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Design Analysis and Fabrication of Manually Operated Machine for On-Row Transplanting of Paddy Rice

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ABSTRACT— Manual transplanting of paddy rice seedlings exposes small scale rice farmers to musculoskeletal disorders as well as back problems resulting from repetitive bending and awkward postures involved. This research is focused on the design analysis of a simple but durable manually operated machine for on-row transplanting of paddy rice. A simple manual rice transplanter was developed consisting of the following basic components: seedling tray, chassis, picking fork/fingers, wheels assembly, transmission drives, pulling mechanism, and float board. Some of the design parameters of considered includes mean forward speed 1.4 m/s, plant spacing 250 mm and assumed loose physical state of rice seedlings. The designed machine theoretically weighting 163.84 N is to be operated by a single operator, and has a planting rate of 777 plants in a minute at the mean forward speed. The component analysis was conducted and power requirement for the machine is 41.3 W well below the power of average man which is 76 W. Following the design specifications, various component parts of the transplanter were fabricated, assembled and tested.

Index Terms— Drudgery, float board, musculoskeletal, on-row, picking fingers, paddy, seedling, Transplanter.

I. INTRODUCTION

Rice (Oryza sativa) is a staple food in many countries of Africa and other parts of the world. This is the most important staple food for about half of the human race [1]. [2] classified rice as the most important food depended upon by over 50 percent of the World population for about 80 percent of their food need. Due to the growing importance of the crop, Food and Agricultural Organization [3] estimated that annual rice production should be increased from 586 million metric tons in 2001 to meet the projected global demand of about 756 million metric tons by 2030. Statistically, Nigeria is the highest importer of rice globally and the largest producer in West Africa.

Rice cultivation mainly depends on the following factor (i) age of the variety (ii) availability of moisture (iii) climatic conditions (iv) availability of inputs and labour [4]. Among these reasons, availability of inputs and labour play a huge role on deciding the method of production of rice. Several attempts have been made to mechanize paddy transplanting operation by introducing various transplanters and research is under progress to reduce the cost of production with less fatigue. Traditional method of rice transplanting requires frequent bending down and straightening up for transplanting process where as mechanical transplanter requires energy for pulling the transplanter in a puddled field.

In Nigeria, rice is grown by broadcasting of seeds and manual transplanting of seedlings. In practicing this method however, framers are exposed to musculosketal disorders as well as back problem due to repetitive bent posture needed in performing the task. Therefore the development of manually operated rice transplanter is considered a promising option as it would saves time, labor, and ensure timely planting optimum plant density that well contribute to high productivity.

II. METHODOLOGY

2.1 Design Considerations

The following factors were considered in the design specifications of the machine.

- Engineering properties of rice seedlings
- Availability of materials
- Strength
- Ease of operation.
- Ease of maintenance
- Material Cost.

2.2 Description of the Machine

The designed rice transplanter consists of the following major component parts: chassis, pulling assembly, seed tray, picking arm, chain drive, base board, ground wheel and central shaft. The rice seedling is loaded on two-sided seed trays which allows easy picking two seedlings each by the picking mechanism that is operated through the help of the ground wheel and four bar linkage. The two seedlings are planted by the oscillation of the picking arm.

2.3 Working Principle

As the process is manual, the worker has to provide the initial motion. When the rice transplanter move forward the ground wheels rotate and there by generate torque to power chain drives through the central shaft. The wheels are provided with the fins so that they can travel easily in the mud. The ground wheels are used to maintain constant distance between the two successive plants. The larger sprocket is provided on the same shaft with the ground wheels while the smaller one placed on the same shaft with the planting mechanism.

As the power will get transmitted to the smaller sprocket, it will rotate and oscillate the 4 bar linkage that forms planting mechanism. As the mechanism oscillates, the planting fingers pick the rice seedlings from the carefully positioned seedling trays and plant them in the mud. The planting finger is designed in such a way that rice plant should be easy to pick and only during the downward motion.

2.4 Component Design Analysis

Ground wheel Design Analysis

Assuming Diameter of the ground wheel d = 260 mm

The perimeter or circumference of ground wheel was calculated using the equation from [5].

$$\text{Circumference of the ground wheel} = 2\pi r \quad (1)$$

$$\text{Radius} = \frac{d}{2} = \frac{260}{2} = 130 \text{ mm}$$

Standard spacing for rice plant = 25cm = 250mm

Circumference of the ground wheel

$$= 2 \times \pi \times 130 = 817 \text{ mm}$$

Number of plants to be planted per ground wheel rotation

$$= \frac{\text{Wheel circumference}}{\text{plant spacing}}$$

(2)

$$= \frac{817}{250} = 3.268 \text{ Plants}$$

Note: This for single picking finger

Therefore for the two picking fingers

$$= 3.268 \times 2 = 6.536$$

Therefore the number of plants that will be planted per each revolution of the wheel will be 6 plants.

Angular Speed of the Wheel

From [6]

$$\omega = \frac{v}{r}$$

(3)

$$N = \frac{60\omega}{2\pi}$$

(4)

Where:

ω = angular speed of the wheel in rad/seconds

v = Average walking speed of a man in m/s

r = radius of the wheel

N = revolution of the wheel in a minute

Adopted walking speed of a man v =1.4 m/s

Assumed radius of the ground wheel r =130 mm = 0.13m

$$\omega = 1.4/0.13 = 10.769 \, rad / sec$$

$$N = 60 \times \frac{10.769}{2} \times \pi = 102.839 \, rpm$$

$$\textit{The revolution of wheel in a minute} = 102.839$$

ANALYSIS OF CHAIN DRIVE

All the power transmission will be achieved by wheel, sprocket and chain mechanism.

Sprocket velocity ratio is given by

$$S_R = \frac{S_1}{S_2}$$

(5)

Where,

S_1 is the number of teeth on the driving sprocket

S_2 is the number of teeth on the driven sprocket

Assuming $S1 = 34, \; S2 = 9$

$$S_R = \frac{34}{9} = 3.78$$

Driving Sprocket N_1

Speed of driving sprocket is equivalent to speed of ground wheel rotation =102.84 rpm

Driven sprocket N_2

From $N_1 \times S_1 = N_2 \times S_2$

(6)

Where:
N_1=speed of driving sprocket
N_2=speed of driven sprocket
S_1=No of teeth on the driving sprocket
S_2=No of teeth on driven sprocket
N_1=102.84rpm
S_1=34
S_2=9
N_2=102.84 x 3.78

$$N_2 = 388.4\, rpm$$

ANALYSIS OF PLANTING FINGERS

Rate of Oscillation of the Planting Fingers

The rate of oscillation of the planting fingers or mechanism is equivalent to the rotational speed of the driven sprocket powering it.

$$i.e\ N_p = N_2 \qquad (7)$$

Where

$N_p = rate\ of\ oscillation\ of\ planting\ fingers, rpm$

$N_2 = speed\ of\ the\ driven\ sprocket\ in\ rpm$

$\therefore N_p = 388.4\, rpm$ or 388.4 cpm

Number of Seedlings Transplanted in a Minute

Since in each cycle of oscillation, a hole is planted by each finger; therefore, number of seedlings transplanted in a minute of planting is determined using the relationship:

$$\dot{s} = n_f \times N_p \qquad (8)$$

Where

$\dot{s} = number\ of\ seedlings\ transplanted\ in\ a\ minute$

$n_f = number\ of\ planting\ fingers$

$N_p = rate\ of\ oscillation\ of\ the\ planting\ mechanism$

$\dot{s} = 2 \times 388.4$

$= 777\ plants$

DETERMINATION OF WEIGHT

The total weight of a machine is calculated considering the length, geometric sections and mass per unit length of individual component materials used and the weight of various metals used was computed from [7].

Weight of Chassis

The Chassis is made up of two different materials that is the angle Iron (25 x 25 x 3) and a hollow square pipe (30mm).

Length of Angle Iron selected

L = (147 x 2) + (200 x 2) + (395 x 2) =194 + 400 + 790 = 1384mm = 1.384 m

Cross Sectional Area of Angle Iron $= (W0 - Wi)$ (9)

$$= (25x\ 25) - (22\ x\ 22) = 625 - 484 = 141\ mm^2$$

$Mass\ of\ Angle\ Iron = Volume\ (v) \times Density\ (\delta)$ (10)

$D(\delta) = Density\ of\ mild\ steel = 7850kg/m^3$

$V = Volume\ of\ Angle\ Iron = 1.95 \times 10^{-4}\ m^3$

$m = 0.000195\ m^3 \times 7850\ kg/\ m^3$

$m = 1.53075\ kg$

$Weight\ of\ Angle\ Iron$

$$= Mass \times gravity \qquad (11)$$

$$m = 1.53075\ kg$$

$$g = 9.81 m/s2$$

$$1.53075 \times 0.81\ m/s^2$$

$$W = 15.016657\ N = 15.02\ N$$

Length of Square pipe.

L=150 + (141 x 2) + (147 + 2) + (80 x 3) + (210 x 2) + (134 x 4)

L=150 + 284 + 294 + 240 + 420 + 536

L=1922mm = 1.922m

L = 1.922m

Cross sectional Area of Square hollow pipe = $(W_0^2 - W_1^2)$ (12)

W_0 = Outer width of the pipe

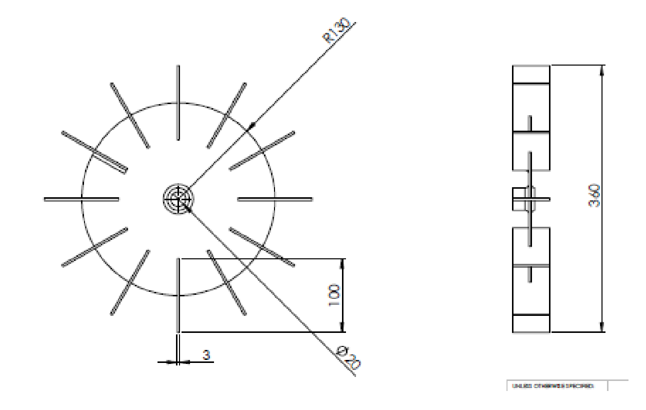

Fig. 1. Ground wheel

W_1 = Inner width of the pipe
W_0=30mm=0.03m
W_1=26 mm=0.026m= $(0.03^2 - 0.026^2)$
Cross Sectional area= $(0.03^2 - 0.026^2)$
C.S.A = 0.0009 - 0.00068 = $0.0002m^2$
Volume of the square pipe = cross sectional area x length
(13)
C.S.A $= 2.2\times 10^{-4}m^2$
L=1.922m
$Mass\ of\ pipe\ = Volume\ x\ Density$
(14)
$Volume\ (v)\ = 4.38\times 10^{-4}m3$
$Density\ = 7850kg/m3$
$m = 4.38\times 10^{-4}3\ \times 7850kg/m3 = 3.437kg$
$Weight\ of\ the\ pipe\ = Mass\ \times gravity$
(15)

$$m = 3.437kg$$
$$g = 9.81m/s^2$$
$$w = 3.437\ \times\ 9.81 = 33.71N$$

$Total\ weight\ of\ Chassis, w_c\ = Weight\ of\ Angle\ Iron\ +\ Weight\ of\ pipe$
(16)

$$w_c = 15.02\ +\ 33.71\ \times 10 - 4 = 48.73N$$

Weight of seed Tray.
Seed Tray is made of 2 mm thick mild steel sheet.
$Length\ of\ metal\ sheet\ used\ = 720mm = 0.72m$
$Width\ = 160mm\ = 0.16m$
$Thickness = 2mm = 0.002m$
$Density\ = 7850kg/m3$
$Substituting\ from\ equation$ 9
$Volume\ = l\ \times w\ \times t$ (17)
$V = 0.72\ x\ 0.16\ x\ 0.002m$
$V = 0.002304\ m^3$
$V = 2.000234\times 10^{-4}\ m^3$
$\therefore Mass = v\ \times\delta$
$m = 2.304\ \times 10 - 4m3\ x\ 7850kg/m3$
$m = 1.8086kg$
Substituting from equation 8
$Weight\ = m\ \times\ g$
$W\ = 1.8086\ \times\ 9.81$
w_t = 17.7424N
Weight of Seed Tray Support, w_{ts}
Seed tray Support is made of 50 mm by 5 mm mild steel flat bar.
Weight of the flat bar used = Width (mm) x Thickness (mm) x length (m) x density
(18)

$$Width\ (w)\ = 50\ mm\ = 0.05\ m$$
$$Length\ (L)\ = 200\ mm\ = 0.2m$$
$$T\ = 5mm = 0.005m$$

$Density\ (\delta)\ = 7850kg/m3$

$$m\ = 0.05\times\ 0.2\times\ 0.005\times\ 7850 = 3.925kg$$
$$Weight\ of\ seed\ tray\ support\ = 38.504N.$$

$Total\ weight\ of\ Seed\ tray\ = weight\ of\ tray\ mild\ sheet\ + weight\ of\ tray\ support$
(19)

$$w_{ts}\ = 17.742\ +\ 38.054\ = 56.246N$$

Weight of Wheels Assembly, w_w
Wheels are made from 8mm thick M.S Plates and 50mm by 3mm flat bar. Figure 1 below presents the ground wheel assembly.

$Disc\ diameter, D = 260mm\ = 0.26m$
$r = 130mm = 0.13m$
$\pi = 3.142$
$Area\ of\ a\ circle$
$= \pi r^2$ (20)
$A\ = 3.142\ \times 130^2$
$A = 53099.8\ mm^2$
$A = 0.05309\ m^2 = 5.3\ x\ 10^{-2}\ m^2$
$Area\ of\ the\ open\ spaces\ on\ the\ wheel\ disc$
$A = 50\ x\ 3$
$A = 150\ mm^2\ = 1.5\ \times\ 10^{-4}\ m^2$
$For\ 12\ spaces$
A=1.5×10^{-4} m^2x 12 =1.8×10^{-3} m^2
Actual Area of the wheel disc = $5.3 \times 10^{-2} - 1.8 \times 10^{-3}$
A= 5.13×10^{-2} m^2
Substituting.
Volume (v) =Area (A) x Thickness (t)
A=$5.13 \times 10^{-2} m^2$
t=0.003m
v= $5.13 \times 10^{-2} m^2$ x 0.003m
v=1.54×10^{-4} m^3
Substituting
Mass (m) =Volume (v) x Density (δ)

$$v = 1.54\times\ 10^{-4}\ m^3$$
$$\delta = 7850kg/m3$$
$$m = 1.54\times\ 10^{-4}\times 7850\ = 1.21kg$$

Substituted from equation 8
Weight (W) = Mass (m) x gravity (g)
m =1.21kg
g = 9.81m/s2
Wt=1.21 x 9.81 =11.870 N

The weight of wheel blades.
The blades are made of 50mm by 5mm flat bars
Area of the blades =Length (L) x width (w)
(21)
L =50mm=0.05m
W=5mm=0.005m
A = 0.05 x 0.005 = 0.00025 m2 = $2.5\times 10^{-4}\ m^2$
For 12 pieces
2.5 x 10-4 x 12 = 0.003m2
Substituting
$Volume\ = Area\ (A)\ x\ Thickness\ (t)$
(22)

$$A = 3.0\ \times 10 - 3m^2$$

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$t = 0.003m = 3.0\ x\ 10 - 3m$
$= 3.0 \times 10^{-3} \times 3.0 \times$ 10-3
$v = 9.0 \times 10^{-6}\ m3$
Substituting
$Mass = Volume\ (v) \times Density\ (\delta)$
$v = 9.0\ x\ 10^{-6}\ m^3$
$\delta = 7850 kg/m^3$
$m = 9.0\ x\ 10^{-6} \times 7850$
$m = 0.07065 kg$
$m = 7.065\ x\ 10^{-2}\ kg$
$Weight = mass \times gravity$
$m = 7.065 \times 10^{-2}$
$g = 9.81 m/s2.$
$Weight\ of\ blades = 7.065 \times 10^{-2} \times 9.81$
$= 0.693N$
$Total\ weight\ of\ wheels =$
$Weight\ of\ wheel\ disc + Weight\ of\ blades$
(23)
$= 11.870N + 0.6931N$
$= 12.5631N.$
$For\ the\ two\ wheels, total\ weight = 2 \times 12.5631$
$w_{wa} = 25.13\ N$

Weight of Pulling Mechanism, wp
Pulling Mechanism is made
from a square pipe of 30mm.
$Weight\ of\ square\ pipe$
$= Volume\ (v) \times Density(\delta)$
$\times gravity(g)$ (24)
$L = 120mm = 0.12m$
$Wt = 30mm = 0.03m$
Area of the square pipe.
$A = (30^2 - 26^2)$
$= 900 - 676$
$= 224\ mm^2$
$A = 2.24 \times 10^{-4} m^2$
$Volume = Cross\ Sectional\ Area\ x\ Length$
(25)
$A = 2.24 \times 10^{-4} m^2$
$L = 0.12m$
$v = 2.24 \times 10^{-4} \times 0.12$
$v = 2.69 \times 10^{-5} m^3$
$Mass\ of\ pipe = Volume \times Density$
$\mathrm{v} = 2.69 \times 10^{-5}\mathrm{m3}$
$\delta = 7850\mathrm{kg/m3}.$
$\mathrm{m} = 2.69 \times 10^{-5}\mathrm{m3} \times 7850\mathrm{kg/m3}$
$\mathrm{m} = 0.221\mathrm{kg}$
$\mathrm{Weight} = \mathrm{Mass} \times \mathrm{Gravity}$
$\mathrm{m} = 0.221\mathrm{kg}$
g = 9.81m/s2
Wp = 0.221kg x 9.81m/s2
= 2.072N.

Weight of Wooden Board.
Wooden board: The type of wood selected is Madrone. Weight of the board determined by first evaluating its volume and then using the following the relationship:
eight wt = Mass (m) x Gravity (g)
Dividing the board into two segments to evaluate it surface area
Area A1 = Length x Breath (L x B)
Substituting
$A_1 = 496 \times 300$
$= 148800 mm^2 = 1.49\ x\ 10^{-1}\ m^2$
$A_2 = 418\ x\ 200 = 83600\ mm^2 = 8.36x\ 10^{-2}\ m^2$
Volume = (A1 + A2) t
Substituting
t =25mm = 0.025m
A_1= 1.49 x 10-1 m2
v = (1.49 x 10-1 + 8.36 x 10-2) 0.025
v = 5.82 x 10-3m3
Mass =Volume (v) x Density (ϱ)
Substituting
v = 5.82 x 10-3m3
D (ϱ) = 7850kg/m3
$\therefore$ m = $5.82\ x\ 10^{-3} \times 7850 = 4.31$kg
Weight, Wt $= 4.31 \times x\ 9.81 = 42.28$ N

Measurement Weight of Accessories
Total Weight of Accessories = 1.95
Total Weight = (Weight of chassis)
+ (wt of seed tray)
+ Weight of wheel assembly
+Weight of (wooden board) +
Weight (Pulling) Mechanism +
Weight of Accessories).
(26)
Weight of Chassis = 48.73N
Weight of seed tray = 56.246N
Weight of wheel Assembly = 12.5631N
Weight of wooden board = 42.28N
Weight of Pulling Mechanism = 2.072N
Weight of Accessories =1.95N
48.73 + 56.25N + 12.5631N + 42.28N + 2.07N +1.95 =163.84N

DETERMINATION OF DRAFT OF THE RICE TRANSPLANTER
The draft of the transplanter is going to be of two components which are from the weight of transplanter and functional looses on the bearings and transplanting mechanism. The following relation is used
$D = D_r + F$ (27)
Where;
D = Total Draft
Dr = Rolling Resistance of the wetted soil
F = Frictional Losses
Dr = $W_t \times R$ (28)
Wt =163.84N
R = 0.03

D_r=163.84N x 0.03
D_r= 4.92N
If 15% of weight is F (frictional losses
Ff = 0.15 x 163.84
=24.58N.
$D = D_r + F$ (29)
Dr = 4.92N
F = 24.58N
$D = 4.921 + 24.58 = 29.5$ N

POWER REQUIREMENT
The machine will be powered manually by pulling force of the farmer. The following relationship was used
.

$P = D \times S$ .. (30)
Where P = Power in Watts
D = Total drafts of the transplanter in Newton
S = Forward speed of the transplanter
D = 29.5N
S = 1.4m/s
P = 29.5N x 1.4 = 41.3 W
The power required is 41.31which is less than the average power of a human being which is 76 W; therefore, the machine can be operated without much drudgery.

TABLE 1: PARAMETERS OF THE DESIGN

Parameter	Description	Value
ω	Angular speed of the ground wheel	10.769 rad/sec
N	Revolution of the ground wheel in a minute	102.839 rpm
S_R	Speed ratio of the chain drive	3.78
N_1	Revolution speed of the driving sprocket	102.84 rpm
N_2	Revolution speed of the driven sprocket	388.4 rpm
N_p	Rate of oscillation of the planting fingers	388.4 rpm
$\dot{s}$	Number of seedling transplanted in a minute	777 plants
w_c	Weight of chassis	48.73 N
w_{ts}	Total Weight of seedling tray	56.246 N
w_{wa}	Weight of the ground wheel assembly	25.13 N
w_p	Weight of pulling mechanism	2.072 N
w_b	Weight of wooden board	42.28 N
w_a	Weight of accessories	1.95 N
w_T	Total weight of the transplanter	163.84 N
D_r	Rolling resistance of the wetted rice field	4.92 N
F_f	Frictional losses on mechanisms	24.58 N
D	Draft of the transplanter	29.5 N
P	Power requirement of the rice transplanter	41.3 W
d	Diameter of the central shaft	12 mm

DESIGN OF THE MAIN SHAFT
The shaft is used to transmit torque from the ground wheel to four bar linkage system via chain drive. Therefore the load acting on the shaft is simply the force required to drive the four bar linkage. which has computed as losses in 3.5.5 above and calculated from the equations given by [5]

$\tau = \frac{16T}{\pi d^3}$ (31)

Where,
τ= Allowable shear stress
T= Torque
d= Shaft diameter

$T = \frac{60p}{2\pi N}$ (32)

P = 41.3w

N = 102.84 rpm

$T = \frac{60 \times 41.3}{2 \times 3.142 \times 102.84}$

$= \frac{2478}{646.162}$

= 3.834Nm

From $\tau = \frac{16T}{\pi d^3}$

$\therefore d^3 = \frac{16T}{\pi\tau}$ (33)

$d = \sqrt[3]{\frac{16T}{\pi\tau}}$ (34)

$d = \sqrt[3]{\frac{16 \times 3.834}{3.142 \times 0.5}}$

d = 3.421 mm

A mild steel commercial shaft of 12 mm is chosen.

III. RESULTS AND DISCUSSION

The results of the design computation and analysis are presented in the Table 1 below.

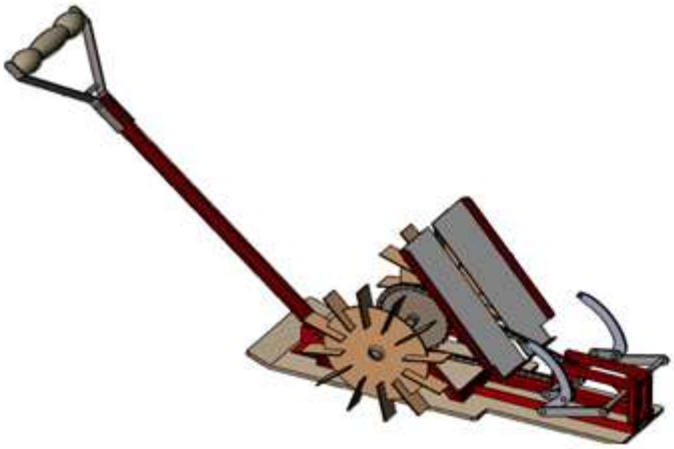

Fig. 2. Isometric Drawing of the Designed Manually Operated Rice Transplanter

Figure 2 below presents the isometric drawings of the designed manual rice transplanting machine.

IV. CONCLUSION

The design analysis of a simple and durable manually operated machine for on-row transplanting of paddy rice was successfully undertaken. A simple manual rice transplanter was developed consisting of other following basic components, seedling tray, chassis, picking fork, wheels assemble pulling mechanism. The power requirement for the machine is 41.3 W well below the average power of a man which is 76 W; designed planting rate being 777 plants in a minute at a mean forward speed of 1.4 m/s. The design upon implementation would contribute immensely to mechanization of rice production in Nigeria; as it could make available to small scale rice farmers a simple yet affordable mechanical transplanter replacing manual transplanting, eliminating drudgery, and the

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