Design of Q450 pellet molding machine and force analysis of its molding assembly based on Solidworks

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Abstract

Energy shortage and environmental pollution is a common serious problem restricting the development of world economy and the society. Biomass energy has become the fourth major energy resource after oil, coal, natural gas energy for the good properties of green, clean, and renewable. So it is important to research biomass energy technology to solve the energy crisis and environmental protection. The technology of biomass densification is a simple solution to make the biomass resource become low cost and high value. In this paper, a new kind of biomass pellet molding mechanism had been deeply studied, and the pellet molding machine, Q450, was designed by the CAD/CAE, Solidworks. The load conditions of three molding assemblies fixed inside the enclosure bodies had also been studied and analysed on the designed machine. Then a method, named FEA (Finite Element Analysis), was conducted to research the mechanical properties of enclosure assembly for the pellet machine in Simulation. Through analysis, the results were obtained that the maximum stress and displacement of enclosure bodies were separately 31.37Mpa and 7.583e^{-2}mm, which could provide the reliable strength and stiffness to the enclosure assembly. It convincingly ensured that Q450 pellet molding machine had enough reliability and security.

Keywords: pellet molding mechanism with plunger-roller ring die, Q450 pellet molding machine, enclosure assembly, strength and stiffness with FEA (Finite Element Analysis)

1 Introduction

At present, energy shortage and environmental pollution is a common serious problem restricting the development of world economy and the society. So it is necessary to develop renewable and green energy for the future, which means a low-carbon, sustainable and scientific development [1].

Bio-energy is a kind of energy carried in organic biological resources. The plants absorb solar energy through photosynthesis, convert CO_2 from the atmosphere into fixed organic compounds, and then the solar energy was turned into biomass energy. Compared with fossil fuels, the biomass burning pollutants such as SO_2, NO_x, and dust are much smaller attributed to its good character of low sulfur, nitrogen, high carbon activity, high volatile components and less ash content [2], which would obviously decrease phenomenon of air pollution and acid rain. So the bio-energy is a kind of green, clean and renewable energy.

Bio-energy is widely distributed with a good renewability and richness in natural resources, but the greatest inadequacy lies in the too scattered distribution, the low original density, and low energy density [3], which severely limits the direct utilization of biomass energy. So technologies should be developed to convert biomass into a new form fuel with high unit density and energy density.

Biomass densification is an important kind of technologies to achieve the target of the biomass resource utilization with low cost, high value and efficiency at present. The process of biomass densification is that compress biomass material physically at heating or room temperature into solid fuels shaped as columnar, cube, or pellet with high unit density after the pretreatment of drying, crushing and etc. [4]. The unit density and combustion value of the solid fuels after processing could respectively reach 0.8~1.4 t/m^3 and 16~21 MJ/kg in terms of kinds of biomass materials such as agricultural straws, grasses, woody resources like wood chips and sawdust. Combustion efficiency could be as high as 90%, and the conversion cost is low as well [5].

Currently, there are many kinds of biomass molding machine, but an objective reality that the high power consumption and quick wear of main molding dies is still existed restricting the development of biomass solid fuels. To overcome shortcomings in traditional molding machines, a completely new kind of biomass pellet molding mechanism with plunger-roller ring die was designed after deeply studied the densification of biomass material in this paper, which effectively avoided the extrusion and friction of biomass material out of molding cavities. It would greatly reduce the power consumption of densification (about 37%-40%), and prolong the service life of forming molds.

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2 Biomass pellet molding mechanism with plunger-roller ring die

The biomass pellet molding mechanism with plunger-roller ring die mainly consisted of plunger-roller component and ring die component, shown in Figure1. Biomass materials were densified into solid pellets by engaging movement of plungers on plunger-roller and forming cavities which were straight through-holes in ring die.

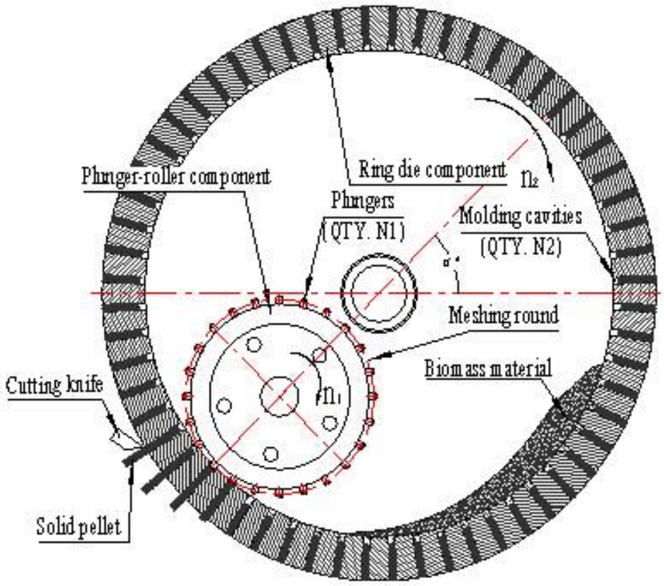

FIGURE 1 The working principle of biomass pellet molding mechanism plunger-roller ring die

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All of the plungers and forming cavities were uniformly distributed along circumference. Let the quantity of plungers and forming cavities of each row separately be N_1 and N_2, the revolving speed of plunger-roller and ring die be n_1 and n_2 in turn. Then when the four parameters matched the following Equation (1), the movement between the plungers and forming cavities was similar to the meshing motion of the gear.

$$\frac{N_2}{N_1} = \frac{n_1}{n_2} = (\frac{Z_2}{Z_1} : gear) , \quad (1)$$

where, N_2 and N_1 were the number of plungers on the plunger-roll and forming holes in the ring die respectively. Z_2 and Z_1 meant the number of gear pair, imitated by the molding part of the pellet machine.

The plunger-roller component and ring die component were homodrumy, eccentric mounted in the enclosure bodies, and the angle of their centre line and horizontal direction was α°. When plungers and couple molding cavities rotated to eccentric forming zone, they had the approximately same instantaneous tangential velocities, but different radial velocities due to tangency. So the plungers and molding cavities had a relative velocity at the stage of engaging, that is, radial extrusion speed for biomass materials. When shattered biomass material filled into cavities due to the action of gravity and centrifugal force, it could be densified through these molding cavities by couple plungers, finally be converted into cylindrical solid pellets, and then be cut off by knife. The process of densification was similar to many pistons extrusion forming molds at the same time, so the designed pellet molding machine in view of meshing motion had a higher productivity and better densification quality than conventional ring die molding mechanism. The biomass material wouldn't gather in the eccentric forming zone because of the angel of α°, which should ensure the meshing plungers only compressing biomass material in forming cavities. There was a gear transmission system between the plunger-roller component and ring die component, guaranteeing their same direction rotation movement with certain speed ratio, shown in the following Figure 2. In order to make sure the better biomass densification of the molding cavities in ring die, the diameter (D) and length (L) of through-hole must maintain a relationship shown in the Equation (2), known from reference [6]:

$$L / D = 5.2 \sim 6.2 , \quad (2)$$

where, L and D indicated seperately the diameter and length of the through-hole in the ring die.

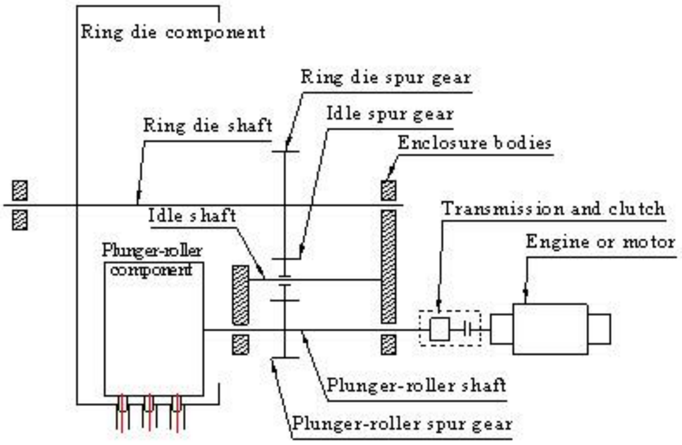
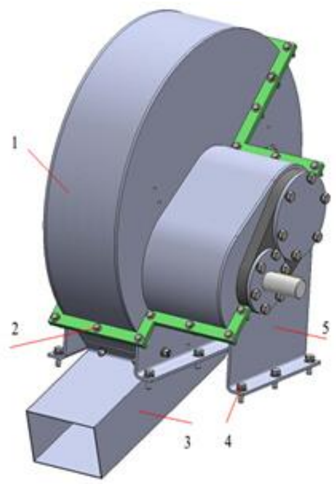


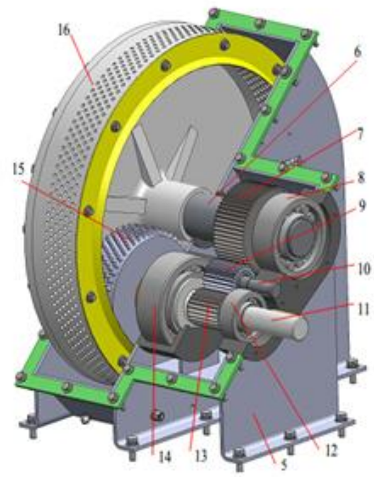
FIGURE 2 The transmission system of biomass pellet molding mechanism with plunger-roller ring die

3 Q450 pellet molding machine

Q450 pellet molding machine was a new type of biomass forming equipment designed with plunger-roller ring die, whose productivity was 450kg/h. It mainly consisted of three parts, enclosure assembly, outlet hopper, and internal molding assemblies (including plunger-roller assembly, ring die assembly, and idler transmission assembly), seen obviously in Figure 3.



(a) Appearance of the molding machine



(b) The internal structure of the molding machine

FIGURE 3 Q450 pellet molding machine

1. Upper enclosure body, 2. Enclosure body connecting bolts, 3. Outlet hopper, 4.Molding machine fixing bolts, 5. Lower enclosure body, 6. Ring die shaft, 7. Ring die spur gear, 8. Ring die cylindrical roller bearings, 9. Idle spur gear, 10. Idle shaft, 11. Plunger-roller shaft, 12. Right plunger-roller cylindrical roller bearings, 13. Plunger-roller spur gear, 14. Left plunger-roller cylindrical roller bearings, 15.Plunger-roller component, 16. Ring die component

The plunger-roller assembly included plunger-roller component 15, plunger-roller shaft 11, spur gear 13, and two cylindrical roller bearings 12 and 14 (product model was NJ2316E). Plunger-roller component and plunger-roller spur gear were connected to the shaft with flat keys, and fixed in bearing seats of enclosure bodies by bearings. The ring die assembly also included ring die component 16, ring die shaft 6, spur gear 7, two cylindrical roller bearings 8 (product model respectively was NJ2319E and NJ2310E), and its mode of connection and installation was same with plunger-roller assembly. For the idler transmission assembly, idle spur gear 9 was fixed on idle shaft 10 by two bearings (product model was NJ2205E), and both ends of shaft were installed in bearing seats, which made the idle gear rotate around the shaft freely. The driving force was input to plunger-roller shaft, and then the ring die component was driven to rotate in a same direction with plunger-roller component at certain speed ratio by idle transmission assembly.

4 Design of Enclosure assembly for Q450 pellet molding machine

Figure 4 was the enclosure assembly of Q450 pellet molding machine designed by Solidworks. The meanings of the numbers were shown in the following.

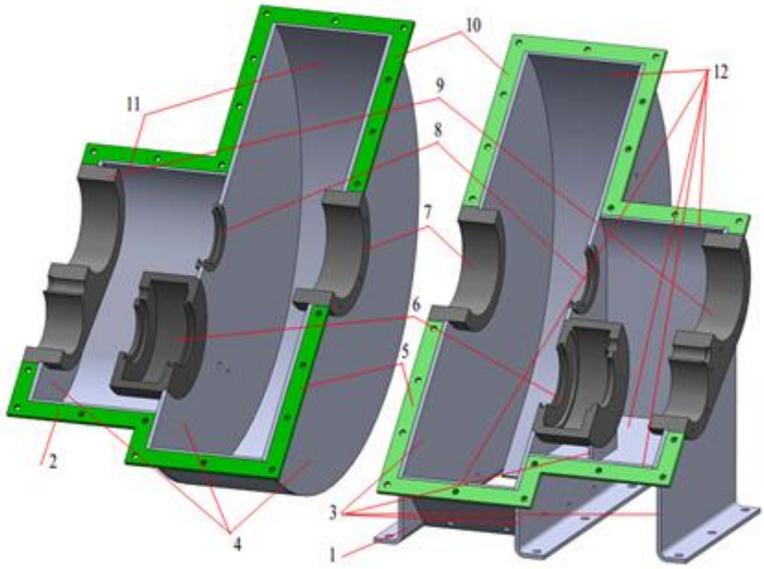


FIGURE 4 Structure of enclosure assembly for Q450 pellet molding machine
1. Lower enclosure body, 2. Upper enclosure body, 3.Vertical plates of lower enclosure body, 4. Vertical plates of upper enclosure body, 5. Connecting flanges (down), 6. Bearing seats of plunger-roller assembly, 7. Bearing seats of ring die assembly, 8. Dustproof felt seats, 9. Integrate bearing seats, 10. Connecting flanges (top), 11. Side plates of upper enclosure body, 12. Side plates of lower enclosure body

From Figure 4, the enclosure assembly was consisting of lower enclosure body 1 and upper enclosure body 2, which were welded together with steel plates. The thickness of all vertical plates and connecting flanges was 8mm, and the one of all side plates was 5mm. To facilitate the installation of internal molding assemblies, 45 split structure was adopted in the whole enclosure assembly. And the material of all steel plates employing in enclosure bodies was Q235-BZ (the mechanical properties were shown in Table 1, which has a better welding performance. The three pairs of bearing seats 6, 7 and 9 always enduring large alternating loads were made of 45 steel possessing good synthesized mechanical properties, and the dustproof felt seats 8 was made of 20 steel good for welding because of low carbon content. The two enclosure bodies were manual welded with E4303 electrodes, and finally fixed together with M16 bolts.

TABLE 1 The mechanical properties of Q235-BZ [unit: Mpa]

Tensile strength σ_B	Yield strength σ_S	Bend fatigue strength σ_{-1}	Shear fatigue strength τ_{-1}	permissible bend stress $[\sigma_{-1}]$
400-420	225	170	105	40

5 Force analysis of molding assemblies

The force distributions of three molding assemblies were shown in Figure 5 and the data calculated listed in Table 2.

TABLE 2 The force values of three molding assemblies

Plunger-roller assembly		Ring die assembly		Idle assembly	
T_g	-130.242	T_h	+17.377	F_{r1}	+87.841
R_a	+11258.133	F_f	-21191.500	F_{t1}	-241.341
G_g	-293.050	G_h	-1519.100	F_{r2}	-70.273
G_{gz}	-163.635	G_{hz}	-212.800	F_{t2}	+193.073
F_{r1}	-87.841	F_{r2}	+70.273	G_3	-20.990
F_{t1}	+241.341	F_{t2}	+193.073	G_{dz}	-7.100
G_1	-12.210	G_2	-123.578		

Note: The unit of T_g, T_h, M was [N.m], and M=-T_g. The unit of rest items was [N], "+" represented the direction of force was identical to the load distribution coordinate system (d), "-" conversely, and the same to Table 3.

From the force analysis in Table 2, support reactions of three pairs of seats were worked out (data listed in Table 3).

TABLE 3 The reactions of support seats [N]

	1	2	3	4	5	6
F_X	-112.282	-130.060	-41.809	-151.264	+32.742	+15.527
F_Y	+3628.451	+7629.683	+15019.920	+6101.307	-11.917	-5.652
F_G	+438.415	+30.480	+1610.399	+245.080	+18.994	+9.007

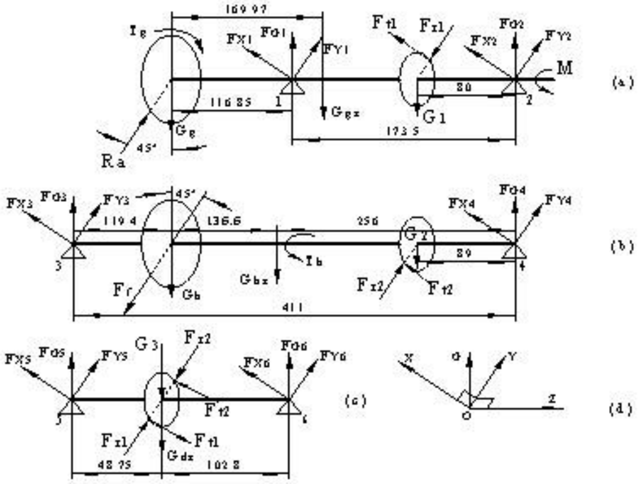


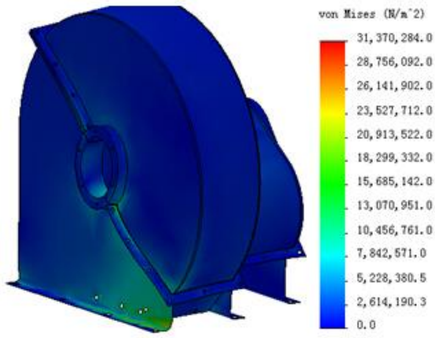
FIGURE 5 Force analysis of three molding assemblies (a) Force analysis of plunger-roller assembly, (b). Force analysis of ring die assembly, (c). Force analysis of idle transmission assembly, (d). Load distribution coordinate system

Note: To plunger-roller assembly, T_g, M expressed respectively total resistance torque, driving torque. R_a^{total}, G_g was radial force and gravity in turn. G_1 was the gravity of roller gear and F_{r1}, F_{t1} indicated separately the radial force and tangential force of the gear. To ring die assembly, T_h was resistance torque. F_f^{total}, G_h was radial friction force and gravity in turn. G_2 was the gravity of ring die gear and F_{r2}, F_{t2} indicated separately the radial and tangential force of the gear.G_3 was gravity of idle gear and idler bearing, and G_{gz}, G_{hz}, and G_{dz} respectively meant gravities of shaft of the roller, ring die and idler.

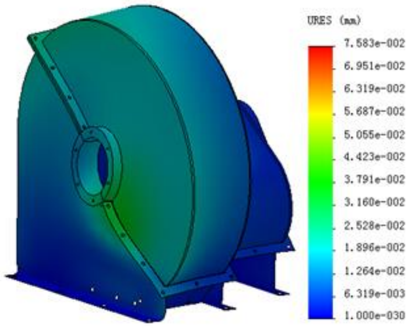
6 FEA (Finite Element Analysis) of enclosure assembly

As the important installation carrier of the pellet molding machine, enclosure body must have the properties of sufficient strength and rigidity to ensure the right position of each forming mechanism in the work process and so as to keep normal engage compression of the plunger pair.

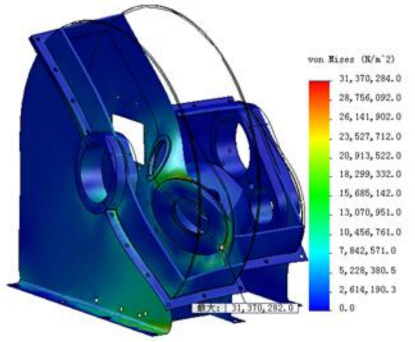
Simulation is a integrate FEA module of Solidworks. The designed 3D models for product could be conveniently executed FEA in this CAE module, and a FEA outcome of enclosure assembly for Q450 pellet molding machine was shown in Figure 6. In the static analysis, the bottom faces of vertical plates of lower enclosure body were fixed, and the loads (listed in Table 3) were applied on support seats of enclosure bodies.



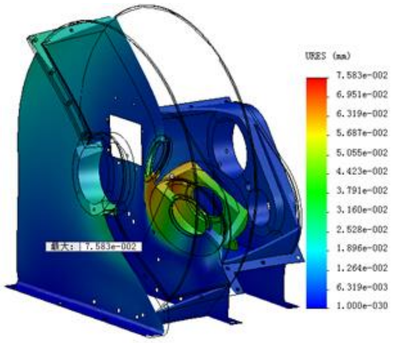
a) Von mises stress nephogram



b) Resultant displacement nephogram



c) Internal von mises stress nephogram



d) Internal resultant displacement nephogram

FIGURE 6 FEA result of enclosure assembly

As it is seen from Figure 6c and 6, the maximum stress σ_{max} and displacement UR_{max} occurred respectively at the oblique lower and upper position of the left bearing seats of plunger-roller, and the value was 36.44 Mpa and 0.07583mm in turn, less than $[\sigma_{-1}]$ and [U] in the following Equation (3).

$$\begin{aligned} &\sigma_{\max} < [\sigma_{-1}] = 40MPa \\ &UR_{\max} < [U] = 0.15mm \end{aligned}, \tag{3}$$

where, [*U*] was the middle class tolerance value of centre distance (OA=198mm) between molding ring die and plunger-roller.

Known from the Equation (3), strength and stiffness of molding enclosure body respectively matched the demands of working, which ensured the right position when compressing biomass materials by molding mechanism and the accurate engagement between plunger-roller and through-holes on ring die.

7 Conclusion

In the paper, a new kind of biomass pellet molding machine, Q450, was designed to convert biomass materials into bio-energy efficiently, and the principles of the key three components in the machine were also introduced in detail.

Then force analyses of molding assemblies were conducted, and FEA was processed on the basis of the data from force analyses. According to the FEA result, the maximum stress and displacement were respectively 31.37*Mpa* and 7.583e-2 *mm*, which distinctly less than the permissible bend stress (40*Mpa*) of Q235-BZ and permissible deformation (0.15*mm*, the Middle Class tolerance of eccentric distance of plunger-roller shaft and ring die shaft which was 198*mm*). So the whole enclosure assembly had sufficient strength and stiffness to ensure enough reliability and security during working for Q450 pellet molding machine.

Acknowledgments

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