Development of an Unequal Speed Co-axial Split-Rotor Thresher for Rice

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ABSTRACT

During high moisture paddy threshing, the separation losses are generally large. However, while attempting to increase cropping intensity, it is often necessary to handle the moist paddy for threshing. Furthermore, in absence of adequate sunshine hours in wet season, crop can't be dried to a desired moisture level before threshing. Keeping these requirements in mind, a co-axial split-rotor thresher was designed for threshing high moisture paddy. This paper describes design and testing of a stationary thresher with an unequal speed co-axial split-rotor for rice in Thailand. First rotor serves mainly the threshing operation, whereas, rotating at relatively higher speed, the second rotor does mainly the separation of rice grains from husk. Faster rotation of second rotor increases separation performance by increasing centrifugal force. Optimum speed for threshing rotor was considered to be 25 m/s (600 rpm with 0.8 m diameter threshing rotor) and a speed for separation rotor was evaluated. For better grain separation, speed of 30.2 m/s (720 rpm with 0.8 m separation rotor) was found optimum. With the material feeding rate of 0.6-1.8 kg/s, the developed co-axial split-rotor thresher reduced the separation losses to 0.7-1.3% at the separation rotor speed range of 27.4-33.5 m/s. By increasing this speed above 33.5 m/s (800 rpm) the grain damage was increased.

Keywords: Rice threshing, split-rotor, rotational speed, separation efficiency, separation losses, Thailand.

1. INTRODUCTION

Agriculture remains an important sector of Thai economy. It contributes 11.4% of GDP, occupying nearly 55% of the total arable land (IRRI, 2007) and employing 49% of country's total labor force (CIA, 2008). Rice is a staple food of Thai people and it bears economic, social and cultural values. Thailand, being the world's leading rice exporter, produced more than 24 million tons of rice during 2005-06 crop year, and exported 6 million tons a year (Anon., 2006). For the past 25 years, Thailand is a leading exporter of rice with a one-third of world's rice export share.

In Thailand, approximately 75% of rice is grown in rain fed areas and only 25% is in the irrigated area. About 11.7% of irrigated area is in the Central plane, with 6.5%, 5% and 1.4% are in the Northern, Northeastern and Southern regions respectively (Singh and Chamsing, 2000). The central plain is an intensively rice cultivated alluvial area. This region comprises the largest irrigated area and thus farmers can grow rice more than once a year and receive the highest yield in the country.

During 1987-1991, agricultural mechanization played an important role in rice production in Thailand. During this time manufacturers around Bangkok successfully developed a locally made rice combine harvester which was popularly used for hiring services. For a Thai-made rice combine harvester, Mantamkarn (1991) and Kalsirisilp (1993) reported total grain losses between 1.3-10.8% due to mismatched feeding rate or travel speed, inappropriate field conditions and higher grain moisture content. It was found that the grain losses were generally caused by the threshing unit of the harvester.

The axial flow thresher, which is the same type that employed in Thai-made rice combine harvester, is the most popular thresher for rice in Thailand. The working of axial thresher is composed of threshing and separating operation, which requires different rotor speeds. The separation process needs faster rotor speed for higher separation efficiency. Normally in axial flow thresher, 80% of grains are separated in the first half of rotor, whereas, only 20% of grains are removed at later half of the rotor. These grains are not only difficult to separate from the straw, but also attribute to high grain losses as they blow out from outlet of the thresher. Grain loss from rice thresher in Thailand usually ranges between 3.35-10% (Nakwattananukul, 1993; Quick, 1998; Karlsirisilp, 2000) which is higher than the prescribed maximum value of three per cent by the ASAE standards for thresher (ASABE, 1997).

Especially in irrigated areas, nowadays, Thai farmers tend to grow rice more than one crop a year. Often they need to harvest rice with high moisture content during the rainy season. This brings high separation losses during threshing by the combine harvester. The high moisture content makes it difficult to separate grains out of straw. Furthermore, separation losses increase when the thresher operates at high feeding rate. So there was a need to develop a suitable thresher to thresh wet paddy with minimum grain losses.

This paper presents the applicability of co-axial split-rotor with unequal speed to thresh paddy with high moisture content. The designed threshing unit consisted of two co-axial split-rotors which rotate at different speeds - one for threshing and separation, and another mostly for final separation. The second rotor needed faster speed than the first one to increase centrifugal force. The prototype was tested and found to be promising with lower values of separation losses and power requirement. Details are presented in following sections.

2. DESIGN OF A PROTOTYPE

2.1 Design Concept

Separating efficiency of an axial flow threshing cylinder largely depends on the length and diameter of cylinder (or area of separation) and the peripheral speed of the cylinder. However, the length of threshing cylinder is limited by size of the combine harvester (width of chassis). Therefore, increasing peripheral speed is a promising option to increase separating efficiency, especially with compact size of thresher. As shown in Fig. 1, the developed threshing rotor and separating rotor are mounted on the same axle but they can rotate at different peripheral speeds.

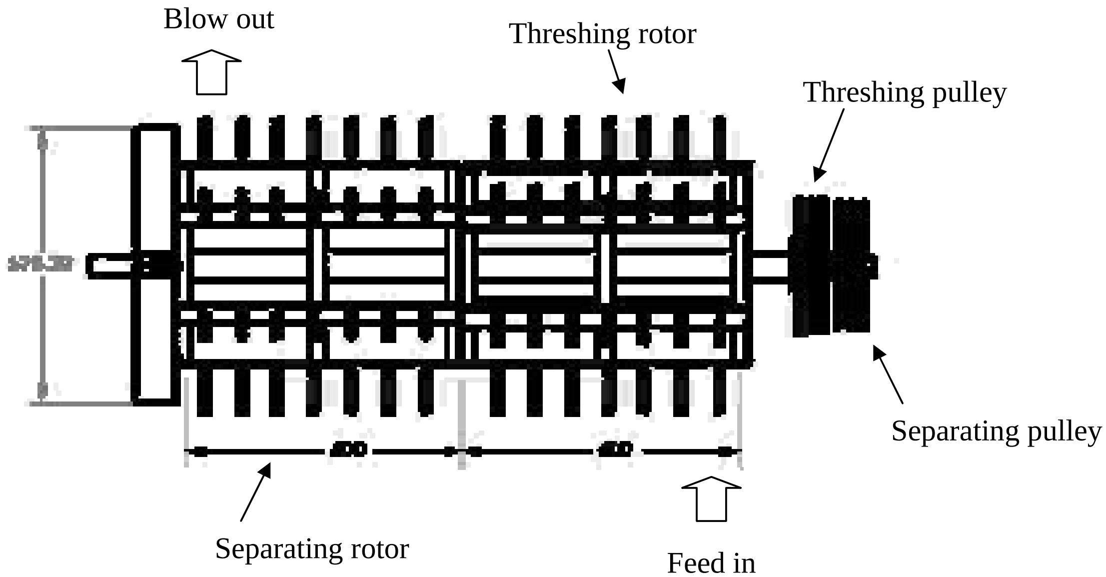

Fig. 1. Schematic of co-axial split-rotor thresher for rice (all dimensions are in mm)

For the modification, the smallest available sized Thai-made rice-thresher with 0.8 m rotor diameter and 1.2 m cylinder length was used. The recommended suitable speed of threshing rotor was 25 m/s (600 rpm) which was also maintained in this design. More than 80% of grains are retrieved under the threshing rotor. Faster speed of the separating rotor increased the centrifugal force and thereby increased separating efficiency. Furthermore, the speed of threshing rotor must be less than separating rotor to avoid grain damage. Preliminary test results suggested increasing speed of separating rotor up to 33.5 m/s is possible but more speed than this will damage the grains. The prototype of co-axial split-rotor thresher is shown in Fig. 2. Under the cylinder is the grain pan, which is also modified for studying the separation process along the cylinder length. The grain pan was divided into 12 sections with 100 mm width.

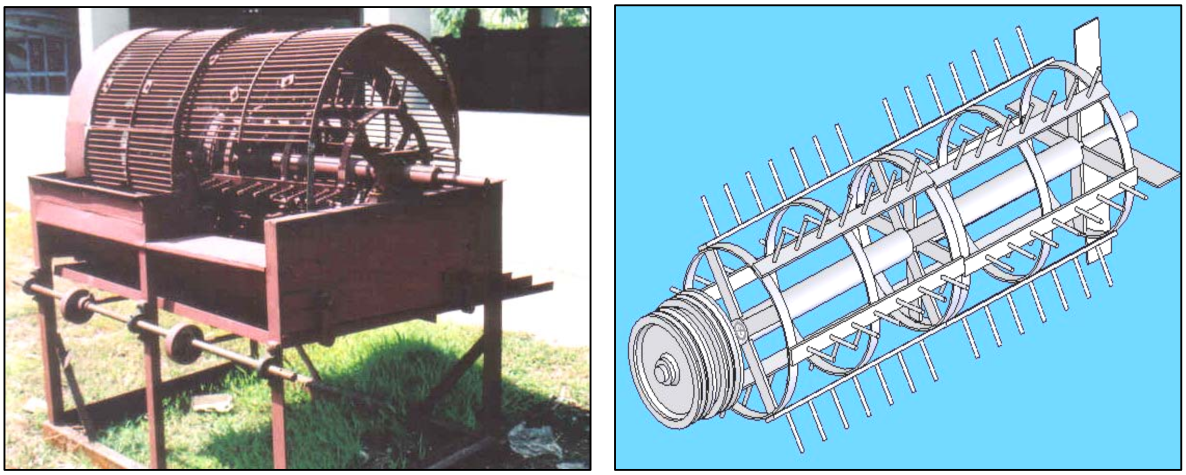

Fig. 2. Prototype of the co-axial split-rotor rice thresher

2.2 Design Specifications

The co-axial split-rotor thresher prototype was developed. A split-rotor was assembled on the same frame used for Thai-made thresher. Two pulleys, one for threshing rotor and another for separating rotor, were mounted at the front end. Design specifications are listed in Table 1.

Table 1. Specifications of major components of the developed prototype

Component	**Design value**
Threshing rotor	
Diameter	0.8 m
Length	0.6 m
Separating rotor	
Diameter	0.8 m
Length	0.6 m
Total length of thresher	1.2 m
Concave wrap angle	80^{o}
Cylinder type	Spike tooth

2.3 Experimental Details

Experiments were conducted with the newly designed prototype at the Machinery Department of the Rajamangala University of Technology, Suwarnabhumi, Thailand.

The *Chainat-1* rice variety was used for testing. This is the second crop rice and can be grown all the year. The second crop accounts for high grain losses during threshing because it is grown during rainy season and thus harvested at high moisture content. The crop was cut 10~15 cm above ground and collected for experiments. It was wrapped with plastic sheet to avoid moisture loss during the testing. Physical properties of the test material were measured (Table 2).

Table 2. Physical properties of test material (*Chainat-1* variety, age 110 days)

Property	Value
Plant density	506 plants/m^2
Grain yield	0.449 kg/m^2
	4,490 kg/ha
Total material	17,868 kg/ha
Grain moisture content	26.75% (d.b.)
Straw moisture content	64.29% (d.b.)
Grain-Straw ratio	1: 2.978
Average straw length	72 cm

To evaluate the machine performance, material feeding rate and speed of separating rotor were varied and the performance was evaluated. Tests were replicated thrice. Optimum operating range, corresponding to low separation losses and low power consumption, was determined. Pre-tests were performed before actual tests to ensure that the test can cover the range that was intended to study and then divided the level of each factor over the range. The two experimental parameters, feeding rate and speed of rotor were varied at four levels each (Table 3).

Table 3. Experimental factors and their levels of variation

Material feeding rate, kg/s (kg/h)	Speed of separating rotor, rpm (m/s)
0.6 (2,160)	600 (25)
1.2 (4,320)	655 (27.4)
1.5 (6,480)	720 (30)
2.4 (8,640)	800 (33.5)

2.3 Experimental Setup

The material was uniformly spread over a 15 m long and 0.4 m wide flat belt conveyor before it is fed into the thresher at the intake port. Different material feeding rates (0.6, 1.2, 1.8 and 2.4 kg/s) were achieved by varying quantity of material over the conveyor. Different speeds of separating rotor (600, 655, 720 and 800 rpm) were obtained by changing pulley on the separating rotor shaft.

To collect separated grains, sections were made to divide rotor length into twelve compartments. The grain collection pan was placed under the rotor (Fig. 3). At the same time net sack was used to collect material which blows out of the outlet. This blown out material was further processed to separate straw out of the grain and weighted for calculation of grain loss. Thus, the amount of grains collected in each section of the grain pan provided cumulative grain distribution along the rotor length from front to the end.

Fig. 3. Sectional compartments to collect separated grains and covering of thresher outlet port with net sack

Torque transducer, coupled with a data logger, was used to measure and record torque at the main drive shaft (Fig. 4). Catman software was used to interface data logger with computer through Spider-8.

Fig. 4. Use of torque transducer to measure the torque at the main drive shaft

An inductive proximity switch and speed counter were used to measure rotational speed of main shaft and rotating speeds of threshing rotor and separating rotor (Fig. 5). All experiments were conducted at the same time to avoid changes in the physical properties of the material used in the experiments. Test material was safe guarded against the rain, sunshine and wind.

Fig. 5. Use of an inductive proximity switch to measure rotational speed

3. RESULTS AND DISCUSSION

Data were collected for grain losses (measured at the thresher outlet), torque at the main shaft (for power consumption calculation), amount of grains in each section of grain pan (for analyzing separation distribution and cumulative grain separation along the rotor length), and rotational speed of the rotors and main drive shaft.

3.1 Effects of Material Feeding Rate and Separation Rotor Speed on Grain Separation

The statistical analysis by ‘F’ test showed that the material feeding rate was the most influencing factor (Table 4), followed by the speed of separation rotor for threshing of a high moisture paddy. As a general observation, grain separation losses decreased with increasing rotor speed, but the losses increased rapidly with increasing feeding rate (Fig. 6). Considering a ceiling value of 3% separation losses (ASABE Standards, 1997) it is evident that the optimum values for speed of separation rotor was in the range of 655-800 rpm (27.4-33.5 m/s) and that for material feeding rate was in the range of 0.6-2.4 kg/s, except at 600 rpm and 2.4 kg/s feeding rate.

Table 4. Analysis of Variance

Source of Variation	*SS*	*df*	*MS*	*F*	*Pvalue*	$F_{0.001}$	$F > F_{0.001}$
Rotor speed (A)	3.37	3	1.12	115.68	4.66E-11	9.005937	Significant
Feed rate (B)	13.43	3	4.48	461.42	9.65E-16	9.005937	Significant
Interaction (AB)	1.27	9	0.14	14.56	4.02E-06	5.983855	Significant
Error	0.16	16	0.0097				
Total	18.23	31					

3.2 Grain Separation along the Rotor Length

About 80% of total grains were separated up to the mid length of rotor drum, while the separating rotor separated remaining 20% of the grains. Figure 7 depicts such a distribution of separated grains along the rotor length at 720 rpm. The trend was similar at all feeding rates of the material.

3.3 Power Requirement

Increasing rotor speed obviously increased power consumption at all feeding rates of material. Figure 8 shows the maximum power consumption of the developed co-axial split-rotor at its main shaft. Average power consumption at rotor speeds of 600, 655, 720 and 800 rpm were 17.56, 19.76, 25.87 and 29.85 kW respectively. The power consumption at optimum speed of separation rotor (655 – 720 rpm) with 2.4 kg/s material feeding rate was in the range of 19.76 – 25.87 kW.

3.4 Economic Analysis

Economic analysis of using developed-prototype was performed (Table 5). Standard assumptions were made in calculating various costs. The total annual cost (895 USD/year) comprised of fixed (360 USD/year) and variable costs (535 USD/year). Assuming 100 working days in a year and 14 ton/day machine output, the hiring of thresher from middlemen costs 80 USD/day, which leads to net saving from the prototype as 9 USD/day. The payback period for this machine is 22 months or 2 years approximately.

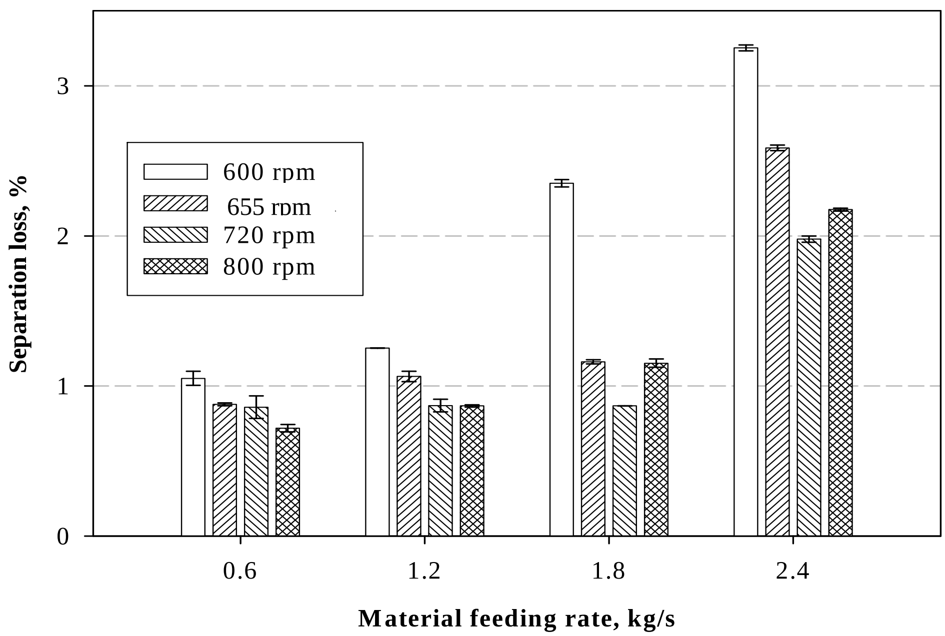

Fig. 6. Effects of separation rotor speed and feeding rate on grain separation losses

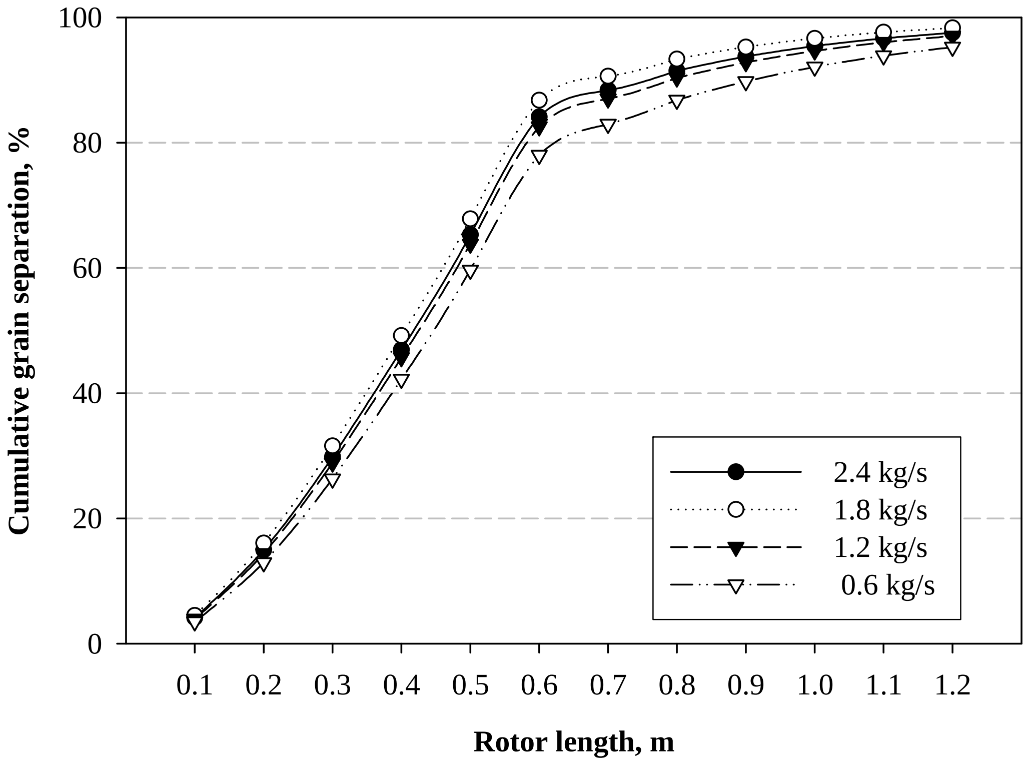

Fig. 7. Cumulative grain separation along the length of the rotor at 720 rpm speed

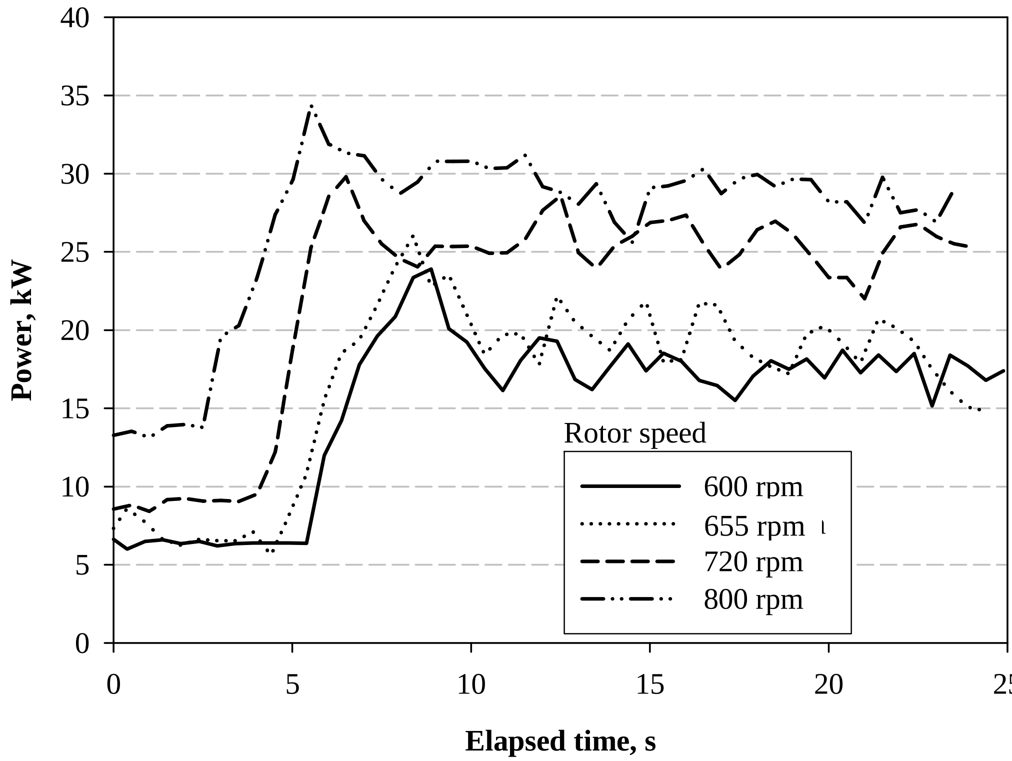

Fig. 8. Effect of speed of separation rotor on power consumption at 2.4 kg/s material feeding rate

Table 5. Economic evaluation of the developed prototype*

Item	Value	Unit
Purchasing cost	1,715	USD
Useful life	10	years
Salvage value (10% of purchase price)	171	USD
Annual fixed charges		
Depreciation	154	USD/year
Interest on investment (7%)	120	USD/year
Repair and maintenance (5%)	86	USD/year
Total fixed cost	360	USD/year
Variable costs		
Labor wages for loading and unloading (2 laborers/day)	15	USD/day
Fuel (1 USD/liter, 35 liter/day)	35	USD/day
Lubrication (10% of fuel consumption)	4	USD/day
Daily variable cost	54	USD/day
Annual variable cost (100 working days/year)	535	USD/year
Total annual (Fixed + Variable) cost	895	USD/year
Daily total cost	89	USD/day
Production cost per ton of rice output	6	USD/ton
(Machine capacity = 14 tons/day)		
Normal hiring price of thresher =	6	USD/ton
	80	USD/day
Total saving per day = (89 - 80) USD/day	9	USD/day
Payback period (approx.)	2	years

* Assuming 1 USD = 35 THB

4. CONCLUSIONS

The co-axial split-rotor thresher prototype was successfully developed and evaluated for its performance. The results revealed that if operated within 655 – 720 rpm separation rotor speed and at 0.6 – 1.8 kg/s material feeding rate, the grain separation losses were only 3%, i.e. 0.7 – 1.3%. Furthermore, this operational range corresponds to lower power consumption.

The grain separation process at higher rotational speed, while keeping threshing within the safe speed limits, the co-axial split-rotor offered fewer grain losses. The coaxial split-rotor therefore, found suitable for threshing the Thai rice having higher moisture content. Further studies are intended to mount this newly developed thresher on the currently used Thai combine harvester and test its performance in the actual field.

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