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**Research Article**

# Design of the Soymilk Mill based on TRIZ Theory

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**Abstract:** The soymilk mill is an important food machine, but its volume is too large to be suitable for house using. This study first analyzes some problems in the soymilk mill miniaturization. For these problems, the thinking tools, evolutionary tools and contradiction solving tool of TRIZ theory are used to resolve the conflict in the integration of grinding and boiling and in the keep grinding effect, to tackle the optimization problem in the grinding stria structure and mill plate speed, then the Dwarfs method and substance-field analysis model is used in solving the interference and the conditions water supply problems which are encountered in the design of the global structure and a micro soymilk mill is designed. Finally, the mechanical analysis model about soy granules, soymilk particles in the grinding zone and the computational model of motor starting torque are obtained; they provide the reference data for application of soymilk mill.

**Keywords:** Food machine, innovative design, soymilk mill, TRIZ theory

## INTRODUCTION

The soymilk has rich vegetable protein to greatly meet the demand for the people of the protein, in addition to containing vitamin B1, B2 and iron, calcium too, especially water-soluble calcium, which could suit calcium deficiency of the elderly people and growing adolescents. The famous American magazine "Outlook economy" clearly pointed to the mid-21$^{st}$ century vegetable protein will dominate in people's lives, so the development of the soybean milk industry is very important and the soymilk industry needs support by soymilk preparation equipment. Nowadays, the United States retains its position as the first soybean producing countries in the world and achieves the production process industrialization automation by a variety of processing equipment and production lines. Japanese soymilk is processed four phases of soaking soybeans, grinding, boiling soymilk, filtered and each stage have been mechanized and work closely together in all phases of production, so the soymilk efficiency and quality are very high. In China, the soymilk preparation is relatively long history and is processed by handmade stone in a long time. The automatic soymilk household is created until 1995 and people did not like it due to the unstable motor, not following the program operation, relatively high repair rate, easy boil paste and other deficiencies Later, as the technology improved, the automatic soymilk machine was into millions of households, but main of them are the pattern of the blade cutting soy to prepare soymilk (Wu, 2006).

Comparing grinded soymilk than cut soymilk through experiment, the former has good nutrient, such as its contents of calcium, iron and zinc than that of the later. The soymilk grinded by stone mill is originated in China and is using nowadays, in more than 2,000 years of history. There have been multiple types processing tools. 1970s, Buguan Town Machinery Factory in Pinglu County of Shanxi Province has used the local granite resources and has created the stone mill driven by a motor through the skillful combining to ancient techniques and modern elements. The mill zone of stone mill divided into the two parts of fixed and rotating and is a horizontal structure. The fixed part is the half cylindrical groove, which is on a long side of a rectangular stone and corresponding with a rotation part. The rotating part is made to cylinder and the middle hole is dug to penetrate the drive shaft. The mutual contact area between semicircle stone groove and the rotating cylindrical surface are engraved stria with ancient stone-like pattern; in addition, the corresponding part blocked the transmission form the combination product. Qi *et al.* (2012) designed a lightweight, clean, low-cost, easy-to-use mechanical stone soymilk mill, improved the structure of the lighter plat and the more reasonable grinding stria, but did not realize the integration of soymilk preparing and soymilk boiling, is not easy to use in families.

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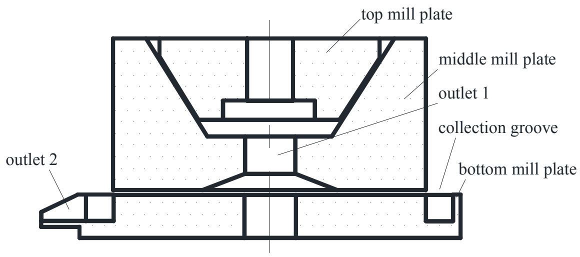



Fig. 1: Two types structure of stone soymilk mill

In this study, the problems of the existing in stone soymilk mill are found and TRIZ theory is used to solve these problems, then a new type miniature automatic soymilk mill is designed and its structure and relative analysis results are given.

## THE PROBLEMS EXISTED IN STONE SOYMILK MILL

Figure 1 (Qi *et al*., 2012), to a conventional automatic stone soymilk mill, there are two structures, one structure is the traditional upper and lower plate, this structure grinds soymilk relying on gravity of the upper plate and the friction between two plates. Usually this structure requires relatively large radial size of the upper and lower plates and the heavy upper plate, so it is not easy to miniaturized and not suitable for home-use. Another is a three-plate structure, implement soybean course grinding between the upper and middle plates and fine grinding between the middle and lower plates. This structure has relatively small radial dimension, but it is difficult to realize how to drive the plate. Taken together, there are problems existing in the automatic stone soymilk mill, so it is necessary to design effective home-use soymilk mill:

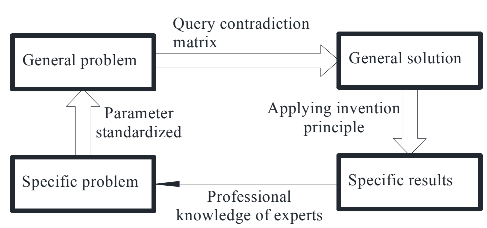
- Soymilk quality related with stone plate scale, the large-scale plate and the slightly better soymilk quality. But used in home, its dimension need be miniaturized and thus faced with the contradiction between the millstones miniaturization and soymilk quality.
- In integrating the soymilk prepared and soymilk boiled in a mill, the problem is faced with the constraints of the spatial structure, the contradiction between the limited functional integration and the space structure need be resolved.
- The cleaning problem of the internal structure disturbed us, once the automatic soymilk mill into the family, the internal structure (or components) cleaning need be considered, if considered equipment detachable and cleanable of internal components in the structural design, the automatic soymilk mill can smoothly enter into the ordinary family.
- Grinding parameter optimization problem, the mill effect rely on structures and parameters of grinding and the reliable grinding parameters need be obtained through the optimization of grinding parameters, so that the soymilk produced by this mill is superior to the existing soymilk.

## THE PROBLEMS TACKLED BY TRIZ THEORY

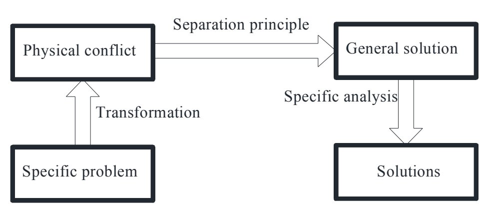
Analyzing the above four questions, the former two are conflict problems and the later are structure and parameter expansion optimization. TRIZ theory can get a better solution to these problems and the following is that the different tools of TRIZ theory is used to solve the above problems (Jiang *et al*., 2010a, b, c, d, e and f).

**Solution of conflict problems:** The conflict resolution of TRIZ principle is the general law for solution to the conflict and includes the technical conflict and physical conflict. Technical conflict is that one aspect of the system is improved and the other aspect is weakened. Such as to increase the inertia of the flywheel in the mechanism system, will generally increase the quality or geometry of the flywheel, so that the flywheel shaft strength will decrease, or the size of mechanism space will increase.

Figure 2a, for the specific problems, when found a technical conflict, which should be described using specific terms in the technical field. Subsequently, the parameters of both sides of the conflict are standardized (TRIZ theory has 39 standard parameters and some




(a) Technology conflict




(b) Physical conflict

Fig. 2: The solving process by using of the TRIZ theory

Table 1: The conflict parameters standardization

| Conflicts | The standard description of conflicts |
|---|---|
| Conflict between space miniaturization and the integration of soymilk preparation and boil | 7 - moving objects volume/38 - degree of automation |
| Conflict between structure simplifies and the disassembly structure | 36 - the complexity of the device/ 34 - Maintainability |

Table 2: The summary table of conflict matrix

| | 1-33 | 34 | 35-37 | 38 | 39 |
|---|---|---|---|---|---|
| 1-6 | | | | ↓ | |
| 7 | → | ↓ | → | 35, 34, 16, 24 | |
| 8-35 | | | | | |
| 36 | → | 1, 13 | | | |
| 37-39 | | | | | |

literature has been extended to 48). According to the standard parameter, the TRIZ contradiction matrix is inquired and the recommended invention principles is found (TRIZ theory has 40 invention principles). These invention principles are applied to solve the conflict and combined with experts knowledge of this field, the right solutions for specific problems are obtained. (Jiang, 2011; Jiang *et al*., 2012)

Physical conflicts is that an object have two opposite needs, such as the tool of the machine should have a very high hardness, so that its cutting is relatively easy, but too hard to reduce tool toughness and the tool is easily broken. For physical conflict, separation principle is used. The TRIZ theory has four principles of separation:

- The spatial separation
- The time separation
- The conditions separation
- System level separation and each separation principle corresponds a series of invention principles for solving problems

Figure 2b, for a specific problem, if the problem of physical conflict should be found, then the appropriate separation principle is sought. In accordance with the corresponding invention principles, a final solution would be obtained.

**The solutions of technical conflict in soymilk mill:** Seen from the above analysis, the conflicts faced in the soymilk mill are mainly technical conflict. According to the solving process of the TRIZ theory conflict in Fig. 2, the conflict parameters are described by standardized terms and the conflict matrix is inquired, then the recommended invention principles are found and the recommended invention principles are analyzed, so a solution to this problem is obtained.

In innovative design, the soymilk mill faces two technical conflicts that space miniaturization is contradicted with the integration of soymilk preparation and boil, the conflict between the spatial structure simplifies and the disassembly structure. These contradictions are described with the standard parameters of TRIZ theory, as shown in Table 1.

According to the conflicts parameters standardized in Table 1, contradiction matrix of TRIZ theory is inspected and then the recommended principles of the invention are found, are shown in Table 2.

From Table 2, to solve the conflict 1, using the invention principles 35, 34, 16, 24; in addition to solve the conflict 2, using the invention principles 1, 13. These invention principles are explained as follows:
The first invention principle is dividing principle:

- An object is divided into independent parts
- The object is divided into easily assembled parts
- Improve the separability of an object

The thirteenth invention principle is the principle of reverse effect:

- Flip objects, or turned the process
- The active part is changed to a fixed object, or its fixed part becomes active
- The direction of action is reciprocal

The sixteenth invention principle is no reached or excessive action principle, if it is difficult to obtain requirements with hundred percent efficacies, you should get slightly smaller or slightly larger effect. The twenty-fourth invention principle is the "intermediary" principle:

- Can migrate or send intermediate objects
- Attach another object (easy to separate) temporarily to a particular object

The thirty-fourth invention principle is partially removing and regeneration principle:

- The parts that completed their task, or no longer used should be removed (dissolved, evaporation, etc.) or directly be changed in their study
- The elimination part should be directly regenerated in the study process

The thirty-fifth invention principle is the principle of parameter changes:

- To change the state of aggregation
- Change the concentration or density
- Change the flexibility
- Change the temperature

Seen from the principle of the above recommendations, for the conflict 1, using the intermediary principle is appropriate. The bottom plate

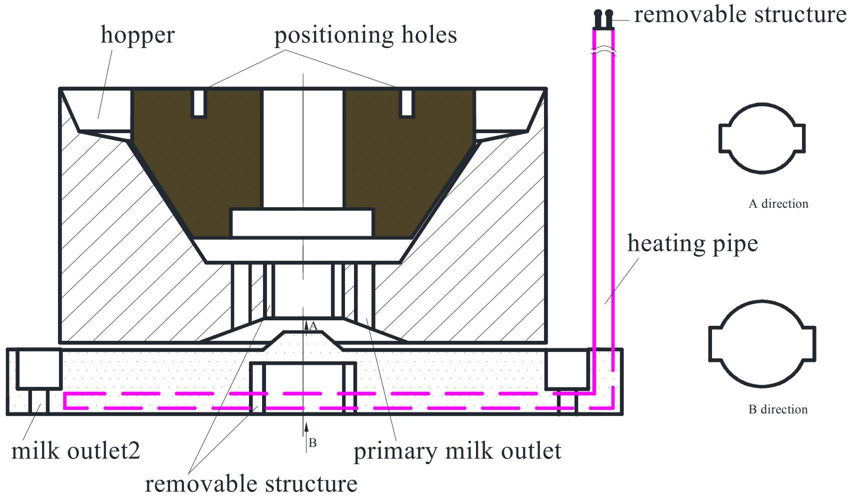



Fig. 3: The technical conflict solution

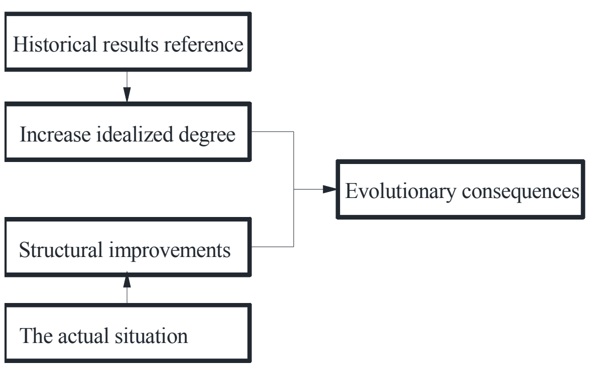



Fig. 4: The evolutionary paths of soymilk mill

is acted as the intermediary. The heating tube is installed in its internal and the soybean is ground into a granular, becomes soymilk, then is heated by the heating tube inside of the bottom plate, to complete the process of boiling soymilk, so that the spatial dimensions are saved. Figure 3 the heating pipes are installed in the intermediary, inside of the bottom plate and drawn from the outside of the collection tank.

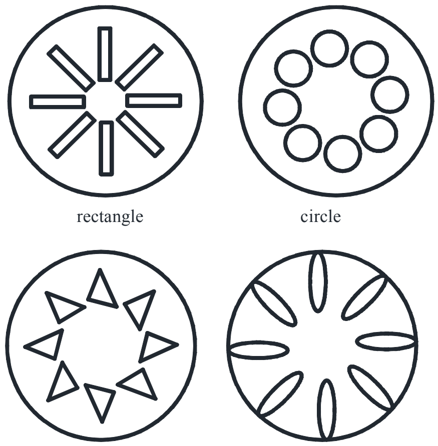
For the conflicts 2, using the dividing principle is suitable, some components are made in the separated parts and it is easy to clean after disassemble. Two flanges are designed in the center hole of the middle and bottom plate (Fig. 3), thus make the motor to drive the middle plate and fix the bottom plate in the bottom of mill. Two pillars are set on the upper plate; make the upper plate to fix on the upper cover body.

**The solutions of physical conflict in soymilk mill:** The conflict between the plate miniaturized and soymilk quality based on the previous analysis is a physical conflict. To physical conflict, using the spatial separation principle to solve is effective. Find the corresponding invention principles according to the separation principle; the split principle is applied to resolve this conflict. The traditional upper plate is divided into two parts, the upper plate and the middle plate, so the soybean should process the two grinding phase to complete repeated grinding in a smaller space process and the radial scale of the plate can be reduced and maintains the mill effect by increasing the grinding times. Meanwhile, in order to subsequent grinding stria manufacturing, the material should facilitate processing, the material components is beneficial to human body, here the cast iron materials is chosen (its anti-rust should be considered).

**Resolving the expansion optimization problems:**

**Structure optimization:** The grinding stria of plate need be optimized and the evolution tool of the TRIZ theory is applied to resolve it. The evolution modes are inquired and the mode 2 and the mode 10 are selected. According to these two evolutionary mode, that is the mode 2-increase the idealize degree or level and the model 10-the system evolution starting from the structural improvements, the grinding stria parameters are analyzed and the evolutionary paths are shown in Fig. 4.

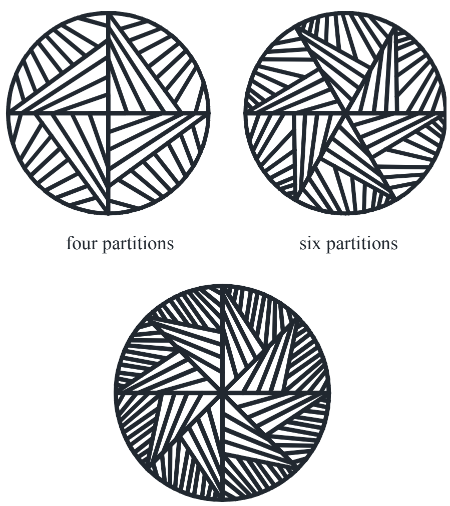
Increasing idealized degree is desired mainly from the developed history of grinding stria structure parameters. Stone grinding stria evolutionary process was mainly the grinding stria shape change and grinding stria changed by the grinding material. In China's spring and Autumn Period, the millstone grinding stria likes pits and its shape are a rectangle, circle, the triangle, spindle, etc. and are very irregular, discrete distribution on the upper and bottom plate. In the Eastern Han Three Kingdoms period, the grinding



rectangle circle

triangle ellipse

(a) Spring and autumn and the warring states periods



four partitions six partitions

eight partitions

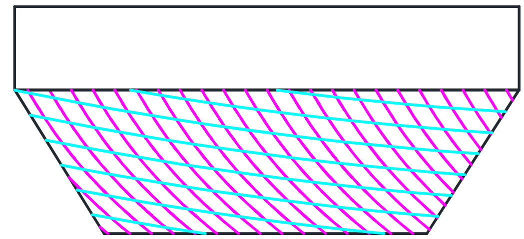
(b) Eastern Han three kingdoms

eight partitions ten partitions

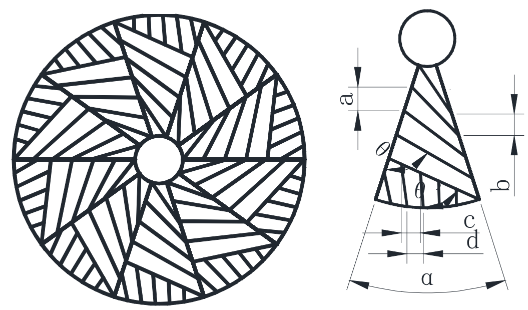
(c) Sui and tang dynasties

Fig. 5: The grinding stria developing process

stria diversified development and the shape of the grinding stria is radiation partition slash type, four districts, six districts of the eight districts. In Sui and Tang dynasties, stone mill is at a mature stage of development, the grinding stria is divided eight districts, or ten districts, these grinding stria structure changes are shown in Fig. 5. There are two kinds grinding strias, penetrating and non-penetrating, according to different grinding materials. Grinding stria for grinding powdered materials, such as flour, is non-penetrating and the grinding slurry material (such as soy milk), grinding stria is penetrating. With the processing technology of the grinding process, multi-zone grinding stria can be fine processed and the multi-zone structure is beneficial to soymilk finely produce. So the grinding stria parameters are chosen to the ten districts, its groove is penetrated in order to flow in soymilk.



(a) The first mill zone




(b) The second mill zone

Fig. 6: Grinding stria design in different grinding zone

The evolutionary path 10 is the structure improvement. According to the design analyzed previously, the three-plate structure is used and two mill regions are divided to mill the soybean. First grinding area is the foundation of the soymilk process, the processing effects directly determines the ability of produced soymilk and the whole soybean is broken into small particles in this area. The upward force component should be avoided as the stone plate is moving, that is, avoid the adding soybean overflow out of the plates along with the process. Therefore, for the first grinding zone, the grinding stria cannot be directly copied to the aforementioned experience, grinding stria structure should be improved to avoid overflow of soybean. The shape of the upper plate and its stria are shown in Fig. 6a.

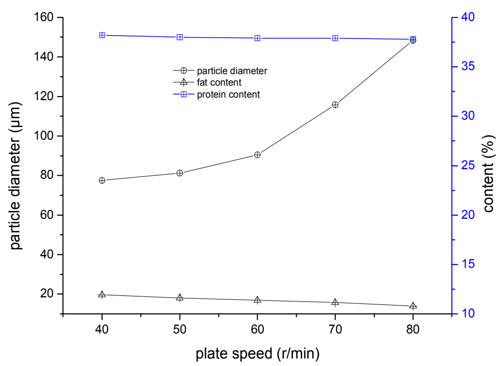



Fig. 7: The relationship among the plate speed, particle size, and the protein and fat content

In the second grinding zone, i.e., the gap between the lower surface of the middle plate and the upper surface of the upper plates, with reference to the historical experience, the grinding stria structure with 10 partitions is used and the grinding stria is designed with high precise, thus the grinding force and the discharge force are balanced, the design results are shown in Fig. 6b.

**Optimization of mill parameter:** According to the extraction principles in the invention principles of TRIZ theory, the extracted key parameters are analyzed. From the practice, the plate speed is a key factor affecting the effect of soymilk preparing, so the plate speed should be optimized. Here a particle size, protein and fat content are as indexes and the grinding plate speed is optimized by application of the experimental results in the reference (Qi *et al*., 2012). The relationship among the plate speed, particle size and the protein and fat content is shown in Fig. 7. Seen from this figure, the higher the speed, the bigger the soymilk particles and the smaller the protein and fat content. At same time, the lower the plate speed, the better quality the soymilk. Under considering milk production time, the choice of 50 r/min is appropriate.

## DESIGN AND ANALYSIS OF THE NEW SOYMILK MILL

**Structure design of the new soymilk mill:** According to the above solving by TRIZ theory, the new model soymilk structure is designed (Fig. 8). The main study process is: the end of motor shaft has two flanges, the center hole on the upper plate is larger than the radial dimension of that flange, there are two corresponding groove on the center hole of the middle plate, the motor shaft extends to the middle plate through the upper plate, drives the middle plate in rotation. The upper plate does not rotate, because it is jammed by the ended rotary column. And the bottom plate would be held stationary by the flange of the base, so that the first grinding cut area is formed in the upper plate and the middle plate and the second grinding zone is formed in the bottom plate and the middle plate. The soybean is cut respectively constituting and soymilk flow into the base, the heat pipe in the bottom plate heats to boil soymilk. Water in the process comes from the tank over

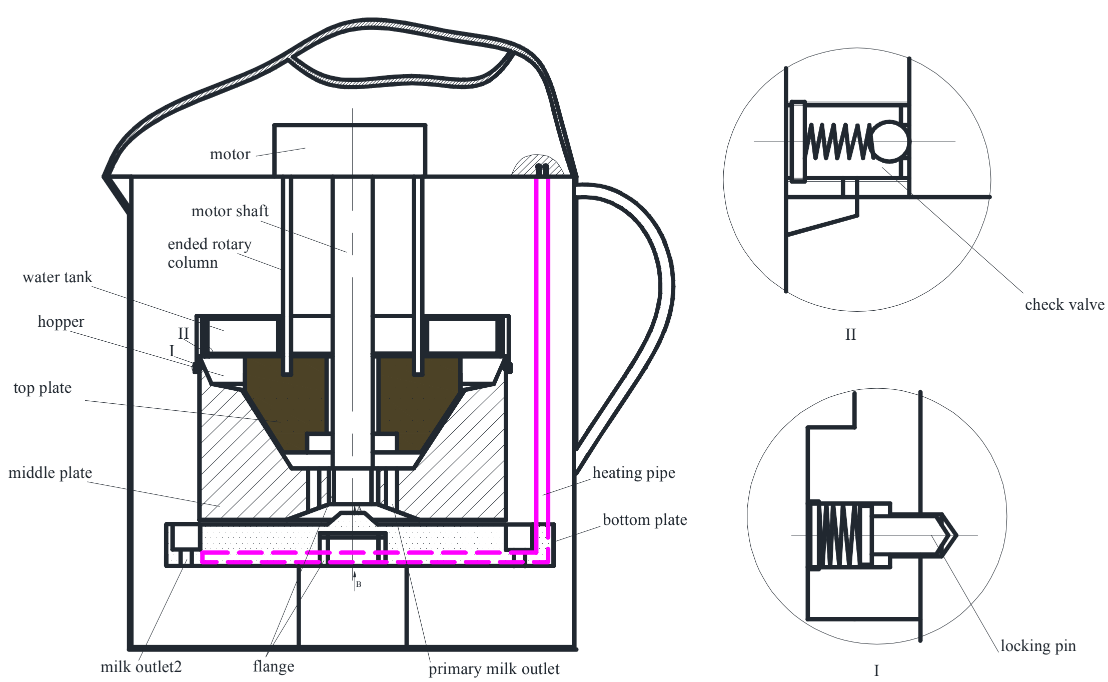
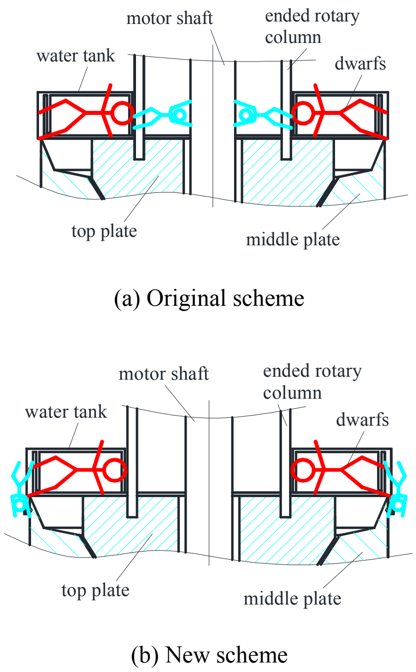


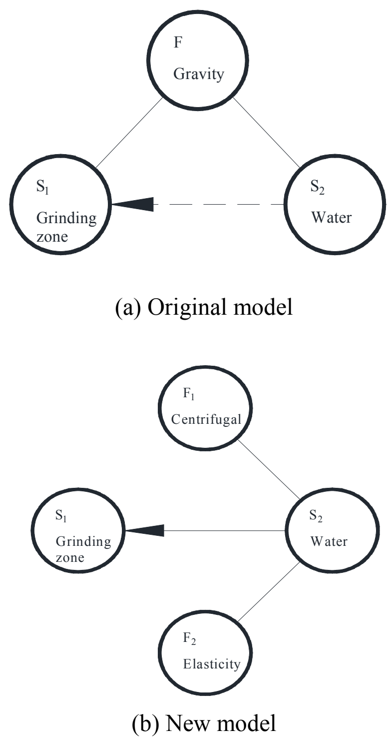

Fig. 8: The structure of the new soymilk mill




(a) Original scheme

(b) New scheme

Fig. 9: The interference problem is used by the dwarfs method




(a) Original model

(b) New model

Fig. 10: Using the substance-field model to solve the feeding water in tank rotating

the upper plate, the tank attached with the middle plate through the outside of the locking pin, the centrifugal force is generated, so that the one-way valve on the sidewall is open, the water flows out for soymilk preparing.

In overall structural design, there are two difficult problems need to be addressed:

- Water tank rotates with the middle plate and avoid interference the ended rotary column
- Water tank supplies water only in running

For the former, the dwarf's method in TRIZ theory is used to resolve (Fig. 9). The virtual water tank is constituted by some dwarfs, the original plan is that the middle dwarfs tightly connected with the motor shaft, thereby achieve rotation together with the motor shaft, but these dwarfs will be blocked that columns, which remain the upper plate stationary. According to the dwarfs of the TRIZ theory, the dwarfs in the middle of tank are adjusted to the periphery side and tightly connected with the middle plate, to achieve the same rotation aim with the motor shaft and not interfering the ended rotary column, i.e., the center of tank is empty for the rotary column being through it, while in the circumferential connection with a locking pin with the middle plate, is shown in region I structure of Fig. 8.

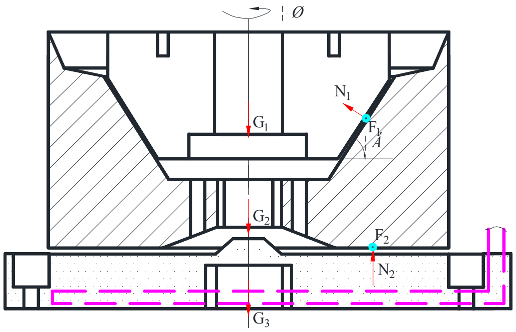
For the latter, if the openings are in the bottom of the tank, the water gravity fed continuously water to the grinding zone and that only feeding water when grinding is not guarantee, the substance-field analysis method of TRIZ theory is used to tackle this problem. The three elements of this system are: the water, the grinding zone, gravity (field). The substance-field model is established in Fig. 10a and this model is system type with "useful, but not a full action". Find the TRIZ Standard Solution (Table 3 to 7 in Zhao *et al*. (2010)) and use dual substance-field model, introduce the centrifugal force and the elastic potential energy field to strengthen the control of the water flow. The opening is in the bottom of the tank circumferential side and the one-way valve is installed, with the one-way valve spring action, the water cannot flow under static condition. When the tank is rotated, centrifugal force is generated, causes the one-way valve is opened, water flows into the grinding zone (Fig. 10b).

**Mechanics analysis of soymilk mill:**

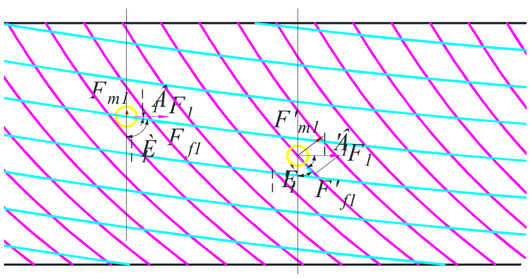
**Mill force analysis of milled soybean:** Grinding soymilk functions is realized mainly by the friction among the plates. Three plates are taken for the study objects; the force in the plate is shown in Fig. 11. For the first grinding zone (Fig. 11) $N_1 = G_1$, thereby the friction cutting force is obtained:

$$F_1 = \mu N_1 = \mu G_1 \cos\alpha \tag{1}$$

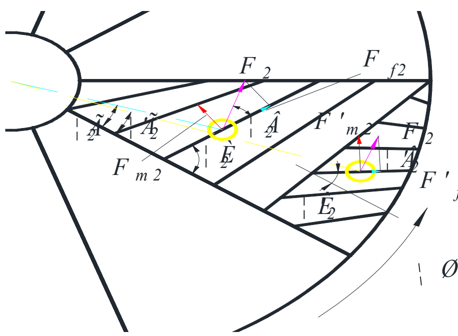
The $F_1$ direction is pointing out of the study and perpendicular to the study, the $G_1$ included the gravity of the tank. Similarly, for the second grinding zone, the friction cutting force is as follows:




(a) Total force status




(b) The force on the first mill region




(c) The force on the second mill region

Fig. 11: The force on the plate

$$F_2 = \mu N_2 = \mu(G_1 + G_2) \tag{2}$$

where,

- μ = Friction coefficient
- $G_1$ = The gravity of the upper plate (included the gravity of the tank)
- $G_2$ = The gravity of the middle plate

Seen from the above two equations, the friction force of the first grinding zone related the upper plate gravity and the cone angle and the frictional grinding force can be changed by adjusting the cone angle and plate gravity. The friction force of the second grinding zone related the gravity of the upper plate and the middle plate, if increase the friction force, need increase the gravity of the above two plates, so the high-density material is generally used (to the above mention, the material is high-density cast iron).

Figure 11b, in the first grinding zone between the upper plate and the middle plate, the mill force $F_{m1}$ and the transport force $F_{f1}$ of soybean are:

$$F_{m1} = F_1 \sin\beta_1 = \mu G_1 \cos\alpha \cos\theta_1 \tag{3}$$

$$F_{f1} = F_1 \cos\beta_1 = \mu G_1 \cos\alpha \sin\theta_1 \tag{4}$$

where, $\theta_1$ is the angle between the grinding stria and axis of the upper plate and it is constant.

Figure 11c, in the second grinding zone between the bottom plate and the middle plate, the mill force $F_{m1}$ and the transport force $F_{f1}$ of soymilk particles are:

$$F_{m2} = F_2 \sin\beta_2 = \mu(G_1 + G_2)\cos(\theta_2 - \gamma_2) \tag{5}$$

$$F_{f2} = F_2 \cos\beta_2 = \mu(G_1 + G_2)\sin(\theta_2 - \gamma_2) \tag{6}$$

where,

- $\theta_2$: The angle between the grinding stria and the region separated radius line, is a constant value
- $\gamma_2$: The angle between the radius direction of particles and the region separated radius line, it varies with the soymilk particles moving, which ranges 0-36°

**Motor starting torque analysis:** The friction torque $M_f$ between rotational parts and static parts and the inertia torque $M_i$ are overcome in the moment of the motor starts, which is calculated as follows:

$$M = M_i + M_f \tag{7}$$

$$M_i = J\varepsilon \tag{8}$$

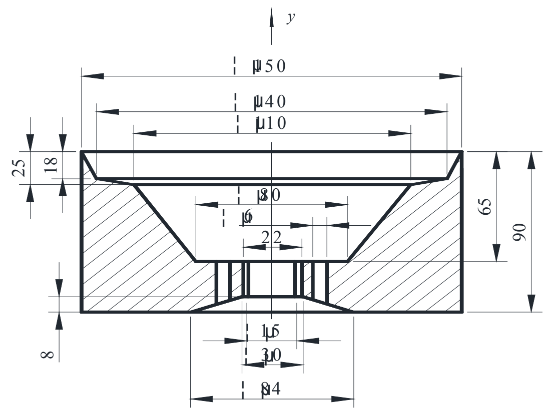
$$M_f = Fr \tag{9}$$

where,

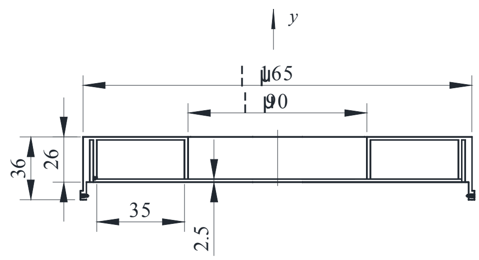
- J = The rotational inertia of the rotational parts
- ε = The angle speed of the rotational parts
- F = The friction force
- r = Average friction radius

The sizes of two rotary parts are shown in Fig. 12, the calculated mass of the middle plate is 6.7 kg and the rotational inertia is 0.024 kg/m$^2$; the mass of the water tank is 1 kg and rotational inertia is 0.005 kg/m$^2$, the total rotational inertia *J* is 0.029 kg/m$^2$. The plate reaches its nominal speed from start to 50 r/min lasted about 0.1 s and the angular acceleration ε is 50 π/3 rad/s$^2$, by the Eq. (8), $M_i = J\,\varepsilon = 1.25$ N/m.

Because of the mass of the upper plate is 3.7 kg, the total mass over the middle plate is 4.7 kg, the total



(a) Middle plate



(b) Water tank

Fig. 12: The rotary parts

mass over the bottom plate is 11.4 kg, a friction coefficient is 0.6, the average friction radius of the upper plate and the middle plate is 0.05 m, the average friction radius of the upper plate and the middle plate is 0.061 m, so $M_f$ = 0.53 N/m is obtained by the Eq. (9). Thus, according to Eq. (7), the total driving torque $M = M_i + M_f$ = 2.05 N/m is calculated and given a safe factor of 1.2, the motor drive torque is 2.50 N/m.

## CONCLUSION

In analyzing the existing problems of soymilk machines, TRIZ theory is applied to solve them. The new home-used soymilk mill is designed and mechanically analyzed; moreover, these results provide reference data for new soymilk designing:

- TRIZ theory is applied to the soymilk mill design, the conflict matrix tool is used to solve the problem of the conflict problem: space miniaturization is contradicted with the integration of soymilk preparation and boil, the conflict between the spatial structure simplifies and the disassembly structure. The plate stria structure optimization is used of evolutionary tools and the plate speed optimization is used of the invention principles, then the new structure and the suitable plate speed are obtained.
- To better optimize soymilk structure, the mechanics analysis of soymilk mill is processed, the force calculation model of the soybean and the soybean particles are given and the motor starting torque model is constructed, thus the practical reference for grinding stria scales parameters and motor parameter selection and optimization is provided.

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