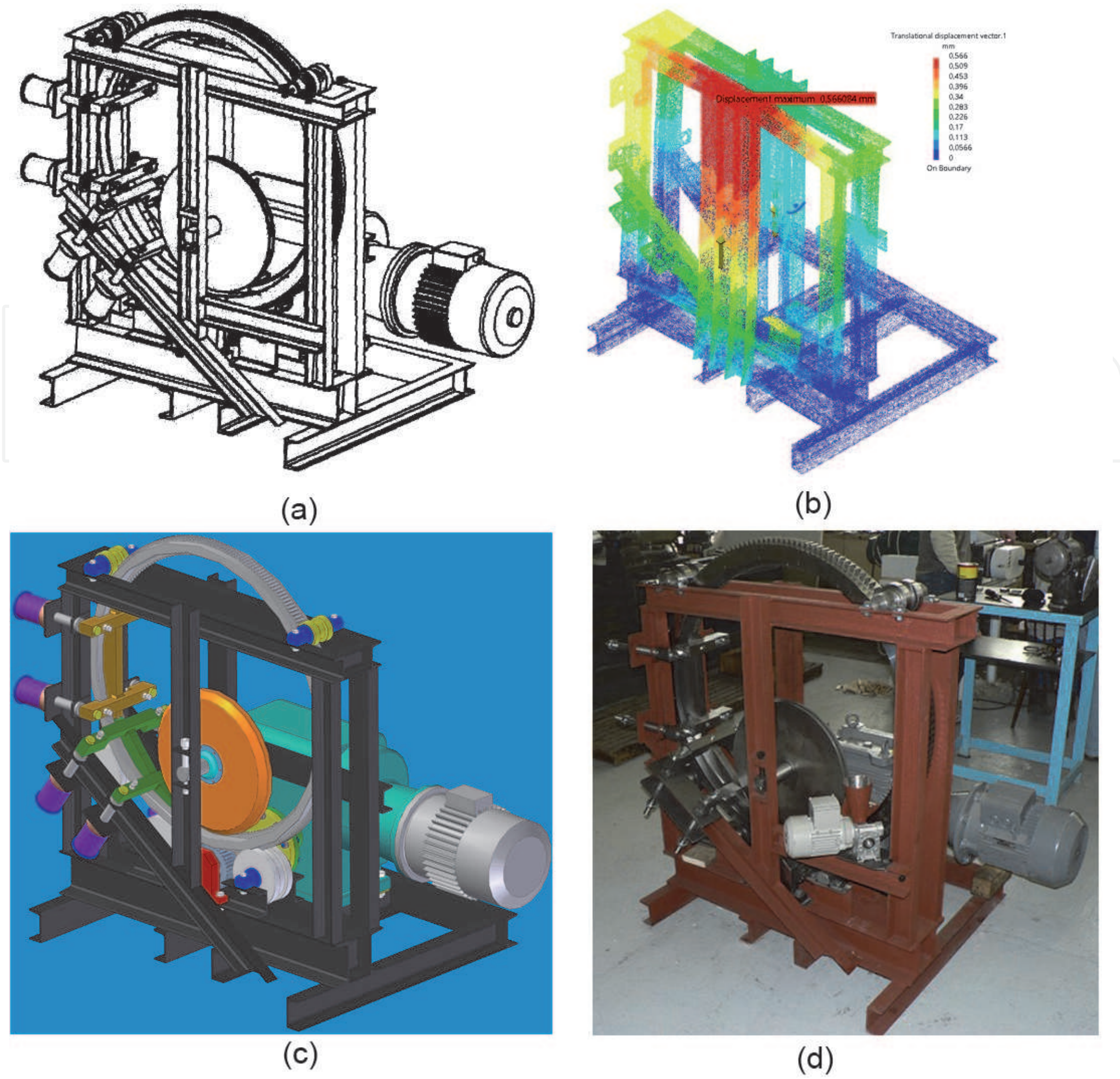


Figure 22.
Design of the ring compacting press. (a) Axonometric view, (b) FEM analysis, (c) 3D model and (d) function model.

performed on the functional model. The objective of the first set of measurements was to determine the required density of a briquette on the functional model. The second very important task in this experiment was to determine the maximum pressing force for the set density of the briquette.

6. Inverted kinematics

The subject of the solved project is the development and optimization of a new progressive, patent-protected construction of the inverted kinematics of a compaction screw briquetting press. There is the justified assumption that the solved construction would remove the stated faults.

The essence of the proposed solution of the compacting machine with “inverted kinematics” is that the rotational part of the machine is a body in which the screw is firmly mounted and in the centre of the rotational drum is a fixed non-rotating mandrel. So the rotational action is not performed by the press but a pressing chamber whose important part is the screw [18]. And on the other hand, the compacting instrument which in this case we call the mandrel is firmly held in the machine’s frame and performs no movement.

The variable construction of the press with a rotational pressing chamber and a stationary instrument according to UV 7380 (**Figure 23**) is made up of a cylindrical or conical pressing chamber (1) with a pivotal bearing in its axial axle; on the inside the covering of which is a firmly held open orthogonal or clinogonnal helix (2) with a progressive or constant incline. In the axis of the cylindrical or conical pressing chamber (1), a cylindrical or conical stationary instrument (4) is firmly held in the frame (3). The pressing chamber (1) the drive mechanism (5) is connected with the moving unit (6) either directly or through a gearbox.

A compaction machine with inverted kinematics is made up of three main constructional sections—the pressing chamber, the rotating screw firmly connected with the rotating chamber, and the fixed pressing instrument, the mandrel. Each of the three main construction elements can be in different versions. In the case of the pressing chamber, this could be a cylindrical (**Figure 23a**) or conical shape (**Figure 23c**) with a diminishing cone diameter in the flow direction of the compacted material. The screw is prepared either with progressive inclination (**Figure 23a**) or with constant inclination (**Figure 23b** and **c**), and the pressing instrument is manufactured like the pressing chamber, either in conical or cylindrical shape (**Figure 23a** and **c**) or with conical shape (**Figure 23b**). The difference is that in the case of the conical version, the cone's diameter will increase in the direction of the material flow.

The proposed possibilities allow the creation of eight basic solution combinations for the compacting inverted kinematic machine.

The inverted kinematic compacting machine brings along a number of advantages [19]:

- Low energy demand due to the rotating cover. For rotations on a larger diameter, the lower torque is sufficient for producing pressing power equally great to in the case of a conventional apparatus.

- The simpler constructional solution for cooling or heating the pressing machine thanks to its rigid unmoving mounting.

- The construction eliminates the wearing of the front parts of the screws more than with the classical design. In the proposed solution, the tip of the stationary instrument is not moulded, does not turn and is located in the phase of the process which could be called calibrating/compacting. The tip just defines the space and the material simply bypasses it.

- The bearings on which the rotary compression chamber is mounted are not axially loaded because the force acts in a critically small diameter.

In line with industrial model SK 7380, it is possible to power the inverted kinematic compacting machine in a number of ways:

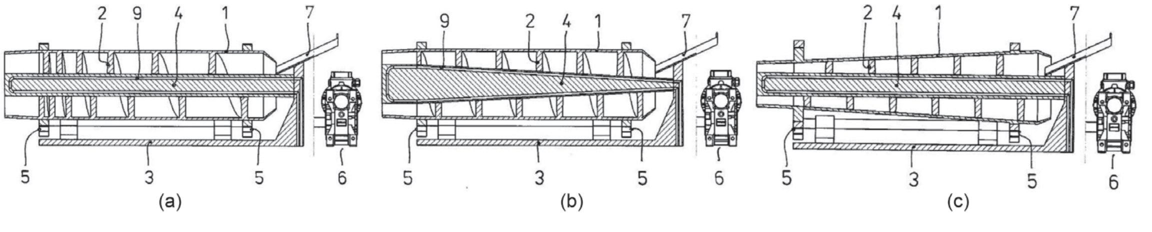


Figure 23.
Possible combinations of the proposed patent solution [18]. (a) Cylindrical body, progressive ascension of the screw, cylindrical mandrel, (b) cylindrical body, constant ascension of the screw, conical mandrel and (c) conical body, constant pitch of the screw, cylindrical mandrel.

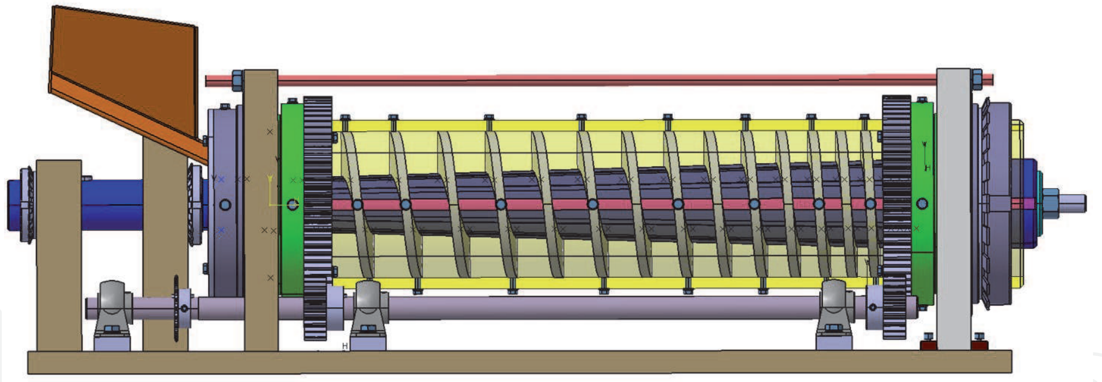


Figure 24.
New original design of the screw briquetting press.

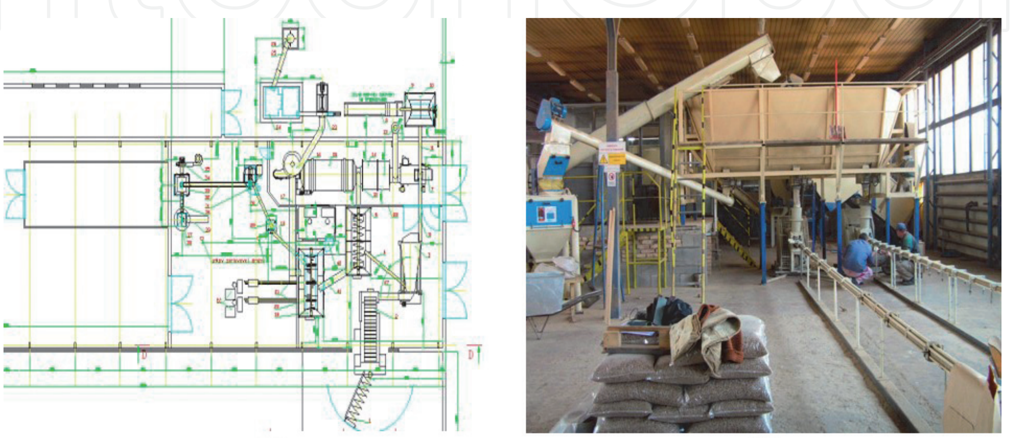
- The machine drive by means of a gearbox can be worked out in two methods. The first method, where the axle of the drive shaft is identical or parallel to the axis of the drive shaft, is called direct drive through the gearbox. The second method, where the axle of the drive shaft is perpendicular to the drive shaft axle, is referred to as cranked drive through the gearbox.

- Machine drive through chain or belt drive. In this method, the torque contribution is very advantageous because the connection element, be it belt or chain, takes on the role of a safety element.

The various combinations of the make-up of the briquetting press and its drive methods offer sufficiently varied opportunities for research, development and selection of the optimal solution. In **Figure 24**, a 3D model is shown [20].

7. Design of the briquetting and pelleting lines

Until now we have carried out projects on 51 lines for briquetting wood waste. Within this number there are nine installations in Slovakia, two in Estonia and one each in the Czech Republic and Hungary [21]. Those in Slovakia include lines for the LandR company in Pezinok, IMEKO Malacky, Excellent Bratislava, Kéri Trnava, NORBA Prievidza, Defektospol Údavské, Obecný podnik Lehota pod Vtáčnikom, Colorspol Novoť, Ekomix-Natúrprodukt Vrbové and JUGA Lučenec (**Figure 25**).



(a) (b)

Figure 25.
Combined line for briquette and pellet production for JUGA. (a) Layout of machines and (b) real view of the line.

In Estonia we designed two lines in Tabasalu for the KRK Moigu company, in the Czech Republic for the Dřevoterm firm in Náchod and in Hungary for the GUEM company in Salgotarjan.

The implemented projects show the positive contribution brought about by the original resolutions for compacting machines.

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