SIMULATION OF SOUTHERN POTATO GRADER BASED ON ADAMS
/
基于 ADAMS 的南方马铃薯分级机构仿真研究

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Keywords: *ADAMS, southern potato, grader, simulation*

ABSTRACT

Based on the analysis of existing grading methods, this study focuses on developing a new grading scheme for southern potato, which can automatically adjust the distance between two rolling bars. Using ADAMS software the dynamic simulation model of potato grader has been established, and the simulation results showed that the little potato P1, middle-sized potato P2 and big potato P3 were separated successively. It could strongly prove that this design is feasible. There was little motion when the potatoes were under grading, which indicated that the device worked smoothly. The analysis results of contact forces showed that as the weight of the potato increases, the force between it and the rolling bars enhances, especially for the force between the potato and the movable bars, as in the experiment the maximum value of the contact force between P4 and moving roll was 813.7N. The conclusions can provide the basic data to the optimum design of sample machine.

摘要

分析已有物料分级方法，设计出一种可自动调节辊杆间距的南方马铃薯机械化分级方案；应用 ADAMS 软件构建马铃薯分级机构动态仿真模型，仿真试验结果表明：小薯 P1、中薯 P2、大薯 P3 先后被分离出来，机构设计方案可行，薯块在辊杆上跳动较小，机构运动较平稳；接触力分析结果表明：薯块与辊杆接触力随薯块质量增大而变大，其中与动辊杆接触力变化最显著，试验中超大薯 P4 与动辊杆的极值接触力达 813.7 N；该研究为样机制作提供了优化设计基础。

INTRODUCTION

China is one of the main potato producing countries in the world. In 2013 its cultivated area reached up to 8421 acres and the yield was more than 19.18 million tons, which ranked first in the world *(MOA Department of Plantation Management, 2014)*. In China, "The major production of potato is in the north, while the economic benefit is in the south ". It is because planting winter potato in the south can take full advantages of the idle paddies after rice harvest. Its planting time is short and can go into the market very soon, which can make up for the shortages of the season-restricted northern potato. With its high economic efficiency, the southern potato is popular with the market and the planting households. At present, potato planting in southern China has gradually transferred to the mechanized production not only in planting, but also in field management and harvesting. But the mechanization in potato grading progresses slowly, people still use manual grading method, which is labour-intensive and inefficient, and at the same time can't respond quickly to market demands *(PingYuan Xiong et al, 2011)*. Grading equipment imported from abroad are expensive and difficult to maintain, while the domestically developed grading equipment is still in trial stage and of low efficiency, especially when it is faced with the juicy and thin-skinned southern winter potato, they can help to make high injury rate. Grading method is the key of potato grading equipment, so this study focuses on designing a simple and efficient grading mechanism based on the physical properties of southern potato. By using the ADAMS software to make kinematics analysis, this study will verify the correctness of the device design scheme and make clear the kinematic parameters, which can provide designing basis for the prototype production.

MATERIAL AND METHOD

Existing grading methods

There are several methods in fruits grading: mesh screen method, grid cylinder method, weight grading method, optical method and rolling-bars grading method *(Blasco et al, 2009; LiangLong Hu, et al, 2007; LiuFang ShenTu et al, 2014; Mendoza et al, 2014; Riquelme et al, 2008; XiaoPing Yang et al, 2014;*

*YiBin Ying et al, 2014).*Mesh screen method is a widely used grading method. Its grading accuracy can reach to 95% within the error range of 12.7mm, but this method can make the fruits wear with the mesh seriously, which will easily harm the skin of fruits. Grid cylinder grading equipment consists of several rollers, each roller has unique gap between its grid bars, and the gap will extend as the roller ranges from the minimum level to the maximum level. When the fruit's size is smaller than the gap, it will fall into the corresponding hopper. This method has high efficiency, but the fruits collide and strike strongly in the equipment, which can make them easily be injured. Weight grading method is based on the principle of leverage. It firstly puts the fruits and the counterweight into two cups at both ends of the stent. When the counterweight is pushed slowly along the stent to the spindle, the trimming moment reduces, which will make the cups lose imbalance and tip over, and the fruits will fall into the appropriate hoppers. Because this method bases solely on weight index, its reliability is mediocre. It requires the fruits put into the cup singly, which will results in low grading efficiency. Optical grading method uses image processing technology to make non-contact measurements. The fruit is irradiated with light of certain wavelength, and the reflecting signals will tell its colour, maturity and size characteristics. When the fruit satisfies the grading conditions, the controlling device will pick it to the corresponding conveyor belt. This method is of innovative technology, high grading accuracy and efficiency, but it requires high level of professional knowledge and high cost. Besides, with its immature technology, optical grading method is difficult to be promoted. The principle of the rolling-bars grading method is equipping a rotating roller to the conveyor. When the size of the fruit is smaller than the gap between two adjacent rollers, it will fall into the corresponding hopper. Such an equipment runs smoothly, but requires that the gap between the rollers should be variable to achieve different size fractions. Southern winter potato with its high moisture, thin skin and crisp pulp, is prone to bruising and skin scratching. The design below takes the rolling-bars grading method. By optimizing the installation of adjacent roll bars, it achieves the goal of automatically adjusting the gap to meet the requirement of grading different sizes of potatoes.

Structure design of the grader

Southern winter potato can be seen approximately as an ellipsoid *(ChunHai Wang, et al, 2008)*. Its grading depends on the minor dimension of the ellipse (d), d $\in$(37,100) mm. The potatoes are divided into four levels, grading parameters are listed in Table 1. The process of potato grading is: The potatoes enter from the feed inlet to the conveyor belt and spread out evenly, then they enter the first grade transferring area (level 1 grading area), in this area the potatoes of d$\in$(37.50) mm fall into the first level discharge port, while the remaining potatoes continue processing on the belt and go into the second grade transferring area (level 2 grading area), in this area the potatoes of d$\in$ (50.70) mm fall into the second level discharge port, the remaining potatoes then go into the third grade transferring area (level 3 grading area), the potatoes of d$\in$ (70,100) mm fall into the third level discharge port, and finally the oversized potatoes of d> 100mm are output from the end of the grading equipment. The structure diagram of the southern winter potato grading equipment is shown in Figure 1.The conveyor belt is made up of a series of rolling bars, and the potatoes locate in the gaps of the adjacent bars. The bars are divided into fixed rolling bars and movable rolling bars, and the fixed roll bars are installed into the fixed chain plate while the movable rolling bars are installed into the chain plate with a sliding chute in the middle and the bars can move up and down in the chute. The movable rolling bars are placed upon the grading baffles whose distribution is a ladder-like shape. When the movable rolling bars fall from one grading area to the next, with their own gravity and the extrusion of the potatoes, they will drop into the next baffle, and the gap between the bars becomes larger, resulting in the separation of the potatoes whose sizes are accord with this gap. The grading levels are shown in Figure 2, where δ1=36.2mm, δ2=50mm, δ3=70mm, δ4=100mm.

Table 1

Potato grading parameters

Level	Minor dimension, d [mm]	Mass, m [kg]
1	37 < d < 50	0.029 < m < 0.071
2	50 < d < 70	0.071 < m < 0.19
3	70 < d < 100	0.19 < m < 0.57
4	d>100	m＞0.57

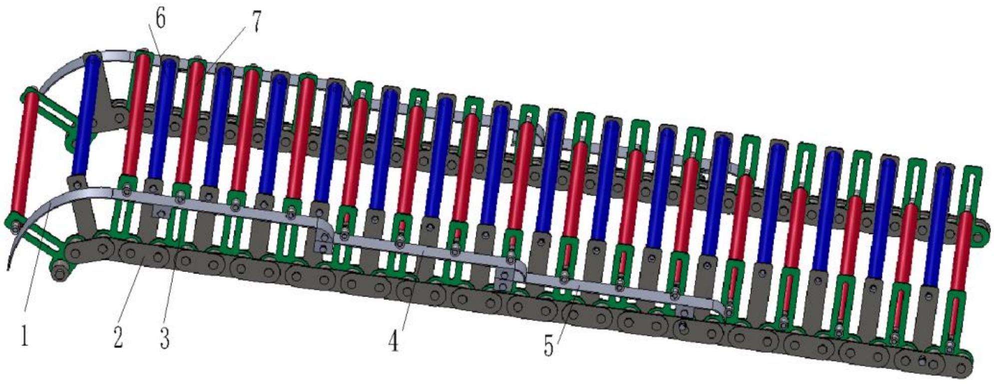


Fig.1 – Schematic on the structure of the Grader
1 – The grade 0 baffle; 2 – The fixed chain plate; 3 – The movable chain plate; 4 – The first level baffle; 5 – The second level baffle; 6 – The fixed rolling bar; 7 – The movable rolling bar

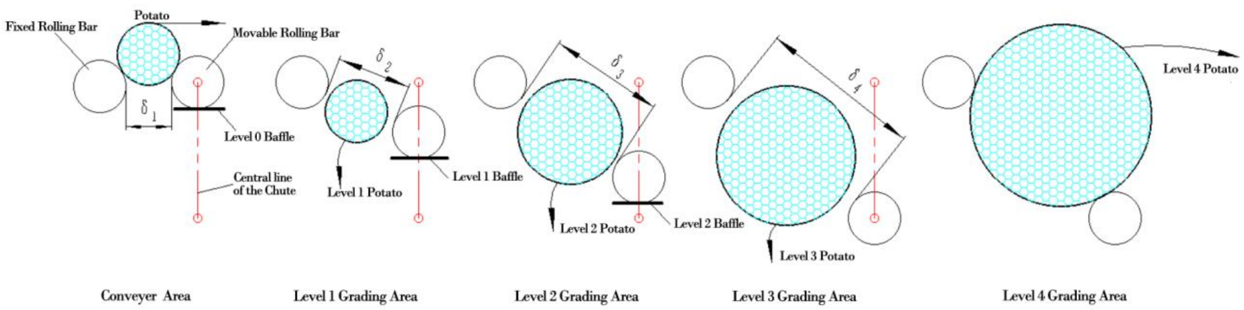


Fig.2 – Schematic on potato grading

Equipment modelling

This study used the 3-D designing software SolidWorks to construct the three-dimensional model of potato grading mechanism. To simplify the model and reduce the software loading time, this model had omitted the nuts, bolts, pins, washers and other fasteners. As the final ADAMS model is made up of basic components, such an ellipsis would not affect the simulation result. Exporting the 3-D model into Parasolid format (extension as * .x_t), then putting into the ADAMS software, setting the properties of the components and the kinematic pair, eventually the final simulation model is shown in Figure 3. The geometry dimensions and physical parameters were measured in this research. Based on measurement results, this study defined 4 potato levels P1, P2, P3, P4 as the test samples, the modelling parameters are shown in Table 2.

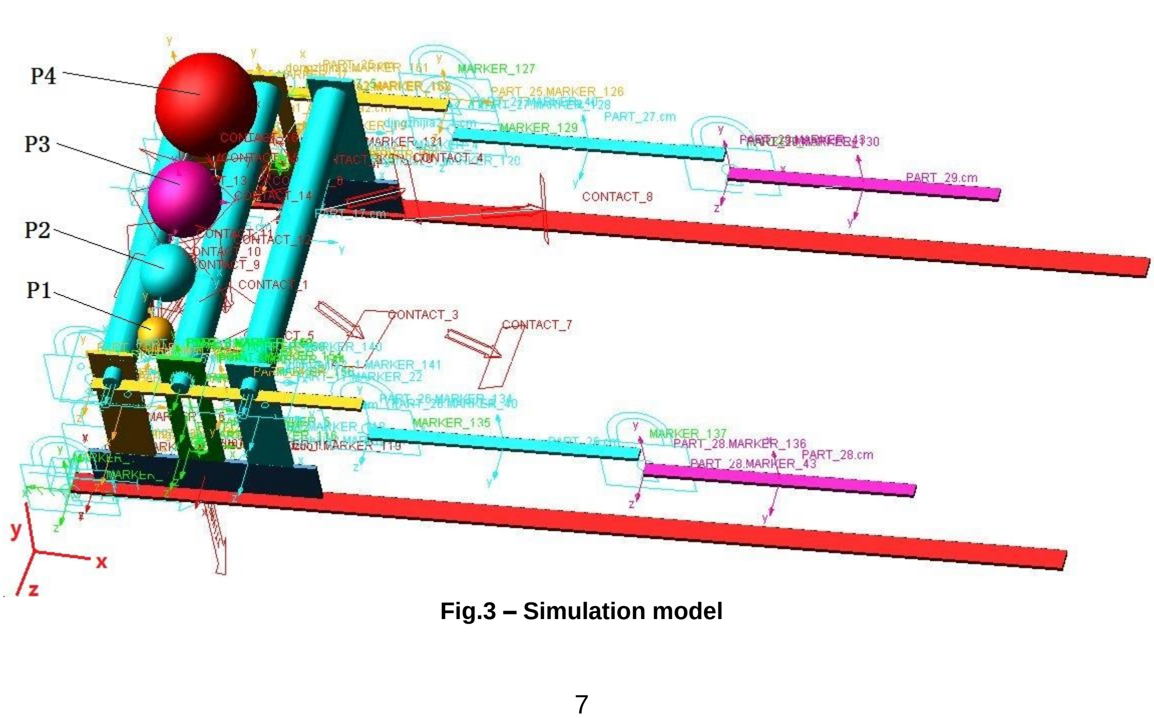


Fig.3 – Simulation model

Table 2

Parameters of the potato model

Type	Minor axis, b [mm]	Major axis, a [mm]	Density [kg/m3]	Mass, m [kg]	Center coordinates [mm]
P1	40	45	1.08×103	0.041	(-38.1, 200.18, -39.5)
P2	60	65	1.08×103	0.130	(-38.1, 220.38, -111.5)
P3	80	80	1.08×103	0.307	(-38.1, 234.35, -203.5)
P4	110	115	1.08×103	0.787	(-38.1, 252.60, -320.5)

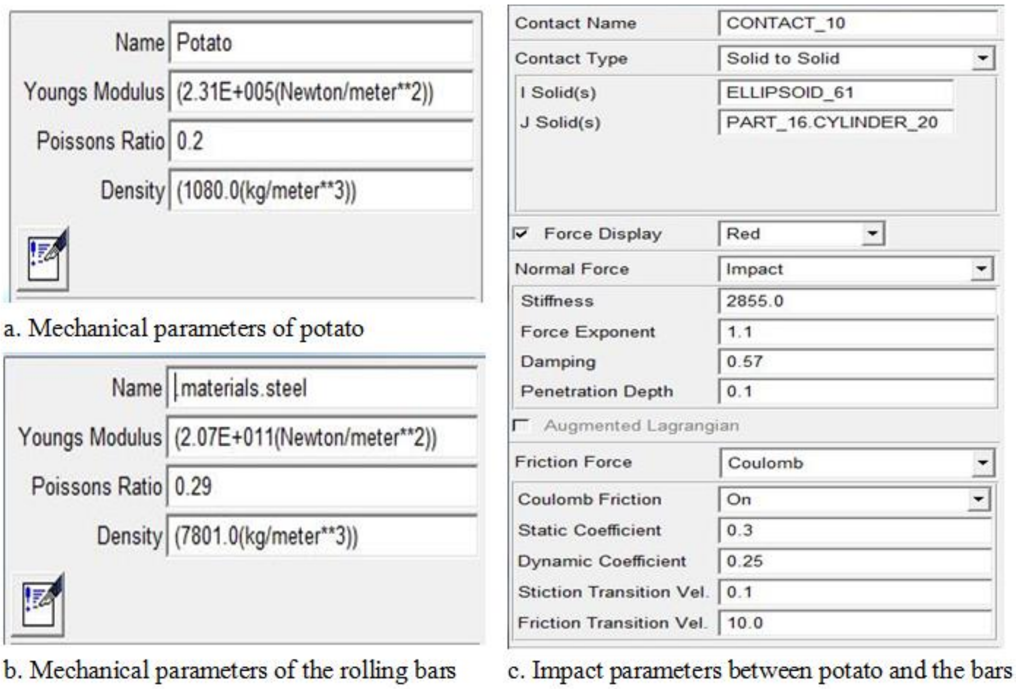
There is contact impact force between the potato and the rolling bar, and its function can be represented by the spring-damping model *(XueBin An, ShangFeng Pan, 2014)*. The contact impact force *F,* is defined as:

$$F = k \cdot g^{e} + step(g, d_0, c_0, d_{\max}, c_{\max}) \cdot \frac{dg}{dt}, \text{ [N]} \quad (1)$$

where:

k represents stiffness of the spring; g is the penetration depth between potato and rolling bar; e represents shape index which determines the shape of the force- displacement curve; d_0 is the starting value of g, which in this case is 0; c_0 is the initial value of *step()* function, when d_0 is 0, c_0 will be 0;d_{max} is the maximum allowable penetration depth; c_{max} is the maximum damping value adopted when it reaches the maximum allowable penetration depth; *step()* represents step function.

It also set the material of the potatoes, the material of the rolling bars, and the Impact parameters between potato and the bars as shown in Figure 4.



a. Mechanical parameters of potato

b. Mechanical parameters of the rolling bars

c. Impact parameters between potato and the bars

Fig.4 – Mechanics parameter settings of potato and the bars

RESULTS

Motion simulation

Setting the forward velocity of the initial conveyor as 200 mm/s, the simulation time as 4s, the steps of simulation as 120, this study respectively has measured the displacements in the Y direction, velocities in the X direction and the accelerated velocities in the Y direction of the centroids of potato P1, P2, P3 and P4. The results are shown in Figures 5-7.

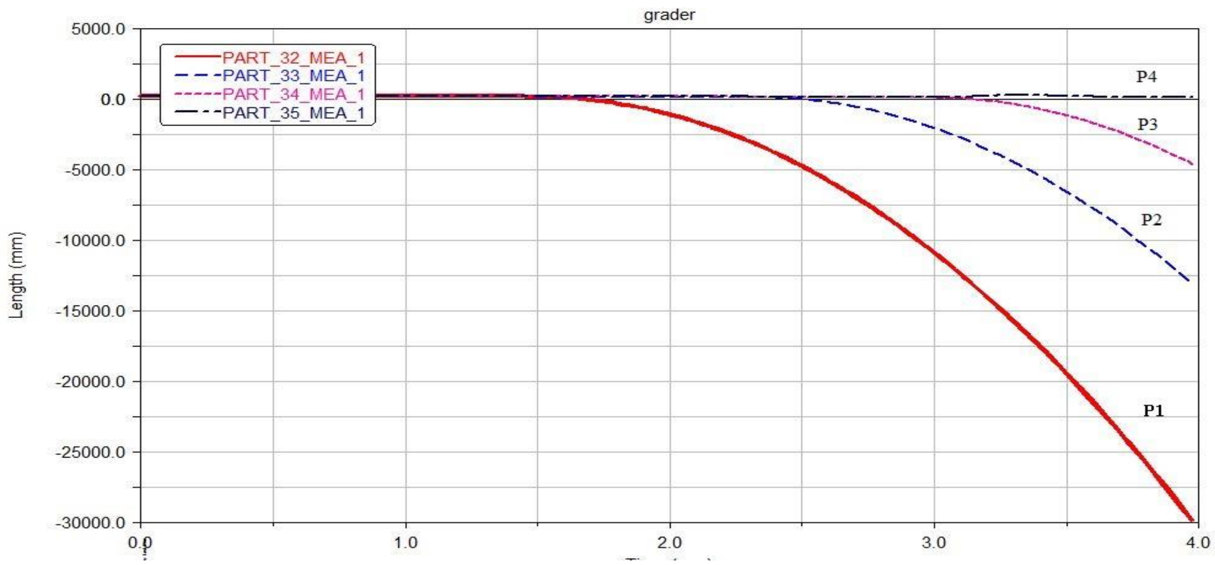


Fig.5 – The displacements of potatoes' centroids in the Y direction

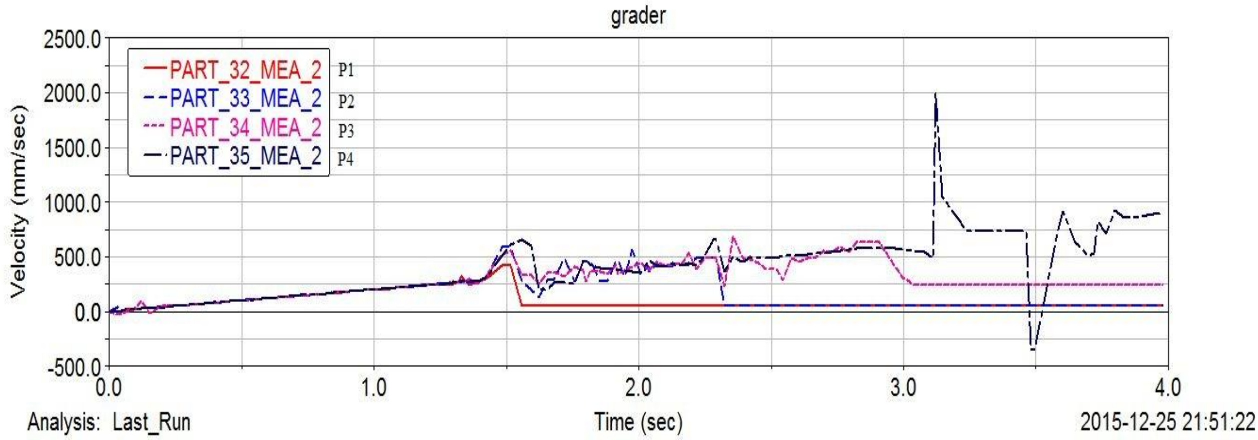


Fig.6 – The velocities of potatoes' centroids in the X direction

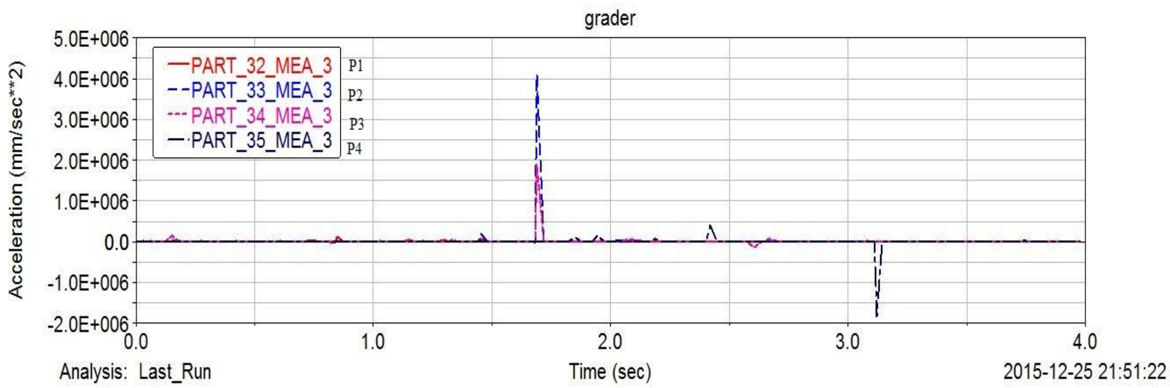


Fig.7 – The accelerated velocities of potatoes' centroids in the Y direction

As shown in Figure 5, when the simulation time was 1.6s, 2.4s, 3.1s, the displacements in the Y direction of potato P1, P2, P3 turned from 0 to negative values, and continued to decline in parabolic forms, indicating that the potatoes had been separated through the gaps. The little potato P1 was the first to be separated, then the middle-sized potato P2 was separated, and finally the big potato P3 was separated, the oversized potato P4 still moved along to the end of the conveyor. The simulation results were consistent with the mechanism designing theory, which proved the correctness of the designing scheme.

As shown in Figure 6, the forward velocities of potato P1, P2, P3 in the X direction fluctuated slightly, but they were basically stabilized. The main reason of the speed fluctuations was that, the potatoes collided constantly with the fixed rolling bars in front and back of them when moving forward, which generated accelerated velocities in the corresponding directions and thus affected the velocity value in the X direction. After potato P3 was separated, the potato P4 was observed an instantaneous speed fluctuation, but it still remained in a stable value range.

Figure 7 shows that the accelerated velocities along the Y-direction of potato P1, P2, P3, P4 were relatively flat in the whole process, indicating that the potatoes moved fairly slightly in the Y direction, which proved that the equipment worked relatively stable. However, when the movable rolling bars moved from one baffle to the next, the potatoes jumped fairly strong in the Y direction. The situation was: In the first grading, the potato P2 made the maximum movement while the P4 made the minimum; in the second grading, the potato P4 made the maximum movement while the P3 almost remained still; in the third grading, P4 made the maximum movement in the negative Y direction.

Analysis of contact force

Southern potato is tender and has thin skin, which makes it easily injured when colliding with the rolling bars in the grading process. Literatures and experiments show *(Bentini et al, 2006; YongYing Sang et al, 2008)*, the force to ruin a potato is 251.6N. To make a comparative analysis of the contact forces, this study respectively have measured the contact force of P4 with two fixed rolling bars and a movable rolling bars, the contact force of P1 with the rear fixed rolling bars and the movable rolling bars. The results are shown in Figure 8 and Figure 9.

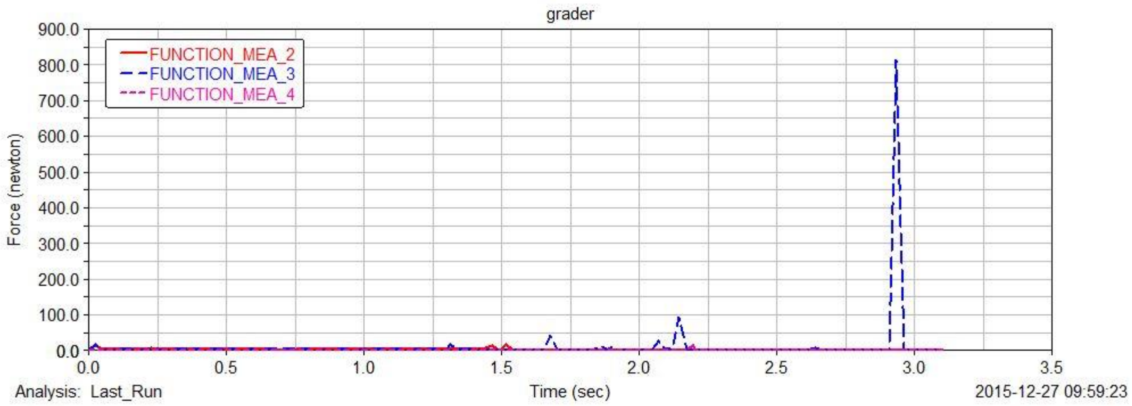


Fig.8 – The contact force of P4 with fixed/ movable rolling bars

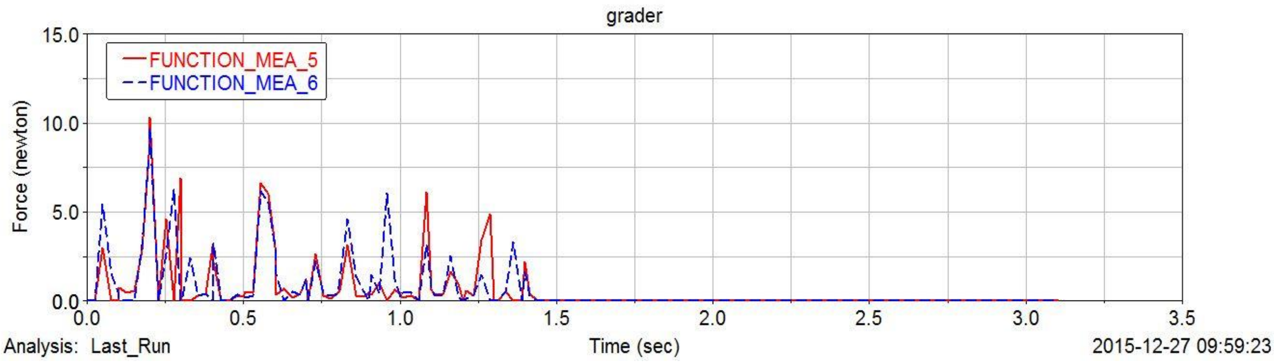


Fig.9 – The contact force of P1 with fixed/ movable rolling bars

As shown in Figure 8, the contact force between P4 and the fixed rolling bars was relatively small, which was not more than 20N. The contact force between P4 and the movable rolling bars rose to its maximum value when movable rolling bars falling into the lower baffle, the maximum values shown respectively as 42.68 N, 92.51 N, 813.7 N. Obviously the contact force between P4 and the movable rolling bars in the third grading was larger than the maximum destructive force of potato. While optimizing the design, a layer of rubber should be wrapped to the movable rolling bars to reduce the contact force.

As shown in Figure 8-9, in 0-1.5s, the average contact force between P1 and the fixed rolling bars was 3 N, only about 50% of the P4's, the extreme contact force between P1 and the movable rolling bars was 11 N, about 26% of the P4's. It indicated that the contact force increased as the quality of the potato increased, which was most significant in the extreme contact force.

CONCLUSIONS

- This study used the software of SolidWorks to establish a three-dimensional model for potato grading, and imported the model into the ADAMS, set the properties of the components, materials, the kinematic pairs and the Impact parameters, and finally built a dynamic mechanical model.
- Simulation analysis showed that, P1, P2, P3 were isolated successively, which means that the mechanism design is correct. The potatoes jumped only slightly upon the rolling bars, which indicates that the device works steadily.
- The analysis of contact force showed that the bigger the quality of the potato was, the greater the contact force between it and the rolling bars was. Such a principle was most significant in the extreme contact force between the potato and the movable rolling bars. In the experiment, the maximum contact force between P4 and the movable rolling bars was 813.7 N. The study can provide a basis for optimizing the design of prototype production.
- The further research is in progress to add a conveyor belt, potatoes will be transported to grading mechanism automatically. Conveying speed and grading speed are very important motion parameters for grader, so this study will focus on the effect on grading quality and efficiency under different conveying speed and grading speed, also analyze the variation of impact force between potatoes and bars, two adjacent potatoes, aiming to get the best motion parameters.

ACKNOWLEDGEMENT

This work is carried out with financial support from science and technology department of Guangdong province in China, science and technology program (No. 2015A030401097), and reform project of higher education teaching and research in Guangdong province "Mechanical innovation experimental platform building based on virtual experiment".

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