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Integrated Design for Biomass Compression Molding Machine Based on CAD Technology

Huazhou Liu*, Yanhong Shi

Zhengzhou Railway Vocational & Technical College, Zhengzhou 451460, China
lhuazhou4537@163.com

This paper explores the architecture of the complete biomass compression molding machine based on CAD technology. Here is one biomass fuel molding machine with low energy consumption, high yield, long service life, and high density of molded fuels, designed in the flat die roller forming mode as required by design tasks after transmission scheme and master parameters are defined, provided that the advantages and disadvantages of all types of molding machines are analyzed. This equipment will fill up the gaps of traditional models in terms of high development cost, unreasonable architecture design, and short service life of key components.
As a huge energy consumption super-country, China suffers from the pressure from both brisk energy demand and the environmental concerns due to more and more fossil energy consumption. The biomass fuel processed using compression molding technology can help alleviate the energy shortage, improve the ecological environment, and establish a sustainable energy system. On this basis, China has been driving into the fast lane of economic and social development. As a late starter, China never involved the investigation on such biomass compression molding technology until the 1980s. In recent years, the piston compression molding machine (CMM) based on hot press molding principle and the ring-mode compression granulator based on viscosity-shear principle, respectively developed by Henan Agriculture University and Shandong University as pioneers in the field, have been typical models in the study. Few ever involved the flat-mode granulator (FMG). Here we take it as a study case, analyzes the available flat-mode CMMs, and eventually works out a type of more practical flat-mode granulator by integrating relevant design theories and application technologies.

1. Introduction

Biomass compact molding technologies such as straw have won the favor of those developed countries in the world. They have invested enormous financial and human resources to explore and develop compact molding technologies. The United States began studying compression molding fuel technology as early as the 1930s and developed the screw compressor. In order to dispose timber waste, Japan has also been exploring mechanical piston molding technology since the 1930s and developed a rod-like fuel molding machine around 1954. They also introduced granulated fuel technology from the United States before and after that year and developed it into Japan industrial system for compression molding. By 1983, a dozen of particle molding plants had been put into service with a capacity of more than 100,000 tons biomass granular fuel. In the late 1970s, impacted by the world energy crisis, oil price heaved, compression molding technology had aroused wide concern from many countries in Western Europe such as Finland, Belgium, France, Germany, and Italy. Asian countries such as Thailand, India, Philippines and Malaysia had also started pertinent studies since the 1980s, except Japan. There are four major types of foreign biomass molding technologies, i.e. granulator, screw continuous extrusion molding machine, mechanical drive impact molding machine and hydraulic drive impact molding machine
In China, nearly 20 biomass molding lines were introduced in the 1990s, from then on, many research institutes got down to the development for molding machines. A tradition in China is that straw could be burnt directly since ancient times. At that time, straw was the primary source of rural living fuel before using coal. In the 1970s, the straw energy devaluated since coal and petroleum became more popular, coupled with the

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impact from energy crisis broke out in the 1980s when China also introduced the strategy for sustainable development of energy resources. During the "Eighth Five-Year Plan" period, as a national key project, the biomass impact and squeeze briquetting press technology was studied by China Agricultural Machinery Institute of Energy and Power, Liaoning Energy Research Institute, Chinese Academy of Forestry Institute of Forest Chemical Industry, the Institute of Chemical Industry of Forest Products CAF, and the Chinese Academy of Agricultural Engineering, pushing the R&D work develop forward in our country. In the wake of the emergency of biomass densification and carbonization technologies, certain developments have gained in China's biomass compression molding industry. Since the 1990s, more than 40 SMEs, including the energy sectors, township enterprises and individual producers in some provinces and cities in China have actively introduced advanced technologies for industrialized production.

2. Literature review

Biomass energy is the only renewable energy source that can be stored, transported, and fixed. It has the characteristics of large reserves, wide distribution, environmental friendliness, and zero carbon emission reduction (Aziz and Hanafiah, 2017). It plays an important role in six renewable energy sources. The commonly biomass energy raw materials include agricultural residues, forestry residues, livestock and poultry excrement, energy crops (plants), industrial organic wastewater, urban domestic sewage and garbage (Abd Latif et al., 2016). Biomass energy is the fourth largest energy source after oil, coal and natural gas. China's biomass resources are relatively abundant, and agricultural and forestry residues account for a large proportion. By-products of agricultural and forestry processes, known as residues, may act as a primary source of renewable energy (Daioglou et al., 2016). However, biomass such as agricultural and forestry residues has the disadvantages of resource decentralization, low energy density, small bulk density, and inconvenient storage and transportation, which seriously restricts its large-scale application. However, people justify non-involvement with decentralization precisely because of their past effort (Coleman, 2014).

In 1992, after the World Conference on Environment and Development, European and American countries began to vigorously develop biomass energy. The European Union plans to have 12% of renewable energy in 2010, and it can replace 20 million tons of oil each year. The biomass with low cost accounts for about 80%. Many countries have formulated corresponding development and research plans, such as Japan's sunshine plan, India's green energy project, the United States' energy farm and Brazil's alcohol energy plan. Some advanced economy such as Korea, USA, Japan, Germany and France were also compared in reference to their patent data, policies and renewable energy attractiveness to identify the options that contributes to their innovative capability in renewable energy technologies. Some policy recommendations were provided in order to foster innovation in Brazil (Xu et al., 2017). In addition, a lot of manpower and funds are invested in the research and development of biomass energy. Taking the United States, Sweden, and Austria as examples, the conversion of biomass into high-grade energy sources has reached a considerable scale, accounting for 10%, 16%, and 10% of the country's primary energy consumption. Brazil is the only country in the world that does not supply pure gasoline, and bioenergy has a large proportion in the national energy consumption structure. From the mid-1970s, Brazil began to use sugar cane to produce fuel ethanol. The effect of fuel ethanol content (10, 85 and 100%) on primary emissions and on subsequent secondary aerosol formation was investigated for a Euro 5 flex-fuel gasoline vehicle (Timonen et al., 2017). From 1996 to 1997, the country produced 13.7 billion L of fuel ethanol. There are 4 million cars using pure ethanol, which greatly reduces the foreign exchange expenditure on imported oil. After more than 30 years of hard work, Brazil has built a complete fuel ethanol industry chain. Brazil began implementing the biodiesel program from January 1, 2008. The government increased the proportion of biodiesel in regular diesel from 3% to 4% from July 1, 2001 and reached 5% in 2010.

The United States is the world leader in the use of biomass. According to reports, there are more than 350 biomass power stations in the United States, and the total installed capacity of biomass power generation has exceeded 10,000 M. the stand-alone capacity reaches 10-25MW. It is predicted that by 2010, biomass power generation capacity will reach 13,000 MW. In the 1970s, the particle-formed fuels were promoted in the United States, Canada, and Japan. At the same time, these countries have researched and developed stoves that use pelletized fuel specifically for home or conservatory heating. In North America, more than 500,000 households use this special heater. The annual production of pelletized fuel in the United States reaches 800,000 L. The United States formulated the "Ethanol Development Plan" in the late 1970s and began to promote the use of ethanol gasoline for motor vehicles. It also accelerated the development of wood-fired power generation and fuel ethanol, using crops and their wastes to produce ethanol as a vehicle fuel. It is planned that by 2010, biomass will provide about 53 million tons of ethanol. Biomass energy is Canada's most important renewable energy after hydropower. It provides Canada with 6% of primary energy. By 2020, Canadian renewable energy (excluding hydropower), especially biomass energy, will increase by 56%.

In China, biomass energy can not only ease energy shortages and reduce environmental pressure, but its special significance also helps solve the “three rural issues”. The energy structure of Hebei can be optimised since the proportion of coal in total primary energy consumption can fall from around 80% in 2015 to below 30% in 2030 and the proportions of transferred electricity, natural gas, nuclear energy and renewable energy can increase rapidly. Some specific additional policy instruments are also suggested to support the low-carbon transition of energy system in Hebei under the framework of the coordinated development of Beijing-Tianjin-Hebei area, and with the support from the central government of China (Qu et al., 2017). China's biomass energy is very rich. The annual output of organic waste such as agriculture and forestry are 2.209 billion tons, which has broad prospects for development. Biomass energy accounts for nearly 70% of the total rural energy consumption and accounts for nearly 1/4 of the country's total energy consumption. It is predicted that China's biomass energy development and utilization will reach 275M tons quasi-coal in 2050, accounting for 8% of the primary energy supply.

Biomass has been used as an energy source for thousands of years. So far, there are still more than 1.5 billion people in the world using biomass as their living energy, but the use of biomass is no longer simply burning. However, it is based on the efficient use of modern technologies. Biomass energy conversion and utilization methods mainly include combustion, thermochemical methods, biochemical methods (Wobiwo et al., 2017), and physical chemistry methods, which can be converted into secondary energy sources. At present, the use of biomass energy mainly focuses on the research and development of direct combustion, biomass gasification, biomass liquefaction and biomass solidification technology. It is found that biomass is a high-quality fuel due to its low-pollution characteristics and is particularly suitable for combustion conversion and utilization. The energy generated by biomass combustion can be used in fields such as cooking, indoor heating, industrial processes, district heating and power generation, and cogeneration.

3. Architecture of biomass CMM

The flat-mode granulator consists of the motor, the transmission part, the roller, the feeder and extractor, and the rack. This paper focuses on the description, analysis and design of the transmission and roller parts, break through the traditional design concepts, and develop a new flat mold granulator that features simple and reliable structure, compact size, simple drive, high molding efficiency, low power consumption per ton, and other advantages.

3.1 Molding principle

As designed, this flat-mode granulator adopts an action roller (pressure roller moves and flat die is static), that is, the press roller matches up the roller bearing during the operation of the molding machine, while the flat die is secured on the tank. During installation, there is a certain clearance between the press roller and the flat die. When the flat-mode granulator works, the stirred biomass raw materials are continuously and smoothly conveyed into the feeder chamber, where the feeder squeegee evenly flattens the raw materials on the flat die surface. Spindle drives the press roller to rotate. The friction among the press roller, flat die and the biomass raw materials forces the roller to rotate around its axis. Rotation of the press roller generates pressure force to squeeze the material into the flat die hole. When the material overcomes the friction resistance, the molded fuel will be continuously extruded out from the flat die hole, and eventually cut into a certain length as required by a cutter mounted on the spindle.

Flat-mode granulator mainly uses the hot briquetting process to produce biomass pellet fuel. But the disadvantage of this process is that it will lose part of the biomass energy and cause certain pollution to the surrounding environment. This paper breaks through the traditional ideas, adopts the normal temperature molding process instead to make the biomass pellet fuel. The flat-mode granulator is improved in structure to adapt to this process. The technical specifications of the designed flat-mode granulator are shown in Table 1.

Table 1: Specifications of fat die granulator

Total power	30KW	Yield	0.8-1.2t/h	Total power
Particle diameter	φ8×12~14	Particle density	0.8-1.4g/cm	Particle diameter
Water (Mt)	≤20	Ash (Ad)	1-2%	Water (Mt)
Heat value	3200kcal/kg	Particle forming temperature	≤100°C	Heat value

In order to realize the idea that biomass pellet fuels are produced through the normal temperature molding process, the overall transmission scheme of the designed flat die granulator is defined as shown in Figure 1.

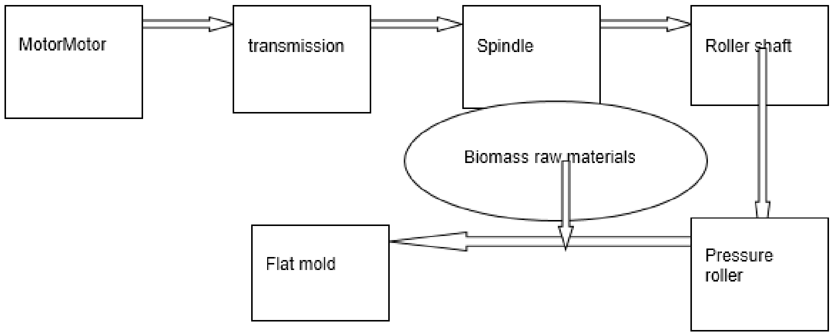


Figure 1: Plane particle molding machine transmission scheme

3.2 Roller assembly

The press roller as a key part of the biomass flat die granulator is used with the flat die to squeeze the biomass raw material into the flat die hole. There are 2~3 press rollers distributed in the feeder chamber in available FDGs. Concerning the structure and cost, two symmetrical press rollers are designed here. In the working process, the press roller wears more seriously as one of the principal vulnerable parts on the molding machines. We first improve its intensity and abrasive resistance from raw materials in order to reduce wear. For this purpose, we choose the alloy carburizing steel as a roller material. With reference to the relevant book, the roller material is defined as 20CrMnTi, carburized and quenched, the surface hardness reaches 40~48HRC. According to Jing Guoxian's conclusion drawn from the "Study on dislocation wear of biomass flat die granulator", the cylinder-shaped press roller is rebuilt into a circular cone body with appropriate parameters set so that the linear velocities of points at the contact line between press roller and the flat die are equal. In this way, the press roller only rolls on the contact surface without slippage so that the abrasion loss on the profile is consistent, which not only ensures that the play between the press roller and the flat die changes a little, but also extend the roller service life. When the press roller reaches 1:5 taper and dips at 10 degrees, it is relatively reasonable in shape. Excircle surface of the press roller is processed into a tooth profile, trapezoidal or rectangular to strengthen the capacity of roller to seize biomass raw materials, thus improving its work efficiency. In order to achieve its capacity as designed, a 3D model of the press roller is determined through theoretical calculation and relevant experience, as shown in Figure 2.

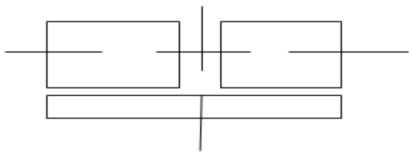
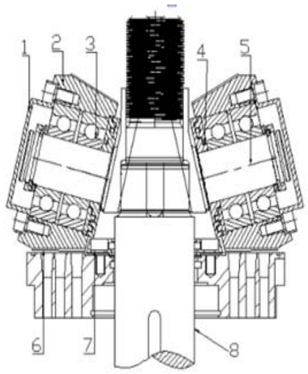


Figure 2: Cylindrical roller

3.3 Flat-mode structure

The flat mold is a key wear component of the biomass granulator. According to relevant statistics, in the pellet fuel workshop, the maintenance cost of the flat die accounts for more than 30% of the whole molding machine. Therefore, whether the flat die is well designed determines how the cost and the quality of the briquettes fuel are. Flat die material should feature high strength, high surface hardness, and corrosion resistance. Here we choose 40CrMo, whose hardness after quenching reaches 60~68HRC. In addition to this, we also must elaborate the opening area of the flat model, the size and arrangement of the die hole, the aspect ratio, and the linear velocity and other parameters. This 3D structure of the flat die is shown in Figure 3.



1- Bearing end cap 2-Pressure roller 3-Bearings 4-Qu road sealing ring 5-Roller shaft 6-Flat mold 7-Sealing ring 8-Spindle

Figure 3: Rolling parts structure

4. Flat-mode fatigue simulation

The ANSYS fatigue simulations include the safety factor and fatigue cycle limit times (fatigue life). The former indicates the ratio of the fatigue limit stress that the structure can withstand within the fatigue life as designed to the stress obtained by ANSYS simulation calculations. For example, the ultimate stress of a structure is 25MPa, and the design life is 1.5×107 times. ANSYS fatigue calculation show that when the fatigue life of 1.5×107 times as designed is reached, the fatigue limit load subjected to the structure is 12 MPa, i.e, the structure safety factor is 30 MPa/25 MPa=1.2. If the fatigue life of mechanical part reaches 106~107 times in the project, it can be deemed as infinite. In this paper, given that the flat die works in hostile environment, the fatigue life of flat die is set to 107 times.The obtained flat die fatigue life and safety factor are shown in Figure 4 and 5, respectively.

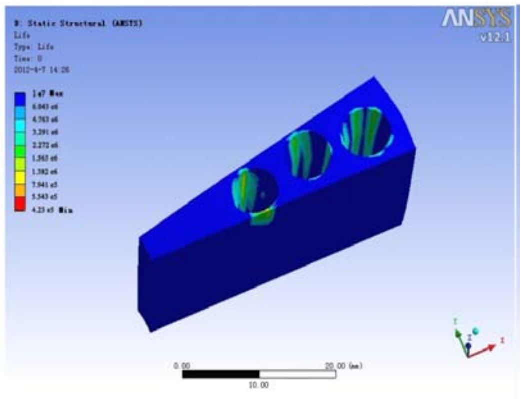


Figure 4: Flat mode fatigue life cloud

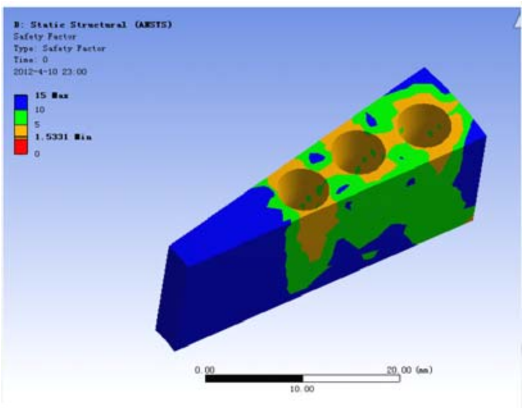


Figure 5: Safety factor cloud

As shown in Figure 4, the maximum times of stress cycles are 10 7, the life reduction only occurs in the chamfer position; the times of stress cycles is 10 5, a minimum fatigue life occurs in this position; which roughly coincide with the position of maximum equivalent stress, i.e. danger point, from static analysis. As shown in Figure 5, most positions on the flat mode are absolutely safe. Though its safety factor is distributed unevenly, the minimum safety factor is 1.5, greater than 1. It can be considered that the whole flat mode is safe during working time.

5. Conclusion

This paper bases the design on practical applications, breaks through the concept of the hot briquetting process to realize the new type of biomass granulator using room temperature molding process by CAD/CAE on the premise that available molding equipment developed at home and aboard are compared. It features simple structure, low cost, stable system, and high efficiency. With reference to a flood of pertinent literature, the state-of-the-art and future development trend of biomass pellet molding technology are expounded here, in addition to the comparison between the advantages and disadvantages of current biomass molding equipment and various molding processes. The room temperature molding process is determined for designing flat die granulator. The finite element analysis software ANSYS Workbench simulates the fatigue life of the flat die as designed. The results show that the designed flat die well fit the bill as the fatigue life required.

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