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Design of a Handheld Multipurpose Telescopic Device for High Altitude Jobs in Rural Areas in West Africa Sub Region

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Abstract— This work sought to design a handheld multipurpose telescopic device for high altitude jobs in rural areas, in order to minimise the difficulties, risks and cost involved in undertaking such jobs. This handheld device comprises a telescopic pole, locking keys, an adjustable head, and various attachments for the head. The attachments designed for this telescopic pole include paint roller, cleaning brush, sweeping brush, and harvesting bag. The telescopic pole could be folded up to about 2.5 m for easy mobility and storage, and it can be extended up to 9 m. The maximum mass of attachment that the device can carry without failure is 7.304 kg, which is the weight of about 16 fruits It is recommended that additional studies should be conducted to design more attachments for the device.

Index Terms— Painting, cleaning, harvesting, telescopic pole, harvesting bag, attachment

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1 INTRODUCTION

Painting, cleaning and harvesting at high altitudes have been difficult and risky jobs in both rural and urban areas.

Research conducted by the Bureau of Labour Statistics shows that falls are one of the top four causes of fatal occupational injuries from 1992 to 2009 [1]. In the sub region, when tall walls are to be painted and objects mounted at high altitudes are to be cleaned or fruits on tall trees are to be harvested, ladders or ropes are used to ascend to the desired height before the jobs can be done. These methods can result in serious injuries or even death. In some cases, wooden or metallic structures are built for the same purpose, which could be time consuming. Though some low time consuming machineries like lifts have been made available in some urban areas, the cost of hiring them has limited the patronage of these lifts to mostly the rich. This work seeks to design a handheld multipurpose telescopic device for high altitude jobs in rural areas, in order to minimise the difficulties, risks and cost involved in undertaking high altitude jobs.

1.1 Existing Devices for High Altitude Jobs

According to [[2],[3],[4],[9],[11]], some of the devices that have been developed for high altitude jobs like painting of tall walls, cleaning of objects mounted at high altitudes and harvesting of fruits on tall trees are:

1. Telescopic pole
2. Lift
3. Extension ladder
4. Scaffolding
5. Multi-tree climber

1.2 Limitations of the Existing Devices for High Altitude Jobs

Some of the disadvantages of the existing devices include

1. Difficulty in mobility and high purchasing cost of devices like the lift and scaffolding;
2. Time consumption in installation of devices such as the scaffolding;
3. Rick of falling in using devices such as the lift, scaffolding, extension ladder and multi-tree climber.
4. Restriction to a specific job for devices such as the extension pole and multi-tree climber.

2 CONCEPTUAL DESIGN

2.1 Design layout and description

The handheld device in Fig 2 comprises a telescopic pole, locking keys, an adjustable head, and attachments for the head (Paint roller).

The telescopic pole is made up of four members which are cylindrical and hollow. However, each member has a different length and sectional diameter. The members are arranged in a way that makes it possible for the pole to be reduced or folded to almost the length of the largest member. Each member has a locking mechanism at its tip that allows the tail end of preceding member to be locked to it after extension.

The adjustable head is fitted on the tip of the smallest member at the top end of the pole. The adjustment head and its attachments could be attuned to any angle within its range. The adjustable head is made up of two cylindrical and hollow parts, which are joined together at one end by means of a bolt and nut. Furthermore, one of the parts is mounted on the pole, while the other part provides means for the attachments to be joined to the adjustable head.

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International Journal of Scientific & Engineering Research Volume 6, Issue ÑÈ2Ì×ÛÌÔÉÌÛ-2015
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Each telescopic pole has four designed attachments or accessories. These are, a paint roller, cleaning brush, sweeping brush, and harvesting bag.

Fig 2 Proposed Design

2.2 Description and Functions of the Main Components of the Design

Telescopic Pole

The telescopic pole is designed to reach high altitude as high as 9 m. The biggest section of the pole is designed with 6082-T6 aluminium alloy which has a light weight (density of 2710 kg/m^3) and a high strength to weight ratio of 122 kNm/kg [5]. The smaller sections of the pole are designed with NEMA grade FR-5 glass-epoxy laminate which has a very light weight (density of 1850 kg/m^3) and a high strength to weight ratio of up to 151 kNm/kg [7].

Fig 3 Telescopic Pole

Locking Key

The key is used to lock the pole at its joints like a screw and its tail part is threaded wing as shown in Fig 4.

Fig 4 Locking Key

Adjustable Head

This is fixed on the tip of the smallest member of the telescopic pole. It provides means for various attachments to be joined to the pole. The adjustable head (Fig 5) could be adjusted to suit a specific job.

Fig 5 Adjustable Head

Paint Roller

This is a 9 inch paint roller, made up of a frame and a cover as shown in Fig 6. The frame consists of a fibreglass cage, a shank which passes through the axis of the paint roller, and an internal bearing.

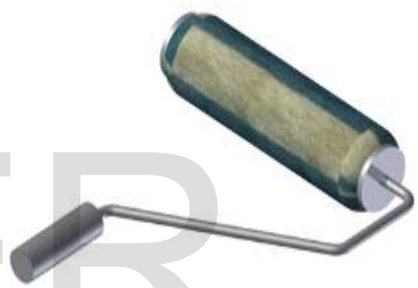

Fig 6 Paint Roller

Cleaning Brush

As shown in Fig 7, the cleaning brush is rectangular in shape and it consist of a plastic head with a polyester fabric material on one surface of the head. A cylindrical extension from the head of the cleaning brush is designed to be fixed into the adjustable head.

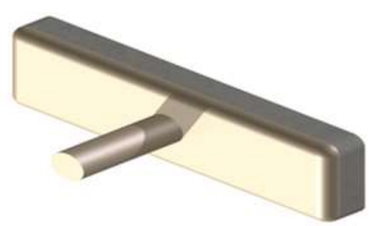

Fig 7 Cleaning Brush

Sweeping Brush

The sweeping brush is made up of a plastic triangular shaped head, with a long bristle material on the base surface of the head (shown in Fig 8).

International Journal of Scientific & Engineering Research Volume 6, Issue ƝǊ2Ì×ûÌÔÉÌû-2015
ISSN 2229-5518

Fig 8 Sweeping Brush

Harvesting Bag
As shown in Fig 9, this consists of a steel ring (about 0.4 m diameter), a net (preferably nylon net with holes of diameter 20 mm) mounted around the ring, and a stainless steel cutting tool mounted on a part of the ring.

Fig 9 Harvesting Bag

3.0 Design Calculations

3.1 Introductory Calculations

The free body of the pole is considered when it is extended to it maximum length and raised to an assumed angle of 60° to the horizontal, having the paint roller as the attachment, and with the operator's secondary grip distanced 'a' from the primary grip as shown in Fig 9 (the weight of the device is neglected)

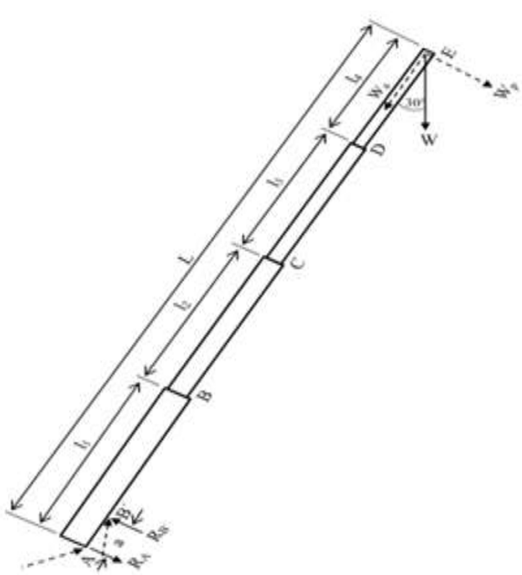

Fig 10 Free Body Diagram of the Device in a Painting Operative Mode

Considering the perpendicular loading, the free body diagram is given as Fig 11.

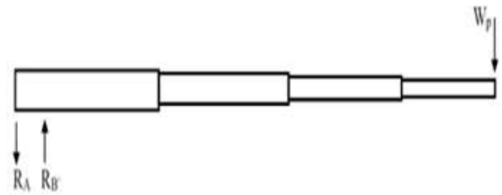

Fig 11 Free Body Diagram of the Device Considering Perpendicular Loading

Summing the forces in the vertical plane and equating to zero gives:

$$R_B = R_A - W_P = 0 \quad (1)$$

$$R_A = R_B - W_P$$

Taking moment about A,

$$W_P L - R_B a = 0$$

$$\Rightarrow R_B = \frac{W_P L}{a} \quad (2)$$

Substituting (2) into (1) gives,

$$R_A = \frac{W_P L}{a} - W_P$$

$$R_A = \frac{W_P}{a}(L - a) \quad (3)$$

Knowing that the weight (W) is given by:

$$W = mg \quad (4)$$

where,
m = mass of the paint roller
g = acceleration due to gravity (9.81 m/s)

From the volume and density of the material used for the paint roller frame and cover, the mass of the paint roller frame and cover is given as 0.15 kg and 0.05 kg respectively. Therefore, the total mass of the paint roller is 0.2 kg.

$$W = 0.2 \times 9.81 = 1.962N$$
$$W \approx 2N$$

Also, from Fig 10,

$$W_p = 2\sin 30° = 1N$$

Knowing that, L = 9 m
l_1 = 2.5 m
l_2 = 2.3 m
l_3 = 2.2 m
l_4 = 2 m
a = 0.9 m

International Journal of Scientific & Engineering Research Volume 6, Issue ʼn2Ì×ÛÌ ÔÉÌÛ-2015
ISSN 2229-5518

$$R_{B'} = \frac{1 \times 9}{0.9} = 10N$$

From (1)

$$R_A = 10 - 1 = 9N$$

3.2 Design of the Telescopic Pole

The major modes of failure of the device when it is considered horizontally are:

1. Shear
2. Bending

The material selected for the biggest member (AB) is a 6082-T6 aluminium alloy with yield strength (Sy) of 270 MPa, modulus of elasticity (E) of 71 GPa and density of 2710 kg/m [5]. The material selected for other members (BE) is a NEMA grade FR-5 glass-epoxy laminate [6] with ultimate strength (no yield strength since material is brittle) of 280 MPa, modulus of elasticity of 19 GPa and density of 1850 kg/m^3 [7]. Since the pole is made up of two materials, the members (segments) AB and BE are considered based on their materials and the smaller τ_{max} is chosen for the pole.
For member AB, S_y is 270 *MPa* and n is 1.3 and for BE, S_y is 280 *MPa* and n is 2.5, therefore
From Table 1, the factor of safety for the biggest member is taken to be 1.3, and that of the other members is taken to be 2.

Table 1 General Recommendations for Factor of Safety

Applications	Factor of Safety
For use with highly reliable materials where loading and environmental conditions are not severe and where weight is an important consideration	1.3 - 1.5
For use with reliable materials where loading and environmental conditions are not severe	1.5 - 2.0
For use with ordinary materials where loading and environmental conditions are not severe	2.0 - 2.5
For use with less tried and for brittle materials where loading and environmental conditions are not severe	2.5 - 3.0
For use with materials where properties are not reliable and where loading and environmental conditions are not severe, or where reliable materials are used under difficult and environmental conditions	3.0 - 4.0

(Source: Anon., 2015f)

The telescopic pole is considered segment by segment, and since it is hollow, the inner and outer diameter will be determined.
From the maximum shear stress theory [8],

$$\tau_{max} = \frac{S_Y}{2n} \quad (5)$$

where,
τ_{max} is the maximum shear stress in the member.
S_y is the yield strength of the material.
n is the factor of safety.

Since the pole is made up of two materials, the members (segments) AB and BE are considered based on their materials and the smaller τ_{max} is chosen for the pole.
For member AB, S_y is 270 *MPa* and n is 1.3 and for BE, S_y is 280 *MPa* and n is 2.5, therefore,

$$\tau_{max} AB = \frac{270}{2 \times 1.3} = 103.85 MPa$$

$$\tau_{max} = \frac{280}{2 \times 2.5} = 56 MPa$$

This implies that, the permissible τ_{max} for the pole is 56 *MPa*.
Also, according to maximum shear stress theory [10]

$$\tau_{max} = \frac{1}{2}\sqrt{\sigma_b^2 + 4\tau^2} \quad (6)$$

where,
τ_{max} is the maximum shear stress in the member.
σ_b is the bending stress due to bending moment.
τ is the transverse shear stress.

But, for a hollow member [8]

$$\sigma_b = \frac{32M}{\pi d_o^3 (1 - k^4)} \quad (7)$$

$$\tau = \frac{8V}{\pi d_o^2 (1 - k^2)} \quad (8)$$

Imputing (7) and (8) into (6),

$$\tau_{max} = \frac{1}{2}\sqrt{\left(\frac{32M}{\pi d_o^3 (1 - k^4)}\right)^2 + 4\left(\frac{8V}{\pi d_o^2 (1 - k^2)}\right)^2} \quad (9)$$

where,
M is the maximum bending moment in the hollow sment,
V is the maximum shear force in the hollow segment,
d_o is the outer diameter of the hollow segment,
k is the ratio of the inner diameter (d_i) to the outer diameter (d_o) of the hollow member.

$$k = \frac{d_i}{d_o} \quad (10)$$

International Journal of Scientific & Engineering Research Volume 6, Issue ŉ2Ì×ÛÌÔÉÌÛ-2015
ISSN 2229-5518

Segment DE

Segment DE is assumed to have a fixed support at point D with a load at point E as shown in Fig 12.

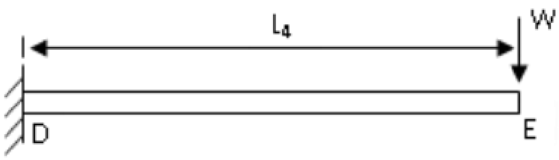

Fig 12 Segment DE

The free body diagram is given as:

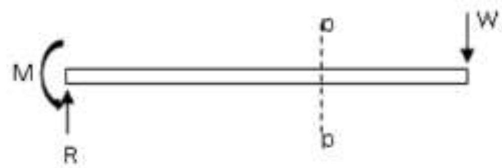

Fig 13 Free Body Diagram of Segment DE

From Fig 13,

$$R_D = W_P \quad (11)$$

Taking moment about D,

$$M_D = W_P l_4 \quad (12)$$

For section p-p (where $0 \le x \le l_4$),

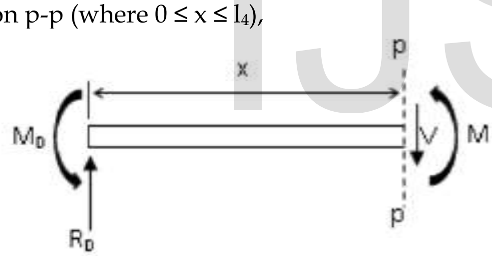

Fig 14 Free Body Diagram of Section p-p

From Fig 14,

$$V = R_D = W_P \quad (13)$$

Taking moment about p-p,

$$M = -M_D + R_D x$$

$$M = -W_p (l_4 - x) \quad (14)$$

When x = 0 in (13) and (14),

$$V = W_P$$

$$M = -W_p l_4$$

When x = l_4 in (13) and (14),

$$V = W_P$$

$$M = 0$$

The shear force (V) and bending moment (M) diagram of segment DE are shown in Fig 15.

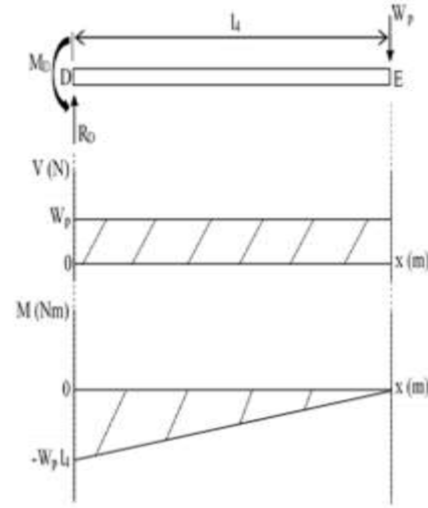

Fig 15 Shear Force and Bending Moment Diagram of Segment DE

From Fig 15,

$$V_{max} = W_P = 1N$$

Similar procedures were followed and the following relations and values were obtained for the remaining members (segments).

For segment CD:

The shear force and bending moment is given as

$$V_{max} = W_P = 1N$$

$$M_{max} = W_P (l_4 + l_3) = 4.2Nm$$

For segment BC:

The shear force and bending moment is given as

$$V_{max} = W_P = 1N$$

$$M_{max} = W_P (l_4 + l_3 + l_2) = 6.5Nm$$

For segment AB:

Segment AB is assumed to have a load at point A and B[1], with a fixed support at point B

R_A and R_B has already been found in the introductory calculation

For section y-y (where $0 \le x \le a$),

The shear force and bending moment is given as

$$V_{max} = \frac{W_P}{a}(L + a) = 9N$$

International Journal of Scientific & Engineering Research Volume 6, Issue ʹǡ ʹͲͳͷ-2015
ISSN 2229-5518

$$M_{\max} = W_P(L+a) = 8.1Nm$$

3.3 Determination of Inner Diameters of the Members

Segment AB

For segment AB, d_o is taken to be 45 mm in order to make it suitable for griping. Using (8), knowing that the maximum shear force and maximum bending moment in member AB are 9 *N* and 8.1 *Nm* respectively, k is found to be 0.9980.
From (10),

$$d_i = kd_o = 44.91mm$$

Though the calculated value for inner diameter is 44.91 mm, which implies $d_i \approx d_o$, therefore, a d_i of 42 *mm* is chosen.

Similar procedures were followed to come out with the diameters for the other segment.

The table below gives the sizing of the various segment

Table 2 Summary of Sizes of the Segments of the Telescopic Pole

Segment	K	Outer Diameter d_o [mm]	Inner Diameter d_i [mm]	Length L [mm]	Moment of Inertia I [mm^4]	Area A [mm^2]
AB	0.9778	45.00	42.00	2500	17304.73	69.90
BC	0.9500	40.00	38.00	2300	23309.83	122.52
CD	0.9118	34.00	31.00	2200	20264.01	153.15
DE	0.8518	27.0	23.00	2000	12350.39	157.08

3.4 Analysis of the Telescopic Pole

The pole is analysed by finding the critical load that can be detected in the device, in order to find the maximum allowable mass of attachment that can be carried by the pole.

Critical Load

The critical load for the pole could be determined from the computation of the critical load of the segments AB and BE.

$$P_{cr} = \frac{C\pi^2 EI}{l^2} \tag{15}$$

where, P_{cr} is the critical load, *E* is the modulus of elasticity of the material, *l* is the length of the material, C is a constant which depends on end conditions and I is the moment of inertial.
For member AB, *E* is 71 *GPa*, *l* is 2.5 m, *I* is 17304.73 mm^4 and *C* is taken to be ¼ (for the pole having one end being free and the other being fixed), therefore,

$$P_{cr} = \frac{\frac{1}{4}\pi^2 \times 71\times10^9 \times 17304.73\times10^{-12}}{2.5^2}$$

$$P_{cr} = 129.800N$$

For section *BE*, *E* is 19 *GPa*, *l* is 6.5 m, I is $I_{BC} + I_{CD} + I_{DE}$ and *C* is taken to be ¼ (for the pole acting as one end being free and the other being fixed), therefore,

$$I = I_{BC} + I_{CD} + I_{DE} \tag{16}$$

$$I = 23309.83 + 20264.01 + 12350.39$$
$$= 55924.23$$

$$P_{cr} = \frac{\frac{1}{4}\pi^2 \times 19\times10^9 \times 17304.73\times10^{-12}}{6.5^2}$$

$$P_{cr} = 62.053N$$

Therefore, the allowable critical load for the pole is taken to be 62.053 N.

3.5 Allowable Mass of Attachment

The critical load will act along the axis of the pole, (Fig 10) taking P_{cr} to be W_a,

$$P_{cr} = W\cos 30^o$$

$$W = \frac{62.053}{\cos 30^o} = 71.653N$$

$$W = mg$$

$$m = \frac{71.653}{9.81} = 7.304kg$$

Based on the design, 7.304 kg is the maximum mass that the telescopic pole can carry without failing.
Considering the operator is using the harvesting bag attachment to harvest Hawaiian Pawpaw (commonly found in supermarkets), which weighs about 0.45 kg [12].

$$\text{Maximu allowable number of fruits} = \frac{7.304}{0.45} = 16.23kg$$

Depending on the operator's strength and comfort, he or she can carry up to 16 fruits (for fruits weighing 0.45 kg).

International Journal of Scientific & Engineering Research Volume 6, Issue ʃN0ɯ2Ì×ÛÌÔÉÌÙ-2015
ISSN 2229-5518

3.6 Conclusions

From the design analysis, it can be concluded that:

1. A handheld telescopic mechanism has been designed for painting tall walls, cleaning objects mounted at high altitudes, and harvesting fruits on tall trees, in rural areas.
2. Amongst other attachments for the device, is a harvesting bag which can carry up to 16 fruits (7.304 kg) and also prevent fragile fruits from falling and subsequent damage during harvesting.
3. The device is designed to retract to about 2.5 m for easy mobility and storage, also it can extend up to 9 m.

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