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DESIGN IMPROVEMENT OF INDIGENOUS BEATER WHEAT THRESHER IN PAKISTAN

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Mechanical wheat threshing has gained a spectacular popularity in Pakistan over a short span of time and so is the population of beater-wheat threshers that are being manufactured and marketed by the roadside vendors with little scientific and engineering experience. In fact, the major problems on conventional threshers have been identified as bulky weight, poor machine performance, human accidents and a high fuel consumption rate. A review of the conventional thresher suggests presence of three heavy flywheels with little scientific argument and similarly poorly designed threshing beaters and five MS rings on the beater-drum appear injudicious and unscientific. A horizontal throw of straw from the exhaust-blower takes away a noticeable amount of grains with it. Conventional threshers have witnessed terrifying accidents for the persons feeding the material without any safe crop feeding system. The local manufacturers least care about the fabrication drawings of the conventional machines and therefore their knowledge of manufacturing is restricted to the whims and wishes of "*ustad-shagird*" (seniors juniors). Therefore, the present study has been planned for investigation and improvements in the prevalent design of the indigenous beater-wheat thresher to bring about durability, reduction in weight of machine and grain losses in addition to an accident free and cost effective thresher. Modified designs and fabrication drawings of various components such as flywheel, beater, beater drum, blower and feeding conveyer were prepared. Total weight of redesigned beater wheat thresher was reduced from 1600 kg to 1300 kg and the grain damage was reduced four times. The mean threshing efficiency was increased from 98% to 99%. The replacement of the three flywheels by one redesigned flywheel of required size saved 24.37 kN-m energy. The fluctuation in speed was reduced to 3.05 times and coefficient of energy 3.11 times than that of conventional thresher By redesigning and redeveloping the direction of fan blower exhaust, the mean grain cleaning efficiency improved from 97.44 to 98.18 % causing elimination of grain loss through straw blowing process. A newly designed feed conveyor uniformed the feeding rate that not only eliminated overloading of thresher but also reduced the fuel consumption by 1.3 L/hr (15 kW).
Keywords: Beater wheat thresher, agricultural machinery, total weight, flywheel, energy

INTRODUCTION

In Pakistan, there are about 500 units manufacturing agricultural machinery and implements, with a capacity of 1.38 million per annum such as wheat threshers, sugar cane crushers, chaff cutters, sprayers, rice hullers, rice husking machines, rice polishing machines, ploughs, drills, cultivators, plant protection equipment (Ahmad, 2004). The traditional methods of seed separation from the stalks are uneconomical, time consuming and laborious. The development of mechanical threshers for the purpose has clearly an edge over conventional methods and has reduced the drudgery of work to a great extent. Chaudhry (1979) found the total loss of wheat from bullock threshing, semi-mechanical threshing; threshing with thresher and combine harvester amounted to 3.11, 2.68, 2.01, and 1.2% respectively. The combine harvester had the minimum and the thresher had the 2nd last minimum grain losses indicating the importance of thresher use as compared with the bullock threshing.

At present, about 139777 wheat threshers are being used in Punjab alone (Anonymous 2012). Considering an average use of nearly 150 hours per year with consumption of diesel oil as 7.50 l/h/tractor @ Rs.105/L, the total cost of fuel consumed annually on wheat threshing in the Punjab is estimated at 16.5 Billion (PAK) rupees (US $ 168 Million @ 1$=98.1 Rs). This is a substantial amount of money for an oil importing country like Pakistan.

Unfortunately little scientific argument is available for either the sizes or the weights of the flywheels and the beaters except the market norms. Similarly, the centrifugal fan blower causes grain loss through its exhaust outlet (Khoshtaghaza and Mehdizadeh, 2006). Manual feeding of the crop into threshing drum in conventional machines is also a main cause of human accidents (Singh *et al*., 2005) in addition to erratic vibrations. Mufti *et al*., (1989) has reported that 16% of human injuries are associated with unsafe operation of threshers in Pakistan. Mohan and Patel (1992) recorded that thresher caused 2% of total agricultural injuries 150–200 thousand serious injuries, Kumar *et al*., (2002) though they are used only for a few days in the whole year. In view of heavy flywheels, crude design of cylinder beaters, unsafe crop feeding mechanism and poor blower design, this study was undertaken to design and fabricate flywheel, cylinder beaters, fan blower, and crop feeding conveyor system of conventional beater wheat thresher.

***Working process of beater wheat thresher*:** Tractor operating at rated engine speed operates the thresher through universal shaft attached on power take off drive (PTO) at 540 revolutions per minute (rpm). The universal shaft transfers power through belts-pulley transmission system to crop feeding, threshing, separation and cleaning units. Wheat crop manually fed in the hopper of conventional thresher is threshed by fast revolving beaters of the threshing drum through impact and rubbing action in the clearance between beaters and concave. Both the separated grains and chopped straw pass through the concave grates and fall onto the sieves. The tossing action of oscillating sieves separates grain from larger straw chaff and allows them to fall onto small hole-mesh sieve underneath. The straw chaff is sucked vertically upward by radial centrifugal fan blower and thrown out of the thresher through the exit outlet installed at the rear side of thresher. The grains are further cleaned from small straw pieces and debris by air coming horizontally from small blower across the bouncing mixture of grain and material other than grains (MOG).

Non-scientifically developed conventional wheat thresher components

A thresher manufactured by Noorani Industries Sumandri Road, Faisalabad Model 2010 was procured and coupled with MF-375 Massey Ferguson tractor for the present study in Post Graduate Research Station (PARS) research area University of Agriculture, Faisalabad Pakistan during threshing season 2010 & 2011. Following thresher components had been non-scientifically developed:

***i. Flywheel*:** The conventional thresher has three flywheels for controlling the vibrational fluctuations. The two flywheels (each of dia. 0.736 m and weight 80 kg) attached at either ends of the main shaft of threshing cylinder rotate at 818 RPM speed to absorb vibrational impacts resulting from variation in manual uneven feeding. The third flywheel (0.493 m dia. and 60 kg weight) placed with the pulley at the attachment of universal shaft rotates at 540 RPM for minimizing the vibrational effects from the tractor (Fig. 1 & 2). The available flywheels were considered too heavy and demanded redesigning. In order to reduce their weights as well as number, available literature relating mechanical design provides elaborative information for determining energy stored in flywheel, mass and dimensions of flywheel (Khurmi and Gupta, 2008; Shigley and Mische, 2007; Kepner *et al*., 2005).

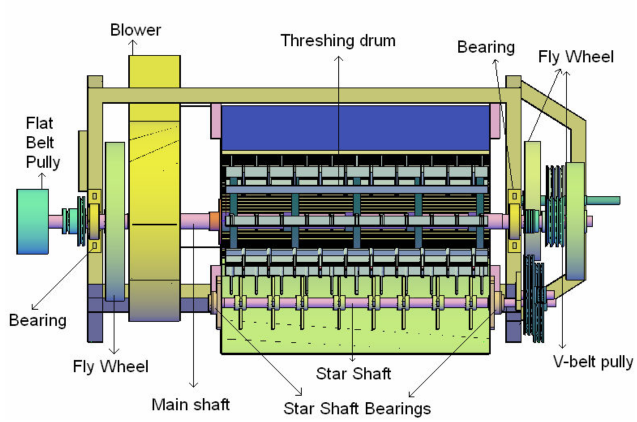

Figure 1. Top view of conventional wheat Thresher

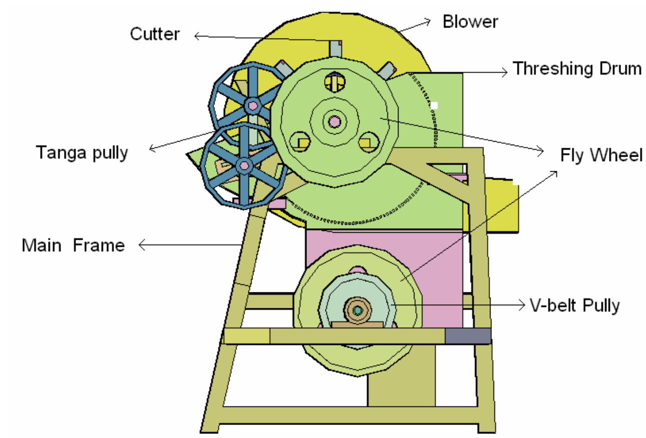

Figure 2. Side view of conventional wheat thresher

***ii. Centrifugal radial fan blower*:** A fan blower having 975 mm fan diameter with 1000 mm casing diameter was employed in the conventional thresher. During field test1-2% wheat grain loss was observed in the outgoing straw on the rear of thresher. Since the wheat is a high valuable food grain crop so the farmers do not accept this thrower loss. Therefore, it was the need of hour to redesign the fan blower to minimize this loss.

***iii. Cylinder beaters*:** It was carefully studied and found that an unnecessary non-technical support was provided to mount 100 beaters/cutters (100 mm x 38 mm x10 mm M.S. flat with tool tips) on horizontally welded angle irons (08 Nos. 50x50x6 mm M.S angle) on the periphery of rings (05 Nos. 50x8 mm M.S. steel cast) of rotating threshing cylinder (1375 mm long). Each beater was mounted by two bolts (16 mm dia x 40 mm long MS) on an MS plate (50 mm x 50 mm x 10 mm) which was welded with the horizontally welded angle iron on the threshing drum. The locally developed design not only overburdened the thresher but also increased operational cost and the manufacturing price of machine up to 20%.

***iv. Crop feeding hopper/chute*:** A 12 gauge M.S. sheet, width 1375 mm (matching the threshing drum dimensions) was employed to develop a hopper to feed manually wheat crop bundles from top of the thresher. Mufti *et al*. (1989) has reported that 16% of human injuries were associated with unsafe operation of threshers in Pakistan. To avoid such human injuries, it is necessary to redesign the feeding mechanism.

Design and testing of thresher components

***i. Design of flywheel*:** As it has been reviewed and decided to redesign a single flywheel that can replace the two bulky heavy weight flywheels, gray cast iron material of density 7200 kg/m3 was chosen. Main objective was to design a single flywheel saving extra weight of two large flywheels on either end of threshing cylinder or one small at the power input point by universal shaft. The design calculations were as follows:

Radius and weight of the redesigned flywheel were 0.4075 m and 100 kg respectively. The mass of the thin disc and hub was neglected while selecting the mass of flywheel. The energy stored in a flywheel has been calculated using the design principles suggested by Jain (1991). Flywheel energy at mean speed, $E = I\omega^2$

$$E = \frac{1}{2}(m * k^2)[\omega]^2 = \frac{1}{2}(m * k^2)\left[\frac{2\pi N}{60}\right]^2 \quad --- \; 1$$

$$\Delta E = \frac{1}{2}(m * k^2)\left[\frac{2\pi N_1}{60}\right]^2 - \frac{1}{2}(m * k^2)\left[\frac{2\pi N_2}{60}\right]^2 \quad ---2$$

$$\text{but } N = \frac{N1 + N2}{N} \quad \text{or} \quad N1 + N2 = 2N$$

$$\text{therefore,} \quad \Delta E = \frac{1}{2}(m * k^2)\left[\frac{2\pi}{60}\right]^2 [2N * (N1 - N2)] \quad ---3$$

$$\text{OR } \Delta E = \frac{1}{2}(m * k^2)\left[\frac{2\pi N}{60}\right]^2 2\,Cs$$

$$Ce - \frac{\text{Max fluctuation of energy}}{\text{mean energy of flywheel}}$$

$$Ce = \frac{\frac{1}{2}(m * k^2)\left[\frac{2\pi N}{60}\right]^2 2\,Cs}{\frac{1}{2}(m * k^2)\left[\frac{2\pi N}{60}\right]^2} = 2Cs \quad ---4$$

$$C_s = \frac{N_1 - N_2}{N} \quad ----5$$

Where, I= Moment of inertia of flywheel; ω = angular velocity of flywheel; E = Flywheel energy, kN-m; ΔE = Fluctuation in flywheel energy; m = mass of flywheel, kg; k = radius of gyration of flywheel = radius of flywheel, m; N = speed of flywheel, RPM; N1 = Maximum speed of flywheel, RPM; N2 = Minimum speed of flywheel, RPM; Cs = coefficient of fluctuation of speed

The effects of PTO speed of tractor on energy of flywheels of both conventional thresher (TH1) and newly developed thresher (TH2) presented in Figure 3 depicted that there was a consistent saving in energy at the flywheel of thresher TH2 from 500 to 630 RPM speed of PTO of tractor. This resulted in saving of tractor fuel. It had been found that mean diesel fuel consumed was 6.2 L/hr and 7.5 L/hr under redeveloped and conventional thresher respectively indicating fuel saving of 1.3 L/hr (15 kWh).

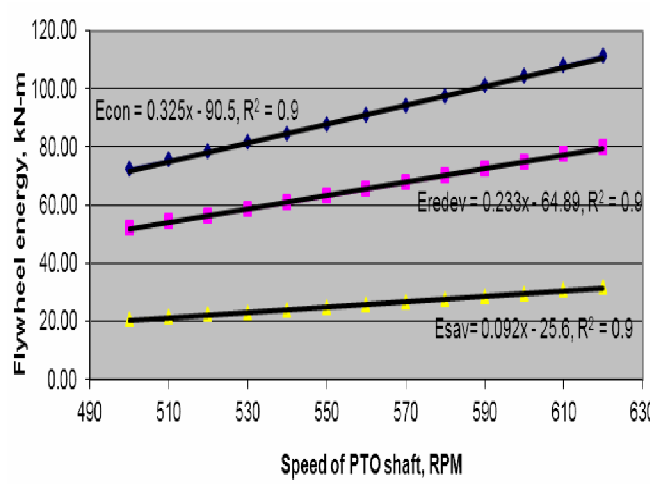

Figure 3. Effect of PTO speed of tractor on energy of flywheel of thresher

Regression analysis performed for flywheel energy at various rotating speeds of wheels produced mathematical models shown in Equations 6, 7 & 8. High values of coefficient of determination (R^2) indicate that these were the best models to predict energy absorbed/stored by the flywheels.

$$E_{con} = 0.32\,X - 90.5 \qquad R^2 = 0.9 \quad ------6$$

$$E_{redev} = 0.233\,X - 64.89 \qquad R^2 = 0.9 \quad ----7$$

$$E_{sav} = 0.029\,X - 25.6 \qquad R^2 = 0.9 \quad ------8$$

Where, E_{con}=kN-m, energy in three flywheels of thresher TH1 design; E_{redev}=kN-m, energy in one redesigned flywheel of thresher TH2; E_{sav}=kN-m, energy saving after redesigning the flywheel

It was physically observed during field testing that PTO speed varied from 500 to 560 RPM of thresher TH1and from 530 to 550 RPM of thresher TH2. The coefficient of fluctuation of speed C_N and energy C_e calculated and presented in Table 1 depicted that the coefficient of fluctuation of speed (C_N) of thresher TH2 and thresher TH1 was 0.037 and 0.113 respectively indicating 3.05 times less fluctuation in thresher TH2. The flywheel design criterion has been in line with the recommendations of Norton (1999) who concluded that the coefficient of fluctuation is a design parameter and be typically chosen between 0.01 and 0.05 which corresponds to a 1% to 5 % fluctuation in shaft speed.

Table 1. Coefficient of fluctuation of speed C_N and energy C_e of both threshers

	Conventional thresher, (TH1)	Redeveloped thresher (TH2)	Reduction ratio (TH1TH2)
Coefficient of fluctuation of speed, C_N	0.113	0.037	3.05
Coefficient of fluctuation of flywheel energy (Ce)	0.230	0.074	3.11

The smaller value of speed fluctuation will result increase in flywheel diameter. This presents a design parameter of flywheel. A larger flywheel will add more cost and weight to the system, which was weighed against the smoothness of operation desired. The coefficient of fluctuation of flywheel energy (Ce) of thresher TH1 and thresher TH2 was 0.23 and 0.074 respectively. This indicated that Ce of thresher TH2 was 3.11 time less than that of thresher TH1. The low fluctuation in Ce of thresher TH2 definitely would have been due to uniform feeding crop employing a newly designed conveyor which has reduced overloading of tractor engine and ultimately reduced fluctuations in engine speed.

***ii. Redesigning centrifugal radial blower*:** A centrifugal radial fan blower having 975 mm fan diameter with 1000 mm casing diameter was employed both in the thresher TH1 and thresher TH2. The straw exit outlet was horizontal (250 mm x 225 mm) in thresher TH1 (Fig. 4), whereas in thresher TH2 was raised 1 m and then made horizontal (Figure 5). Air velocity was measured employing an anemometer at the exit end of thresher TH1 (Fig. 4) and thresher TH2 (Fig. 5) blower and found to be 40 m/s and 36 m/s respectively at 815 RPM speed. Khoshtaghaza and Mehdizadeh (2006) experimentally determined the air terminal velocity of wheat and found that for air separation of wheat and straw, the air flow should be less than 7.04 m/s and more than 4.85 m/s. It seemed that an air velocity of 6 m / s was suitable for separating the straw from grain, however, sometimes weak grains were found on the straw heap in the field. Enough space was not available in the frame to enlarge the size of fan, so alternate was to enlarge the straw outlet length by raising the point of straw exit. The difference in height of 1 m was found optimum at which no grain were observed going out along-with the straw even weak grains which could be due to more resistance to grain movement of 1-m high against gravity. Design calculations of blower had been presented in Table 2.

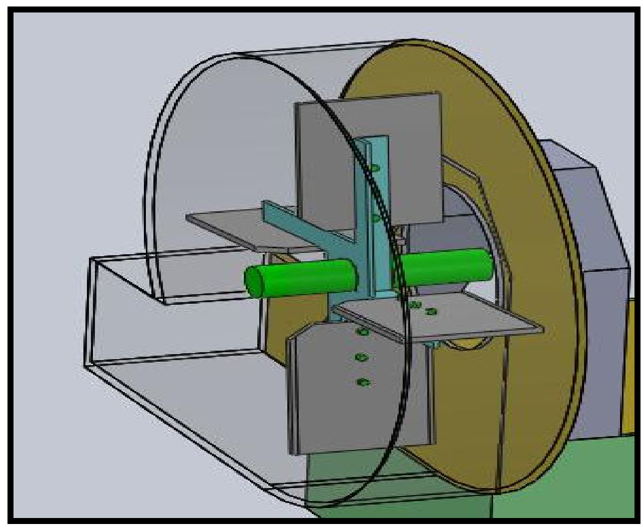

Figure 4. Conventional blower, Casing diameter 1000 mm, Fan dia. 975 mm Outlet size

Table 2. Design calculations of centrifugal radial fan blowers

Parameters	Conventional fan blower	Redesigned fan blower
Fan diameter, mm	975	975
Housing dia, mm	1000	1000
Straw exit outlet area, A, m^2	250 mm x 225 mm = 56250 mm^2 = 0.05625 m^2	250 mm × 250 mm = 62500 mm^2 = 0.0625 m^2
Air velocity at exit, V, m/s (calculated measured with Anemometer)	40 m/s	36 m/s
Air volume flow rate, m^3/s Q = A x V	0.05625 m^2x 40 m/s = 2.25 m^3/s	0.0625 m^2 x 36 m/s = 2.25 m^3/s
Area at suction end, A, m^2 (measured over sieves)	0.615 m x 0.6096 m = 0.375 m^2	0.615 m x 0.6096 m = 0.375 m^2
Air suction velocity, m/s, V = Q / A (measured and calculated over sieves)	2.25 / 0.375 = 6 m/s	2.25 / 0.375 = 6 m/s
Air suction velocity, m/s	6	6

250mm×225mm

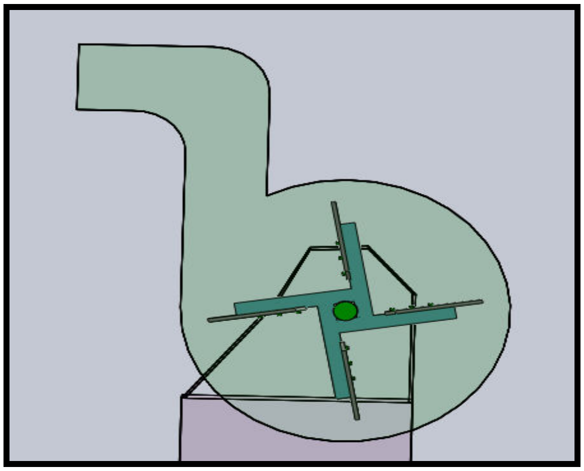

Figure 5. Redesigned blower, Diameter 1000 mm, Fan dia. 975 mm, Outlet size 250mm×250mm

***iii. Design of cylinder beaters*:** As explained previously, each beater was mounted on conventional thresher cylinder by two bolts (16 mm dia x 40 mm long MS) on its MS plate (50 mm x 50 mm x 10 mm) which was welded with the horizontally welded angle iron on the threshing drum. All the redeveloped beaters were directly welded onto the angle iron on the threshing drum which not only reduced the weight of threshing drum (35 kg) but also reduced power requirement of thresher operation. Cost of manufacturing had also been reduced by eliminating the use of high carbon steel chips (25 mm long, 15 mm wide and 10 mm thick) which were welded at the top front end of beaters for threshing the crop by impact and rubbing against the concave bars. The top front end of each redeveloped beater had been made hard enough by making a tungsten bead with arc welding of beater tip. Moreover, each beater bar had been divided into two equal parts and bolted onto the drum at alternate positions instead of welding as a single unit as in thresher TH1. This not only provided ease in repair and maintenance of beaters/bars but also reduced load on thresher due to threshing crop in steps. Both the cylinder beaters have been shown in Figures 6 & 7.

***iv. Design of crop feeding conveyor*:** Keeping in view the human safety, tractor overloading, thresher performance factors, a 1.65 m long and 1.3 m wide replaceable conveyor had been designed, fabricated and field tested for its performance during the wheat threshing season of the year 2011 (Fig. 8). A 14-gauge MS sheet was used to develop 20 cm wide u-channel (5 cm x 20 cm x 5 cm). These U-frames were made into a frame in which two 15-cm dia MS pipes (3-mm wall thickness) were adjusted as rollers over which a canvas belt had to roll over for conveying crop from lower end to upper end of conveyor.

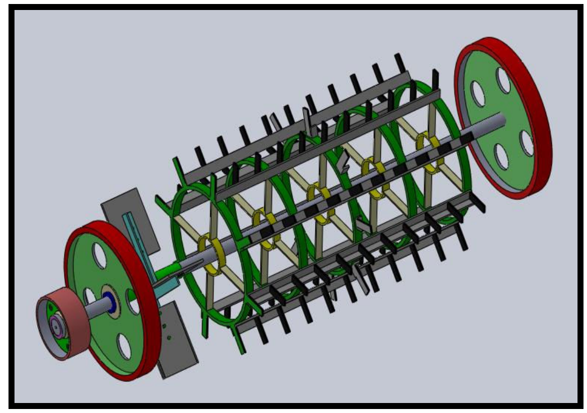

Figure 6. Conventional beater drum with front and rear flywheels

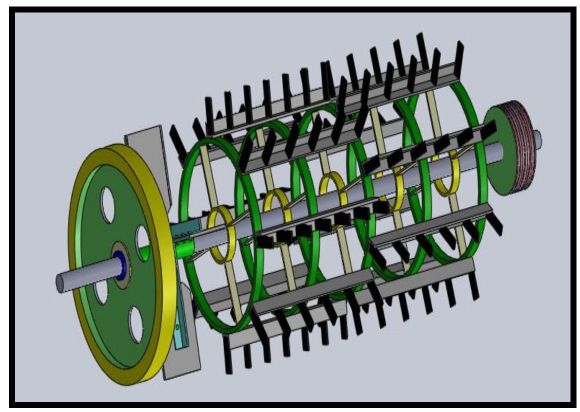

Figure 7. Redeveloped beater drum with one flywheel at rear end

Each roller pipe had a central 50 mm dia shaft as an axle which had ball bearings at either ends in u-frame. Flat wooden bars (50 mm wide x 10 mm thick) were bolted on the conveyer belt at an interval of about 40 cm throughout the conveyor. Three MS angle iron bars (25 mm x 25 mm x 3 mm) were also bolted at equal interval on the wooden bars for holding crop positively to avoid crop slippage during conveying. A 33 cm high 16 gauge MS sheet was bolted vertically along the conveyor length on both the u-channels (right and left channel) to avoid the crop fall down during conveying. A 40 cm high 16 gauge MS sheet had been bolted at an oblique angle of 45^0 for holding the crop at feeding end. Folding square end (5 cm x 5 cm) MS angle iron legs (2 legs 71 cm long each) have been employed to raise the lower end of conveyer 71 cm above ground. From upper side the conveyer U-channels were mounted by bolts on the hopper of feeder end of thresher 30-cm above the star feeder shaft. The crop was conveyed without slippage at 29^0 slopes with horizontal. A belt (B-type) has been employed to transfer power from thresher feeder pulley to a pulley installed on the axle shaft of lower roller of conveyor. The other end of lower axle of conveyer has chain and sprocket to convey power to the sprocket on the center axle of upper roller. The belt moves at a linear velocity of 0.57 m/s for optimum feeding and best crop threshing. A horizontally laying adjustable height control frame has been mounted to control the feeding rate if desired. Figures 9 & 10 present the field operation views of both threshers TH1 & TH2.

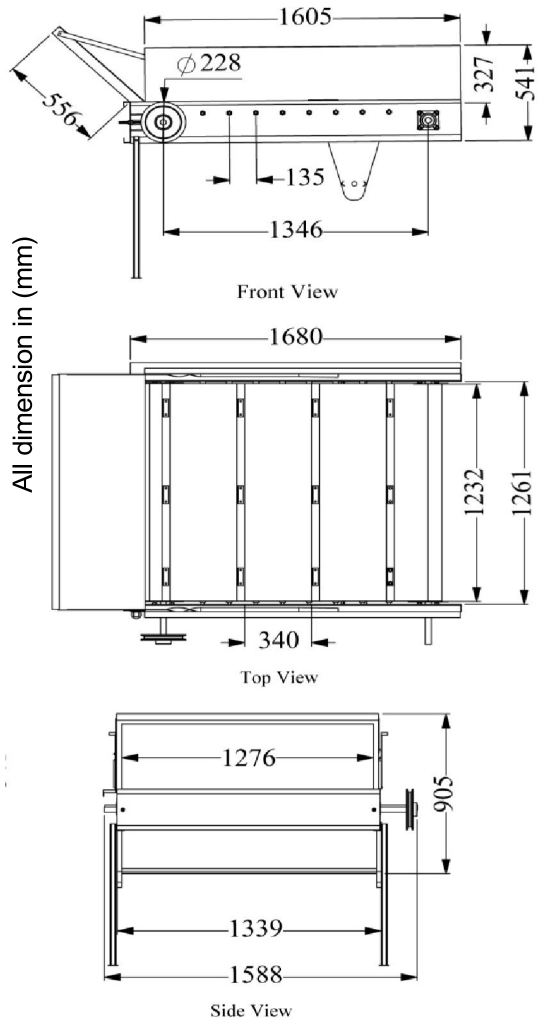

Figure 8. Orthographic views of designed Feeding conveyor

The output capacity of conveyor was determined using the following relationship developed by CEMA (1979) and Ali (2012):

$$\mathrm{CFR} = \mathrm{C.W.}\boldsymbol{V}.\boldsymbol{h}.\ \text{QUOTE}\ .\in.\gamma\ \mathrm{m}\ \boldsymbol{\rho} \text{ --- } \mathbf{9}$$

$$\mathrm{GFR} = c\mathrm{FR}\left[\frac{\mathrm{GSR}}{1+\mathrm{GSR}}\right] \text{ --- } 10$$

Where CFR = conveyor feeding rate capacity, kg/h; C=3600, constant; W= Width of conveyor, m;
V = Linear speed of conveyor, m/s; h=depth of crop in conveyor, m; ρ = Bulk density of the crop material in conveyor slit, kg /m^3; GFR= feeding rate, kg/h; GSR=grain straw ratio.

Figure 9. Conventional wheat thresher (TH1)

Figure 10. Redeveloped wheat thresher (TH2)

***Field testing*:** A 2x3x3x3 factor factorial was employed in CRD statistical design to evaluate the effect of two threshers (TH1 & TH2), three different wheat varieties (Seher 2006, Faisalabad 2008, Lasani 2008), three different crop moisture contents (MC1, MC2 & MC3), at three different crop feeding rates, (GFR1, GFR2 & GFR3) on the grain breakage, threshing efficiency and cleaning efficiency. Crop moisture content was measured by the recommended procedure (ASAE, 2009). Crop feeding rate, grain breakage, threshing efficiency and cleaning efficiency were determined by the relationships suggested by Ukatua (2006). Statistical analysis of results achieved was done using PROC GLM (General Linear Model) procedures of SAS institute (SAS, 2009).

RESULTS AND DISCUSSION

***i. Grain damage*:** The mean grain damage (GD) over varieties was significantly lower under thresher TH_2 (0.48%) than that under thresher TH_1 (1.98%) as depicted in Table 3. The variety Lasani 2008 (V3) had significantly lowest susceptibility to grain damage than other two varieties Seher 2006 (V1) and Faisalabad 2008 (V2). In Table 5, it is clearly reflected that thresher TH1 had more grain damage than thresher TH2 for all the three varieties. It could safely be concluded that thresher TH1 had more aggressive threshing action than thresher TH2 and variety V3 had been strong enough to resist the threshing aggressiveness than the other two varieties V1 and V2. Varieties V1, V2 & V3 had 2.06%, 2.02% & 1.86% grain damage of thresher TH1 & 0.48%, 0.49 % & 0.46% of thresher TH2, respectively. Mean GD of thresher TH2 was 24 times less than of thresher TH1.

The Table 4 depicted that the mean grain damage at moisture content MC1 was significantly greatest (1.31%) than those at MC2 (1.21%) and MC3 (1.18%). Moisture contents MC1, MC2, & MC3 were 11.2%, 13%, and 14.5% on wet basis (wb), respectively.

This indicated that less was the moisture content more was the grain damage. The findings are in line with the findings of Arnold (1964), Bainer and Borthwick (1934), Bunnelle *et al* (1954) and Kanafojski and Karwowski (1972) who reported that seed damage increases as the seed moisture content is reduced from 14%. The best moisture content for harvesting and threshing wheat had been found between 18 to 14% (OAEC, 1969-70). It could be concluded that the decrease in moisture content makes the grain more brittle and prone to more damage with the high impact forces of dynamic beaters installed on rotating drum. Thresher TH2 excelled in low grain damage than thresher TH1 at all the

Table 3 Effect of variety on grain damage of thresher TH1 and thresher TH2

Variety	Mean grain damage (%)		Mean	LSD (0.05)
	TH1	TH2		
V1	2.06^{a}_{a}	0.48^{a}_{b}	1.27_{a}	0.1029
V2	2.02^{b}_{a}	0.49^{a}_{b}	1.26_{a}	0.1051
V3	1.86^{c}_{a}	0.46^{a}_{b}	1.16_{b}	0.0710
Mean	1.98_{a}	0.48_{b}	1.23	0.0532
LSD (0.05)	0.0136	0.1311	0.0652	

Superscripts and subscripts show column wise and row wise comparison respectively; Same alphabets a, b, c etc indicate non-significant difference (α=0.05); V1, V2, and V3 show Seher 2006, Faisalabad 2008, Lasani 2008 wheat varieties respectively

Table 4. Effect of moisture content on grain damage of thresher TH1 and thresher TH2

Moisture content	Grain damage (%)		Mean	LSD (0.05)
	TH1	TH2		
MC1	2.07^{a}_{a}	0.55^{a}_{b}	1.31_{a}	0.087
MC2	1.97^{b}_{a}	0.45^{a}_{b}	1.21_{b}	0.096
MC3	1.91^{c}_{a}	0.44^{a}_{b}	1.18_{b}	0.099
Mean	1.98_{a}	0.48_{b}	1.23	0.053
LSD (0.05)	0.0131	0.1311	0.0652	

Superscripts and subscripts show column wise and row wise comparison respectively; Same alphabets a, b, c etc. indicate non-significant difference (α=0.05); MC1, MC2, and MC3 show 11.2%, 13%, and 14.5% (w.b) moisture content of wheat respectively

Table 5. Effect of feeding rate on grain damage of thresher TH1 and thresher TH2

Feeding rate	Grain damage (%)		Mean	LSD (0.05)
	TH1	TH2		
GFR1	2.33^{a}_{a}	0.66^{a}_{b}	1.50_{a}	0.0964
GFR2	1.92^{b}_{a}	0.44^{b}_{b}	1.18_{b}	0.0578
GFR3	1.70^{c}_{a}	0.33^{b}_{b}	1.02_{c}	0.1186
Mean	1.98_{a}	0.48_{b}	1.23	0.0532
LSD (0.05)	0.0136	0.131	0.0652	

Superscripts and subscripts show column wise and row wise comparison respectively; Same alphabets a, b, c etc. indicate non-significant difference (α=0.05); GFR1, GFR2, and GFR3 show 2560, 2720, and 2880 kg/hr cr feeding rate respectively three moisture levels. Therefore, TH2 had 0.55%, 0.45% & 0.44% and thresher TH1 had 2.07%, 1.97% & 1.91% grain damage at moisture content MC1, MC2 & MC3 respectively. This strengthened the previous conclusion of uniform and smooth thresh-ability for grain detachment from ears and chopping straw. Therefore, it could be concluded that what else the moisture content would be, the beaters without high carbon steel tips but with simple welded tops show better performance results regarding low grain damage, high thresh-ability and high grain cleaning efficiency.

The effect of thresher TH1 and thresher TH2 on grain damage for three feeding rates (GFR) presented in Table 5 depicted that thresher TH2 had significantly lower grain damage than those under thresher TH1 at all the three selected feeding rates (GFR). The mean grain damage of thresher TH2 (0.48%) was significantly lower than thresher TH1 (1.98%). The excellent performance of thresher TH2 strengthened the above conclusions of best new design of beaters over the conventional design of beaters. The horizontal, vertical and axial percent reduction in mechanical vibration in beater shaft was 80.13, 70, 70.52% respectively. The balancing of beater shaft was improved due to proper feed rate of the machine. The grain damage at feeding rate GFR1 was significantly greater than at other two feeding rates and GD at GFR2 was significantly greater than at GFR3.

The results in line with the findings reported by Kanafojski and Karwowski (1972). At lower feeding rate (GFR1= 2560 kg/hr) there would have been more direct contact between grain and beaters than at higher feeding rates GFR2 (2720 kg/hr) and GFR3 (2880) kg/hr. It could, therefore, be concluded that more the direct contact between grain and beaters more will be the grain damage. The results have been found in line with the findings of the OAEC (1970).

***ii. Threshing efficiency*:** The effects of thresher TH1 and thresher TH2 on threshing efficiency (THE) presented in Table 6 indicated that the threshing efficiencies of both the threshers TH1 and TH2 were significantly highest for variety V1 than the other two varieties. Thresher TH1 had 98.26%, 98.21%, and 98.22% and thresher TH2 had 98.92%, 98.88%, and 98.87% threshing efficiencies for varieties V1, V2, and V3, respectively.

The newly developed thresher TH2 excelled in threshing efficiency than thresher TH1 of all the selected varieties. This indicated that newly modified/designed beaters installed on the threshing drum had more capability of rubbing crop ears against concave bars and detaching grains smoothly without damaging than the old beaters having high carbon steel tips welded at the top of each beater.

The Table 7 showed the effect of threshers TH1 and TH2 on threshing efficiency at three moisture contents. The increase in moisture content from MC1 (11.2%) to MC3 (14.5%) resulted in increased threshing efficiency. The greatest efficiency of threshing was observed at MC3 moisture content of thresher TH1 and TH2. Moreover, threshing efficiency of thresher TH2 (98.89%) was significantly greater than thresher TH1 (98.23%).

Mean threshing efficiency at MC1, MC2, and MC3 was 98.49%, 98.59%, and 98.61% respectively. Even-though

Table 6 Effect of variety on threshing efficiency of thresher TH1 and thresher TH2

Variety	Mean threshing efficiency (%)		Mean	LSD (0.05)
	TH1	TH2		
V1	98.26^{a}_{b}	98.92^{a}_{a}	98.59_{a}	0.0759
V2	98.21^{b}_{b}	98.88^{a}_{a}	98.55_{a}	0.1285
V3	98.22^{b}_{b}	98.87^{a}_{a}	98.55_{a}	0.1026
Mean	98.23_{b}	98.89_{a}	98.56	0.059
LSD (0.05)	0.0152	0.1454	0.072	

Superscripts and subscripts show column wise and row wise comparison respectively; Same alphabets a, b, c etc indicate non-significant difference (α=0.05); V1, V2, and V3 show wheat varieties Seher 2006, Faisalabad 2008, Lasani 2008 respectively

Table 7 Effect of moisture content on threshing efficiency of thresher TH1 and thresher TH2

Moisture content	Threshing efficiency (%)		Mean	LSD (0.05)
	TH1	TH2		
MC1	98.18^{b}_{a}	98.80^{b}_{a}	98.49_{b}	0.1068
MC2	98.25^{a}_{b}	98.93^{ab}_{a}	98.59_{a}	0.1138
MC3	98.27^{a}_{b}	98.95^{a}_{a}	98.61_{a}	0.092
Mean	98.23_{b}	98.89	98.56	0.059
LSD (0.05)	0.0152	0.1454	0.0723	

Superscripts and subscripts show column wise and row wise comparison respectively; Same alphabets a, b, c etc. indicate non-significant difference (α=0.05); MC1, MC2, and MC3 show 11.2%, 13%, and 14.5% (w.b) moisture content of wheat, respectively there was no significant difference between the mean threshing efficiency at MC2 and MC3 yet MC3 produced 0.02% greater value of threshing efficiency. It could be concluded from above discussion that the moisture content MC3 (14.5%) being within the best moisture content range for threshing (14-18%) was the best moisture content for threshing.

The effects feeding rate on threshing efficiency of threshers TH1 &TH2 presented in Table 8 indicated that the increase in feeding rate significantly decreased the mean threshing efficiency. The thresher TH2 had significantly greater THE than thresher TH1at all levels of feeding rates. Thresher TH1 had 98.48%, 98.32% & 97.89% and thresher TH2 had 99.09%, 98.84% & 98.74% threshing efficiency at feeding rate GFR1, GFR2, and GFR3 respectively. The mean THE of threshers TH1 and TH2 were 98.23% and 98.89% respectively. As both the threshing efficiency and grain damage had decreased with the increase in feeding rate, therefore, a compromise has to be made that which feeding rate has to be selected from the quality of threshing and economics point of view. Thresher TH2 had lower grain damage and high efficiency values at all the three feeding rates than those observed under thresher TH1. Since the damaged grain are more susceptible for the attack of insect and pest and there was only 0.18% decrease in mean THE at GFR3 than that at GFR1, therefore, it would be better to recommend GFR3 for being on safe side, otherwise select the medium feeding rate (GFR2) of 2750 kg/hr.

***iii. Cleaning efficiency*:** The effects of variety on cleaning efficiency of thresher TH1 and thresher TH2 presented in Table 9 indicated that the mean cleaning efficiency over varieties was significantly greater of thresher TH2 (98.18%) than thresher TH1 (97.44%). This could be concluded that better the thresh-ability better would be the cleaning efficiency. Thresher TH2 might had threshed the crop uniformly and, therefore, chopped the wheat straw uniformly which would have been easy for the fan blower to separate the straw from grain. Mean cleaning efficiencies of thresher TH1 for varieties V1, V2, & V3 were 97.22%, 97.88%, & 97.22% and of thresher TH2 for the same varieties were 97.87%, 98.41% & 97.75% respectively. This indicated that both threshers for, variety V2 had greater cleaning efficiency, whereas V1 had the lowest. The horizontal, vertical and axial percent reduction in mechanical vibration in blower was 56.87, 38.13, 57.76% respectively in TH2. The static and dynamic balancing was considered during the design and manufacturing of the paddles of the blower.

Effect of moisture content on cleaning efficiency of threshers TH1and TH2 presented in Table 10 depicted that overall mean CLE was significantly greatest (98.29%) at moisture content (MC3=14.5%) and lowest (97.62%) at moisture content (MC1=11.2%). It could be safely expected that at MC1 (11.2%) the light chopped straw and broken brittle grain might had more volume to be separated from clean grain than that at MC3 (14.5%) and, therefore, could not be separated easily from threshed grain by the air sucked by the impeller blower, hence resulted in lower cleaning efficiency. So far as the significantly greater value of CLE value of thresher TH2 (98.19%) than that of thresher TH1 (97.71%) is concerned, it strengthened the previous discussion of uniform and smooth threshing capability of redeveloped beaters without high carbon steel. Thresher

Table 8. Effect of feeding rate on threshing efficiency of thresher TH1 and thresher TH2

Feeding rate	Threshing efficiency (%)		Mean	LSD (0.05)
	TH1	TH2		
GFR1	98.48^{a}_{b}	99.09^{a}_{a}	98.79_{a}	0.0389
GFR2	98.32^{b}_{b}	98.84^{b}_{a}	98.58_{b}	0.1036
GFR3	97.89^{c}_{b}	98.74^{b}_{a}	98.31_{c}	0.1434
Mean	98.23_{b}	98.89_{a}	98.56	0.0590
LSD (0.05)	0.0152	0.1454	0.0723	

Superscripts and subscripts show column wise and row wise comparison respectively; Similar alphabets a, b, c etc. indicate non-significant difference (α=0.05)

Table 9 Effect of variety on cleaning efficiency of thresher TH1 and TH2

Variety	Grain cleaning efficiency (%)		Mean	LSD (0.05)
	TH1	TH2		
V1	97.22^{b}_{b}	97.87^{a}_{a}	97.54_{b}	0.6207
V2	97.88^{a}_{a}	98.41^{a}_{a}	98.15_{a}	0.5242
V3	97.22^{b}_{a}	98.28^{a}_{a}	97.75_{b}	0.4248
Mean	97.44_{b}	98.18_{a}	97.81	0.2987
LSD (0.05)	0.4537	0.5846	0.3658	

Superscripts and subscripts show column wise and row wise comparison respectively; Same alphabets a, b, c etc. indicate non-significant difference (α=0.05); V1, V2, and V3 show wheat varieties Seher 2006, Faisalabad 2008, Lasani 2008 respectively

Table 10. Effect of moisture content on grain cleaning efficiency of threshers TH1 and TH2

Moisture content	**Cleaning efficiency (%)**		**Mean**	**LSD (0.05)**
	TH1	**TH2**		
MC1	97.41^{b}_{a}	97.84^{a}_{b}	97.62_{b}	0.6008
MC2	97.74^{ab}_{a}	98.14^{ab}_{a}	97.94^{a}_{b}	0.5452
MC3	98.00^{a}_{b}	98.57^{a}_{a}	98.29_{a}	0.4270
Mean	97.71_{b}	98.19_{a}	97.95	0.2587
LSD (0.05)	0.4537		0.3658	

Superscripts and subscripts show column wise and row wise comparison respectively; Same alphabets a, b, c etc. indicate non-significant difference (α=0.05); MC1, MC2, and MC3 show 11.2%, 13%, and 14.5% (w.b) moisture content of wheat respectively

TH2 had 0.43%, 0.4%, & 0.57% more values of CLE than those under thresher TH1 at moisture content MC1, MC2, & MC3 respectively. The CLE values at MC1, MC2, & MC3 of thresher TH1 were 97.41%, 97.74%, & 98% respectively and of thresher TH2 were 97.84%, 98.14%, & 98.57% respectively.

Effect of feeding rate on cleaning efficiency of threshers TH1 and TH2 had been presented in Table 11 depicted that the increase in feeding rate from GFR1 to GFR3 significantly decreased cleaning efficiency. Even though there was no significant difference among CLE values at three different feeding rates (GFR1, GFR2, & GFR3) of thresher TH2, the CLE at GFR1 was 0.52% & 0.57% greater than those at GFR2 & GFR3 respectively and the CLE at FR2 was 0.05% greater than that at GFR3. Although there was no significant difference between CLE values observed at GFR1 and GFR2 but both were significantly greater that at GFR3 under thresher TH1. The trend of efficiency was like the same as that of threshing efficiency discussed above. This would have been due to the reason that at less GFR1, straw chopping was more; threshing efficiency was also more, so it was easy for fan blower to suck and throw straw easily than that at GFR3.

***iv. Fuel consumption*:** The statistically analyzed results of fuel consumed by both the threshers at the selected feeding rates presented in Table 12 depicted that mean feeding rate GFR1 (2280 kg/hr) had significantly lowest fuel consumption (6.846 L/hr) and feeding rate GFR3 (2720 kg/hr) had greatest fuel consumption (6.852 L/hr). Same effect had been observed under each thresher at all the selected feeding rates. This was obviously true; more the material had to be threshed more would have been the fuel consumption. Thresher TH1 had significantly greater fuel consumption values at all the three selected feeding rates than thresher TH2. This could be due to light thresher drum (35kg less weight of thresher TH2), uniform feeding rate and newly designed conveyor. On an average thresher TH2 consumed 1.3 L/hr less diesel fuel (15 kW, @ 1-liter diesel= (0.893 kg)*(46 MJ/kg)*(0.28 kWh/MJ) =11.5 kWh) than consumed by thresher TH1.

***Conclusions*:**

1. Total weight of redeveloped wheat thresher was reduced

Table 11. Effect of feeding rate on cleaning efficiency of threshers TH1 and TH2

Feeding rate	Cleaning efficiency (%)		Mean	LSD (0.05)
	TH1	TH2		
GFR1	98.26^{a}_{a}	98.55^{a}_{a}	98.40_{a}	0.4315
GFR2	97.88^{a}_{a}	98.03^{a}_{a}	97.96_{b}	0.4249
GFR3	97.00^{b}_{b}	97.98^{a}_{a}	97.49_{c}	0.6883
Mean	97.71_{b}	98.19_{a}	97.95	0.2587
LSD (0.05)	0.4537	0.5846	0.3658	

Table12. Effect of feeding rate on fuel consumption of thresher TH1 and thresher TH2

Feeding rate	Fuel consumption (L/hr)		Mean	LSD (0.05)
	TH1	TH2		
GFR1	7.496^{c}_{a}	6.196^{c}_{b}	6.846_{c}	0.0006
GFR2	7.499^{b}_{a}	6.199^{b}_{b}	6.849_{b}	0.0006
GFR3	7.502^{a}_{a}	6.202^{a}_{b}	6.852_{a}	0.0006
Mean	7.499_{a}	6.199_{b}	97.95	0.0003
LSD (0.05)	0.0005	0.0005	0.0004	

Superscripts and subscripts show column wise and row wise comparison respectively; Similar alphabets a, b, c etc. indicate non-significant difference (α=0.05); GFR1, GFR2, and GFR3 show 2560, 2720, and 2880 kg/hr feeding rate respectively

from 1600 kg to 1300 kg by improving beaters in thresher drum and the grain damage in redeveloped thresher reduced four times.
2. The mean threshing efficiency was increased from 98% to 99% in redesigned thresher.
3. The replacement of the three flywheels by one wheel of required size saved 24.37 KN-m energy.
4. The fluctuation in speed was reduced to 3.05 times and coefficient of energy 3.11 times than that of conventional thresher.
5. By redesigning and redeveloping the direction of fan blower exhaust, the mean grain cleaning efficiency improved from 97.44 to 98.18% causing elimination of grain loss through straw blowing process.
6. Crop feeding system used on conventional thresher caused many fatal accidents every year. In improving the crop feeding system by designing, developing and fabricating a new conveyor, not only smooth uniform feeding rate was achieved yet intake was also increased than the conventional grain feeding rate i.e. 2770kg/hour.
7. The mean saving of diesel 1.3 L/hr (15 kW) was assured.

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