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REVIEW

Study of Grain Conveyor Structure to Reduce Cleaning Time of Combine Harvester

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Abstract

A grain conveyor structure was developed to reduce the time required for internally cleaning a combine harvester. In the developed structure, the horizontal plane parts in the grain conveyor were slanted to promote slipping of grains. Further, the cleaning ports were enlarged and located in optimized positions to enable the easy discharge of grain residues. The results of the examinations conducted using a head-feeding combine harvester indicated that the time required for the removal of grain from the grain conveyor of the developed structure was approximately half of that required using the conventional structure.

Discipline: Agricultural Engineering
Additional key words: efficiency, internal cleaning, prevent contamination

Introduction

If a plurality of crops is harvested with only one combine harvester, it is necessary to prevent contamination with grains of a different type. To prevent contamination in a combine harvester during harvesting, it is necessary to clean the inside of the combine harvester (hereinafter called "internal cleaning") and remove the residual grains therein (hereinafter called "residual grains") (National Agriculture and Food Research Organization 2017). However, because the internal structure of the combine harvester is complex, high-precision internal cleaning requires knowledge about the internal structure of the combine harvester and expertise on internal cleaning. Further, internal cleaning is time-consuming. Even a small model requires over 1 h, and a large model requires half a day or a full day. Technological development that enables high-precision and high-efficiency internal cleaning is thus required at the production field (New Agricultural Machinery Practical Promotion Co., Ltd. 2005). Regarding the effective technology for increasing the precision of internal cleaning, a technique that extracts and manualizes technical knowledge or expertise from a worker has been reported (Shimazu et al. 2015). It is experimentally demonstrated that a beginner who referred the example of the manual created with this technique can perform the internal cleaning with high precision, much like an expert worker (Ministry of Agriculture, Forestry and Fisheries of Japan 2017). However, the time required for cleaning is slightly improved. Therefore, it is difficult to significantly improve the time required for cleaning without improving the structure of the combine harvester.

In this study, we studied the internal structure of the combine harvester manufactured by four farm machinery manufacturers and developed the new structure of grain conveyor in a combine harvester that reduces the time required for internal cleaning (hereinafter called "new structure"). For verifying the effects of the new structure, we studied the influences for harvesting performances and the time required for internal cleaning using a two-cutting rows head-feeding combine harvester modified with the new structure.

Measurement of the internal structure of combine harvester

The structures of the cleaning ports in a combine harvester were measured.

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1. Method

Eight machine models were measured: four farm machinery manufacturers × two models (two and six cutting rows). The parts to be measured are the primary parts that require attention upon cleaning owing to the high amount of grain residues (horizontal conveyor of grain auger and tailing auger, connection parts of grain auger and tailing auger, bottom horizontal conveyor of the tank, top and bottom connection parts of discharging auger). The measurement items are the shape and direction of the cleaning ports.

2. Result

From the measurement result, two types of cleaning ports were discovered. One has a full opening on the bottom or side cover, and the other has a partial opening resembling windows or holes (Figs. 1 and 2). The partially open type is confirmed to have lower visibility from the outside and has more corners where grains tend to remain, compared with the fully open type. The cleaning ports primarily consist of two directions: side direction and bottom direction. For the bottom-direction type, the grains slipped out when the cleaning ports were opened, and slipping had to be promoted using only a blower. For the side-direction type, the grains did not slip out when the cleaning ports were opened, and had to be scattered with a blower. From the results above, it was concluded that the cleaning port that reduces the time required for the internal cleaning is the fully open type and the bottom direction port.

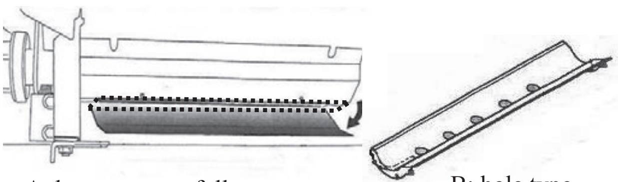


Fig. 1. Bottom cleaning ports of horizontal conveyor
A: referred from the manual of VM217(G) Mitsubishi Agricultural Machinery Co., Ltd.
B: referred from the parts catalog of ER698 KUBOTA Co., Ltd.

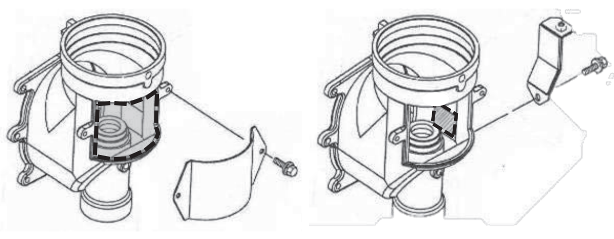


Fig. 2. Cleaning ports of orthogonal parts on the bottom of discharging auger
A, B: referred from the parts catalog of GC698(C) YANMAR Co., Ltd.

Summary of the new structure

From the results of the internal structure measurement, we developed the new structure of grain conveyors that easily remove residual grains during the internal cleaning. The peculiarities of the newly developed structure are as follows.

One of the parts where residual grains tend to remain during the internal cleaning is the connection part between the horizontal conveyor and the vertical conveyor (hereinafter called “connection part”) and the horizontal plane (hereinafter called “grain piled plane”) at the discharging part at the upper end of the vertical conveyor (hereinafter called “discharging part”). Therefore, the first peculiarity of the new structure is the slanting of the horizontal grain piled plane (Figs. 3 and 4 lower step). Owing to this peculiarity, the grains can be easily removed, and the time required for the internal cleaning is reduced. However, this technology is applicable to machine models with grain conveyors of the screw-auger type. Therefore, attention is necessary.

Another one is the vicinities of the cleaning ports. In a combine harvester, the cleaning ports are located at the bottom plane and the connection part where the grains tend to pile up in the grain conveyor. The cleaning port is opened during the internal cleaning and used to remove

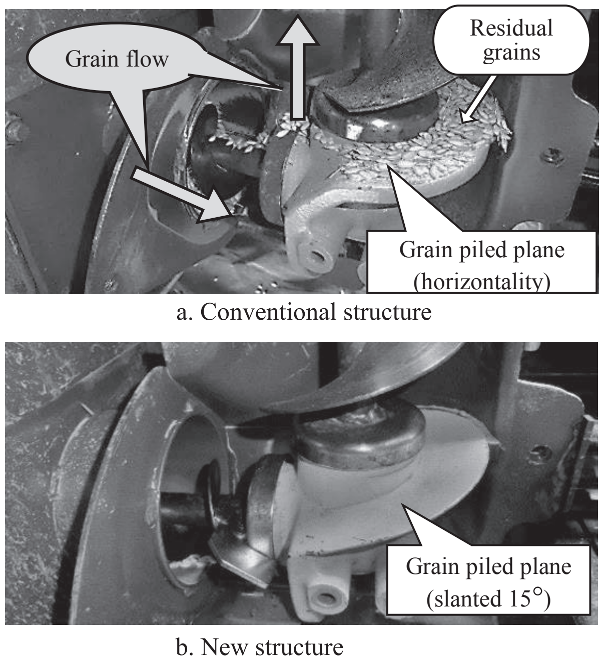
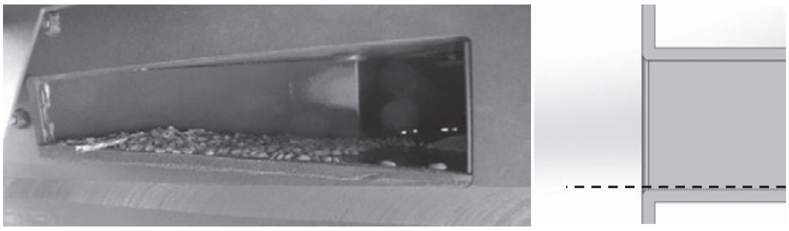
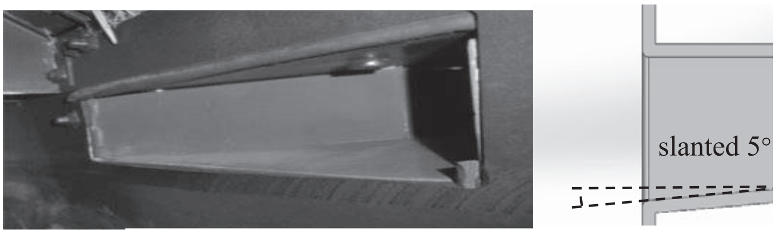


Fig. 3. Connection part of grain augers



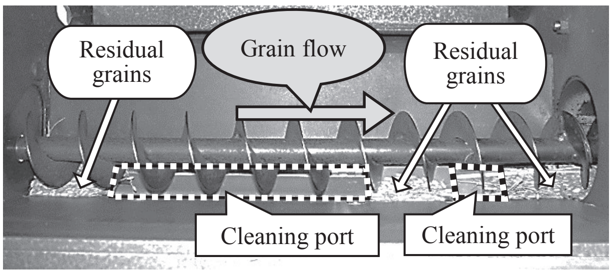
a. Conventional structure (Right: Image of side sectional view)



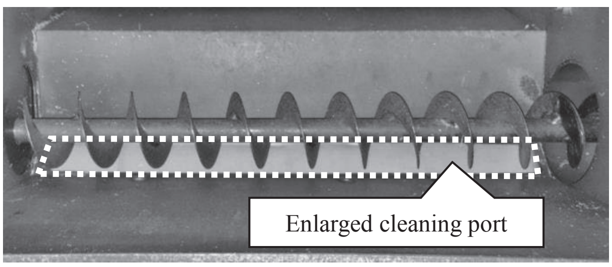
b. New structure (Right: Image of side sectional view)

Fig. 4. Discharging part of vertical auger

residual grains. However, if the size of the cleaning port is too small or the cleaning port is located on the side, the residual grains tend to remain at the corner and the bottom plane. The second peculiarity of the new structure is the cleaning ports located at the bottom of the horizontal conveyor or connection part and the enlarged size of the cleaning ports which sufficiently hinders residual grains (Fig. 5). Owing to this peculiarity, residual grains can be removed as soon as the cleaning port is opened, and the time required for the internal cleaning is reduced. However, this technology is applicable to machine models that have cleaning ports on the grain conveyor.



a. Conventional structure



b. New structure

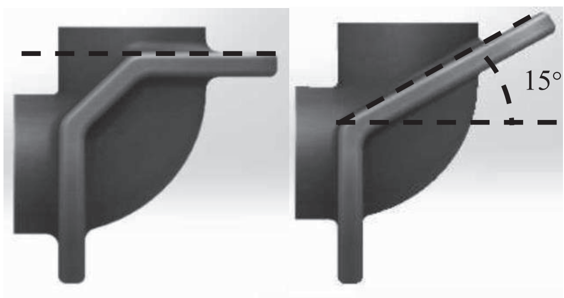
Fig. 5. Cleaning port of horizontal auger

Examination of optimized slanted angle of grain piled plane

For slanting the grain piled plane, it is necessary to examine the optimized angle that promotes slipping of grains without hindering grain conveyance. The influences to promote slipping of grains and grain conveyance were investigated when the grain piled plane is slanted.

1. Material

The sample machine was a two-cutting-rows head-feeding combine harvester (VM217G, Mitsubishi Agricultural Machinery Co., Ltd.). This machine has horizontal and vertical conveyors of the screw-auger type. The grain piled plane on the connection part of the grain auger (hereinafter called “piled plane on the connection part”) was measured. The produced structures are the piled plane on the connection part slanted (hereinafter called “slanted structure”) at four angles (5°, 15°, 30°, 40°) (Fig. 6). The sample crop is dried rice to eliminate the effect of moisture content on the grain slipping performance (variety: *Sainokagayaki,* moisture content: 13%w.b.).



a. Conventional structure b. Slanted structure

Fig. 6. Image of piled plane on the connection part

2. Measurement influence for grain conveyance

(1) Method

It was investigated whether a difference in grain conveyance occurred between the conventional structure and the slanted structure. Initially, the grain auger was driven, and the grains were thrown into the horizontal conveyor that is the start line of the grain conveyor. The amount of grains thrown into was 10 kg, because amount of grains that can be discharged for a sufficient time to see the trend of grain conveyance was 10 kg. Subsequently, the thrown grains were transported to the discharging part of the vertical conveyor which is the goal line of the grain conveyor. The discharged grains were collected by intervals of 2 s, and the conveyance amount per unit time for each structure was measured. The discharging time of 10 kg grains was about 20 s. The interval time was one tenth of the discharging time to see the trend of grain conveyance. In addition, the rate of grain damage was measured. The auger speed was set to a maximum speed of 890 rpm. Three replicates were measured, and the average value was evaluated.

(2) Result

The maximum conveyance amount per unit time of either structure is approximately 2.2 t/h (Fig. 7). No difference was observed between the structures. Further, almost no damage was confirmed in the grains after conveyance. As stated above, a low possibility is inferred for the reduction in grain conveyance at the connection part when the piled plane on the connection part in the grain conveyor of screw-auger type is slanted 40° or less. It is noteworthy that the influence for grain conveyance might vary depending on the difference in the variety of crops, such as wheat and bean; crop conditions, such as high moisture and numerous contaminants; or design specifications, such as large machine and so on. When this technology is put into practice, it is necessary to perform a verification test to the subjected variety of crops or crop condition with the sample machine and measure the influence on the grain conveyance.

3. Measurement of effect to promote slipping

(1) Method

The effect to promote slipping was investigated by slanting the grain piled plane. Initially, the grains piled up on the piled plane on the connection part, and the grain auger was driven. Subsequently, vibration was generated by the grain auger, which caused the grains to slip. A more slippery structure shortens the time required for slipping of grains. Therefore, for each structure, the time from the start of the vibration until all grains slipped out (hereinafter called “time required for slipping of grains”) was measured. The auger speed was set at four levels (445, 594, 742, 890 rpm), from the minimum to the maximum speed. Three replicates were measured, and the average value was evaluated.

(2) Result

For the conventional structure, the grains did not slip smoothly from the piled plane on the connection part. A large amount of grains remained. For the slanted structure, all grains slipped out within 2-114 s. It was confirmed that the larger slanted angle tended to shorten the time required for slipping of grains (Fig. 8). The difference in the time required for slipping of grains was large when the slanted angle is 5°-15°. However, the difference in the time required for slipping of grains was small when the slanted angle was over 15°. This tendency was similar even if the auger speed was different. From the result

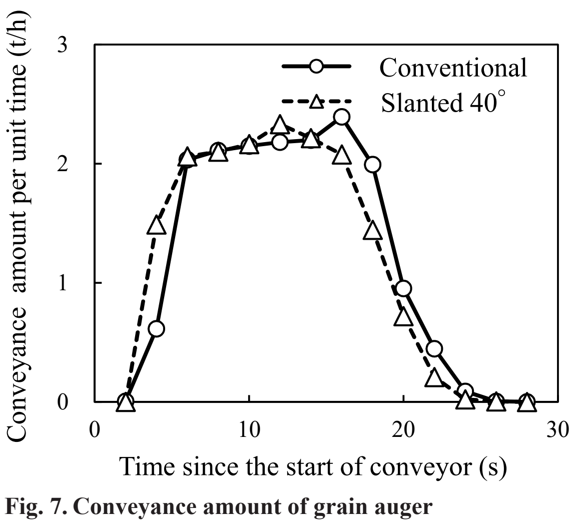


Fig. 7. Conveyance amount of grain auger
(Average of 3 replicates)

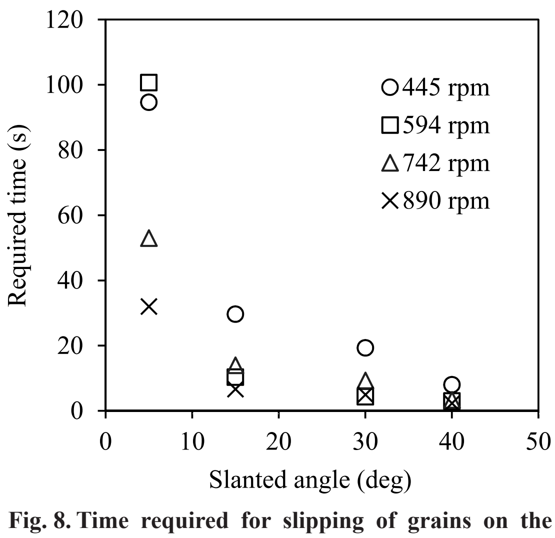


Fig. 8. Time required for slipping of grains on the slanted structure
(Average of 3 replicates)

above, we confirmed that it is possible that the slanting of the grain piled plane reduces the time required for the internal cleaning. Further, it was estimated that the ideal slanted angle is over 15° and the effective slanted angle is over 5° for the rice. It is noteworthy that the result might vary depending on the difference in a variety of crops or crop conditions.

Performance of a combine harvester modified to the new structure

The influences of the differences in structure on the difficulty in residual grains and the time required for the internal cleaning were investigated.

1. Material

The sample machine was a two-cutting-rows head-feeding combine harvester (VM217G). Table 1 shows the modified part and content. The grain piled plane was slanted to 15° (Fig. 3). However, structurally, the grain piled plane on the discharging part could not be slanted to 15°. Therefore, it was slanted to 5° (Fig. 4). The cleaning port on the side was transferred to the bottom and was changed to the fully open type (Fig. 5). Rubbish in grain mixture, damaged grain in grain mixture, separating grain loss and threshing grain loss were measured with a harvest test of rice. From the result of the harvest test, we confirmed that the harvest performance was not affected by the modification (Table 2). The sample crop is rice (variety: *Koshihikari*). The crop conditions were as follows— row space in paddies: 30 cm, column space in

Table 1. Modified parts and contents

Parts	Contents
・Connection part of grain auger ・Connection part of tailing auger ・Bottom connection part of discharging auger	Slant grain piled plane (slanted angle is 15°)
・Discharging part of grain auger ・Discharging part of tailing auger	Slant grain piled plane (slanted angle is 5°*)
・Cleaning port of horizontal conveyor in grain auger ・Cleaning port of horizontal conveyor in tailing auger	Change the cleaning port to the bottom and fully open type
・Cleaning port of bottom connection part in discharging auger ・Cleaning port of top connection part in discharging auger	Change the cleaning port on the side to the bottom

*The parts were slanted 5° because they structurally could not be slanted 15°.

Table 2. Harvesting performances

Measurement item			Conventional structure	New structure
Crop condition	Moisture content of grain	[%]	25.8	26.6
	Moisture content of straw	[%]	64.0	62.4
Operating condition	Operating speed	[m/s]	0.71	0.72
	Throughput of threshing device	[kg/h]	2,279	2,801
Measurement result	Rubbish in grain mixture	[%]	0.55	0.43
	Damaged grain in grain mixture	[%]	0.36	0.14
	Separating grain loss	[%]	1.23	0.87
	Threshing grain loss	[%]	0.41	0.55

(Average of 3 replicate measurements)

paddies: 22 cm, entire length: 96.4 cm, standing angle: 84.2°, moisture content of grain: 26.2%w.b., moisture content of the straw: 63.2%w.b., yield of rough rice: 418 kg/10a (converted with moisture content of 14%w.b.).

2. The discharge function of residual grains by the new structure

(1) Method

A vibration test was performed to evaluate the discharge function of residual grains by the new structure. Initially, rice was harvested 1a (harvesting weight is approximately 50 kg) using the sample machine, and all grains were discharged using a discharging auger. As the result of this process, the sample machine was in the general condition before the internal cleaning. Next, all cleaning ports were opened. Further, the parts were removed that need to be removed during cleaning (concave, oscillating pan, etc.). Subsequently, the threshing rotor, fan, and grain conveyor were driven. The vibration and blow generated by the engine caused the residual grains to slip and scatter. The engine was stopped after 1 min, and the residual grains in each part were measured. The engine speed was set at 3000 rpm (the auger speed is 890 rpm).

(2) Result

Figure 9 shows the mass of the residual grains in each part after vibration in both the conventional structure and the new structure, 246.5 g and 21.4 g, respectively. The residual grains of the new structure were reduced to approximately 91% compared with the conventional structure. For each structure, we confirmed that machine vibration caused the grains to slip and scatter. However, in the conventional structure, the residual grains remained on the closed bottom face or the piled plane on the connection part. Meanwhile, in the new structure, the residual grains were removed by the slanting grain piled plane, and the size and position of the cleaning port were optimized. In the new structure, the part where the residual grains remained was the connection part between the horizontal and vertical conveyors. This part has a horizontal plane that could not be slanted in this modification. It is considered that correspondence is possible to eliminate the horizontal plane of the grain conveyor when designing the machine. As stated above, we confirmed that the residual grains were more difficult to retain in the new structure than in the conventional structure.

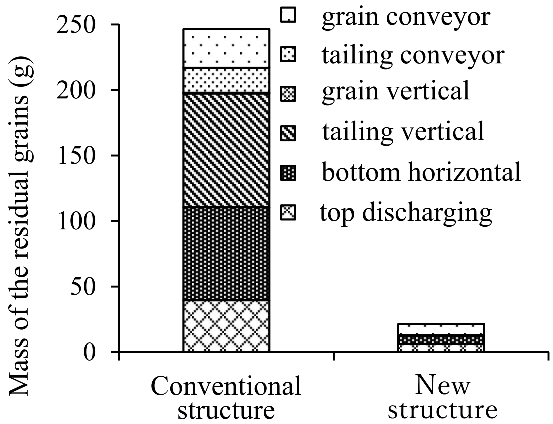


Fig. 9. Residual grain after vibration
(No replicate measurement)

3. Time required for cleaning the new structure

(1) Method

The time required for the internal cleaning was measured due to the difference in structure. Initially, rice was harvested 1a (harvesting weight is approximately 50 kg) using the sample machine, and all grains were discharged using a discharging auger. Next, an expert worker internally cleaned the machine. Further, the time required for each process of the internal cleaning was measured. The work procedure for the internal cleaning is as follows:

Process 1: open the cleaning port and remove the parts that need to be removed during cleaning.

Process 2: remove the residual grains from each part using cleaning tools.

Process 3: close the cleaning port and install the removed parts.

The termination of cleaning was left to the discretion of the worker. After cleaning, the worker was interviewed about the difference in the ease of cleaning owing to the structure. The count of this measurement was 1 time.

(2) Result

The times required for the internal cleaning were as follows:

Process 1 took 16.8 min (common in the conventional structure and the new structure).

Process 2 took 9.2 min in the conventional structure and 5.0 min in the new structure.

Process 3 took 11.2 min (common in the conventional structure and the new structure).

The time required to remove the residual grains is shown in Figure 10. At the horizontal conveyor of the grain auger and tailing auger (Fig. 10 “grain horizontal”) and the horizontal conveyor from the bottom of the tank to the bottom of the discharging auger (Fig. 10 “bottom horizontal”), the time required to remove the residual grains of the new structure was shorter by 80% than the conventional structure. Because these parts are located below and have a wide grain piled plane, the residual grains and the scattered grains from other parts tend to remain on these parts. However, in the new structure, almost all grains slipped out when the cleaning port was opened

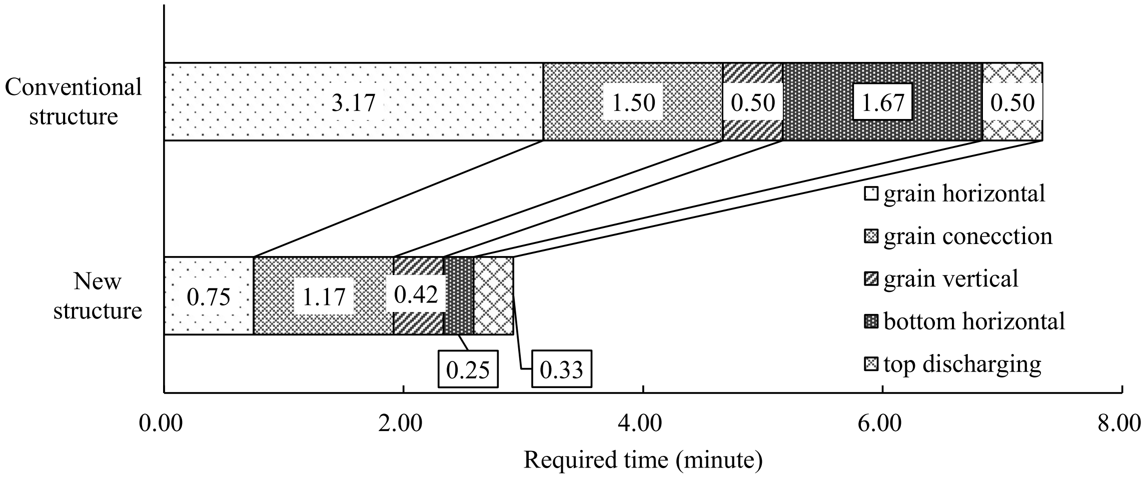


Fig. 10. Time required for internal cleaning
(No replicate measurement)

owing to its enlarged size. Therefore, the removal of grain took a little time. At the connection and discharging parts (Fig. 10 "grain connection", "grain vertical", "top discharging"), the time required to remove the residual grains of the new structure was shorter by 20%-30% than the conventional structure. Almost all grains slipped when the cleaning port was opened owing to the slanting grain piled plane. Therefore, the grain removal required little time. The result of the interview of the worker is shown below. The horizontal conveyor on the bottom of the tank, the connection part on the discharging auger, and the vertical conveyor have low visibility from the outside. It is necessary to visualize the inside condition with the sound of the scattered or slipped grains during the internal cleaning. However, only a few blowing times can promote slipping out of grains owing to the new structure. Therefore, the internal cleaning was easy. As stated above, we confirmed that the modification to the new structure could reduce the time required for cleaning.

Conclusion

In this study, a grain conveyor structure was developed to reduce the time required internally cleaning a combine harvester. In the new structure, the grain piled plane was slanted and the cleaning port was optimized. The new structure promoted slipping of grains and reduced the time required to remove the residual grains, which was shorter by about 50% than the conventional structure. This technology is expected to prevent contamination with grains of a different type.

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