

Technical Solution of the Drive System for Mixing Dough Machine

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Abstract. In the conditions of the global economy, food industry products have a good share in international trade. It is primarily ready-made food products that are ready for use. The basic problem that needs to be solved is the safety and quality of food products. Machine “Planetary mixer” is used for mixing and preparing dough. From the aspect of optimal fulfilment of the working function of the preparing dough “Planetary mixer” has to fulfil the following conditions: - the complete space in which the dough is located must be treated equally with the mixer; - noise and vibration reduction should be ensured and appropriate precision positioning of the machinery's executive bodies; - a compact construction of the drive system is required with the optimum utilization of the available resources. In the paper is presented technical design solution of the drive system for machine based on the demands of regional medium size enterprise and therefore it is limited to the requirements of the investor. The final solution was achieved by using the modern methods of product development.

1 Introduction

Machines in the food industry have a great impact on the quality and safety of food. In this sense, the production of these machines must meet the criteria for the production of machines and equipment that include criteria for design solutions, criteria for applied materials and criteria for technical design standards. Special attention in the design solutions addresses the adequacy of cleaning and sanitation facilities and working conditions in extreme conditions (high or low temperature), etc.

Machine “Planetary mixer” is used for mixing and preparing dough. Planetary mixer PM 100 has a dough bowl with diameter of 500 mm, a volume of 100 liters, so that the minimum dough capacity can be 5 kg and maximum 65 kg. The power of the electric motors is $P = 4$ kW, with the speed $n_M = 1400$ min⁻¹. Speed control is performed via the frequency regulator. The dimensions of the machine are 700x1500x1100 mm and the total mass of the machine is 550 kg. Depending on the customer's needs, a number of execution tools - mixers (wire, spatula, hook) are delivered to the machine. The basis of the machine

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is a massive steel construction, which ensures stability in operation. In accordance with standards, the parts of the machine and the tools that are coming in contact with food are made of stainless steel.

2 Existing solution for machine power

Machine “Planetary mixer” consists of the following assemblies and components (Fig. 1).

- Stand, made of rectangular steel profiles of solid construction.
- Support structures made of steel sheets.
- Drive for lifting and lowering the dough bowl.
- Dough bowl holder.
- Electric motor that, together with a gear unit, forms a whole or a complete module.
- Chain transfer.
- Planetary gearbox with output shaft for fixing dough tools.
- Dashboard.
- Executive tool, dough mixer.
- Dough bowl.
- Dough bowl wheels for easy manipulation of the dough bowl in working conditions.

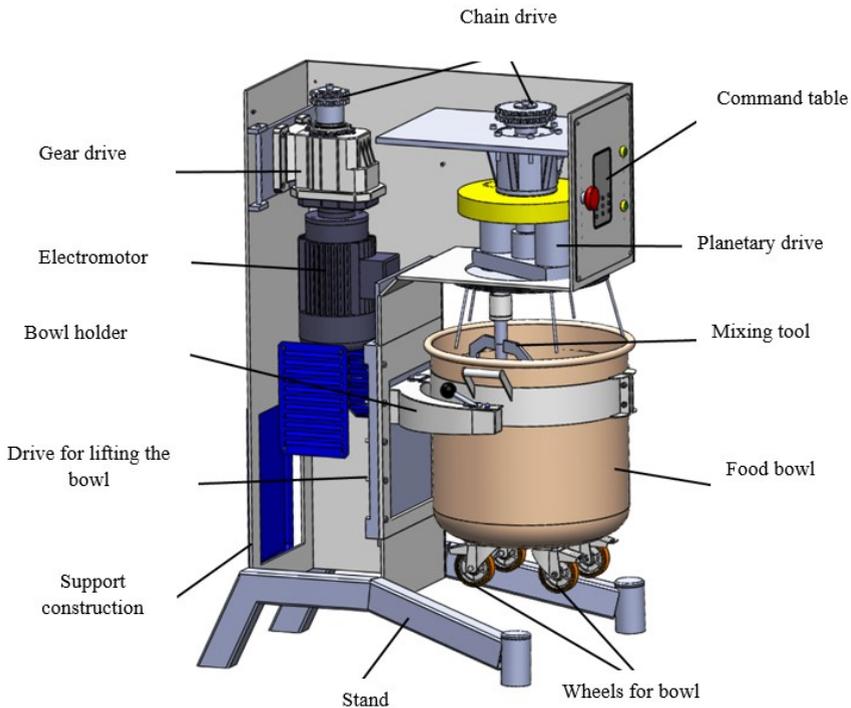
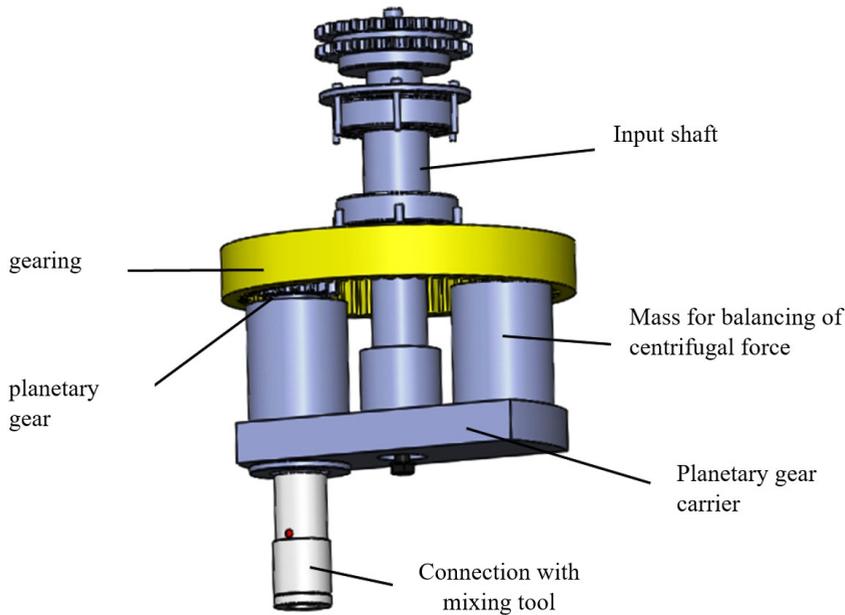


Fig. 1. Structure of machine “Planetary mixer” PM 100

Table 1. Technical data of drive system “Planetary mixer” PM 100

Assembly	Data	Unit	Dimension	Value
Electromotor	Power	P_M	kW	4
	Speed	n_M	min^{-1}	1400
Gear drive	Transmission ratio	i_{zp}	-	21.7
	Output speed	n_{izp}	min^{-1}	64.52
Chain transfer	Chain mark with rollers (two-sided)	12B-2 - DIN ISO 606:2012		
	Step chain	p	mm	19.05
	Number of teeth of a small chainwheel	z_{L1}	-	15
	Number of teeth of a big chainwheel	z_{L2}	-	24
	Transmission ratio	i_{LP}	-	1.6
	Output speed	n_{izp}	min^{-1}	40.32
Planetary transmission	The speed of the planetary gears	n_{upp}	min^{-1}	40,32
	Number of teeth of corrugated gear	z_3	-	113
	Number of teeth of planetary gear	z_2	-	21
	Number of teeth of central gear	z_1	-	71
	Module	m_n	mm	2,5
	Center distance	a_{pp}	mm	115
	Width of the gears	b	mm	40
	Planetary gears material	34CrMo4		
	Material of the corrugated gear	POM VDI 12545		

**Fig. 2.** Planetary gear drive

The planetary gearbox (Fig. 2) is a special construction, with only one planetary gear and no built-in central gear. On the opposite side there is a mass for balancing the centrifugal force. The torque is applied to the planetary gear carrier, which is connected with a fixed toothed wreath. At the same time, the planetary gear performs a complex movement around its own axis and the axis of the gearbox. For the shaft of the planetary gear, an executive mixing tool is directly connected. Thus the mixing tool of the test performs a complex movement turning around its own axis and around the axis of a crowned gear and in this way mix the dough over the entire volume of the dough bowl.

For the given data in Table 1, the calculation of the geometry and carrying capacity of the planetary gear according to DIN ISO 10823: 2006 was performed - Table 2.

The toothed wreath of the planetary gearbox is made of plastic Polyoxymethylen, which in technical literature and market is kept as an abbreviation of POM. It is a semi-crystalline thermoplastic mass produced by polymerization. It has a relatively low friction coefficient ($\mu_{zm} = 0.04 - 0.1$), which allows it to have low slip resistance and consequently reduced wear. It has a satisfactory stiffness, and its price is relatively low. However, these characteristics of POM are only available at low and medium operating temperatures.

The calculation of the capacity of the planetary gear in Table 2 shows that load carrying capacity is not satisfactory. This problem is related to the load carrying capacity of a crowned gear. The toothed wreath is in conjunction with the planetary gears made of heat-treatable steel 34CrMo4. The operating stress on the toothed flank is $\sigma_{Hw} = 80.83 \text{ N/mm}^2$, while the critical value is $\sigma_{HG} = 67.5 \text{ N/mm}^2$, so that the safety level $S_{Hw} = 0.84 < S_{Hmin} = 1$. The operating stress voltage of the foot of toothed gear is $\sigma_F = 115.65 \text{ N/mm}^2$, while the critical stress is $\sigma_{FG} = 77.2 \text{ N/mm}^2$. The safety level of the foot is therefore less than the permitted $S_F = 0.67 < S_{Fmin} = 1.4$, or it can withstand the maximum power $P_{OVmax} = 1.91 \text{ kW}$. Because of this, in the exploitation conditions, the toothed gear of the toothed cone of the planetary gear was damaged.

Table 2. Load carrying capacity of planetary gear of existing solution

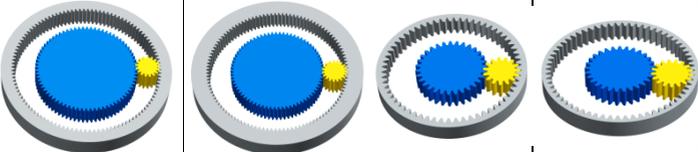
Data	Unit	Dimension	Value
Power	P	kW	4
Module	m_n	mm	2.5
Center distance	a	mm	115
Central gear (fictive)	z_1		71
Planetary gear	z_2		21
Corrugated gear	z_3		113
Input speed	n_{np}	min^{-1}	40.3
Output speed	n_{z2}	min^{-1}	217
Safety level of planetary gear	S_H		9.07
	S_F		2.76
Safety level of corrugated gear	S_H		0.84
	S_F		0.67
Maximal power	P_{max}	kW	1.91

3 Selection of variants of technical design solution

Since the standard gear and chain drive system of the propulsion system of the machine, the planetary mixer has a satisfactory load capacity, there will be no changes in the improvement of the technical design solution in that part. It is necessary to make improvements to the planet drive of the drive part. The reconstruction should be carried out so that the costs are minimal and that the machine's operational function is fully met. So the new solution of the planetary gearbox should be incorporated into the existing available space, which means that the axial distance of the gear unit remains the same $a = 115$ mm. In this sense, the carrying capacity of 4 possible variants of the gear unit was carried out, ie 2 variants with a module $m_n = 2.5$ mm, and two with a module $m_n = 5$ mm. Planetary gear material is the same for all variants. The planetary gearbox is made of heat-treated steel 34CrMo4 and a toothed plastic material POM (Polyoxymethylen). Lubrication of the gear is carried out by grease.

With the previous harmonization of the technical design parameters of the planetary gearbox (central distance, number of teeth, etc.), the geometry and loadability of all variants according to DIN ISO 10823: 2006 was carried out. The results of the calculations are shown in Table 3. The critical element of the gearbox from the aspect of load carrying capacity is the planetary gear made of plastic material.

Table 3. Variants of technical design solution for planetary transmission

Variant		1	2	3	4
Power P [kW]		4	4	4	4
Module m_n [mm]		2.5	2.5	5	5
Center distance a [mm]		115	115	115	115
Central gear z_1 [-]		75	73	31	29
Planetary gear z_2 [-]		17	19	15	17
Corrugated gear z_3 [-]		109	111	61	63
Input speed n_{np} [min^{-1}]		40.3	40.3	40.3	40.3
Output speed n_{z2} [min^{-1}]		259.39	236.44	164.89	150.35
Safety level of planetary gear	S_H [-]	7.81	8.51	11.20	12.33
	S_F [-]	2.76	2.81	5.12	5.01
Safety level of corrugated gear	S_H [-]	0.73	0.79	1.008	1.09
	S_F [-]	0.66	0.66	1.32	1.29
Maximal power P_{max} [kW]		1.9	1.88	3.78	3.68
Lubrication	Grease: Klübersynth PEG 46-1200				
Drawing					

Variants 1. The safety levels of flank and foot of planetary gear is much higher than the critical values, that is, the planetary gear has a satisfactory load carrying capacity. Safety level according to the criterion of endurance of the plastic gear is lower; $S_{Hw} = 0.73 < S_{Hmin}$

= 1. It does not satisfy any load capacity for both of the toothed crown of the toothed $S_F = 0.66 < S_{Fmin} = 1.4$. ie it can withstand the maximum power $P_{OVmax} = 1,9$ kW. The output speed, or the rotational speed of the mixing tool, is $n_{z1} = n_{z2} = 259.39$ min⁻¹.

Variant 2. Planetary gear has a satisfactory load carrying capacity. Not satisfying the safety level according to the criterion of the endurance of the plastic gearing flanks: $S_{Hw} = 0.79 < S_{Hmin} = 1$. It does not satisfy neither the load carrying capacity of foot for plastic gearing $S_F = 0.66 < S_{Fmin} = 1.4$. ie it can withstand the maximum power $P_{OVmax} = 1,88$ kW. The output speed, or the rotational speed of the mixing tool is $n_{z1} = n_{z2} = 236.44$ min⁻¹.

Variant 3. The planetary gear has a much higher load carrying capacity than required. The level of safety according to the criterion of endurance of the toothed flanks of plastic gear has a satisfactory load capacity: $S_{Hw} = 1.008 > S_{Hmin} = 1$. The safety level of load carrying capacity of foot is $S_F = 1.32 < S_{Fmin} = 1.4$. ie it can withstand the maximum power $P_{OVmax} = 3.78$ kW. The output speed, or the rotational speed of the mixing tool, is $n_{z1} = n_{z2} = 164.89$ min⁻¹.

Variant 4. The planetary gear has a much higher load carrying capacity than required. The level of safety according to the criterion of endurance of the toothed flanks for plastic gear: $S_{Hw} = 1.09 > S_{Hmin} = 1$. The level of safety for load carrying capacity of foot of plastic gear is $S_F = 1.29 < S_{Fmin} = 1.4$. ie it can withstand the maximum power $P_{OVmax} = 3.68$ kW. The output speed, or the rotation speed of the mixing tool, is $n_{z1} = n_{z2} = 150.35$ min⁻¹.

The further analysis carried out shows that the best variant is 3, because it can withstand the maximum power of $P_{max} = 3.78$ kW. The value indicated is slightly less than the required power $P = 4$ kW. However, it should be known that the calculation was carried out with an input power of $P = 4$ kW, while the actual power is less due to losses in the gear and chain. If we take the gear ratio of the gearing 0.95 and the chain 0.985, then the power transmitted by the planetary gear $P = 0.95 \times 0.985 \times 4 = 3.74$ kW is obtained. Accordingly, the load capacity of this variant fully meets the required exploitation conditions.

4 Improved solution for machine power

The selected variant of the planetary gearbox has been elaborated in detail. The planetary gearbox gets power over the input shaft and sprocket L_2 (Fig. 2). The power is transmitted to the planetary gear carrier, which is a connected with the drive input shaft of the gear unit with pin (Fig.3). The planetary gear is coupled with a corrugated gearing, which is immovable and firmly connected to the body of the machine planetary mixer.

Planetary gear carrier has a special technical design, thus executing a number of functions. The most important function is the transfer of power from the input shaft to the planetary gear, whereby it must provide adequate clutching of the planetary gear and the corrugated gearing. Additionally, the planetary gear bearing also provides the mounting of planetary gear, with 2 bearings - 6208-2RS1. On the opposite side of the planetary gear, mass is set to balance the centrifugal force.

For the outlet end of the planetary gear shaft, the mixing tool is assembled. The connection is made by a threaded connection, so it enables quick replacement of the tool - mixing dough.

The load carrying capacity of plastic gears is affected by deformations of the teeth connected primarily to bending the tooth itself. The calculation of plastic gears is made according to VDI 2736: 2013. According to the calculation, the bending of the toothed gearing is $f_a = 347$ μm, while the allowed value of the $f_{azul} = 350$ μm, so that the level of safety is $S_{del} = 1.007$.

Therefore, the load carrying capacity of the planetary gearbox fully meets the necessary exploitation conditions.

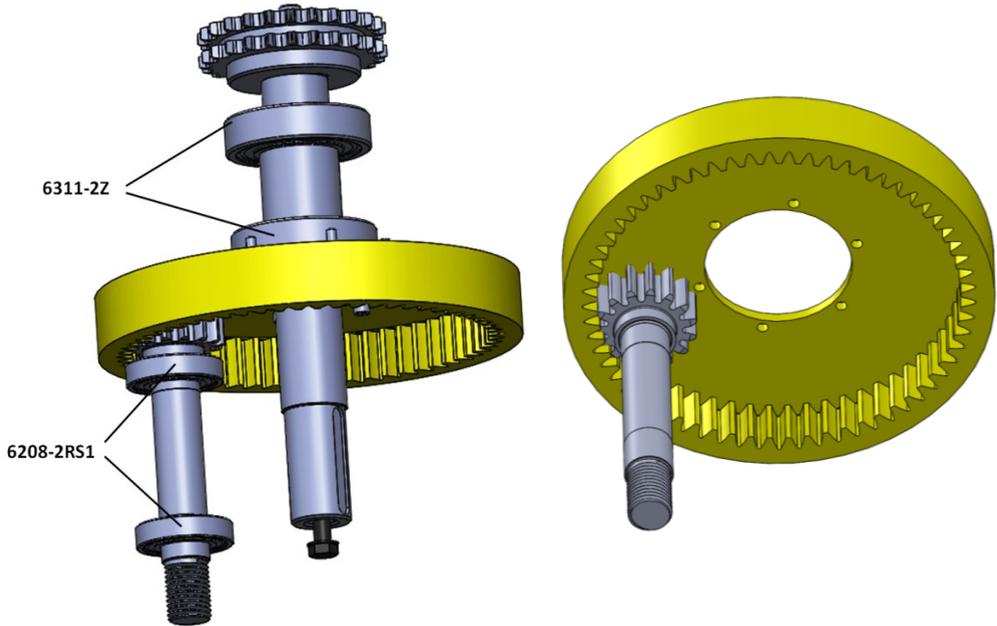


Fig. 3. Technical design solution for planetary gear drive

An important parameter of the drive is that the gearbox has adequate precision, which enables adequate precision of positioning, noise reduction and vibration and energy efficiency. This is taken into account here through the choice of quality of production and tolerance. For real conditions, the quality of planetary gear surfaces is 6, the quality of the plastic gearing 7 as well as the tolerance of the tooth thickness DIN 3967 cd 25 were adopted, so that the calculated values of the normal lateral gap $j_{nw} = 176 \mu\text{m}$, or the circular lateral gap $j_{rw} = 187 \mu\text{m}$ were obtained. This ensures sufficient precision of positioning, noise reduction and vibration as well as energy efficiency.

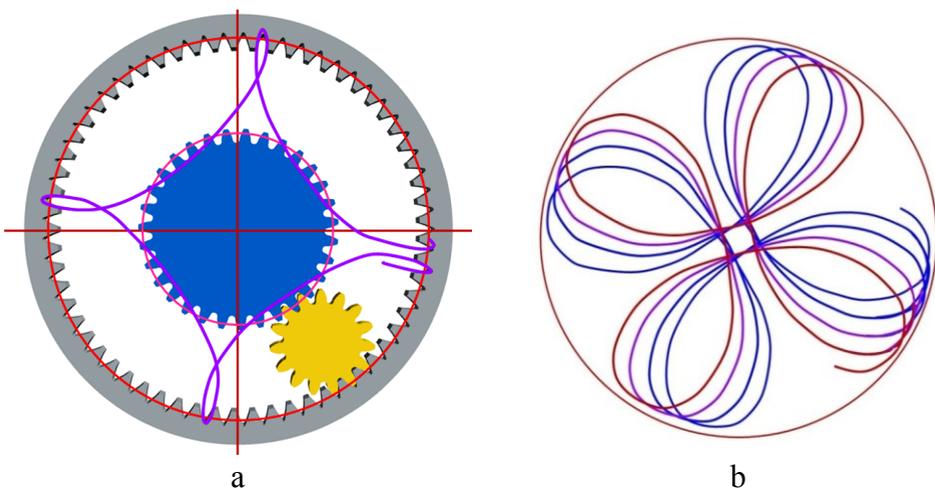


Fig. 4. Gears of planetary transmission (a) and trajectory of tool during work (b)

For optimum fulfillment of the working function of the machine “Planetary mixer” PM 100 it is necessary to have the entire space in which it is food located to be treated by the

executive body of the mixer evenly, which means that the mixer in the space occupies a different position at each turn. In this way, the homogeneous structure of the food in preparation phase is obtained and improves the quality of the food products.

This condition is ensured by an adequate choice of the number of teeth of the planetary gear and the plastic gearing. The number of teeth is thus chosen to come in contact with each other at all times, with different teeth of coupled gears (Fig. 4a). As a result, the dough mixing tool pathways always pass through the various points within the dough bowl working area. The trajectory of the movement of one operating edge of the tool in the working area of the dough bowl is shown in Fig. 4b. As the tool has multiple operating edges, it is ensured that the entire space in which food in preparation phase is treated is evenly.

5 Conclusion

Machine “Planetary mixer” is used for mixing and preparing dough. From the aspect of fulfilling the working function of the mixer for dough “Planetary mixer”, the role of noise, precision of movement and reliability in operation is essential.

Innovative technical design solution of the machine, shown in the paper, fulfills the conditions for optimum fulfillment of the operating function of the machine.

1. The complete space in which the food is located is uniformly treated by the executing tool of the mixer, in that the mixer in the space occupies a different position at each rotation.

2. By selecting appropriate parameters related to tolerances and making planetary gear elements, adequate accuracy of positioning, noise reduction and vibration and energy efficiency are ensured.

3. The adopted planetary gear solution is optimal from the aspect of the available resource of its vital elements. The level of safety of the toothed pair of planetary gear units (foot, flanks and deformation of the teeth) are within the allowed limits with the maximum use of the available load carrying capacity.

References

1. V. Miltenović, R. Mitrović, N. Burkardt, S. Stefanov, A. Miltenović, M., Banić, M. Tica, *Innovation management*, University of Nis, Faculty of Mechanical Engineering. (2017).
2. V. Miltenović, R. Marković, M. Tica, *Construction elements of mechanical engineering I-forms, calculation, application*, (University of E.Sarajevo, Faculty of Mechanical Engineering. 2018)
3. VDI 2736: 2013, Thermoplastische Zahnräder, Stirnradgetriebe, Tragfähigkeits-Berechnung, VDI Richtlinien, Duesseldorf (2014).
4. Report: Improving of technical design solution for drive system of mixing dough - planetary mixer - Project funded by Fund for Innovations of Republic of Serbia. ID 15. (2018).
5. I. Đekić, D., Marković: Influence of machine and equipment in agriculture and food industry on quality and safety of food, Journal “Poljoprivredna tehnika”, (2006)