# A Novel Coaxial Stack System for Petri Dish Dispenser

Te Shan, Zhenguo Sun(✉), Wenzeng Zhang, and Qiang Chen

Department of Mechanical Engineering, Tsinghua University, Beijing 100084, China
shanteqh@163.com, sunzhg@tsinghua.edu.cn

**Abstract.** Traditional stack systems for petri dish dispenser are complex in both structure and control systems, since they are driven by four or more motors. A novel coaxial stack system, with functions of extracting, opening, transferring, closing and inserting of petri dishes, is designed in this paper. It is driven by three motors, resulting in a simple control system. This coaxial stack system consists of a stacking frame, a tray, a step plate, a carrier and a piston. The stacking frame and the carrier are rotating coaxially leading to a smaller space occupation. Mechanical analysis and simulation of the key part of the stack system are described in details. The results of theoretical analyses and actual experiment show that the proposed coaxial stack system can work very well.

**Keywords:** Stack system · Petri dish · Reagent dispenser

## 1 Introduction

Petri dishes are commonly used in medical, chemical and biological laboratories [1, 2], especially for High Throughput Screening (HTS) [3-5]. In order to dispense reagent or liquid effectively, many prototypes have been developed for automation [6, 7]. With the help of modern control technology [9, 10], dispensers become more intelligent. The automatically filling system of petri dishes which applied with reagent dispenser has higher efficiency and labor saving than manually dispensing.

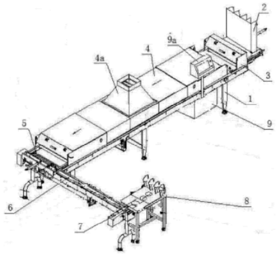
Efficient and stability of the stack systems are important for reagent dispenser. Extracting mechanism is the key technology of the stack system. A stack system can be used to store petri dishes, extract empty dishes from the stacker, transfer dishes from one station to another, insert filled ones back into the stacker. According to the arrangement mode of petri dishes, stack system with aforementioned functions has two main kinds: pipeline stack system and rotating stack system.

Traditional pipeline stack system has large volume occupation and low space utilization. There are many products such as the Petriswiss PS900 [11] and the Petriswiss mini PS 20 [12]. For example, a pipeline stack system (Fig. 1(a)) [13] includes an opening and filling mechanism, cooling chamber, closing mechanism and so on. Petri dishes are transferred in one-way on a belt conveyor, leading to a large area occupation.

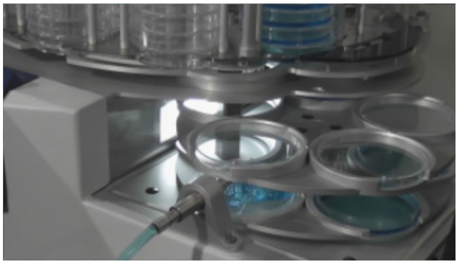
Traditional rotating stack systems, driven by more than three motors, are smaller and complicated in control. Typical commercial products are the Mediajet stacker [14] and the Mediafill stacker (Fig. 1(b)) [15]. For example, a rotating stacker [16] is


H. Liu et al. (Eds.): ICIRA 2015, Part II, LNAI 9245, pp. 511–522, 2015.
DOI: 10.1007/978-3-319-22876-1_44

driven by 4 motors: the first one for rotating the stacking frame, the second one for rotating the carrier, the third one for lifting dishes downward from the stacking frame, the forth one for inserting dishes into the stacking system. The motor action process is complex, a complicated control system will be resulted. The stacking frame and the carrier of most products have different axes which result in a large space occupation.




**(a) Pipeline stack system[13]**



**(b) Rotating stack system**

**Fig. 1.** Traditional stack systems

A novel stack system, named coaxial stack system, was designed in this paper. Driven by three motors, it can fulfill the functions of extracting, opening, transferring, closing and inserting of petri dishes. The stacking frame and the carrier of the coaxial stack system rotate coaxially. This stack system features the advantages of simple control system and smaller space occupation.

The design of the coaxial stack system is introduced in the second section of this paper. Then, the third section gives the mechanical analysis and simulation of the key parts of the coaxial stack system. In the last section, a reagent dispenser with the coaxial stack system is designed and prototyped manufactured.

# 2 Design of the Coaxial Stack System

## 2.1 Components of the Coaxial Stack System

As shown in Fig. 2(a), the proposed coaxial stack system consists of a stacking frame (Fig. 2(b)), a tray (Fig. 2(e)), a step plate (Fig. 2(f)), a carrier (Fig. 2(c)) and a piston (Fig. 2(d)). Fig. 2(g) shows the closed petri dish, the lid and the bottom part of a dish. The carrier, slightly above the base, comprises two coaxial, circular horizontal plates which are superimposed, each pierced with a series of corresponding circular openings; the openings of the upper plate having a smaller diameter than the lids but slightly larger than the diameter of the bottom parts to allow passing of the bottom parts while retaining the lids. This carrier can rotate on z-axis. The step plate is arranged between the upper plate and the bottom plate of the carrier. The tray, above the upper plate of the carrier and consolidated against the base, has two pierced openings. The stacking frame, above the tray, can rotate on z-axis. The piston, whose initial position is slightly above the base, located below the second opening of the tray, can move along the direction corresponding to z-axis.

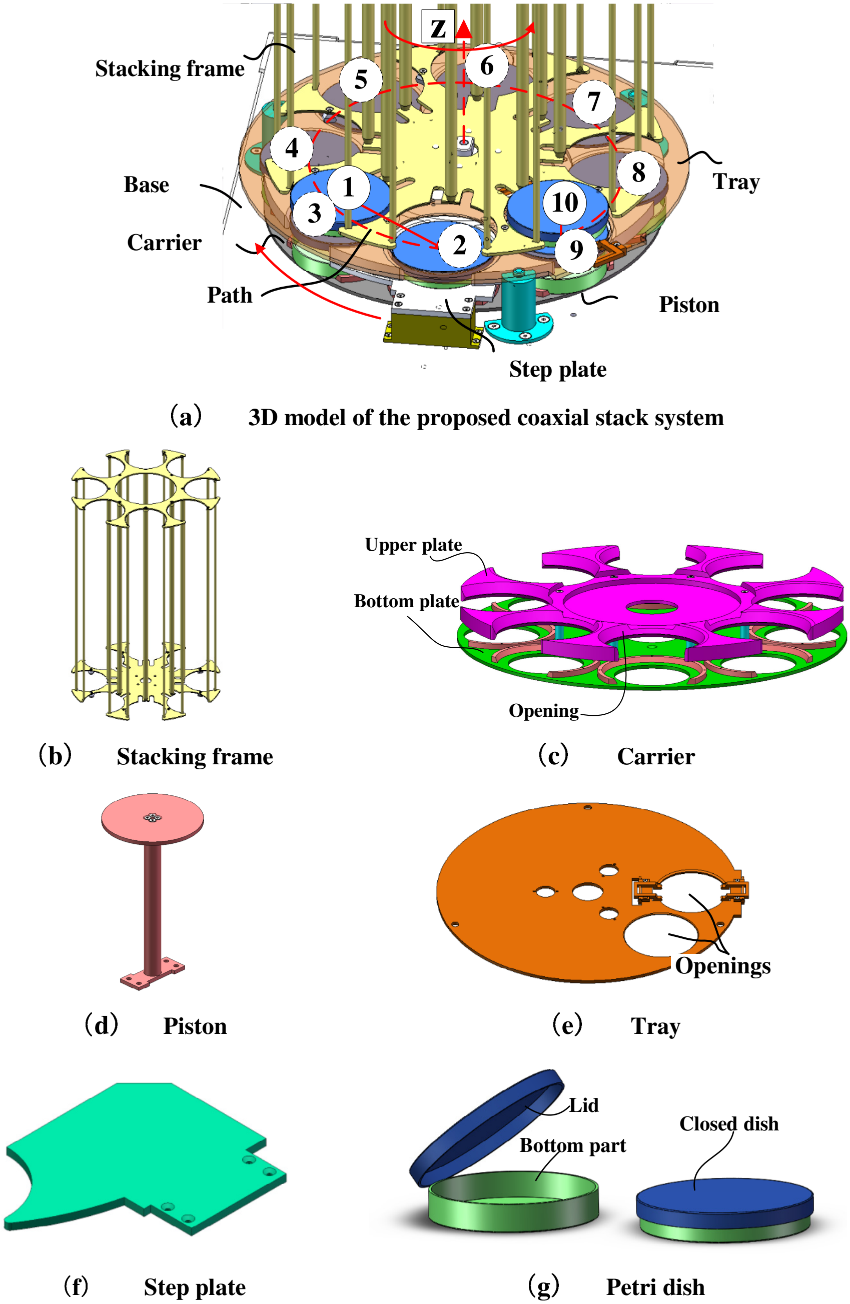



**Fig. 2.** Principle of the proposed coaxial stack system

## 2.2 Operation Process of the Coaxial Stack System

The operation process of the coaxial stack system is described as follows. Step one: the stacking frame rotates counterclockwise for a certain degree (Fig. 3(a)); step two: petri dish A goes along the stacking frame and finally drops into the opening of the upper plate of the carrier above the step plate (Fig. 3(b)); step three: after a short pause, the carrier starts to rotate clockwise for a certain degree, dish A goes along with the carrier and gradually reaches the edge of the step plate, when the carrier has rotated for the certain degree, dish A leaves the step plate, whose lid retained in the opening of the upper plate and bottom part on the bottom plate (Fig. 3(c)) (dish A is extracted and opened). At the same time, petri dish B drops into the opening of the upper plate of the carrier above the step plate. Step four, the carrier continues to rotate (Fig. 3(d)), bringing open dish A with its lid retained distant above the bottom part, from a station to another (dish A is transferred); at the same time, one by one petri dish is fetched out and opened (Fig. 3(d)). Step five, when dish A is carried to the inserting station (Fig. 3(e)), the piston begins to elevate upward, lifting the bottom part of dish A from the bottom plate up into the lid retained in the upper plate, which close the petri dish A, and then the piston lifts dish A into the stacking frame (Fig. 3(f)) (dish A is inserted). Step five, the piston moves downward to its initial position (Fig. 3(g)). The carrier continues to rotate, petri dish is closed and stored one after another (Fig. 3(h), (i), (j)).

A cylindrical coordinate system is established (shown in Fig. 7(a)): the center O coincides with the center of the upper surface of the tray; the r-axis coincides with the connecting line between O and the center of the first opening of the tray; the z-axis is coincided with the direction perpendicular to the tray.

Let $t_1$ represents the time of the stacking frame rotating for a certain degree, s; $t_2$ stands for the time of the carrier rotating for a certain degree, s; $t_3$ stands for the time of closing and inserting one dish into the stacking frame, s; $t_4$ represents the interval time between movements of the carrier, s; $t$ stands for the whole time of one cycle, s.

When a dish is inserting, the carrier must stand still, which means:

$$t_3 < t_4 \tag{1}$$

There are 8 openings pierced in the carrier, so the carrier will rotates 7 times and pause 7 times before one dish is stored. So one gets:

$$t = 7t_2 + 7t_4 \tag{2}$$

At different time, the operated dish is in different position, as shown in Fig. 4. It is obvious that the operated dish A is moving on the cylindrical surface $z - \beta - r_0$($r_0$ stands for the distance between O and the center of the dish).

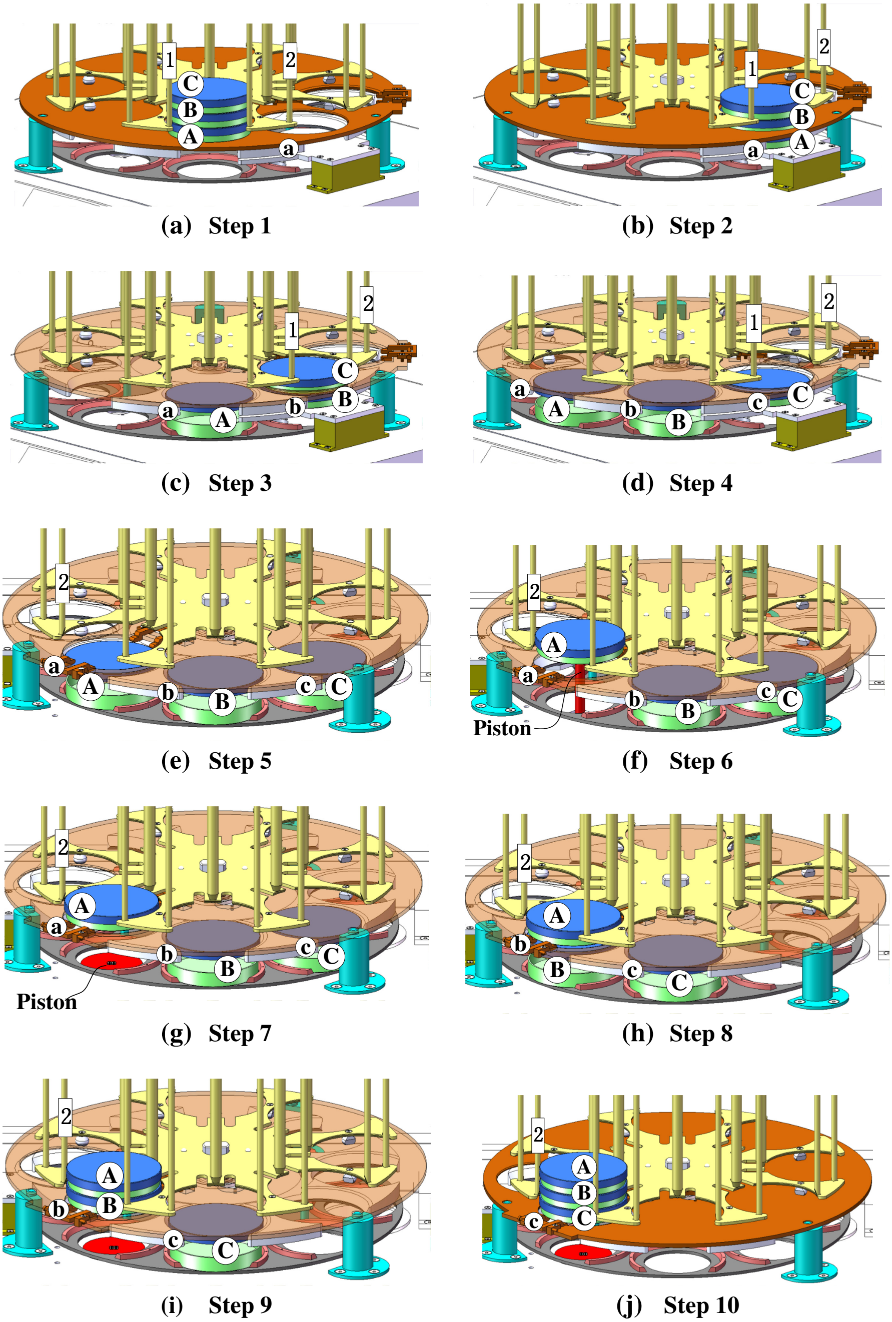



**Fig. 3.** Operation process of the coaxial stack system

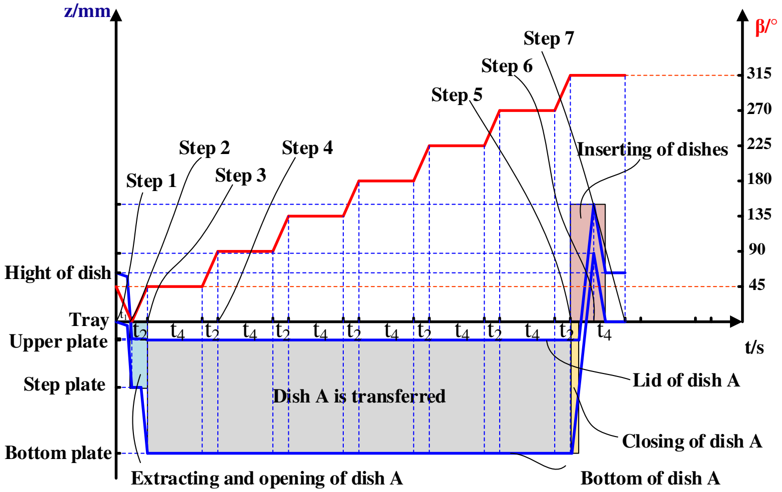



**Fig. 4.** Position of dish A at different time

## 3 Mechanical Analysis of the Coaxial Stack System

This section gives mechanical analysis and simulation of the key part of coaxial stack system. Contact force during dishes falling onto the step plate is analyzed firstly (Fig. 5(b)). After that, the simulation of under what condition the dishes will fall onto the step plate rather than stuck by the openings of the upper plate of the carrier. The result shows that when the dip angle of the guide surface is larger than 0.9 (rad), dishes can smoothly fall onto the step plate. The degree of the dishes can fall onto the step plate relates to the dip angle of the guide surface, the friction coefficient between dish and the step plate and the friction coefficient between dish and the guide surface.

Let:

$G_t$ -the total gravity of a column of dishes, N;

$G$ -the gravity of one petri dish, N;

$n$ -the number of the column of dishes;

$F_1, F_2$ -the supporting force at the bottom right corner of the lowest dish and the bottom left corner of the lowest dish respectively, N;

$f_1, f_2$ -the friction force between the lowest dish and the step plate and the lowest dish and the guide surface respectively, N;

$\mu_1, \mu_2$ -the friction coefficient between the lowest dish and the step plate and the lowest dish and the guide surface, N;

$d_1$ -the diameter of the bottom part of petri dish, mm;

$h$ -the distance between bottom left corner of the lowest dish and the step plate, mm;

$\theta$ -the dip angle of the guide surface, rad;

$\alpha$ -the dip angle of the lowest petri dish, rad;

In order to make dishes falling onto the step plate smoothly, there must be a guiding surface on the openings of the upper plate. When dishes fall from the tray, firstly, the bottom right corner of the lowest dish get to the step plate, while the bottom left corner comes into contact with the guiding surface, then the bottom left corner slide along the guiding surface, and finally get to the step plate. If the dip of the guiding surface is too large, the dish will stuck by the upper surface of the upper plate shown as Dish A, else if the dip of the guiding surface is too small, when the bottom left corner of the lowest dish get to the guide surface, the dish may not be able to slide along the guide surface. The force analysis is shown below when the whole system is balanced:

$$\begin{cases} G_t = F_1 + F_2\cos\theta + f_2\sin\theta & \text{(a)} \\ F_2\sin\theta = f_2\cos\theta + f_1 & \text{(b)} \\ G_t\dfrac{1}{2}d_1\cos\alpha = F_2 d_1\cos(\theta-\alpha) + f_2 d_1\sin(\theta-\alpha) & \text{(c)} \end{cases} \tag{3}$$

Combining equation (a) and (c), the expressions of $F_1$ and $F_2$ is arrived at:

$$\begin{cases} F_2 = \dfrac{\frac{1}{2}G_t\cos\alpha}{\cos(\theta-\alpha)+\mu_2\sin(\theta-\alpha)} \\ F_1 = G_t - \dfrac{\frac{1}{2}G_t\cos\alpha(\cos\theta+\mu_2\sin\theta)}{\cos(\theta-\alpha)+\mu_2\sin(\theta-\alpha)} \end{cases} \tag{4}$$

The maximum static frictional force is approximately equal to sliding frictional force. When the bottom left corner begins to slide along the guiding surface, one gets:

$$\begin{cases} f_2 = F_2\mu_2 \\ f_1 = F_1\mu_1 \end{cases} \tag{5}$$

The force analysis on the horizontal direction arrived at:

$$F_2\sin\theta > f_2\cos\theta + f_1 \tag{6}$$

Set:

$$D = F_2\sin\theta - f_2\cos\theta - f_1 \tag{7}$$

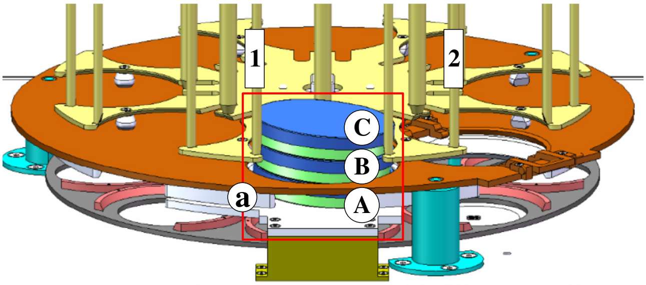
One gets:

$$D = \frac{G_t \cos\alpha(\sin\theta - \mu_2\cos\theta) + G_t\mu_1\cos\alpha(\cos\theta + \mu_2\sin\theta)}{2(\cos(\theta-\alpha) + \mu_2\sin(\theta-\alpha))} - G_t\mu_1 \tag{8}$$

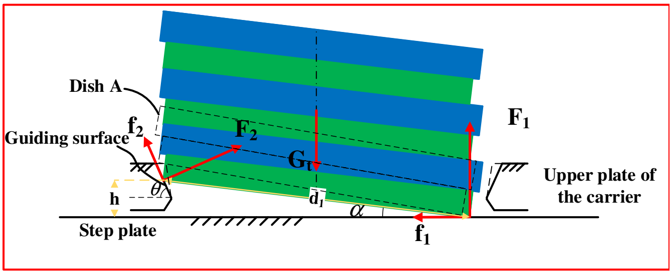
Set $D$ as the function of $\theta$ and $\alpha$. The mass of one petri dish is about 13.47g, so $G$=0.1347N. The range of $n$ is from 1 to 33, so the range of $G_t$ is from 0.1347~4.4451N. $\mu_1=\mu_2$=0.447 based on experimental measurement. The diameter of the bottom part of the dish is 85.8mm, so $d_1$=85.8mm. The distance between the bottom left corner of the lowest dish and step plate ranges from 5.5~15mm, so $h$ is from 5.5~15mm. $\alpha$ is caused by $h$ and $d_1$, one gets:

$$\sin\alpha = \frac{h}{d_1} \tag{9}$$

The range of $\alpha$ is from 0.0641~0.1757. The range of $\theta$ is from 0 to $\frac{\pi}{2}$. For any $\alpha$ from 0.0641~0.1757, the constant value $\theta$ should make sure that $D$ is positive. The relationship of $D$, $\alpha$ and $\theta$ is shown in Fig. 6.




**(a) 3D model when dishes are falling**




**(b) Mechanical analysis of dishes when falling**

**Fig. 5.** Mechanical analysis of dishes when falling

The conclusions from Fig. 6 are listed below:

1) When the dip of guide surface $\theta$ increases, $D$ will increase obviously, which means the degree of dishes smoothly fall onto the step plate increases while the dip of guiding surface increases. When $\theta$ is larger than about 0.9 (rad), the falling will go on smoothly no matter how much $\alpha$ is.
2) When the dip of the lowest dish decreases, $D$ will increase slightly, which means the value of $\alpha$ does not much affect the degree how much dishes will fall onto step plate.

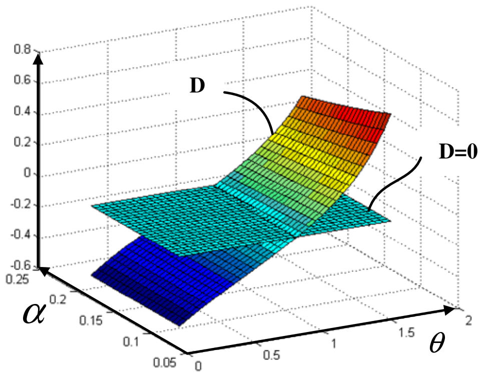



**Fig. 6.** Relationship among $D$, $\boldsymbol{\theta}$ and $\boldsymbol{\alpha}$

## 4 Prototype Reagent Dispenser with the Coaxial Stack System

In the beginning of this section, peristaltic pumps are introduced. Then there comes the components of a reagent dispenser with novel coaxial stack system. Thirdly, a prototype reagent dispenser with the coaxial stack system is manufactured. The specifications of the prototype reagent dispenser are given at the end of this section.

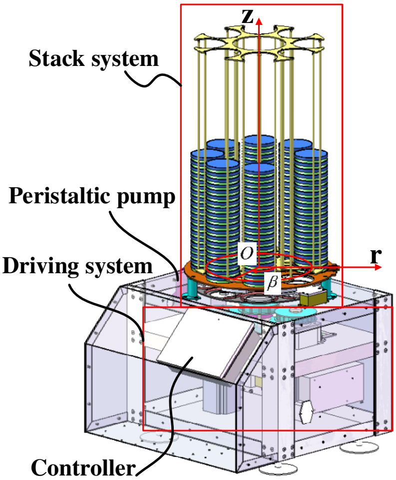
### 4.1 Peristaltic Pump

A peristaltic pump, a biological pump which employs periodic wavelike squeezing motions which travel along a vessel and force the fluid forward, is wildly used in chemical analysis and drug screening. The pump mechanisms do not get in touch with the fluid, ensuring sterility and preventing contamination. This kind of pumps can transfer liquids continuously, which is necessary for HTS.

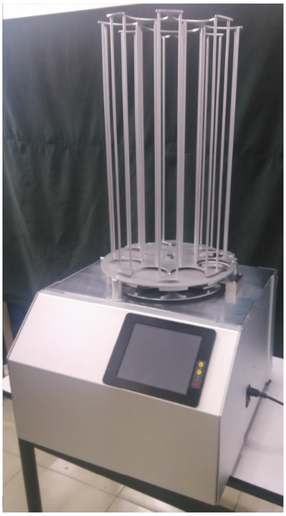
### 4.2 Components of the Reagent Dispenser

The reagent dispenser with coaxial stack system, as shown in Fig. 7(a), consists of the coaxial stack system, a peristaltic pump, the driving system and the controller. First,

the stack system can extract and open dishes, then transport them from one station to another, finally close and insert them. Second, the peristaltic pump, purchased and integrated with the whole device, can deliver the goal liquid from reservoir to opened dishes at the filling station. Third, the driving system of the stack system drives the moving parts of the stack system to move as planned. Forth, the controller controls the driving system.




(a) 3D model



(b) Prototype reagent dispenser

**Fig. 7.** Illustration of the reagent dispenser with the coaxial stack system

A cylindrical coordinate system is established: the center O coincides with the center of the upper surface of the tray; the r-axis coincides with the connecting line between O and the center of the first opening of the tray; the z-axis is coincided with the direction perpendicular to the tray.

### 4.3 Prototype Reagent Dispenser with the Coaxial Stack System

The prototype reagent dispenser with the coaxial stack system is shown in Fig. 7(b). The dip angle of the guide surface is 1.1(rad). Experiments of the prototype with no-load, half-load and full-load have been made, which demonstrate the result of mechanical analysis. In one experiment, 64 dishes are automatically dispensed with this prototype. 20 ml/dish of liquid is supposed to be filled. Table 1 shows the real volume of liquid dispensed in each dish.

**Table 1.** The volume (ml) of liguid dispensed in each dish

| | Column No. | | | | | | |
|---|---|---|---|---|---|---|---|
| **Dish No.** | **1** | **2** | **3** | **4** | **5** | **6** | **7** |
| **1** | 19.89 | 19.93 | 20.01 | 19.99 | 19.99 | 19.98 | 19.88 |
| **2** | 19.95 | 19.92 | 20.02 | 19.98 | 19.96 | 19.96 | 20.04 |
| **3** | 20.01 | 20.08 | 20.08 | 19.97 | 19.99 | 19.94 | 20.05 |
| **4** | 19.95 | 20.04 | 19.90 | 20.03 | 20.00 | 20.05 | 19.99 |
| **5** | 19.97 | 19.96 | 19.99 | 19.89 | 20.01 | 20.09 | |
| **6** | 19.97 | 19.97 | 20.04 | 19.92 | 19.92 | 20.08 | |
| **7** | 19.98 | 20.02 | 19.99 | 20.00 | 19.93 | 19.94 | |
| **8** | 19.95 | 19.96 | 19.94 | 19.98 | 19.98 | 19.97 | |
| **9** | 19.83 | 19.99 | 19.99 | 20.01 | 20.03 | 19.90 | |
| **10** | 19.88 | 19.96 | 20.00 | 19.95 | 20.04 | 19.93 | |

It takes about 9 minutes to finish the whole operation. The precision of dispensing is less than 1% and it takes less than 9 seconds to dispense one petri dish.

### 4.4 Features of the Coaxial Reagent Dispenser

The main advantages of the coaxial reagent dispense are: 1) the number of motors used in this stack system is less than the motors used in traditional stack systems, resulting in the reduction of the complexity of the control system; 2) the carrier is installed right below the stacking frame and does not need extra space, which improves the space utilization of this device.

The main specification of the coaxial reagent dispenser is shown in Table 2.

**Table 2.** Main Specification of the coaxial reagent dispenser

| Items | Parameters |
|---|---|
| Dimensions | 577 mm ×562 mm ×1080 mm |
| Number of motors | 3 |
| Capacity | 200 petri dishes |
| Dish filling speed | 400 dishes/hour |
| Volume to dispense | 10-30 ml |
| Filling precision | <1%(at 20 ml) |

## 5 Conclusion

In this paper, a novel coaxial stack system for petri dish reagent dispenser with functions of extracting, opening, transporting, closing and inserting is designed. The coaxial stack system is driven by three motors which result in a simple control system. The stacking frame and the carrier of this stack system rotate coaxially leading to smaller area occupation. The coaxial stack system can be used for petri dish reagent dispenser with high efficient, simple in structure and control. The result of analyses and experiment has shown that the stack system can operate very well as proposed. A prototype reagent dispenser with the coaxial stack system is manufactured. The capacity of the stacking frame is 200 petri dishes; the velocity of dispensing is about 400 dishes per hour; the volume of liquid can be dispensed is from 10-30 ml and the precision of dispensing is less than 1% (at 20 ml);

**Acknowledgements.** The authors gratefully acknowledge the financial support from the National Key Scientific Instrument/Equipment Development Project of China (No.2012YQ 150087).

## References

1. Lecellier, G., Philippe, S.: Rapid methods for nucleic acids extraction from petri dish-grown mycelia. Current Genetics **25**(2), 122–123 (1994)
2. Sreekumar, T.V., et al.: Single-wall carbon nanotube films. Chemistry of Materials **15**(1), 175–178 (2003)
3. Beydon, M.H., et al.: Microbiological high throughput screening: an opportunity for the lead discovery process. Journal of Biomolecular Screeing **5**(1), 13–21 (2000)
4. Masayoshi, I., et al.: Automated filtration-based high-throughput plasmid preparation system. Genome Research **9**(5), 463–470 (1999)
5. Rudnicki, S., Johnston, S.: Overview of Liquid Handling Instrumentation for High‐Throughput Screening Applications. Current Protocols in Chemical Biology, 43–54 (2009)
6. Stanchfield, J., et al.: Precision 96-channel dispenser for microchemical techniques. BioTechniques **20**(2), 292–297 (1996)
7. Tanguy, L., et al.: Pressure Driven and Regulated Dispenser for the Microliter Range. MicroFluidic Handling Systems, 50–53 (2012)
8. Alexan, A.I., Osan, A.R., Oniga, S.: Advanced Medication Dispenser. Carpathian Journal of Electronic & Computer Engineering **6**(2) (2013)
9. Pak, J.G., Park, K.H.: Construction of a smart medication dispenser with high degree of scalability and remote manageability. BioMed Research International **2012** (2012)
10. Liang, D., et al.: Online liquid calibration technologies. In: Proc. 1st Int. Conf. on Micro Fluidic Handling Systems. The Netherlands, Enschede (2012)
11. Petriswiss PS900. http://www.biotoolswiss.com/agar-filler/petriswiss-agar-filler/index.html
12. Petriswiss mini PS20. http://www.biotoolswiss.com/assets/hp017_ps20-flyer.pdf
13. Yan, C.: Fully-automatic packaging system of disposable plating medium. CN Patent 103466527 A (2003)
14. Mediajet versatile and reliable media processing. http://www.integra-biosciences.com/sites/pdf/flyer/103099_V08_Flyer_MEDIAJET_EN.pdf
15. The power of innovation. For automated pouting and stacking of culture media in petri dishes. http://www.systec-lab.com/images/pdf/Pros_Systec_Mediafill_E.pdf
16. Brelivet, N., et al.: Device for dispensing a product in a petri dish. U.S. Patent No.8,561,376 (2013)