EFFICIENT PELLET MILL FOR WOOD. Part 2.

Pelletizing physics, thermal calculation, roller cooling, water and steam addition number of press-rollers and vibration

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The wood pelletizing process depends on a complex of factors, such as raw material parameters (species, moisture, particle size and shape), or technological and machine aspects (drive power, pellet diameter, additives, etc.). Because of this, it may seem that it is impossible to compare pellet mills of different models objectively. Nevertheless, there is an evaluation method by which machines can be compared in terms of specific productivity, as well as their energy efficiency and production potential.

A study executed by Danish scientists in 2009 examined the influence of temperature, moisture, species and additives on the force and energy of wood pelletizing. In particular, it showed:

- The pelletizing process consists of several phases, in which the forces of friction and viscous friction act.
- The pressure reaches 450 MPa in the working area, which corresponds to a water column of 45 km height (4...4.5 times the depth of Mariana Trench).
- The quality of the experimental pellets met the established requirements over the entire temperature range of experiments from 60 to 160°C.
- Specific energy costs have been determined in 50 kWh/t at 125°C (for pine), excluding die heating and drive efficiency.

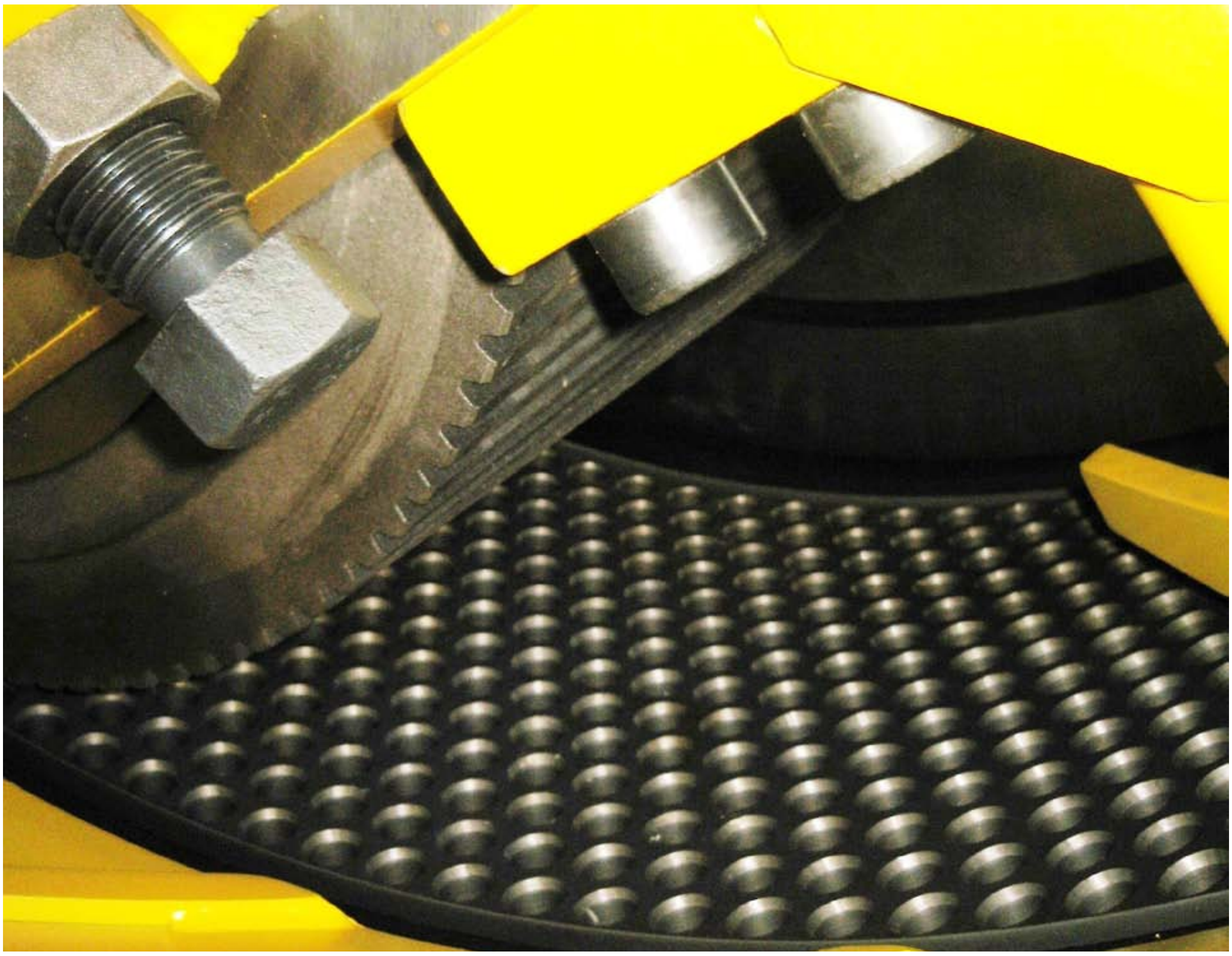

Fig.1. Working surfaces of the die and rollers

PELLETIZING PHYSICS

Based on the study, we can draw the following conclusions about the pelletizing physics:

The process takes place in a wide range of local pressures, since the process phases are carried out simultaneously and multi zonal. The maximum pressure is achievable in local areas with flat surfaces of a die adjacent to the flat surfaces of rollers, taking into account their real relief (Fig.1), namely the presence of holes, chamfers and grooves. But in these areas, the material flows in all available directions, envelops and glues particles that have not been destroyed.

Heating is secondary to pressure, it is an external effect of the work to overcome the friction forces. As known, the work of friction forces turns into heating.

The work of the friction forces is directly proportional to the pressure and the speed of the mutual movement of the process components (or square of the speed - depending on the viscosity in viscous friction). And both of them are determined by the linear speed of the relative movement of the die and rollers working surfaces and the rate of material feeding, which results in a certain material layer thickness (material volume) in working area.

The pelletizing process is usually thought of as lignin melting by heating and its adhesive action. But this view is limited: lignin and cellulose are polymers with amorphous-crystalline structures and consist of several blocks with different melting and flow temperatures. Both contain low-melting fractions with a flow temperature of approx. 30-40°C and below. But more importantly, the flow of all material occurs in the mass up to 100% in areas of high pressure. And although high-melting fractions quickly solidify after the pressure removed, they also assist in the process.

The pellets quality must be ensured by the die, namely the calibrating length of it press-channels, in which the necessary friction is created to compact the pellets in friction phase. That is, the calibrating part of the press-channels depends on the operating temperature: the higher the temperature, the longer the channels should be. The die inconformity with the thermal regime or the raw material is compensated by adhesive additives.

THERMAL CALCULATION

Since there is no external heating in the equipment, all process energy costs are provided by the drive and they are expressed in the generated heat. One can perform a thermal calculation that will show how much raw material may be heated to the operating temperature T_{work}.

It is known that pellet mills of various models show an operating temperature range from 85 to 145°C for pine. Take for comparison two models with polar T_{work} values.

Let's designate them as: LT – low temperature (T_{work} = 85-95°C, estimated 90°C) and
HT – high temperature (T_{work} up to ≈ 145°C, estimated 125°C, Fig.2)

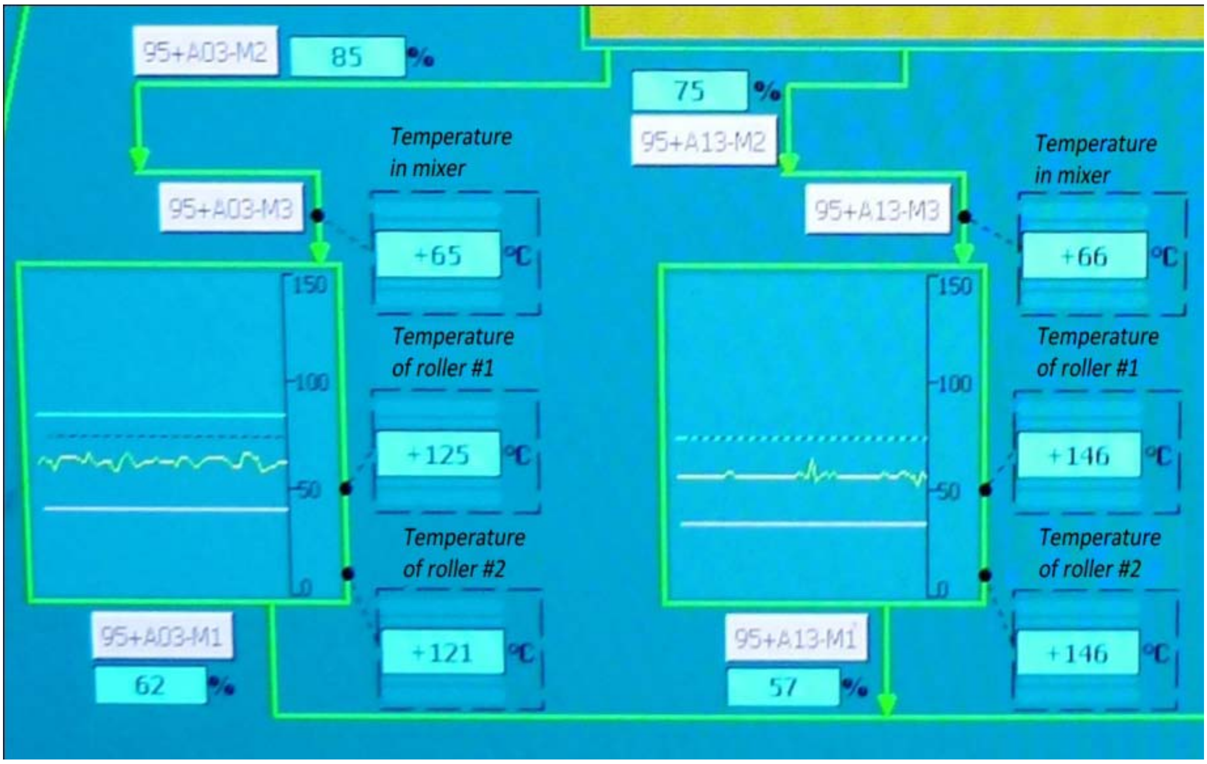

Fig.2. HT pelletizing parameters

Required initial data for calculation:

- the energy amount from the electric drive (motors of 355 kW are used for both models)
- final temperature of the process (estimated T_{work} for pine)
- initial temperature of the process
- specific heat capacities of the process components, namely
  - abs. dry wood and water as parts of the raw material
  - metal of die and rollers - machine parts directly involved in the process (Fig.3)

After, other equipment parts and the environment are heated from the named components.

It should be noted that the raw material enters the processing from the mixer, which is located above and heated from the working area. Let's assume the temperature in the mixer 65°C (Fig.2), it will be the initial temperature of the process.

In addition, the raw material drying occurs due to water evaporation. This event is expressed by the energy of the "water-steam" phase transition. In practice, the drying percentage inside the pellet mill is usually from 2%. Thus, a drying of 2.27% was taken in the calculation, through the result has fully matched with the experimental one. Namely, the calculation has showed the same specific energy costs of 50 kWh/t at similar experimental conditions for HT pellet mill (125°C) (Table 1).

Table 1. Results of thermal calculation for pellet mills of various models with 355 kW drive

Parameter	**LT**	**HT**	
	thermal calculation		experiment
Estimated T_{work}, °C	90	125	125
Productivity following specific energy costs excluding die heating of 50 kWh/t, t/h	–	7,1	7,1
Productivity following specific energy costs including die heating, t/h	12,0	6,8	–

In practice, the drive efficiency and a number of other factors should be taken into account: the load factor LF, which shows how the machine uses the installed engine power, the roller cooling (for HT model), water or steam addition (Table 2).

LF has specific sense. Basically the smoothness of the machine depends on its design, and more precisely on the number of rollers, which will be shown below. But during operation smoothness is ensured by LF, which must be lower the level, when vibrations may occur. For this analysis, we will take LF = 0.6 as recommended for HT model.

Table 2. Performance and energy efficiency

Parameter	**LT**	**HT**
Estimated T_{work}, °C	90	125
Thermal productivity with LF = 0.6, t/h	7,17	4,07
Engine efficiency	97,1%	97,1%
Transmission efficiency	91%	98,5%
Transmission type	double belt	gear
Productivity on rollers TOTAL, t/h	**6,34**	**3,89**
Roller cooling efficiency (at 35°C)	–	105,81%
Productivity on rollers with roller cooling, t/h	**–**	**4,12**
Specific energy costs on rollers, kW*h/t	33,6	51,8
Efficiency on rollers	88%	57%
Reduced coefficient of energy efficiency	**1,54**	**1**

ROLLER COOLING OF HT PELLET MILL AND ITS EFFICIENCY

Elevated temperature is detrimental to both the process and the machine. The main sense of cooling is to improve the operating conditions of the equipment: to reduce excessive wear of moving parts and consumption of roller grease. The nature of cooling there is in transfer of some excess heat from the working area to the refrigerator, while the surplus itself continues to be generated and accounts for more than 50% (Fig.3). Eventually this excess energy costs are wasted up.

In terms of thermal balance, there is also a positive effect. However, it is only 5.81% with a temperature drop by 35°C, following the thermal calculation. And this is without taking into account the energy costs of cooling system operating, the power of which is 1.8 kW. The source of the positive effect is the increase of the wood heat capacity with temperature increase, while the cooling system removes heat at a lower temperature. It is important to consider that the roller cooling efficiency is determined for the same HT pellet mill, but without the cooling system.

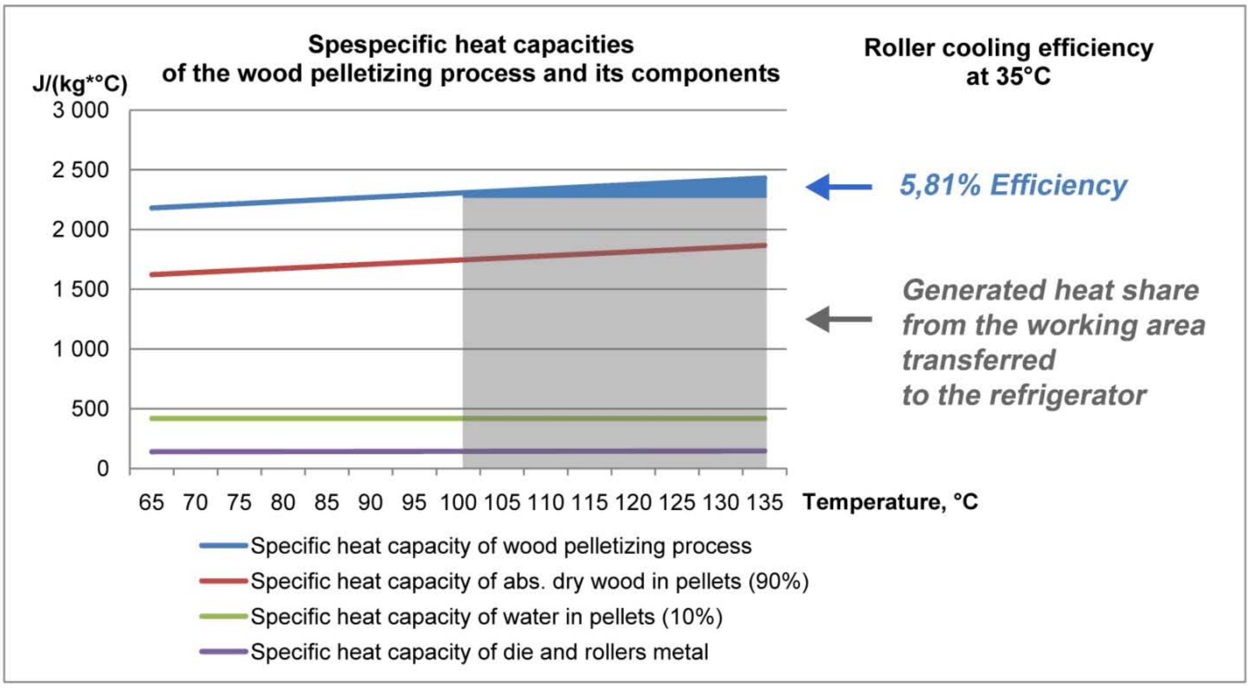

Fig.3. Specific heat capacity of wood pelletizing and roller cooling efficiency

WATER AND STEAM ADDITION EFFECT

According to the study, water acts as a lubricant: when the moisture content of the raw material increases, the pressing force decreases. However, additional energy is spent on heating water, and the drying percentage also increases. Regardless of the initial temperature of the added water, it is preheated in the mixer along with the raw material, and finally in the working area to the operating temperature T_{work}. Due to the high heat capacity of water, its influence on the thermal balance is quite significant.

Water adding in an amount of 5% reduces the productivity of the pellet mill (excluding drying): LT by 4.7%, HT by 6.2%.
Steam adding in the amount of 5%, contrary, increases the productivity of the pellet mill (excluding condensation): LT by 9-12%, HT by 5-7%. The range depends on the initial temperature of the steam 140 or 160°C.

While the water evaporation requires additional energy ("water - steam" transition), the steam condensation occurs with the return of this energy. However, it is not possible to estimate the steam loss and the condensation percentage. In practice, the increase in productivity reached 20% for an analogue of the LT machine with T_{work}=105°C , taking into account the exclusion the negative effect from the previous practice of water adding. In case of lower T_{work}, the positive effect of adding energy by steam can be greater.

NUMBER OF PRESS-ROLLERS AND VIBRATION

The impact of the rollers number on T_{work} and energy efficiency has already been shown in Part 1. There is another aspect of their direct impact on productivity.

Sometimes it is for wood pelletizing that three pressure rollers are used, and not two, as usual, in pellet mills with round die. How rational is this decision?

The typical design of such pellet mills is a fixed shaft, to which a plate with rollers is attached, and a rotor with the die rotates on this shaft (Fig.4,5).

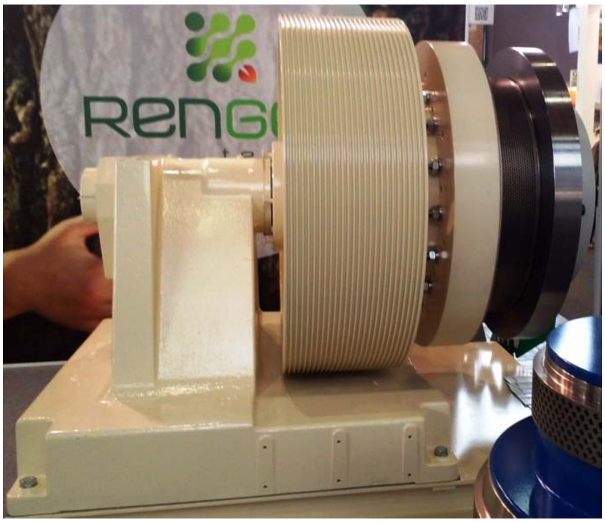

Fig.4. Example of a typical pellet mill design

Fig.5. Main shaft (from spare parts catalog)

If we consider the pressing scheme (Fig. 6), it is clearly seen that when the material is fed to the rollers, torques M and pressing forces F arise. They together induce bending moments of the main shaft.

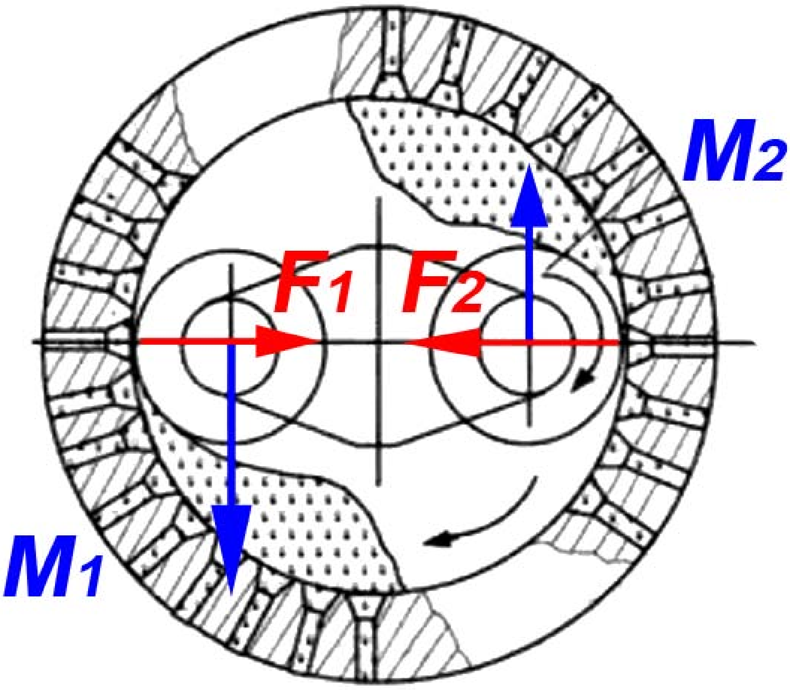

Fig.6. Pressing scheme. $F_1 \neq F_2$, $M_1 \neq M_2$

There can never be a situation when raw material is distributed in such way that these moments are equal. And any of their inequality causes cyclic mutual displacements of the die and rollers - vibrations. Two-roller systems are tended to vibrations and are particularly susceptible to working forces.

If in the plane passing through the axes of the rollers, the two-roller system is limited in displacement by the die, then in the perpendicular plane - only by the rigidity of the main shaft and the main bearing, which take on themselves the main loads. They are so large that can even cause a fracture of the main shaft (Fig.5) or die destruction.

Timely replacement of main bearings is critical to this system. The correct clearance setting between the die and rollers is equally important.

The three-roller systems feature (Fig.7) is the mutual balancing of bending forces and displacements from them in all directions, which mostly eliminates vibrations. Displacements are limited by the die, and with proper clearance setting, the main shaft and bearing are not overloaded. This significantly, at times, increases their service life.

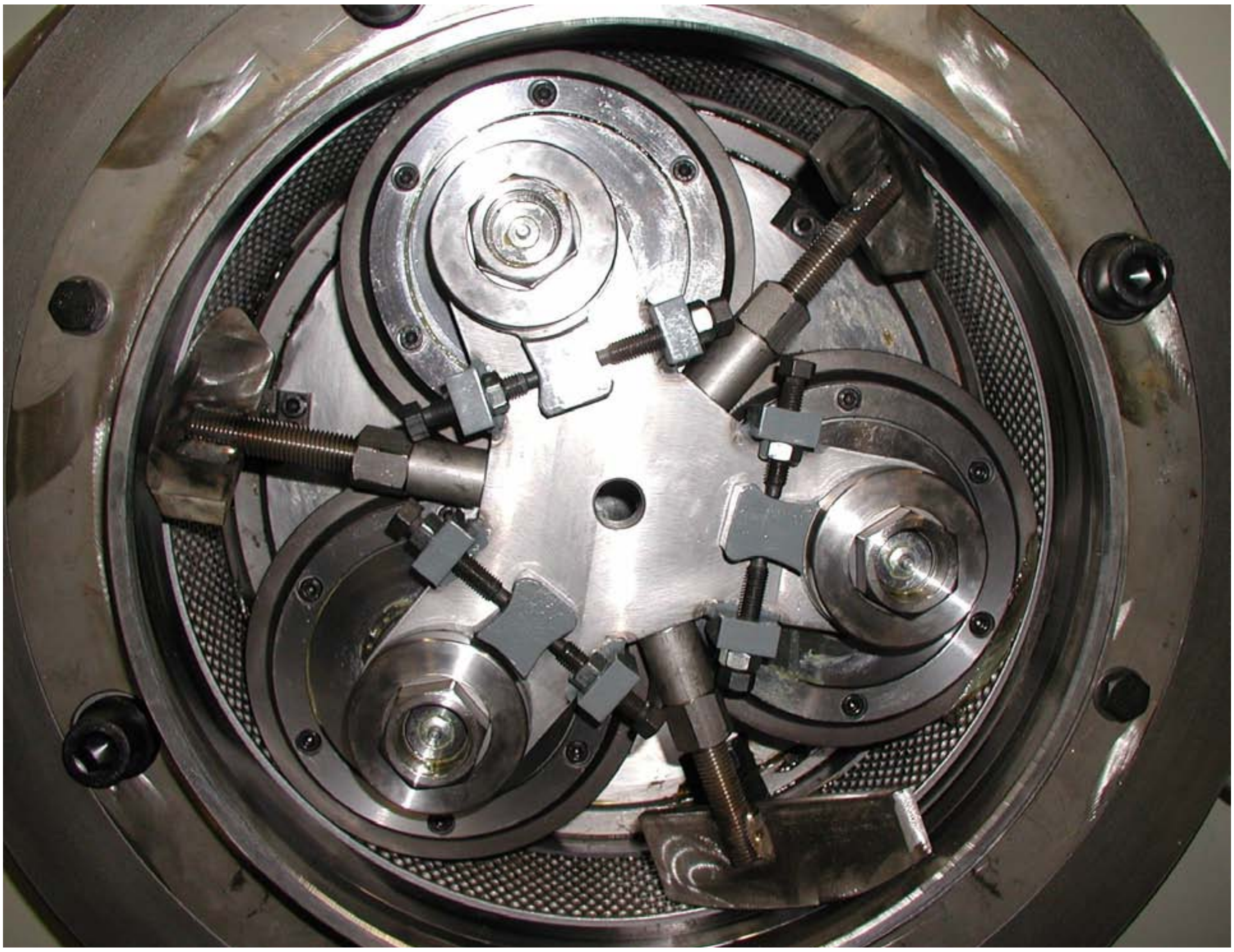

Fig. 7. Three-roller system

In addition, a special feature of some two-roller pellet mills is the elliptical die shape, and the clearance is set by one or more touches of the rollers during die rotation. It means the clearances are different in various points at the die circle.
The die of three-roller machines always has a round profile, the clearances are set by clearance gauge and therefore identical.

Vibrations of two-roller machines are restricted by varying of the workload LF.
Moreover, the raw material feeding may be designed with insufficient capacity, so LF should not reach 80% at 100% supply. In practice, LF is aimed even lower and 60% is recommended. On Fig.3 shows: LF is 62% at 85% feeding, for another machine 57% and 75%, respectively. That is, at 100% feeding LF will be ≤ 76%. Note that LF is not controlled directly, but by feed rate.

For three-roller machines the opposite is true: the LF is able to set up to 100% directly, the raw material supply is regulated automatically, and the feeding power is over designed.

PELLET MILLS POTENTIAL

The operating parameters and production potential of pellet mills are determined by their design, which provides a specific temperature and smoothness of the process, and sometimes requires the setting of limits. For example, in an LT machine, the process temperature is self-limiting up to 105°C, while in a HT one, it can rise over allowable, so this machine needs in automatically controlled stop upon reaching 180°C.

In the long-term development context, the main direction that manufacturers are working is increasing of drive power. However, at present, the 355 kW drive power of HT machines is not fully utilized and with low efficiency.

The drive power growth is more promising for LT machine. Compound feed machines by 400 kW power are already in operation.
Another relevant way is to use the potential of a 355 kW drive by technologically providing of a permanent high LF, when the machine allows it, or by supplying external energy through steam.

These conclusions are verified by experiments, calculations and practical data of machine manufacturers and operators.
According to statistics, LT machine with 355 kW motor provides an average practical productivity for pine at least 4.5 t/h, which corresponds to 36 kilotons per year (8000 hours). For comparison, the annual productivity of HT machine is declared at 30 kilotons, which implies an average productivity 4 t/h at most (Table 3).

FEATURES OF THREE-ROLLER LT PELLET MILLS

- the possibility of vibrations is minimized, the use of drive power is not limited up to 100%
- the design allows to reduce the process speed and specific energy consumption
- roller cooling does not required
- the use of three rollers instead of two does not increase operation costs, since their wear depends on the amount of pellets produced by each roller

These factors, together with other design solutions, create a basis for increasing the specific productivity of pellet mills and maintenance costs reducing (Table 3).

Table 3. Service parameters of LT and HT pellet mills

Parameter	LT	HT
Number of press-rollers	3	2
Drive power, kW	355	355
Annual productivity (8000 hours), kiloton	≥ 36	≤ 30
Roller cooling	not required	desirable
Die and rollers change	electric hoist	hand winch or electric hoist (option)
Transmission type	double belt	gear
Climate requirements, °C min	no	+15
Gear oil change, h (volume, l)	no	2 000 (100 l)
Vibrations	no	yes
Replacement of bearings and belts (if any), h	≥ 25 000	6 000 main shaft bearings 10 000 gearbox bearings
Weight with engine and raw material feed, t	18,5	7,8