The Pharma Innovation Journal 2021; SP-10(10): 163-167

www.ThePharmaJournal.com

The Pharma Innovation

ISSN (E): 2277- 7695
ISSN (P): 2349-8242
NAAS Rating: 5.23
TPI 2021; SP-10(10): 163-167

www.thepharmajournal.com
Received: 01-08-2021
Accepted: 03-09-2021

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Performance evaluation of a bullock operated rotary gear transmission system for paddy threshing

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Abstract
Annual use of draught animals needs to be increased to reduce the burden of maintenance cost of bullocks, which can be possible by using post-harvest machines in rotary mode. Performance evaluation of a bullock operated rotary gear transmission system was conducted for paddy threshing by a hold-on type paddy thresher with respect to various parameters namely rotary system, physiological and machine parameters at three different levels of working radii in rotary mode. The lowest draft requirement, highest speed of operation of bullocks and highest thresher drum speed were observed to be 454.34 N, 0.73 m sec^{-1} and 435.45 rpm respectively at 3.8 m working radius. At this working radius, the physiological parameters of working bullocks such as pulse rate, respiration rate and body temperature were found to be within sustainable loading capacity of the bullocks. The machine parameters like threshing capacity and threshing efficiency were observed to be highest of 136.87 kgh^{-1} and 94.34 per cent respectively at a working radius of 3.8 m. The average mechanical transmission efficiency and performance index of the rotary system were found to be 64.84 per cent and 12.36, respectively.

Keywords: draft requirement, speed of operation, threshing capacity, thresher drum speed, threshing efficiency, pulse rate, respiration rate, body temperature

Introduction
In Odisha, the small and marginal land holdings constitute 83.8 percent of the total land holdings available and this will further increase with population growth. These categories of farmers mostly depend on draught animal power for different field operations such as tillage, sowing, transportation etc. Though the draught animals remain idle for a considerable period of time during a year they need to be fed throughout the year whether they are put to use or not. Therefore, the draught animals are required to be engaged for more number of days in a year by operating post-harvest gadgets through a rotary gear transmission system so that the burden of maintenance cost of draught animals can be minimized.
A number of rotary gear transmission systems have been developed in India and other parts of the world (Tiwari and Mishra, 1984; Starkey, 1989) [9, 7]. But the mechanical transmission efficiency of these gear units was reported to be within the range of 37 – 50% (Anon, 1988). Evaluation of post-harvest gadgets fitted in animal operated rotary gear unit such as wet grinder, potato peeler and potato slicer, chaff cutter, flour mill, briquetting machine and rice mill were conducted earlier (Mohapatra *et al*., 2017; Swain *et al*., 2013; Ghosal *et al*., 2012; Shinde *et al*., 2016; Choudhary *et al*. 2017; Korram *et al*., 2018) [17, 8, 3, 6, 2, 4].
In Odisha University of Agriculture and Technology (OUAT), one rotary gear transmission system was installed in College of Agricultural Engineering and Technology (CAET) campus by ICAR sponsored All India Coordinated Research Project on Utilization of Animal Energy. It was proposed to conduct a study on effect of working radii on rotary system parameters, physiological parameters of bullocks and machine parameters during threshing by a hold-on type paddy thresher.

Materials and Methods
Bullock operated rotary gear transmission system
The bullock operated rotary gear system consisted of a gearbox having spur and bevel gears with pinions of different ratios, main shaft and belt & pulley arrangement (Fig.1). The gearbox made up of 6 mm thick pressed mild steel plate and was rectangular in shape with a dimension of 660 x 579 x 274 mm. The spur gear and pinion had 77 and 16 teeth, respectively and meshed with bevel gears. The bevel gear and pinion had 43 and 7 teeth, respectively which transmit power to the main shaft (Fig. 1).

All the gears were made up of heat treated alloy steel. The combined speed ratio of spur and bevel gears was of 1:29.56 which was transmitted through the main shaft. Another counter shaft was connected to the main shaft through flat pulley and belt to further increase the speed ratio by 1:4. A 75 x 75 x 5 mm MS hollow square bar of 4500 mm length was fitted over the gearbox to be pulled by the bullocks in a circular path to rotate the system. One ratchet assembly was provided with the gearbox to prevent the backflow of power to the bullocks when they stop.

The performance of the bullock operated rotary gear transmission system available in CAET campus was evaluated for paddy threshing (Paddy variety-Swarna, high yielding, medium duration) using a hold-on type paddy thresher with three different working radii of 3.0, 3.4 and 3.8 m. The evaluation was conducted with respect to rotary system parameters, physiological parameters of working bullocks and machine parameters of the hold-on type paddy thresher (Fig 2). The rotary system parameters included draft requirement, thresher drum speed and speed of operation of bullocks. The physiological parameters of working bullocks included pulse rate (beats per minute), respiration rate (blows per minute) and body temperature (^{0}C) while the machine parameters included threshing capacity and threshing efficiency. A commonly used hold on type paddy thresher was used to evaluate the performance of the rotary gear transmission system. This paddy thresher can also be operated by one hp single phase electric motor. The detailed specifications of the hold on type paddy thresher are given in Table 1. A prony brake dynamometer was used to study the mechanical transmission efficiency of the gear system. The rotational speed of the counter shaft was measured by the help of a tachometer. The input draft by the bullocks for pulling the horizontal beam was measured with the help of a load cell. Medium size non-descript local bullocks having pair-weight of 944 kg were used to operate the rotary gear system. A hold-on type paddy thresher was evaluated in this rotary system to study its performance. All other parameters were measured using standard procedures.

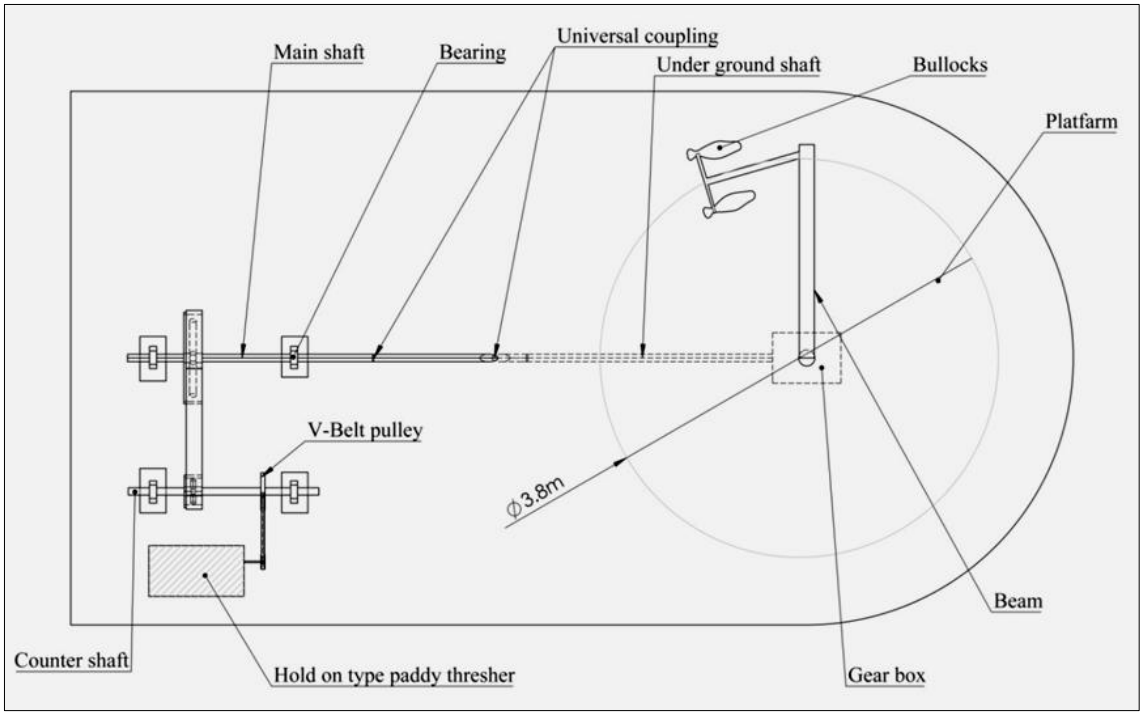

Fig 1: Schematic diagram of bullock operated rotary gear transmission system

Fig 2: Operation of paddy thresher in bullock operated rotary gear system in CAET campus

Table 1: Salient specifications of the hold on type paddy thresher

Sr. No.	Components	Dimensions
1.	Overall dimensions (LxBxH), mm	630x1200x760
2.	Type of threshing drum	Wire loop type
3.	Length of the threshing drum, mm	800
4.	Diameter of the threshing drum, mm	330
5.	No. of wire loop per slat	15
6.	Height of wire loop, mm	50
7.	Diameter of wire loop, mm	04
8.	Arrangement of wire loop	Staggered

Performance index of the roraty system

The performance index of the rotary system was developed considering the quantity, quality and power requirement parameters. The dimensional analysis of various parameters was done and the performance index was determined by using the following formula.

$$\text{Performance index} = \frac{\text{Quantity} \times \text{Quality}}{\text{Power requirement}}$$

Quantity was determined based on the following parameters

1. Threshing capacity (TC), kgh^{-1}
2. Speed of operation of bullocks (SOP), kmph
3. Thresher drum speed (TDS), rpm
4. Input draft, N
5. Output torque, N-m

Quality was calculated based on the following parameters

1. Mechanical transmission efficiency, $\eta_{mechanical}$
2. Threshing efficiency, $\eta_{thresher}$

Power requirement of the rotary gear system was taken as input power in Watts

Dimensional analysis of different parameters

1. Threshing capacity = $[ML^0T^{-1}]$
2. Speed of operation of bullocks = $[M^0LT^{-1}]$
3. Thresher drum speed = $[M^0L^0T^{-1}]$
4. Input draft = $[MLT^{-2}]$
5. Output torque = $[ML^2T^{-2}]$
6. Mechanical transmission efficiency = $[M^0L^0T^0]$
7. Threshing efficiency = $[M^0L^0T^0]$
8. Input power = $[ML^2T^{-3}]$

Quantity is expressed as [Threshing capacity] [Speed of operation] [Thresher drum speed] [Input draft]$^{-1}$ [Output torque]

$[ML^0T^{-1}]\ [M^0LT^{-1}]\ [M^0L^0T^{-1}]\ [MLT^{-2}]^{-1}\ [ML^2T^{-2}]$

$= [ML^2T^{-3}]$

Quality is expressed as [Mechanical transmission efficiency] [Threshing efficiency] $[M^0L^0T^0]$

$[M^0L^0T^0]$

$= [M^0L^0T^0]$

Power requirement is expressed as [Input power] = $[ML^2T^{-3}]$

$$\text{Performance index} = \frac{[ML^2T^{-3}][M^0L^0T^0]}{[ML^2T^{-3}]}$$

$= [M^0L^0T^0]$

Results & Discussion

The results of the performance of the rotary gear transmission system for a hold-on type paddy thresher has been discussed in the following sections

Effect of working radius on rotary system parameters

The results on effect of working radius on rotary system parameters such as draft requirement, thresher drum speed and speed of operation of bullocks have been presented in Table 1. The mean draft requirements for 3 levels of working radius were found to be significant. The highest mean draft of 505.31 N was recorded with a working radius of 3.0 m while the lowest mean draft requirement of 454.34 N was recorded with a working radius of 3.8m. The mean draft was observed to increase with decrease in working radius. This may be due to the fact that the torque requirement of the rotary gear system increased with decrease in working radius.

The mean speeds of operation of bullocks for 3 levels of working radius were found to be significant. The mean speed of operation of bullocks was found to be 0.73, 0.66 and 0.59 m sec^{-1} at working radius of 3.8, 3.4 and 3.0 m respectively. The results revealed that the mean speed of operation of bullocks increased with increase in the working radius. The reason was that the load on the bullocks decreased continuously with increase in working radius.

The mean thresher drum speeds for 3 levels of working radius were found to be significant. The highest mean thresher drum speed was 435.45 rpm with a working radius of 3.8 m while the lowest mean thresher drum speed of 395.91 rpm was recorded with a working radius of 3.0 m. The mean thresher drum speed was observed to increase with an increase in the working radius. The reason may be due to the fact that speed of operation of bullocks increased with increase in working radius.

Effect of working radius on physiological parameters of working bullocks

The results on effect of working radius on physiological parameters of working bullocks such as pulse rate, respiration rate and body temperature is presented in Table 1. The mean pulse rates of the working bullocks for 3 levels of working radius were found to be significant. Highest mean pulse rate of 75.14 bpm was recorded with a working radius of 3.0 m while lowest mean pulse rate of 64.13 bpm was recorded with working radius of 3.8m. The mean pulse rate was found to be increased with decrease in working radius.

The mean respiration rate of the working bullocks for 3 levels of working radius was found to be significant. The highest mean respiration rate of 37.29 bpm was recorded with a working radius of 3.0 m while lowest mean respiration rate of 22.86 bpm was recorded with working radius of 3.8 m. The mean respiration rate of the working bullocks was observed to increase with decrease in working radius.

The mean body temperature of the bullocks was found to be 37.96, 38.07 and 38.26 ^{0}C at different working radius of 3.8, 3.4 and 3.0 m respectively. This indicated that mean body temperature increased with decrease in working radius. The CD at 5% was found to be 0.14.

The physiological parameters of the bullocks namely pulse rate, respiration rate and body temperature increased with decrease in working radius. Decrease in working radius causes more and more draft requirement which results in increased load on the bullocks. The results indicated that the physiological parameter of the bullocks is a function of load

which ultimately depends on working radius. These results are in agreement with the observations on physiological response of bullocks for operating post-harvest gadgets like wet grinder, potato peeler and potato slicer, chaff cutter, flour mill, briquetting machine and rice mill (Mohapatra *et al*., 2017; Swain *et al*., 2013; Ghosal *et al*., 2012; Shinde *et al*., 2016; Choudhary *et al.* 2017 and Korram *et al*., 2018) [17, 8, 3, 6, 2, 4].

Effect of working radius on machine parameters

The results on effect of working radius on machine parameters such as threshing capacity and threshing efficiency have been presented in Table 1. The mean threshing capacity of the hold-on type paddy thresher at3 levels of working radius was found to be significant. The mean threshing capacity of 136.87, 126.77 and 117.80 kgh^{-1} was observed at a working radius of 3.8, 3.4 and 3.0 m respectively. The mean threshing capacity was observed to be increased with increase in working radius.

The mean threshing efficiency of the hold-on type paddy thresher at 3 levels of working radius was found to be significant at 5% level. The highest and lowest mean threshing efficiency of 94.34 and 91.06 per cent was observed with a working radius of 3.8 and 3.0 m respectively. The mean threshing efficiency was observed to be increased with increase in working radius.

The above results on threshing capacity and threshing efficiency of the hold-on type paddy thresher indicated that these values increased with increase in speed of operation of bullocks. The speed of bullocks was dependent on the working radius and increase in working radius reduces the draft load on the bullocks resulting an increase in the speed of operation of bullocks. However, out of the three working radii of 3.0. 3.4 and 3.8 m, the threshing capacity and threshing efficiency were found to be highest in case of 3.8m.Therefore, the working radius of 3.8 m was selected to calculate the mechanical transmission efficiency of the rotary gear system.

Table 2: Effect of working radius on rotary system, physiological and machine parameters in rotary gear transmission system

S. No.	Parameters	Working Radius, m			SE(m) ±	$CD_{0.05}$
		3.8	3.4	3.0		
	Rotary system parameters					
1.	Mean draft requirement, N	454.34	481.72	505.31	3.27	10.18
2.	Mean speed of operation of bullocks, m sec^{-1}	0.73	0.66	0.59	0.01	0.02
3.	Mean thresher shaft speed, rpm	435.45	414.89	395.91	2.59	8.07
	Physiological parameters					
4.	Mean pulse rate, bpm	64.13	70.00	75.14	0.44	1.38
5.	Mean respiration rate, bpm	22.86	30.29	37.29	0.47	1.46
6.	Mean body temperature, ^0C	37.96	38.07	38.26	0.04	0.14
	Machine parameters					
7.	Mean threshing capacity, kgh^{-1}	136.87	126.77	117.80	1.20	3.74
8.	Mean threshing efficiency, %	94.34	93.11	91.06	0.20	0.64

Mechanical transmission efficiency of the rotary gear system

The results of the mechanical transmission efficiency of the rotary gear system have been presented in Table 3. The mechanical transmission efficiency of the system was found with a medium size pair of bullocks and a working radius of 3.8 m with respect to different loads applied by the prony brake dynamometer. The input power was calculated considering the draft and speed of operation of bullocks while output power was calculated considering the force observed in the prony brake dynamometer and rotational speed of the counter shaft. The force applied at the prony brake dynamometer varied from 12 to 186 N while the corresponding load on the bullocks varied from 271.6 to 952.2 N. Accordingly, the relationship between input draft and output torque was found out which was used to find the output torque for operation of the paddy thresher with respect to draft input (Fig. 5). The speed of operation of bullocks was observed to vary within the range of 2.08 to 3.02kmph. Accordingly, the mechanical transmission efficiency of the system was found to vary within the range 60.38 to 69.62 per cent with average value of 64.84 per cent.

Table 3: Mechanical transmission efficiency of the rotary gear transmission system

S. No.	Input Parameters			Output Parameters			Efficiency%
	Draft, N	SOP, kmph	Input Power, W	Output Torque, Nm	Shaft Speed, rpm	Output Power, W	
1.	212.00	3.12	183.73	0.0	396.74	0	0
2.	271.60	3.02	227.84	3.6	365.12	137.58	60.38
3.	304.50	2.98	252.06	8.1	185.23	157.04	62.30
4.	365.30	2.86	290.21	13.5	129.87	183.51	63.23
5.	434.80	2.74	330.93	21.0	95.36	209.60	63.34
6.	495.20	2.61	359.02	26.7	82.54	230.67	64.25
7.	578.80	2.50	401.94	35.1	71.55	262.86	65.40
8.	690.60	2.30	441.22	40.5	69.12	293.00	66.41
9.	814.23	2.10	474.97	46.5	67.00	326.09	68.66
10	952.20	2.08	568.65	58.5	65.58	401.55	69.62
Average							64.84

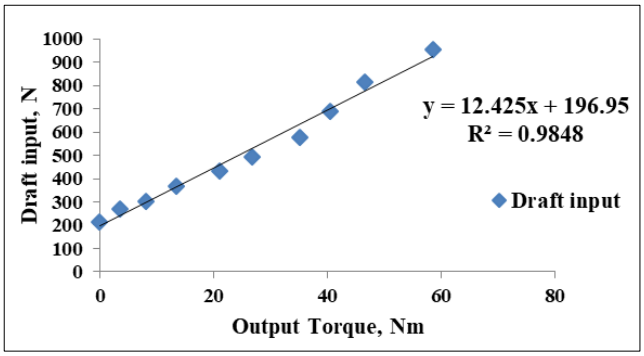

Fig 3: Relationship between draft and output torque

Performance index of the rotary gear system

The performance index of the rotary gear system was calculated using equation 1. The values of performance parameters used to calculate the performance index have been presented in Table 4. The threshing capacity, speed of operation of the bullocks, thresher drum speed, output torque, mechanical efficiency, threshing efficiency, input draft and input power were 136.87 kgh^{-1}, 2.63 kmph, 435.45 rpm, 20.72 Nm, 94 per cent, 61 percent, 454.34 N and 331.67 Watts respectively.

$$\text{Performance index} = \frac{\text{Quantity} \times \text{Quality}}{\text{Power requirement}} \quad \ldots (1)$$

$$\frac{(TC \times SOP \times TDS \times \text{Output torque} \times \eta_{mech} \times \eta_{thresher}}{\text{Input draft} \times \text{Input power}}$$

$$\frac{136.87 \times 2.63 \times 435.45 \times 20.72 \times 0.61 \times 0.94}{454.34 \times 331.67}$$

$$= 12.36$$

The performance index of the rotary gear system was found to be 12.36.

Table 4: Values of performance parameters used to calculate performance index

S. No.	Parameters	Values
	Threshing capacity,kgh^{-1}	136.87
	Speed of operation of bullocks, kmph	2.63
	Thresher drum speed, rpm	435.45
	Output torque, Nm	20.72
	Mechanical efficiency, per cent	61
	Threshing efficiency, per cent	94
	Input draft, N	454.34
	Input power, Watts	331.67

Conclusion

Considering the overall performance of the rotary gear system for paddy threshing by a hold-on type paddy thresher, the working radius of 3.8 m was found to be optimum considering the three working radii of 3.0, 3.4, and 3.8 m. The average mechanical transmission efficiency and the performance index of the rotary gear system were observed to be 64.84 percent and 12.36 respectively. The performance of the rotary system can be improved with development of a better rotary gear system with higher mechanical transmission efficiency and this could be achieved by increasing the gear ratio and eliminating the counter shaft to minimize power losses.

Acknowledgement

The authors are grateful to the support provided by ICAR, Government of India through the All India Coordinated Research Project on Utilization of Animal Energy being operated in Department of Farm Machinery and Power, College of Agricultural Engineering & Technology, Odisha University of Agriculture & Technology, Bhubaneswar, Odisha.

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