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# Optimization of Combine Harvesting, Threshing, and Separating Systems for Reducing Corn Loss

**Roohollah Mohammad Sanabadi Aziz[1] , Sherwin Amini[2]**

1. Research Instructor, Jihad Institute of Engineering (Located at 16km of Old Road Karaj, Tehran, Iran.
2. MS Student in Mechanization Engineering, KhouzestanRamin Agriculture and Natural Resources University, Khouzestan, Iran.

***Corresponding Author email:*** rohollahmohammad@yahoo.com

**ABSTRACT:** Harvesting corn with a combine harvester leads to a certain degree of loss and thus reduces profits; although this loss cannot be fully eliminated, it can be controlled to areasonable degree. Preparing the combine for harvesting corn is a process involving the replacement of the harvest head and the concave and also the placement of cover plates on the threshing drum. A major obstacle in harvesting corn is the prevention of grain loss, which mostly occurs during the harvesting process at the combine head (when separating corn cobs from the stalks) and at the threshing drum and the concave (because of the corncobs' breaking). The present research was conducted in a 400 acres farm property of the Seed and Plant Improvement Institute, Maize and Forage Crops Research Department, with prerequisites being a threshing drum speed of 750rpm and a crop moisture content of 11.6% on dry basis. The crop yielded and the amount of grain loss measured indicated that, when conventional heads exerting vertical force for separating the stalks are used, the degree of grain loss during harvesting becomes excessive; these heads cause a great amount of crop loss. Results of the present study were manifested on the combine cutter bars; therefore, for reducing harvest loss occurring at the combine header, headers made in Iran should be significantly modified. The first step taken in this respect was to design and implement necessary modifications to the two main parts of the machine, i.e. the "corn head" and the "feeder unit".

***Keywords:*** Corn Combine, Reducing Harvest Loss, Combine Header Modification, Threshing Drum and Concave, Feeder Unit

## INTRODUCTION

The increasing population of the world is faced withshortageof food and thus needs to expand its production of high yielding crops such as corn in order to overcome it. In terms of the global area under cultivation, corn comes third after wheat and rice. The rate of corn production has surpassed the rate of wheat and rice production over the last few years and is ranked first among agricultural products (Tajbakhsh, 1996). Mechanized harvesting of crops has long been a goal of farmers. The purpose of harvesting is the timely collection of grains and their separation from chaff and other waste parts with maximum quality and minimum amount of loss possible. In this regard, choosing the right method of harvesting and the appropriate equipment depends on the type of crop, the cultivation method and the climatic conditions (Sirvastava et al., 1990). The rate of corn loss when using a combine for harvesting corn depends on multiple factors such as the moisture content of the grain, ambient temperature, farm condition (stagnancy), combine condition (new or rusty) and the driver's level of experience. Together or separately, these factors can greatly increase grain loss. Knowledge of the aforementioned factors alongside the application of proper mechanisms of harvesting can reduce the rate of loss to a reasonable degree. Behrouzilar et al. (1995) conducted a study on the rate of crop loss for combine-harvested grains and cereals and planned to find out the global range of crop loss. They assessed factors contributing to crop loss in combine-harvested grains and cereals and concluded that in Iran, this rate is higher than the global standard, which is 4-5%. In their study on grain loss in commercial harvesting of oilseeds, Price et al. (1996) found out that the ideal grain loss can be around 2 to 5%. Under Iran's normal climatic conditions, losses of 20-25% have also been recorded

(Anonymous, 1997). As the combine feed rate increases, the overall loss rockets. The reason is that the straw walkers are overloaded (Navid et al., 2004). In another research, parameters such as speed of progression, peripheral speed of the threshing drum, the space between the cylinder and the sub-cylinder, size of sieve holes, fan speed and moisture content were measured (Rahama et al., 1999). Researchers also measured any form of loss occuring at the platform, the threshing drum and the separating and the cleaning system; they reported the mean loss to be 12%. In another research, the mean loss for combine harvests were reported to be 3.4% --1.5% of which pertained to platform loss (Bukhari et al., 1983). The use of a separating platform increases combine capacity by 50-100% due to the reduction in the amount of straw transferred to the separating and the cleaning systems (Tado et al., 1998). In order to prevent grain loss and removal of corn chaff at the combine header, the pulling sprocket and the rasp bars need to be adjusted closer to each other. The gathering chain speed and the pulling sprocketspeedalso need to be increased in low-performance farms so that the combine input increases and its maximum capacity does not drop (Hoffman, 2004). Adjusting the header to crop conditions is a major step in preventing harvest loss (Campbell &Alswager, 2003). Platform loss is reported to be equivalent to 50% of the total combine loss (Shahrestani&Minayi, 2001). High cylinder rotation is another major factor contributing to grain damage and cob breaking (Maier & Parsons, 1996). Mechanization is an important part of agricultural development; automation, proper machine use and optimal use of machine technology increase efficiency, reduce costs and enhance production rates. To be self-sufficient in securing the country's corn supply, all areas of the corn production process should be run with maximum efficiency. Since the purpose is to increase corn production and tpminimize its import (almost to zero), no loss should be tolerated–especially not at the harvesting stage, which can be subject to a high percentage of grain loss.

## MATERIALS AND METHODS

This project pursued to modify and optimize combine header systems and to achieve minimum grain loss in the production of corn; therefore, the first step was to purchase a combine corn head in order to study and analyze its systems. The source of corn loss occurring at the header was then identified along with other types of loss occurring at the system so as to identify their contributing mechanisms while taking all things into consideration and to then prepare for the standard testing and evaluation of the existing header. The next stage was to examine combine header operation mechanisms and to modify them according to the demonstrated causes of loss occurring in the combine for minimizing purposes. The final step was to conduct a trial run of the modified combine header on the farm so as to examine its degree of grain loss post modification and to compare it against its previous state.

### *Examining combine header*

The examined system was a 4-rowcorn head that could be installed on John Deere 955 Combine Harvester. This head is designed to separate corncobs from their stalk and to then feed them to the feeder unit. This head has4 rows set at a fixed 75 cm distances of one another. The main parts of the system are:

a) The Frame
b) The Power transmission system
c) The Harvester (corn cutter)
d) Grain conveyor

Corn Head Technical Specifications:
Required power: 45 hp
Input rotation: 600 rpm
Number of rows: 4
Harvest rate: 4 acres per 8 hours
Weight: 1000 kg
Length: 320 cm
Width: 280 cm
Height: 130 cm

Figure 1. Overview of the corn head

***Designing and proposing a proper mechanism***

At this stage of the project, combine head mechanisms directly in contact with the crop and causing corn loss were first examined; then, based on the envisioned mechanisms, necessary modifications were made taking into account the functioning of the examined head components.

***Examining the combine header's feeder unit mechanism***

As the combine harvester rides along the farm, the crop is fed to the feeder unit that then separates the cobs from their stalks. The feeder unit is responsible for the separating process; the movable parts of this unit derive their power from the mechanism's embedded gearbox. The parts enabling the separating and feeding of the corncobs are as below:

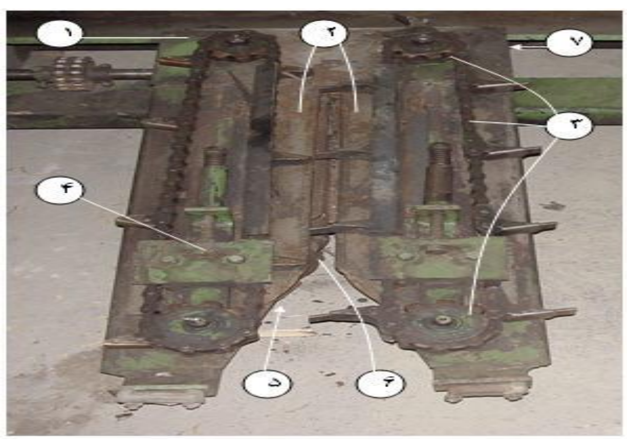

Figure 2. Feeder unit mechanism

U-shaped frame
Cutter bars
Chain conveyor mechanism
Chain tightener spring mechanism
Sprocket
Straw walker
Gearbox

***Feeder mechanism (of existing combine headers)***

The feeder unit parts can be divided into two general categories of fixed parts and movable parts. The fixed parts include the U-shaped frame, the chain tightener spring, the cutter bars and the straw walker. The movable parts include the chain, the roller chain and the sprocket wheel. The power transmission system transmits power to the gearbox.

***Separating corncobs from the stalks***

The corn head was designed by the factory in such a way as to form an attack angle with the farm when installed on the combine. The examined 4-row corn head also boasts three head covers that direct the corn stalks into the feeder unit while the combine harvester is moving through the field. Thus as the combine moves along the corn fields, corn stalks flow into the feeder unit. Parts directly involved in separating the corncobs from the stalks are the cutter bars (1) and the sprockets (2). As formerly mentioned, the cutter bars are placed on the U-shaped frame and two sprockets are also placed under the frame. The sprockets rotate against each other by means of their movable gear. The direction in which the sprockets rotate is devised in a way that an opposite rotation against each sprocket draws the stalks down (into the cutting bars). Given the conical shape of the sprockets, upon flowing into the feeder unit, the corn stalks do not immediately contact the sprockets; rather, they only gradually get exposed to the sprockets while moving through the feeder unit. The sprockets are installed in such a way as to draw the corn stalks down into the cutting bars. The space between the cutter bars is adjusted based on the dimensions and size of the harvested corncobs in such a way that the cobs cannot freely move through these spaces; in addition, since the sprockets' blades overlap each other, the stalk continues to be drawn and the corncob is thus separated from its stalk. The cob breaks along its own axis at its end so that the corncob ears also loosen from the stalk.

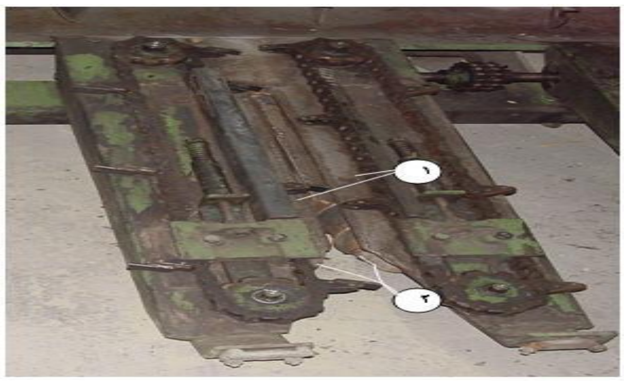

Figure 3. System for separating the cobs from the stalk

***Conveying corn cobs to the feeder unit***

Once separated from the stalk, the cobs should be conveyed to the threshing drum and the concave. This moving is carried out through three conveyors, two of which are installed on the combine header and one inside the combine harvester. Once the crops have been fully separated, they should be conveyed to the header augerso as to be gathered; they are then sent through the conveyor. The first conveyor ("grain conveyor") is installed in the feeder unit. Machine parts directly involved in conveying the corncobs to the feeder unit include:

Conveyor chain
Motor roller chain
Moving roller chain
Bushings placed on the chain

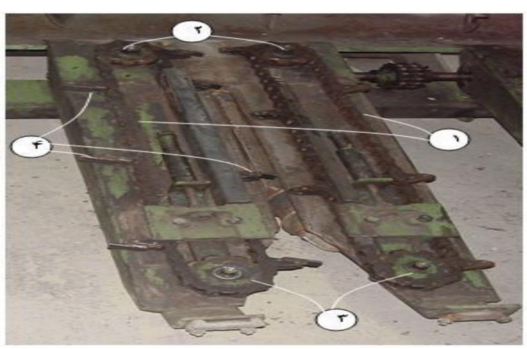

Figure 4. Grain conveyor

***Proposed mechanism for reducing corn loss***

As previously mentioned, the stalks get pulled down by the sprockets in the corn head; the corncobs, too, are rapidly being pulled downso that they get stuck between the cutter bars and get separated from the stalk.

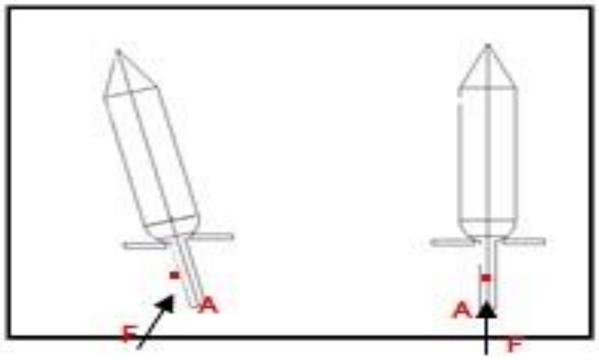


Figure 5. Proposed mechanism for reducing corn loss

In existing heads, when the cobs are being separated from the stalk, the cobs are pulled along their longitudinal axis, which exerts a vertical force on the base of the cobs;as a result, the cobs get broken from the base and the corns also get separated from the cobs.

Figure 6. Cobs breaking along their longitudinal axis

Our proposed mechanism aims to reduce loss of corns when the corncobs are being separated from the stalks. Since the main reason for the separation of the corns from the corncobs was the vertical force exerted along the longitudinal axis of the cobs, this study aims to modify the current mechanism and instead achieve one that minimizes the force exerted on the cobs. Once necessary modifications are made to the mechanism separating the cobs from their stalks, direction of the pulling force and thus the separation deviates from along the cob's axis so that separating the cobs from the stalks can be easily achieved without unnecessary loss-provoking shocks or vibrations. The latter can be accomplished by creating variance between the cutting bars' altitudes. These modifications have three advantages:

Due to the exertion of force at a more suitable angle, separating the cobs from the stalks is easier and requires less power and force. The reduction in the collision force is highly effective in preventing loss of the corns during the stage where the cobs are being separated from the stalks.

Direction of force exerted on the grains has changed–yet another modification contributing to the reduction in corn loss.

Stalks are broken right at their junction with the cobs (point A); as a result, the cob ears are also separated from the cobs since they are joint to the stalks too. Therefore, if, during the separating stage, the stalk is broken right at its junction with the cobs, all the cob ears will break as well. It is clear that reducing waste input to the combine harvester (particularly to the threshing drum and the concave) positively affects quality of the operation. Creating a variance in the cutting bars' altitudes changes the direction of F force exerted on the end point of the cob so that F is no longer exerted along the axis of the cob; consequently, the force exerted in the direction of the axis becomes part of F.

***Proposed mechanism for reducing loss***

As previously mentioned, reducing the amount of loss can be achieved by decreasing the axial tensile force to the minimum effective degree possible, which means that a variance should be created between the cutter bars' altitudes in the feeder unit. To create this variance, filler plates are installed underneath a cutter bar in order to place it higher above the other cutter bar.


Figure 7. Filler plates

It should be noted that the chain conveyor mechanism and the chain tightener spring mechanism are also positioned on the cutter bars. Moving the position of the cutter bars repositions these mechanisms as well; therefore, changes that should be made to all three parts are described:

**Creating variance in the altitude of a cutter bar**

The intended variance to be createdbetween the cutter bars' altitudes for testing the reduced rate of corn loss was 10 and 15mm; the filler plates used for creating this altitude variance had a diameter of 5mm.


Figure 8. The feeder unit frame

The corn head has 4 rows, that is, four separating mechanisms; one mechanism received 10mm of altitude variance, another one received 15mm of it, and the other mechanisms remained intact so that the amount of loss in each harvesting path could be examined and the effect of the amount of altitude variance on the degree of grain loss could be measured.

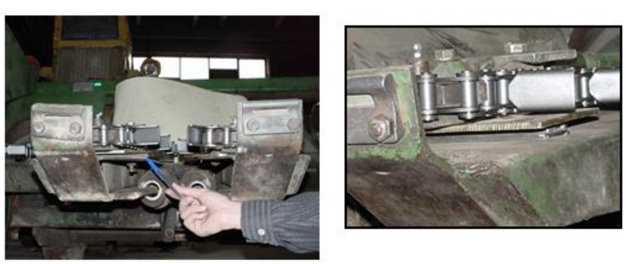
Figure 9. Cutter bars

***Repositioning the chain tightener spring mechanism***

The chain tightener spring is placed on top of the cutter bars; changing the position of the cutter bars thus repositions this spring as well. The chain tightener spring can only be moved vertically; therefore, the mechanism itself will not be modified, instead, the screws mounting the mechanism on the U-shaped frame will only be placed 20mm higher than their previous position.

Figure 10. Chain tightener spring mechanism

***Grain conveyor chain mechanism installation and set up***

The conveyor chain mechanism is also placed on top of the cutter bars; therefore, changing the position of the cutter bars repositions this mechanism as well. As previously mentioned, the grain conveyor chain mechanism consists of two roller chains (a motor roller chain and a movable roller chain) and a chain, and each feeder unit contains two grain conveyor mechanisms. The movable roller chain is placed on the L-shaped tightener spring mechanism; moving the latter results in the modification and repositioning of the movable roller chain. The grain conveyor's motor roller chain is positioned along the axis of the movable gear of the gearbox conveyor chain. Given that the motor roller chain should also be repositioned along the aforementioned axis once the position of the cutter bars changes, the length of the axis should be adjusted and suitable filler gaskets should be designed for the accurate adjustment of the space.

Figure 11. Mounting the chain mechanism on the feeder unit frame

As previously mentioned, modifications are only made totwoout of the four units existing in the feeder unit; in one of the units, one cutter bar is placed 10mm higher above the adjacent cutter bar and, in another unit, one other cutter bar is placed 15mm higher above the adjacent one. Therefore, the length of the axis of the gearbox conveyor chain's movable gear should be increased by 20mm.

Figure 12. Mounting the gearbox when the axes' altitudes vary

This axis, which was welded to the center of the gearbox, is removed; a new axis with more suitable length is designed and welded instead to the gearbox. Modifications are only made to two out of the four units of the header feeder unit.

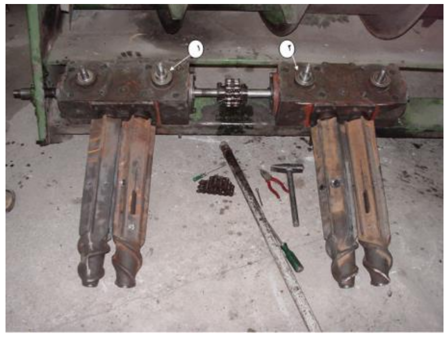
Figure 13. Mounting the sprockets and the gearbox

Filler gaskets with a diameter of 5mm were used to mount the roller chains up to the desired altitude. The present study employs a sample altitude variance of 10 and 15mm. In order to place the conveyor's motor roller chains in the two chosen units of the feeder unit, two filler gaskets were used in one unit and three in the other one.


Figure 14. Mounting the roller chain when the altitudes vary

Mounting the movable and the motor roller chains higher up to the desirable altitude made the installation of all parts of the feeder unit in the desirable positions possible.


Figure 15. Mounting all feeder unit plates

Examining farm operations including system settings and method of information collection

Once the harvesting unit of the combine harvester is prepared and properly installed by replacing the defective pieces with new ones adjusted to the metallurgical structure in mind, the combine harvester was transferred to the 400 acres farm property of Seed and Plant Improvement Institute in order to be evaluated based on its harvesting performance. It is worth noting that the initial investigations revealed that the sensitive pieces of the header were made of ordinary iron materials and their excessive corrosion was owing tothe use of poor material; however, the material used in making the pieces was modified and the new pieces were installed on the harvesting unit.In the trial run of the new pieces installed on the combine, 2 differentareason the farm were harvested;the below Figures displays the second area harvested and the movement of the combine on the rows.

Figure 16. The harvesting head during the trial run on the farm

Prior to harvesting the crops in the 400 acres farm property of Seed and Plant Improvement Institute, hygrometry tests were conducted on the crops. The hygrometry test was carried out in 2 to 3 different areas in each patch of the land so as to measure the correct harvesting moisture content.Below Figures s show the corn kernels being removed and their moisture content being examined.

Figure 17. Hygrometry test on the farm

In addition, the rotation of the threshing drum was tested prior to harvesting the crops so as to ensure its reliability. The threshing drum’s rotation as shown on the telemeter was read several times and its approximate rotation was set at 780rpm so as to prepare for the harvesting operation.

Figure 18. Reading the threshing drum’s rotation and optimizing it for harvest

The entire crop in the two areaspresented by theSeed and Plant Improvement Institute were harvested; sampling and combining the remainder of the harvested crop was performed and measured with standard methods.

Figure 19. Post harvest farm

The prerequisites for performing this research in the 400 acres farm property of the Seed and Plant Improvement Institute, Maize and Forage Crops Research Department, were: Threshing drum speed of 750rpm and crop moisture content of 11.6% on dry basis

Table 1. Comparison of mean, standard deviation, and standard error of the mean

**Paired Samples Statistics**

| | Mean | Std. Deviation | Std. Error Mean |
|---|---|---|---|
| GL3 | 12.9580 | 11.76318 | 3.03724 |
| GL4 | 9.4280 | 8.67716 | 2.24043 |

As shown in Table 1, the mean combine loss at the header is higher in GL3treatment compared to GL4; in other words, the amount of loss in GL4 treatment is lower than GL3. That is to say, there is a lower amount of loss at the header when the space between the cutter bars is 15mm rather than 10mm.

Table 2. Comparison of means and mean differences of the two treatments using a 2-tailed paired t test

**Paired Samples Test**

| Treatments | Paired Differences | | | | | t | df | Sig. (2-tailed) |
|---|---|---|---|---|---|---|---|---|
| | Mean | Std. Deviation | Std. Error Mean | 95% Confidence Interval of the Difference | | | | |
| | | | | Lower | Upper | | | |
| GL3 - GL4 | 3.5300 | 4.17792 | 1.07873 | 1.2163 | 5.8437 | 3.27 ** | 14 | .006 |

Table 2 shows that, for the paired data, the mean difference is 3.53 $g/m^2$ , the standard deviation 4.18 and the standard error of the mean 1.08 $g/m^2$. The minimum and maximum confidence intervals are 1.22 $g/m^2$ and 5.84 $g/m^2$ respectively. The 2-tailed paired t test showed that, at a probability level of 1%, the measured is 3.27 $g/m^2$ with an alpha lower than 5%. In other words, there is a significant difference between the treatments.

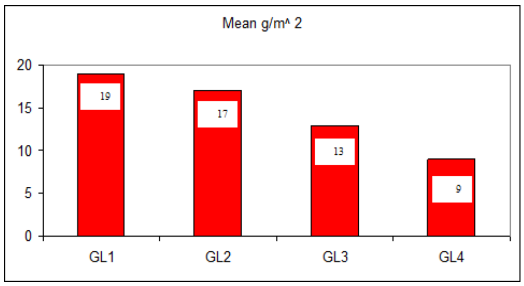

Figure1. Mean grain loss with the combine corn head

As shown in Diagram 1, treatment with the 15mm filler has a lower amount of grain loss compared to the treatment with the 10mm filler and the one without any.

In Iran, corn harvesting is accompanied with a great amount of grain loss. Harvesting machines can significantly contribute to the reduction of grain loss in the process of harvesting; however, improper machine design and the use of poor material in their construction has led to a great degree of difficulty in harvesting, which is why examining these machines is of great importance.

The 1% reduction in grain loss in the combine, particularly the combine header, is very significant. With the knowledge that about 1.1 to 1.3 million tons of corns are harvested every year, the researchers aimed to reduce the amount of corn loss occurring at the combine header and so they had to modify and optimize the combine harvester's mechanism; in this respect, they examined a used header and performed a structural analysis of all its different parts, including the straw walker, the pulling sprocket, the conveyor chain, the cutting bars, the U-shaped frame and generally the feeder unit mechanism. Header systems including the power transmission system and the other parts were studied. The present study focused on the mechanism separating cobs from the stalks and the dynamic factors associated with it, which is considered to contribute greatly to corn loss occurring at the combine header since it is often at this stage that the corn stalk breaks and a great portion of the stalk as well as the corns on its surface are crushed due to the high separation speed and the severe shock exerted on them –and this is how grain loss is increased during harvesting. In this regard, changes were made to the combine header in which the stalks are being pulled down by the sprockets and, given the conveyor's high speed, are getting stuck between the cutter bars and ultimately result in the cobs getting separated from them. In conventional headers, when the cobs are being separated from the stalks, their direction of pulling is along their longitudinal axis, which then results in the majority of the stalks getting crushed and broken.If proper modifications are made to the cutting bars using proper filler plates and if the presumptions hold, the exerted force, the tensile direction and therefore the separating movement is deviated from along the cob's axis and separation of the cob from the stalk occurs with ease and without any shocks; the result is that grain loss is reduced during the separation process. A 4-row header was thus used on the combine and specific modifications were made to the cutter bars, then, one row was designated on the farm as the control with no filler plates used in the combine header for its harvesting, and in three other rows, filler plates of 5, 10 and 15mm were inserted between the cutter bars so that an altitude variance was fashioned and comparisons could be made between the harvests of all 4 rows and the ideal filler plate size could be determined.

## CONCLUSIONS

Results obtained from the harvests and their amounts of grain loss indicate that, in conventional headers wherein a vertical force is exerted to separate the stalks, damage to the crops is too great and the amount of less excessive. Given results of the present study and their significance as manifested on the cutter bars, it is necessary to make modifications to combine headers made in Iran so as to reduce the amount of grain loss in them. Attention should be paid to the materials used for the construction of headers, particularly the cutter bars, the straw walkers, the pulling chains and the axes so as to reduce the amount of loss at the combine header. Measuring grain moisture content, ensuring the proper rotation of the threshing drum and the concave and adjusting the space between them prior to starting the harvesting process greatly contribute to reducing the amount of grain loss we currently experience with combine corn heads.

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